Canadian Grizzly Bear Management Series

Resource road management

Trans-border Grizzly Bear Project,
Flathead Grizzly Bear Project,
fRI Research Institute Grizzly Bear Program,
South Rockies Grizzly Bear Project,
Elk Valley Grizzly Bear Project,
University of Alberta

RESOURCE ROADS AND GRIZZLY BEARS IN BRITISH COLUMBIA AND ALBERTA, CANADA

photo: Stefan Himmer

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EXECUTIVE SUMMARY

Natural systems have faced unprecedented challenges in recent decades that have resulted in accelerated losses of biodiversity and ecosystem function across the globe. Roads are one feature of human impacts on natural systems that have been influential, both through their direct footprint and facilitating human access into previously inaccessible areas. However, road influences also can be mitigated and managed to reduce their effect while maintaining their economic and social value.

Here we reviewed the scientific literature on the relationship between grizzly bears, human motorized access, and the efficacy of motorized access control as a tool to benefit grizzly bear conservation in western Canada. We suggest landscape road targets that will benefit bear conservation. For context, there are currently about 15,000 grizzly bears in British Columbia and an additional 900 in Alberta. However, there are currently ~750,000 km of resource roads (non-highway dirt/gravel roads to access timber and mining resources) in BC and ~43,000 km in Alberta grizzly bear range but determining the number of usable roads remains challenging. Resource roads are increasing in BC at a rate of 10,000 km of new roads per year, but no data are collected on the rate roads become unusable, either through natural processes or deactivation.

There are generally two mechanisms of grizzly bear response to motorized access: 1) increased human-caused mortality of bears and 2) reduced habitat effectiveness either through displacement or direct habitat loss. Female grizzly bear survival has the greatest influence on population trend but is reduced in habitats with higher road densities and human use, creating a situation where roads could limit grizzly bear populations. Once they are 2-year olds, a large majority of bears in areas of moderate human interface are eventually killed by people, and almost all are killed near roads. Open road density (roads that are open to resource industry and the public) and the amount of secure habitat (i.e. habitat > 500 m from an open road) in female grizzly bear home ranges are important predictors of their survival. Furthermore, there is a strong link between few or no roads in the most important habitats and viability of a bear population. Several examples of well-studied populations in Canada have demonstrated that having few or no roads in high quality habitats is beneficial to a population's conservation status. Bears deposit fat needed for hibernation and reproduction in late summer and fall. This time frame, however, overlaps with many hunting seasons creating human-wildlife conflicts resulting in many bears being shot in perceived or real defence of life and property. Limiting motorized access into these important forage habitats would safeguard bears from many backcountry human-related mortalities.

The evidence is clear that motorized access into grizzly bear habitats can have significant negative consequences. We found it impacted grizzly bears at the individual and population levels through effects on bears' habitat use, home range selection,

movements, population fragmentation, survival, and reproductive success that ultimately were reflected in population density, trend, and conservation status. Motorized access management—where roads are fully closed or restricted to the motorized public but may remain accessible to short-term industry use—was an effective mitigation and should continue to be integrated into land use and wildlife management activities, particularly where grizzly bear conservation or recovery is a priority.

Because habitat quality varies enormously, as does the number and behaviour of people in a region, there is not a universal threshold of motorized human access, above which negative outcomes would be expected for bear populations. However, most research in areas of moderate habitat quality, moderate human interface, and recovering bear populations suggested that an open road density (km of roads open to motorized public traffic per km^2 of area) of 0.6 km/km^2 is a rough threshold above which female grizzly bears may have unsustainable survival rates or levels of habitat avoidance and such areas become population sinks (areas of local population decline sometimes sustained through immigration). We note, however, that this threshold is not perfectly universal and habitat quality, seasonality of important food resources, proximity to human settlements, and local bear density might result in place-specific motorized road density thresholds higher or lower than the 0.6 km/km^2 (~0.3 in sensitive units of lower habitat quality – ~0.9 km/km^2 in highly productive units) motorized road density guideline.

From a grizzly bear conservation perspective, the distribution of roads is also important. For example, having a high concentration of roads in a small area is much different from having roads spread evenly across a broad area, even though the overall road density may be equal. To account for distribution, the proportion of the vegetated area (i.e., excluding rock and ice) that is > 500 m from an open road, often termed "secure habitat", has been used. In some areas of moderate habitat quality, female grizzly bears experience higher survival when at least ~60% of their home range is secure habitat. It is also beneficial if secure habitat patches are at a minimum, large enough to accommodate the daily movements of females.

Based on the reviewed scientific literature and our cumulative experience we suggest the following guidelines on the when, where, and how of managing motorized access to ensure successful grizzly bear conservation:

WHEN:

1) Motorized access management is likely to benefit grizzly bear conservation if any of the following conditions are met within the monitoring unit used by the respective provinces (Watershed units in Alberta, and Landscape or Management Units in BC):

a) roads exist in highest quality grizzly bear habitats, or in areas with population limiting energy-rich food resources (salmon, berries, etc.);

b) open road densities exceed 0.6 km/km^2;

c) less than least 60% of the unit's area is secure habitat (i.e. > 500 m from an open road in patch sizes of at least 10 km^2).

WHERE to enact access management in order of priority:

1) threatened populations;

2) populations with conservation concerns (unsustainable mortality rates, and high human footprints);

3) areas where roads occur in the highest quality habitats;

4) within and adjacent to identified linkage areas between population units;

5) areas that are expected to exceed motorized route thresholds due to increasing open road densities associated with planned and ongoing resource extraction activities.

HOW:

Evidence suggests motorized access management benefits are more likely to be realized if habitat quality is integrated in the planning and decision-making process. As stated in 1a, it is important that the highest quality habitats and the surrounding areas have few if any roads. We also suggest that medium quality habitats containing non-limiting resources such as riparian areas or avalanche chutes be managed close to or below 0.6 km/km^2 and with at least 60% of the monitoring unit in secure habitat. Finally, as long as there is credible mapping of habitat quality in the management unit, the portion of the monitoring unit with lower quality habitats can be managed at road densities > 0.6 km/km^2. We also recommend that the entire unit's average open road density (containing low, medium and high road densities) be roughly < 0.6 km/km^2 with at least 60% secure habitat in patches > 10 km^2.

While there is no science-based estimate of what total road (open, restricted, and closed) density might be conducive to grizzly bear, habitat, and biodiversity conservation, we suspect there is a threshold beyond which there are measurable negative impacts to grizzly bears (and other species) at both the individual and population level. A landscape saturated with roads would not be conductive to productive grizzly bear populations, even if they were closed. We encourage land use managers developing access rules to consider such a metric that includes the ecological needs of grizzly bears, but also a wider spectrum of biodiversity (amphibians, reptiles, fish, birds, small mammals, ungulates, carnivores, etc.) and overall habitat (erosion, terrain stability, water pollution, etc.) conservation.

Motorized access can best be managed at scales that optimize the protection of important habitats to benefit the distribution, survival, reproduction and density of female grizzly bears. The distribution of important food resources will dictate the spatial configuration of motorized access management needs for bears. We believe that this will be best realized when applied across small geographic areas, such as Watershed Units in Alberta or Landscape Units in BC, especially when the goal is to secure access to food. However, it may be necessary and practical to also manage motorized access at larger scales to secure movement areas among populations.

As motorized access is managed, it is beneficial if standardized measurement methods are used to monitor and assess road-related metrics. We found that current road layers often included non-passible roads due to planned reclamation, vegetation regrowth, or slumping, thus updated and accurate road layers are essential but difficult to maintain. It is also important that government land managers use science-based habitat maps including key foods and connectivity areas when available to help plan motorized access to benefit bears. Local knowledge can be used in areas without habitat and foods-related maps.

GLOSSARY

Motorized access management: a term reflecting restrictions to motorized traffic on roads in the backcountry for the benefit of wildlife and ecosystems.

Road: a track or gravel/paved road traversable by pickup trucks or Off Highway Vehicles (OHVs).

Off Highway Vehicle: a motorized vehicle capable of operating off highways, including but not limited to quads, side-by-sides, tracked vehicles, or motorcycles.

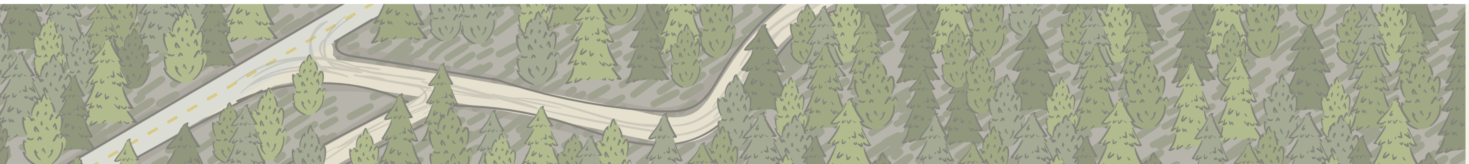
Road density: a measure of roads traversable by pickup trucks or OHVs in km/km2.

Open road: a road that is open to everyone, industry and the public.

Restricted road: a road that is not open to the public, but allows industrial use.

Closed road: a road that is closed to everyone.

Seasonally closed road: a road that is closed during a certain season, for instance the late summer - early fall berry season when bears feed intensively to store energy for hibernation.



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INTRODUCTION

Natural systems and wildlife have faced unprecedented challenges in recent decades resulting in accelerated loss of biodiversity and ecosystem function across the globe (Sala et al. 2010, Barnosky et al. 2011, Hooper et al. 2012), resulting in extinction rates approximately 100 times natural rates (Celabos et al. 2015). These trends are occurring while a decades-long environmental mitigation effort sweeps the globe (Sectetariat of the Convention on Biological Diversity 2014, Wilson, 2016). This conundrum clearly suggests that protected areas are not mitigating the ever expanding and intensifying human footprint (Wilson 2016, Dinerstein et al. 2017, Sanderson et al. 2002, Venter et al. 2016). The corollary is that if we want to maintain biodiversity and sustainable supportive ecosystems, we either need to increase and diversify the protected area system (Wilson 2016, Dinerstein et al. 2017), ensure the varied types of protected areas are linked by functional connectivity networks (Dinerstein et al. 2017), manage the intervening matrix of multiple-use lands to a higher standard, or some combination of the above (Lamb et al. 2018a).

One sphere within the increasing human footprint is the ubiquitous presence of roads which can have unintended negative effects on natural systems and wildlife populations (McLellan 1990, Forman and Alexander 1998, Fahrig and Rytwinski 2009, Ibisch et al. 2016). The scientific literature contains many motorized access-impact studies touching all levels of our natural systems and species including aquatic and terrestrial ecosystems (Trombulak and Frissell 2000), amphibians and reptiles (Hels and Buchwald 2001, Fahrig and Rytwinski 2009), birds and large mammals (Fahrig and Rytwinski 2009, Beneitz-Lopez 2010), and large carnivores (Basille et al. 2013, Ceia-Hasse 2017).

While this document is focused on one large carnivore species, the grizzly bear (*Ursus arctos*) in British Columbia (BC) and Alberta, it also is a reflection of our modern globe. We are not alone with the issues presented here. While biodiversity loss in Canada is less than many parts of the globe, we do have significant extinction risk for several endemic species and extirpation risk within BC and Alberta for several species with a broader distribution (Rainer et al. 2017). Finally, Canada is a stronghold for 24% of the planet's remaining wilderness, but ongoing resource extraction is reducing Canada's wilderness, compromising grizzly bear populations and furthering the loss of biodiversity (Lamb et al. 2018a).

After protected areas, motorized access controls (on routes that include roads and OHV tracks) have been the cornerstone of the recovery of threatened grizzly bear populations for the past 3 decades in the contiguous United States (U.S.) where grizzly bears in the Yellowstone and Northern Continental Divide ecosystems have all but recovered (though legal debates are ongoing, Kendall et al. 2009, Mace et al. 2012, Schwartz et al. 2006). Populations have increased significantly and geographic expansion has occurred in both ecosystems from historic lows prior to 1970 (Kendall et al. 2009, Schwartz et al. 2006). These successes are lessons

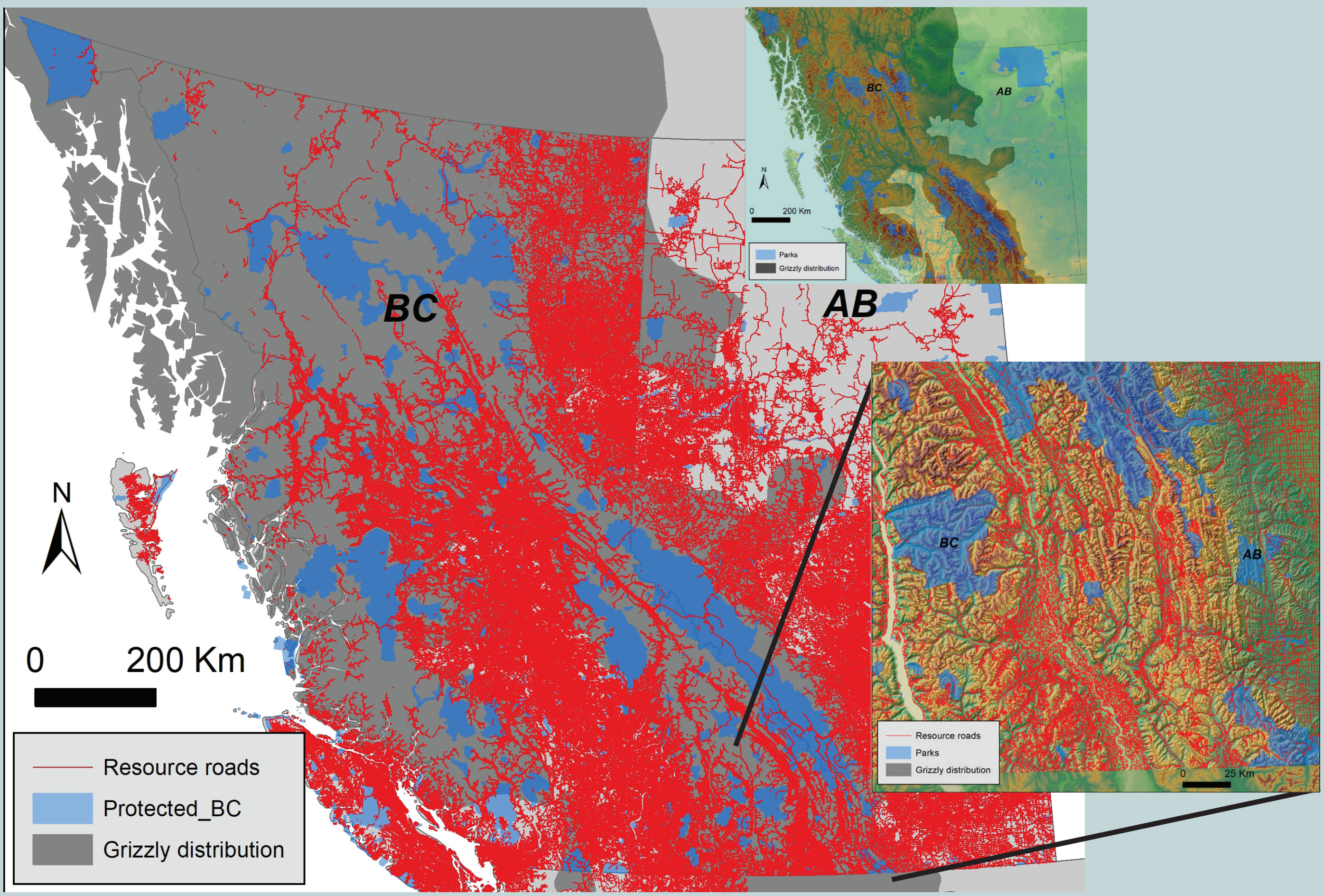
for grizzly bear management in Canada where there is high and increasing human-bear overlap.

Alberta grizzly bear populations were first designated threatened in 2010 and management of road densities (excluding OHV tracks) is a key strategy in the province's latest “draft” Recovery Plan (Alberta Environment and Parks 2016). Although BC has almost 10 times as many grizzly bears as there are in the lower 48 states or Alberta, there are a few population units in BC that are either of-concern (“threatened”) or well below their potential numbers (Hamilton and Austin 2004, BC Ministry of Environment 2012, McLellan et al. 2016). BC has no provincial-scale road management strategy and road building has been extensive, although some regional motorized access control initiatives have existed for decades (Fig. 1).

We reviewed the scientific literature on the relationship between grizzly bear ecology, human motorized access, and the efficacy of

FIGURE 1.

Grizzly bear distribution and resource roads across Alberta and BC. Resource roads are non-highway, dirt or gravel roads to access timber and mining resources. This map does not reflect all OHV tracks.



motorized access controls as a tool in grizzly bear management to answer three questions:

1) What are the effects of motorized access on grizzly bear populations?

2) Is motorized access management effective to reduce any negative effects of roads?

3) If yes, how should it be implemented to maximize efficacy?

There are many economic and social benefits of road networks in our backcountry ecosystems. Roads are the backbone of our forestry, mining and energy industries, and enable people to easily recreate in remote natural environments. The road network, however, is potentially costly to our naturals systems. The goal of this report is to assess that cost and the tools that can help mitigate them.

GRIZZLY BEAR RESPONSE TO ROADS

Grizzly bear response to motorized human access generally occurs via 3 mechanisms. In the likely order of their influence on grizzly bear populations in Alberta and BC they are: increased human-caused mortality, habitat displacement, and direct habitat loss (Fig. 2).

Mortality

In areas with human/bear overlap a large majority of grizzly bears over the age of two are eventually killed by people and almost all are killed near roads (shot, not hit by vehicles). Studies from across west-central North America report that humans cause between 77-90% of grizzly bear mortalities (McLellan 1989, 2015, McLellan et al. 1999, Garshelis et al. 2005, Schwartz et al. 2006, Mace et al. 2012). Where humans and bears overlap, adult bear survival decreases (Gunther et al. 2004, Schwartz et al. 2006, 2010, Boulanger et al. 2013, Boulanger and Stenhouse 2014, Lamb et al. 2017). Because most bears are killed near a road (Benn and Herrero 2002, McLellan 2015), it's not surprising that increased motorized access into grizzly bear habitat increases bear mortality (Nielsen et al. 2004a, Schwartz et al. 2010, Boulanger and Stenhouse 2014, Proctor et al. 2017).

The most important mechanism influencing grizzly bear population growth emanates from the combination of 2 factors. First, female survival has the greatest influence on population trend (McLellan 1989, Eberhardt et al. 1994, Garshelis et al. 2005, Harris et al. 2006, Mace et al. 2012) and second, female survival is reduced in habitats with higher road densities where people use the roads (Schwartz et al. 2010, Boulanger and Stenhouse 2014). Open road density and the amount of secure habitat in female home ranges are important predictors of female survival and both contribute different yet important components influencing survival (Mace et al. 1996, Wakkinen and Kasworm 1997, Schwartz et al. 2010).

Taking the link between high road densities and elevated female mortality rates further, Alberta researchers found female survival was not only inversely related to road density, but low female survival also resulted in local population declines when road densities exceeded 0.75 km/km^2 (Fig. 2, Boulanger and Stenhouse 2014). The specificity of this effect will vary across Alberta and BC as a result of variation in traffic volumes, human lethality (tendency to kill bears), and habitat quality, but Boulanger and Stenhouse (2014) demonstrates the link between road density, female survival, and the potential for population decline.

When trying to understand grizzly bear population dynamics and the role of mortality, it is useful to consider the relationship between food resources and mortality. Food resources drive animal abundance (Hilderbrand et al. 1999, Sinclair and Krebs 2002, Carbone and Gittleman 2002, Brasher et al. 2007, McLellan 1994, 2011, 2015, Lamb et al. 2017, 2018b, Proctor et al. 2017). However, mortality rate can determine how close a population gets to

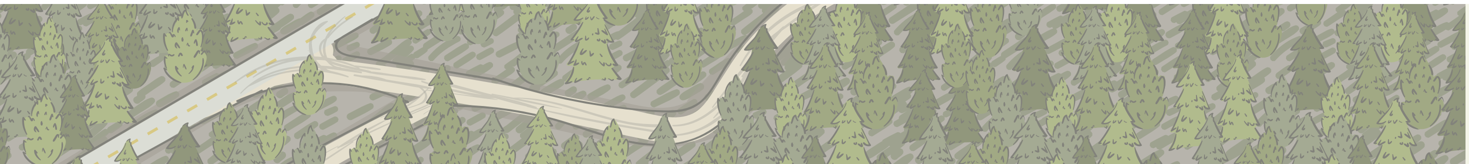
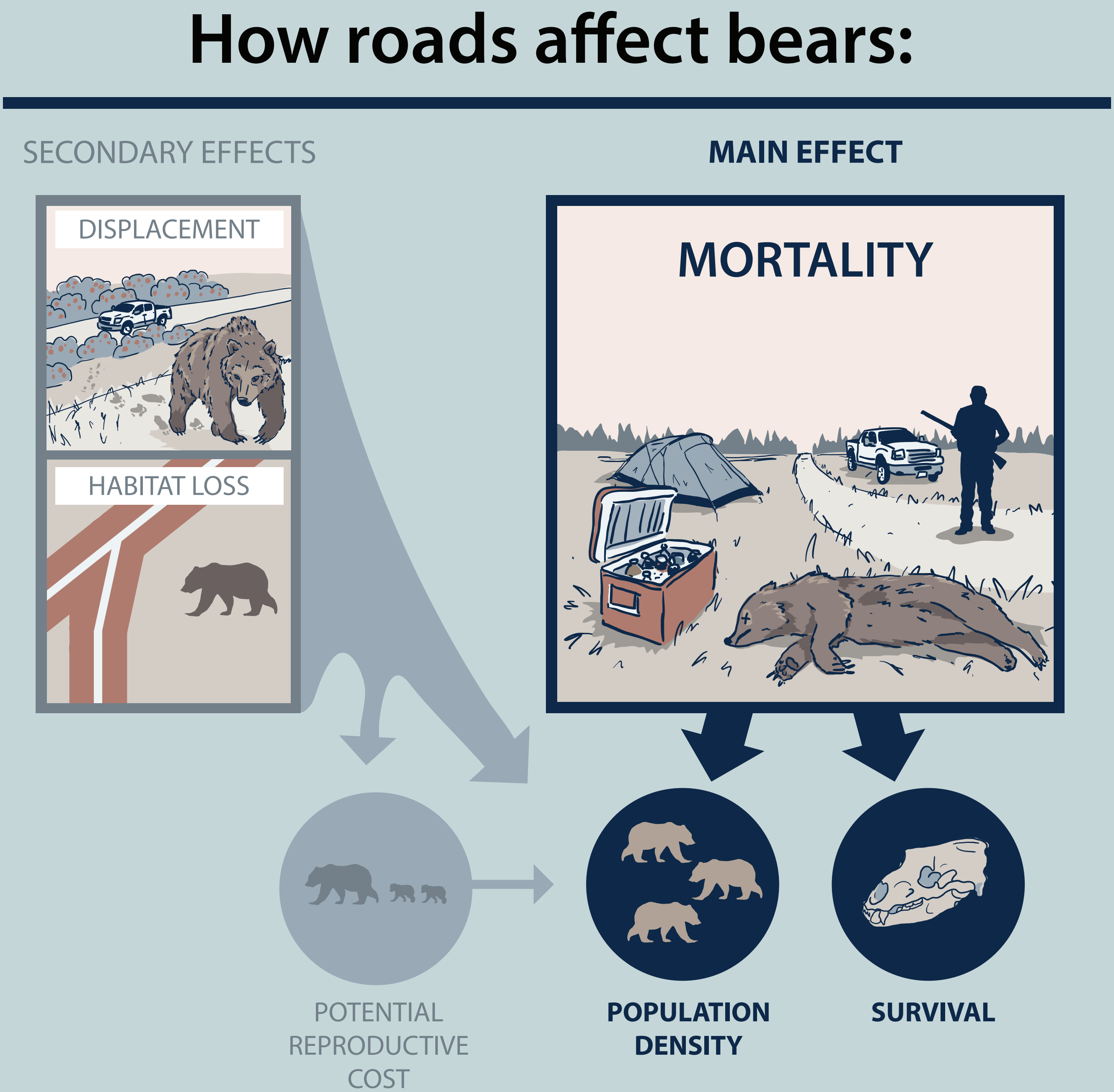


FIGURE 2.

Schematic of mechanisms of grizzly bear response to roads. The main effect of mortality ultimately reduces density. Secondarily, displacement and direct habitat loss potentially affect reproductive output and density.



its food-limited density and can have a significant influence on conservation status (Proctor et al. 2017, Lamb et al. 2017). Conservation status is not necessarily determined by bear density because it can naturally range by two orders of magnitude (100x) across North America (McLellan 1994, Hilderbrand et al. 1999, Mowat et al. 2013). Even though measuring potential grizzly bear density, or carrying capacity, is challenging, conservation status has been partly predicated on how far a population is below their potential density as a result of excessive human influence. A low-density population could be that way because food is naturally limited, while a higher-density population may be well below its potential because of human mortality, often a result of high road densities (Mowat and Lamb 2016, Lamb et al. 2017, 2018b).

Excessive human-caused mortality is the main cause of current grizzly bear conservation issues in several, but not all, population units in our region. For example, motorized access related mortality was the most important limiting factor in the plateau portion of a central BC study area near Prince George, but food was the most important limiting factor in the mountainous section (Ciarniello et al. 2007). Mortality was thought to be a major factor in a population decline in the South Rockies GBPU of southeastern BC that was likely initiated by a multi-year food shortage (Mowat and Lamb 2016, Lamb et al. 2017) as was documented in the adjacent Flathead Valley (McLellan 2015). While food resources set the potential density of these populations, conservation issues arose from excessive human-caused mortality.

In Alberta, a mortality risk analysis supported the hypothesis that human access (indexed by distance to roads) and edge habitats near water sources were important predictors of reported grizzly bear mortality (Nielsen et al. 2004a). A similar analyses in southeast BC examined a combination of reported and unreported mortalities and found similar results where road density, distance to roads, highways and lower elevation open habitats near riparian areas (often valley bottoms) best predicted grizzly bear mortality (Proctor et al. 2017). Both these studies used mortality databases that were skewed towards reported mortalities which are likely biased toward front country mortalities. Therefore their results may not accurately reflect unreported mortalities that occur in backcountry settings. Including a better sample of unreported mortalities in southeast BC, McLellan (2015) found 86% of the 26 radio-collared bears killed by people were within 120 m of a backcountry road when killed. Similarly, 20 years of radio collar bear data from across Alberta found 100% of all human-caused mortalities within 100 m of all-weather gravel roads or highways (G. Stenhouse, unpublished data).

The cumulative evidence is compelling; motorized road access into grizzly bear habitat does reduce grizzly bear survival, particularly females, and will usually affect density and sometimes conservation status.

Displacement

Displacement from habitat near roads has the potential to reduce grizzly bear habitat effectiveness, body condition, reproductive rates, and ultimately population density due to habitat loss (McLellan and Shackleton 1988, Mace et al. 1996, Hertel et al. 2016). Brown bears in Scandinavia decrease berry foraging in response to hunting pressure, causing a measurable nutritional cost likely resulting in poorer body condition and reduced reproductive success (Hertel et al. 2016). However, the full story on grizzly bear habitat use near roads is complex because roads can be both attractive and disruptive.

Roadside foods can attract bears under several circumstances. Roads are often associated with logging or oil/gas development where seeded roadside forage provides high quality nutrition for grizzly bears particularly in spring (Nielsen et al. 2004b). While these seasonally attractive foods can potentially improve female body condition and reproductive success, the benefits of roadsides are offset by reductions in survival (Mattson et al. 1987, Boulanger et al. 2013). To offset this mortality risk, some bears use roadside habitats at night (McLellan and Shackleton 1988, Martin et al. 2010, Northrup et al. 2012, Cristescu et al. 2013, Ordiz et al. 2011) or become habituated to nutritious habitats near roads and human developments in protected areas (Mattson et al. 1987).

Roads can be disruptive because bears generally avoid traffic (McLellan and Shackleton 1988, Berland et al. 2008, Graham et al. 2010, Roever et al. 2010, Northrup et al. 2012, Proctor et al. 2017, Lamb et al. 2018b). However, the degree to which habitat selection studies demonstrate “some degree of avoidance” of roads as opposed to a sample of bears that have succeeded in not dying near roads remains unknown. Consequently, road avoidance remains difficult to discern from survival in the absence of a manipulative or before/after study. Nevertheless, on average it appears that bears avoid roads with vehicular traffic but exceptions exist to this rule.

While grizzly bears tend to avoid roads at the individual level, especially those that receive moderate - high traffic volumes, there are important caveats to road influence at the population level. Roadside habitats in many cases do not provide limiting resources during some seasons (spring and late fall) and bears may avoid roads more when their populations are below carrying capacity when alternative and unused habitats are available, thus dampening any population level effects (McLellan 2015). We conclude that grizzly bears avoid open roads, but the evidence of individual (body condition and reproduction) and population level (density, trend) effects are less certain.

Spatial extent of road influence

The spatial extent of road-effects on female survival was variable in the literature. The quality of foods along roadsides also influences roadside habitat use and such use can vary by bear sex and age. The spatial scale at which roads and associated human presence affect grizzly bear survival and behaviour varied across studies, but is at a minimum 100 m (McLellan and Shackleton 1988), and up to 1000 m (Kasworm and Manley 1990). Most commonly, researchers reported the effects of roads extended to 500 m; bears avoided habitat and/or were killed within this distance (Mattson et al. 1987, Mace et al. 1996, Ben and Herrero 2002, Schwartz et al. 2010, van Manen et al. 2016). Therefore we recommend that 500 m be considered the width of influence when deriving road related metrics.

Habitat loss

There are approximately 750,000 km of resource roads (not including all OHV tracks) in BC. Assuming a road width of approximately 10 m, there is somewhere in the range of 7500 km^2 of vegetative habitat loss across BC due to road footprint (although some eventually re-vegetate). This represents ~1% of the 750,000 km^2 of occupied grizzly bear territory within BC. Likewise in Alberta the ~43,000 km of roads (not including all OHV tracks) in potential grizzly bear habitat (Boulanger and Stenhouse 2014) representing 0.25% of the 173,000 km^2 of grizzly bear range in Alberta. It is challenging to translate this habitat loss into an estimate of the number of bears lost, but is certainly > zero.

WHEN ARE ACCESS CONTROLS A BENEFICIAL TOOL FOR GRIZZLY BEAR CONSERVATION?

Motorized access controls can take many forms that range from legislation or signs to physical closures such as deep cross ditches or gates to re-establishing vegetation on road beds (see “Tools for managing access” section).

Both BC and Alberta have public policies to ensure the long-term sustainability of grizzly bear populations in their current distribution. Alberta has an official Provincial Recovery Plan (Alberta Environment and Parks 2016), and BC has a Provincial Conservation Strategy and Wildlife Program Plan (BC Ministry of Environment 1995, 2010). To realize those policies, the science suggests that both provinces should apply motorized access controls where road densities are high and grizzly bear conservation is a concern. There are large areas of grizzly bear distribution, particularly in northwest BC, where motorized access management may not be necessary due to current low road densities, but considering trends in resource extraction, road development, and increasing human populations, motorized access management should be on the radar of managers even in those areas. Much of southern and central BC and all of Alberta’s provincial lands have high road densities and bears would benefit from increased motorized access management. We recognize that motorized access controls have been applied effectively in some areas of each province. However, while much has been done, large tracts of heavily roaded bear habitat still exist. In this section we discuss the evidence behind our conclusions by looking into grizzly bear response to variation in human motorized access.

Female home range selection, bear density, and the 0.6 km/km^2 threshold

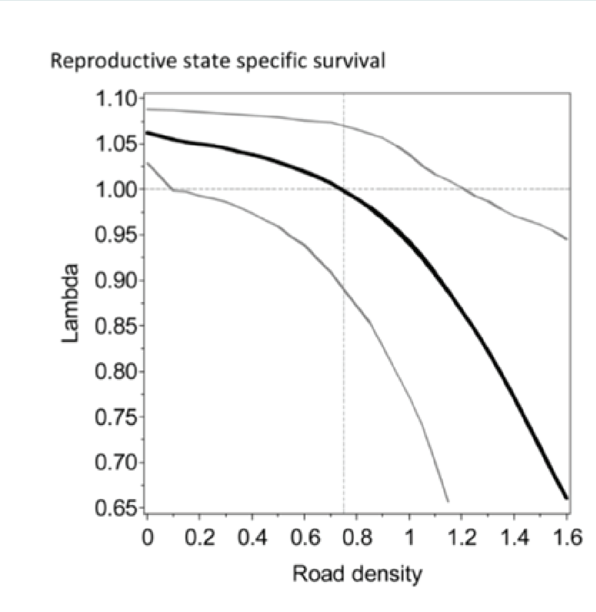
The U.S. has used motorized access controls as a cornerstone of their Threatened population recovery effort in the lower 48 states for 30 years; it has largely worked within their larger conservation management toolbox, and is supported by a body of science (Kendall et al. 2009, Mace et al. 2012, Schwartz et al. 2010). Other mortality reduction actions also were taken so it is difficult to tease apart the proportional influence for each concurrent action. Prior to 1993, there were at least 237 grizzly bears across 23,300 km^2 in the Yellowstone ecosystem (USFWS 1993, -136 in 1975, USFWS website https://www.fws.gov/mountain-prairie/es/GYE%20Grizzly-FAQs.pdf). That estimate has since grown to a minimum of 700 bears over 50,280 km^2 (van Manen et al. 2016, USFWS website https://www.fws.gov/mountain-prairie/es/GYE%20Grizzly-FAQs.pdf). The US Northern Continental Divide Ecosystem population grew from a crudely estimated 440-680 animals across 24,800 km^2 prior to 1993 (Mace et al. 2012, minimum estimates of 300 bears, USFWS 1993) to a data-based estimates of 765 in 2004 across 33,480 km^2 (Kendall et al. 2009), and has been increasing at approximately 3% annually (Mace et al. 2012).

Managers in the US applied a motorized access management system that allows for varying proportions of the planning area to have different road densities ranging from no roads to minimal roads to unrestricted road densities (regulations include OHV trails). Approximately 55-68% of the planning area must be > 500 m from an open road (i.e., roadless or 0 km/km²), ~19-33% should have a road density of < 0.6 km/km², and 19-26% may have > 1.2 km/km² total road density[1] (both closed and open roads). Landscape application of these rules and spatial patterns are flexible but it is suggested that these areas have at least a 10-year window of consistency to allow bears to adjust and benefit from secure habitat (W. Kasworm, USFWS Cabinet-Yaak Recovery Coordinator, pers. comm.). These rules were derived based on work by Mace et al. (1996) and Wakkinen and Kasworm (1997) who found these were the approximate conditions that surviving and reproducing female bears selected for in their home ranges within otherwise diminished remnant populations in northwest Montana. We are not advocating that this system be applied in Canada, but rather that elements of their system be considered. In the following paragraphs we outline the existing data in regards to the relationship between home range selection, population density, and road density.

The 0.6 km/km² road density threshold, first identified by Mace et al. (1996), has been roughly observed by other researchers in multiple study areas. However, note that not all researchers calculated road densities in exactly the same way; variation often depended of what digitized roads layers were available with several researchers including all motorized routes that included roads traversable by pickup trucks and trails suitable for only OHVs, while a few excluded OHV trails. Despite this variation, we feel the resulting patterns are meaningful. Mace et al. (1996) found that females were surviving and reproducing in areas with road densities < 0.6 km/km². The surrounding landscape where females were not found, had road densities of 1.1 km/km². Similarly, work in Alberta found that female survival was consistent with population declines in areas with road densities > 0.75 km/km² (Fig. 3, Boulanger and Stenhouse (2014). In the BC Granby-Kettle population, researchers found that the optimal threshold road density was ~0.5 km/km² (range 0.4 – 0.6) and that grizzly bear density was ~3-4 times higher in habitats with road densities < 0.6 km/km² than in habitats with > 0.6 km/km² (Fig. 4, Lamb et al. 2018b). Across the south Selkirk and Purcells Mountains of southeast BC

FIGURE 3.

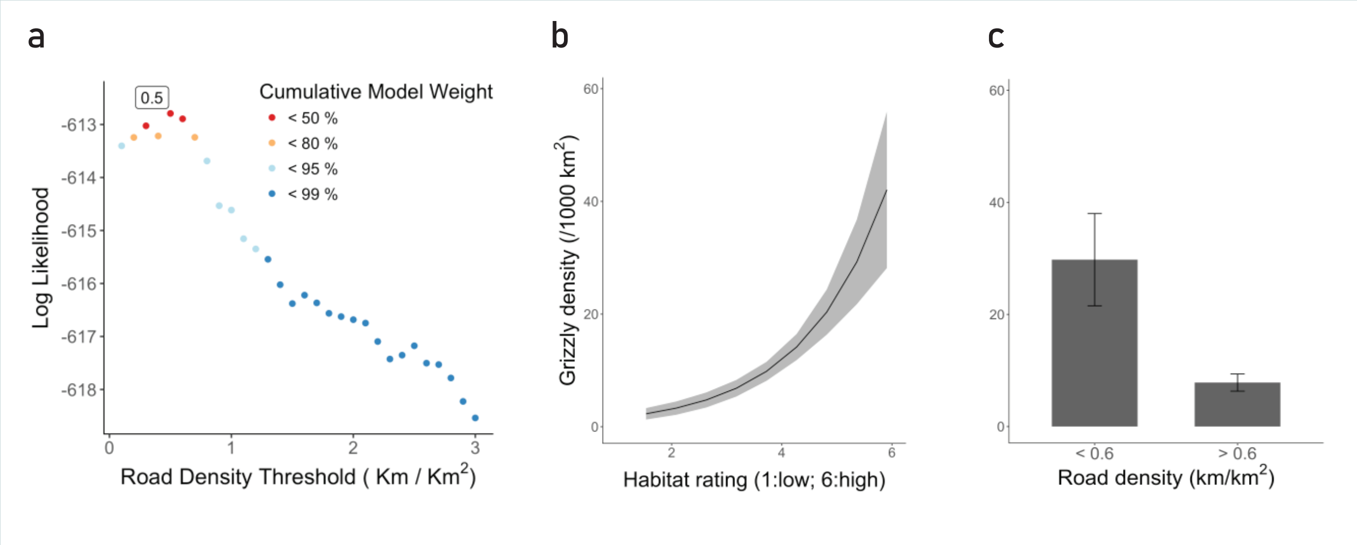
Road density threshold for stable population growth relative to female grizzly bear survival in western Alberta. Adapted from Boulanger and Stenhouse (2014). Areas with road densities > 0.75 km/km² correspondingly had Lambda (population growth), values below 1.0 representing a population in decline.



[1] These percentages do not sum to 100, because their categories overlap.

FIGURE 4.

a) The optimal road density threshold (0.5 km/km^2) in the Kettle-Granby Grizzly Bear Population Unit of south-central BC in 2015. The threshold was derived from the distribution of log likelihood values and cumulative model weights used to find an optimal road density breakpoint (best fit of the data when grizzly bear density was classified into two groups, above and below each breakpoint) for grizzly bear density and, b) Evidence of the positive relationship between habitat quality and bear density in the Kettle-Granby population as determined from the predicted responses of the most supported model. Road density was fixed to > 0.6 km/km^2 and, c) Grizzly bear density in habitats with road densities greater than and less than 0.6 km/km^2. Habitats with the lower road densities had much higher grizzly bear densities than areas with road densities above 0.6 km/km^2. Adapted from Lamb et al. (2018b).

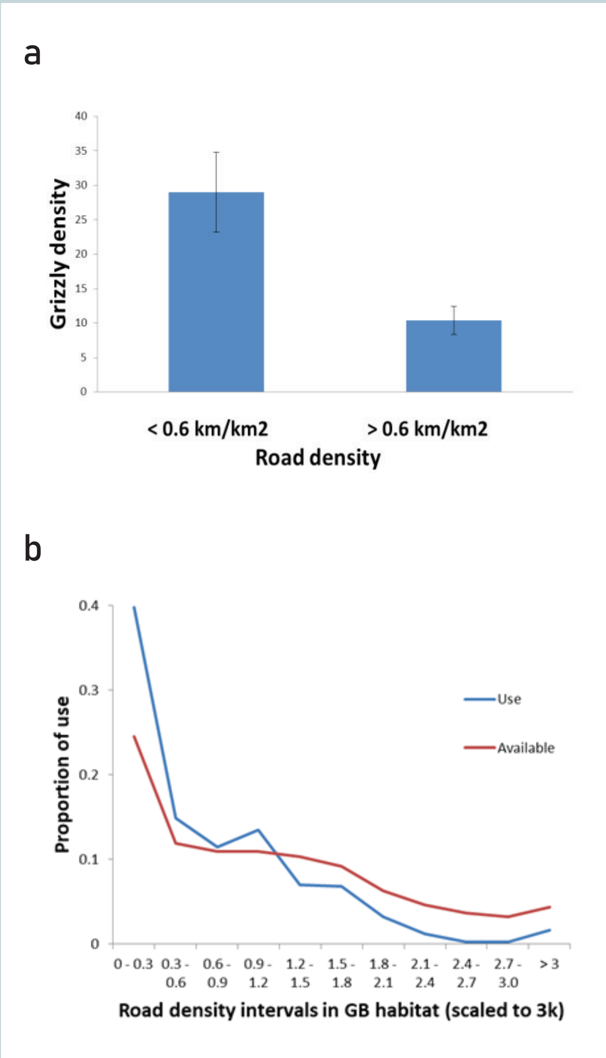


researchers found radio collared females selected and survived in home ranges with average road densities of 0.5 km/km² (Proctor et al. 2017). Similar to Lamb et al. (2017), Proctor et al. (2007) also found grizzly bear densities to be ~3 times higher in habitats with road densities < 0.6 km/km² relative to habitats with road densities > 0.6 km/km² (Fig. 5).

Home range selection as reported by Mace et al. (1996), Wakkinen and Kasworm (1997), Lamb et al. (2018b) and Proctor et al. (2017) is likely more a function of survival than active selection. That is, female bears tend to have a higher survival in habitats with lower road densities (Schwartz et al. 2010, Boulanger and Stenhouse 2014) therefore some portion of apparent home range selection reflects bears surviving longer in habtiats with fewer roads. In a multi-scaled analysis, assessing areas the size of daily use vs. the size of a female home range, researchers found bears were using habitats with higher road densities on a daily basis, yet their home ranges contained lower road densities on average.These results suggested that survival was more important than avoiding roads (Apps et al. 2013). So rather than refer to this as "home range selection", a more appropriately descriptive term might be "home range selection and survival".

FIGURE 5.

Differential grizzly bear density in the South Selkirk and Purcell Mountain habitats with open road densities above and below 0.6 km/km^2, and b) Female grizzly response to open road density, used (telemetry locations of bears, blue line) vs available habitat (all habitat in area, red line). Adapted from Proctor et al. (2017). Bears are more likely to use, or survive in, habitats with road densities below 0.6 km/km^2.



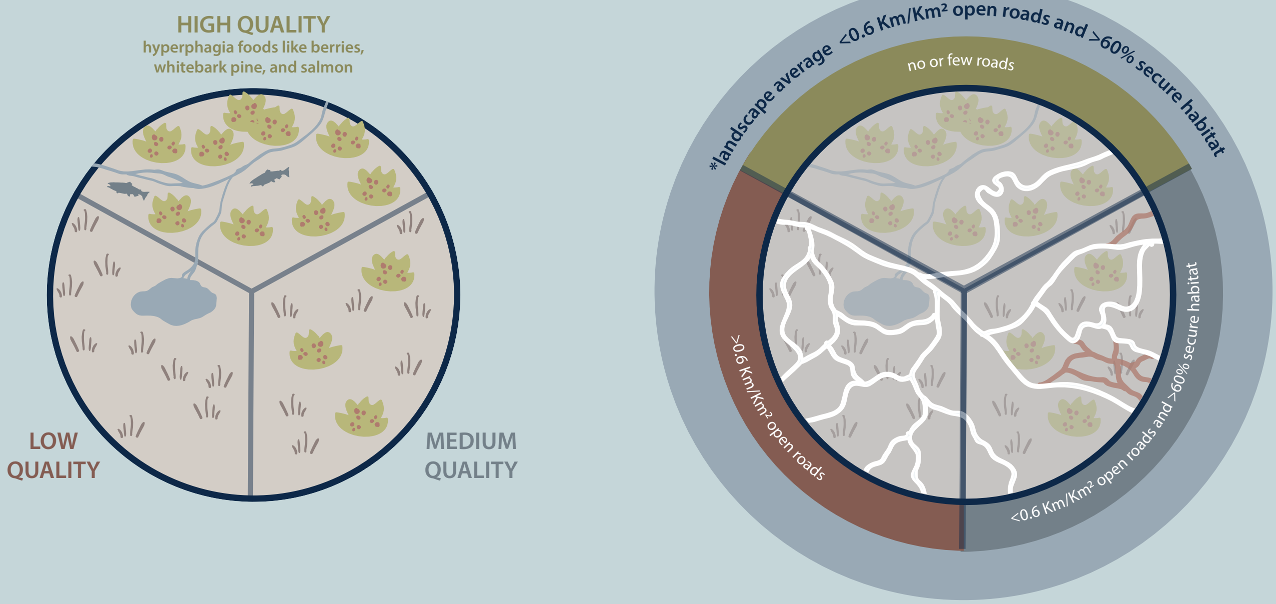
An interesting example is the Threatened Stein/Nahatlatch population in southwest BC (McLellan et al. 2016). Here, a small (≈10 adults), isolated and low density population declined from 7.4 to 6.5 bears/1000 km^2 between 2005 and 2015 even though there are only ≈0.2 km/km^2 of open roads (McLellan et al. submitted). This area has generally poor habitat quality that limits bear reproduction to where it can only compensate for minimal human-caused mortality and shows that a road network of 0.6 km/km^2 does not guarantee recovery or a sustainable population. When food is a limiting factor, as suspected in the Stein/Nathatlatch bear population, even a 0.6 km/km^2 road density may bring too much mortality risk for that population to recover or be sustainable until habitat management can yield a better food supply.

The Stein/Nahatlatch also demonstrates an important issue in road research and management. The road layer showing a road density of 0.2 km/km^2 was developed by removing all naturally closed roads impassable with an OHV while the government road layer shows a road density of ~0.6 km/km^2. This discrepancy suggests that we need consistent and equivalent road layers within and across our provinces. We suspect that the rate of road degradation through landslides and vegetative growth is faster in the wet, rugged Coast Mountains (where the Stein/Nahatlatch population is located) and interior wetbelt than in the dry interior.

Although road densities matter to grizzly bears, thresholds might occasionally be population specific. For example, in the Flathead Valley (Wildlife Management Units 4-01) of southeast BC, a DNA-based survey in 2007 yielded an estimated density of 65 bears/1000 km^2 across the 1585 km^2 management unit. Unit 4-01 is a small area with a high density of bears where the open and restricted road density is approximately 1.2 km/km^2. In the southern half of this unit, where bear densities are the highest, there were 0.74 km/km^2 of 2-wheel drive roads plus 0.9 km/km^2 of smaller, often ephemeral roads (McLellan 2015). This is a very productive area and bear

FIGURE 6.

Schematic of how landscape level motorized access controls might look when applied relative to grizzly bear habitats. Berry fields and salmon streams represent important energy-rich hyperphagia food habitats there would be very few or no roads. Areas of medium quality habitat would be associated with < 0.6 km/km^2 open road densities and > 60% secure habitat > 500 m from open roads that might see some roads restricted or temporarily closed (brown lines) and lower quality habitats are associated with road densities > 0.6 km/km^2. These areas could be managed to control access such that the overall area has patches > 60% secure habitat and < 0.6 km/km^2 road density.



reproductive rates can compensate for a higher level of human-caused mortality better than most other areas; the Flathead population unit had the highest density of human-caused deaths of grizzly bears in BC. Furthermore, in this management unit, a natural separation of critical foods and roads, coupled with decades of strategic motorized access management, have helped to enable continued resource development and a high density of bears. The most important summer and early fall habitat for grizzly bears was higher elevation, post-forest fire areas where huckleberries were plentiful and the habitat was essentially roadless. The most important spring habitats in this area are riparian areas and avalanche chutes where some roads have been closed or have naturally grown over. Areas of high road densities were restricted to the broad, lodgepole pine and clear-cut dominated valley bottom that is generally of less value to grizzly bears. Also of importance, the entire area is over an hour drive from the nearest permanent human settlement so the roads see little public use except during the fall hunting season.

The Flathead example demonstrates a relevant and well documented example of how the relationship between roads and habitat quality is important when setting open road motorized access targets. First, having no or very few roads in the higher quality habitats with important food resources (in this case, large huckleberry fields) across the late summer and fall (i.e. ungulate hunting season) hyperphagia (intensive feeding to gain weight for winter hibernation) season, has been very beneficial to grizzly bear reproductive rates, survival, and ultimately bear densities (McLellan 2015). This supports our conclusion that management consider no or low road densities around the best habitats when possible. Second, the Flathead example supports a moderate density of roads in medium quality habitats especially during non-limiting seasons such as spring. And third, in areas of less productive habitats, there has been little motorized access control (Fig. 6). Such a motorized access management strategy, where there is no motorized access to very important habitat, would likely work in other areas with outstanding food sources such as along the limited stretches of salmon spawning streams where bears can more easily catch fish.

Restricted roads vs totally closed roads

Researchers in southern BC found that female bears did not avoid restricted roads (roads only open to the forest industry) whereas they avoided roads open to the forest industry and the public (Wielgus et al. 2002). In southern Alberta, researchers found that roads closed to the public were not avoided by bears, and habitats near those roads were used at similar levels to unroaded areas (Northrup et al. 2012). Another study looking at grizzly bear habitat use and response to mining activity, during and post-mining, found that females with cubs were more likely to tolerate mining activities than other cohorts of bears (Cristescu et al. 2016). These examples suggest that industrial use of roads may not be as detrimental to grizzly bears as recreational use of roads that are open to the public. Indeed, areas with total road densities > 0.6 km/km² can sustain grizzly bear numbers representative of the overall habitat quality if some proportion of roads are closed (or restricted) to the public (Lamb et al. 2018b)

Grizzly bear response to secure habitat

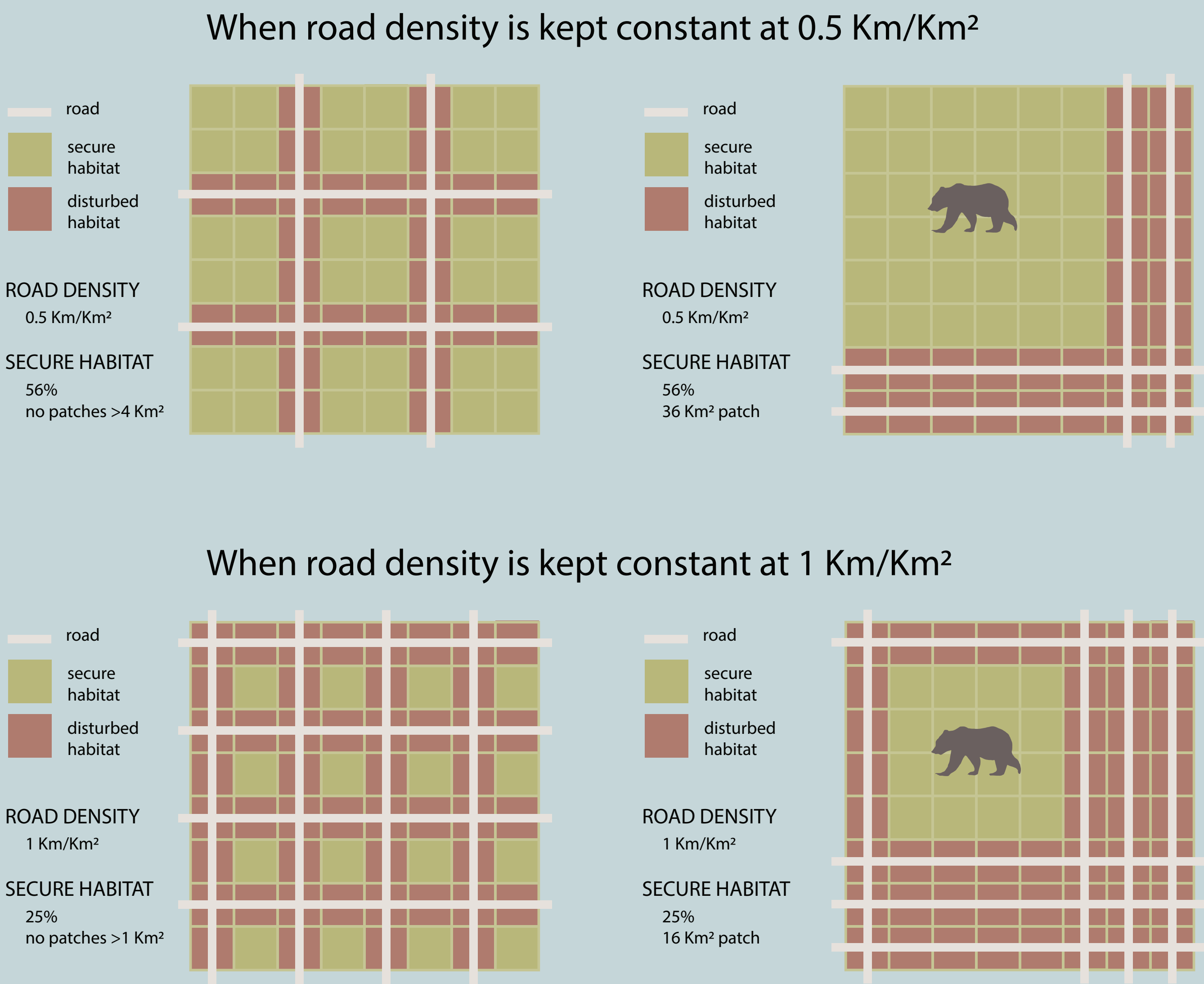
In addition to road densities, female home-range selection and/or survival was also related to the proportion of habitat > 500 m from an open road (Fig. 7, termed 'secure habitat' by most authors). Studies in northwest Montana's Rocky Mountains found female grizzly bears selected for and survived in home ranges with 56% secure habitat as compared to 30% secure habitat outside the composite female home range (Mace et al. 1996). Consistently, to the west, female grizzly bears selected and survived in home ranges with 55% secure habitat relative to 23% -34% secure habitats in the greater area of the Yaak and Selkirks Mountains (Wakkinen and Kasworm 1997). Across the border in Canada, researchers found female grizzly bears selected and survived in secure habitats with 74% secure habitat as compared to available habitats with 56% secure habitat (Proctor et al. 2017). The Canadian study measured secure habitats in patch sizes > 9 km² as suggested by Gibeau et al. (2001) to provide females with lower mortality risk within their average daily movement areas. The distribution and configuration of roads can influence secure habitat patch sizes significantly (Fig. 7). Evenly spaced roads, even at an otherwise acceptable road density, can provide very little security in patches within the range of average daily movements, requiring that bears cross roads multiple times daily to meet their needs. These patterns suggest that road density and secure habitat with minimum patch-size, should be included in motorized access targets.

In the U.S. Yellowstone ecosystem, road densities and the amount of secure habitat within female home ranges had a large influence on their survival (Schwartz et al. 2010). Both road density and the proportion of secure habitat contributed

FIGURE 7.

Schematic of the relationship between road density and the proportion of secure habitat. Evenly spaced roads across a unit can result in small patches of secure habitat (i.e. areas > 500m from an open road) that require female grizzly bears to cross roads often during a day (panels on left). Managing road distribution to yield larger patches of secure habitat (panels on right), even at similar road densities, should benefit females and result in healthier grizzly bear populations.

Road distribution matters:



different yet important components influencing survival: road density had more influence on survival as the proportion of secure habitat within female home ranges decreased.

Fragmentation as a result of excessive roads

Roads have been shown to disrupt bear movements influencing dispersal away from the maternal home range and ultimately influencing population-level fragmentation. In northwest Montana (Graves et al. 2014) and Scandinavia (Bischof et al. 2017) backcountry roads imposed resistance to dispersal, although no links were identified to population-level consequences. In a large landscape investigation, researchers found that human-caused mortality, when combined with settlement patterns and highway traffic, was responsible for extensive population fragmentation across much of southeast BC, western Alberta and northwest US in occupied bear territory (Proctor et al. 2012): road densities were the most influential variable in mortality risk of grizzly bears across their study area (Proctor et al. 2017). Further work in BC went on to reveal mechanisms that included human settlement patterns and excessive human-caused mortality, to which high road densities and human settlement were likely contributors (Lamb et al. 2017, Mowat and Lamb 2016); corroborating and further explaining population-level fragmentation caused by Highway 3 through the Canadian Rockies (Proctor et al. 2012). In other work, detailed analyses of movements of 38 GPS-collared grizzly bears in the BC Highway 3 area of the Rocky Mts. found that the main highway reduced the odds of crossing movements by 44% while industrial main lines (forestry and energy sector roads) reduced the odds of crossing movements by 9 to 20% (Apps et al. 2013). Only the main highway (~3700 vehicles/day) blocked movements of about half the collared bears while all bears crossed less-busy roads (Apps et al. 2013). These examples reveal the link between excessive road densities and fragmentation.

CONCLUSION 1

Motorized access has been shown to influence grizzly bears at the individual and population levels. People in motorized vehicles affect grizzly bear habitat use, home range selection, movements, population fragmentation, and demography including survival and reproduction, which ultimately affects bear density, population trend, and conservation status. Integrating habitat quality into road management improves the efficiency and effectiveness in reaching management goals, such as managing for few or no roads within 500 m of habitats containing late summer and autumn hyperphagia (energy-rich) food resources such as major berry fields, salmon streams where bears can effectively catch fish, and high quality whitebark pine stands. Further, in populations with moderate habitat quality and close to human settlements, road densities near 0.6 km/km^2 with > 60% secure habitat (i.e. > 500 m from an open road) are meaningful thresholds that if not exceeded, female grizzly bears may have sustainable survival rates. In other areas, population-specific thresholds may be appropriate, such as where conservation is a major concern because poor habitat quality limits reproductive rates and very little human-caused mortality can be sustained. In areas that are further from human population centers and have large patches of high quality habitat, the bear population could tolerate higher overall road densities provided large, high quality patches have no roads.

WHERE TO APPLY MOTORIZED ACCESS CONTROLS

In this section we consider where motorized access controls might be applied. First, we look at the conservation status of population units. Second, we examine geographic scale at which it is most efficient and effective to monitor and apply road management. Third, we look at specific habitats that would be most beneficial for application of motorized access controls.

Conservation status

While it is important to manage all population units for long-term sustainability, different ecological or anthropogenic factors result in varying conservation risk among populations. We therefore view threatened, or populations of conservation concern (declines, unsustainable mortality rates, or high human footprints), as a first priority for motorized access management consideration. Managers should examine the causes for threatened status - long-term food resource declines, excessive human-caused mortality related to front country conflicts, back country road-related mortality and habitat security declines, or some combination of the four. When back country mortalities and habitat displacement are involved and population recovery is a management goal, closing roads that enter any of the higher quality habitats should be a priority. If the overall road density is over 0.6 km/km^2 and there is < 60% secure habitat, then efforts should be made to continue to eliminate roads in the better habitats until these targets are met.

A second priority would be population units that are partially or well connected to adjacent units. Some units may be population sinks for a larger region providing greater incentive to consider access controls to improve habitat security and recover these areas. Further, linkage areas (e.g. Proctor et al. 2015) that have the potential to allow genetic and demographic exchange between neighbouring populations should be candidates for motorized access controls. In all cases, threatened status is exacerbated by lack of inter-area connectivity, and occasionally might be the sole cause of their threatened status. Managing for improving secure habitats in linkage areas will improve the chances of successful inter-area connectivity leading to more sustainable populations.

Finally, we recommend that areas with significant resource extraction planned, that otherwise have a relatively high wilderness character, would benefit from motorized access planning as resource industries develop. Public acceptance of motorized access controls will be easier on new roads than those that have a tradition of use.

Population, management unit, or watershed scale

The scientific literature is less clear on what scale is most appropriate when applying road management. The distribution of quality habitats and important food resources will influence, to some degree, the spatial configuration of management strategies. Motorized access monitoring and control management may best be carried out at scales that optimize the protection of important habitats to benefit the distribution, survival, reproduction and density of females across a broad area.

Both Alberta and the lower 48 states of the U.S. have chosen to manage road density within geographic areas that approximate the size of several overlapping adult female home ranges (~200-500 km², Alberta Environment and Parks 2016, USFWS 1993). Their respective logic is to partition road density targets across larger population units so as to not cluster low road densities within only one portion of a larger population unit, thereby conferring some habitat security for females across the larger population unit. The U.S. example has the strength of a successful decades-long recovery program behind it.

BC is not currently managing for road density across the province, but has several local initiatives. Within BC there are several scales typically used to manage wildlife and ecosystems. Grizzly Bear Population Units (GBPUs, average size ~13,500 km²) are the legal units in which grizzly bears are assessed for conservation status. While this scale is useful at a coarse level, our experience suggests that this scale is too large for effective motorized access management. Conservation benefits may accrue when motorized access controls are monitored and applied at scales small enough to benefit female grizzly bears across the larger GBPUs. In many cases the Wildlife Management Unit (WMU, average size 3800 km²) may be more appropriately sized and in some cases the Landscape Unit scale (average size 800 km²) may be best. This decision will depend on local conditions. Smaller geographic areas may benefit grizzly bears as managers spread out motorized access controls to the benefit of more females. On the other hand, geographic areas that are too small can create excessive workloads on managers. This issue might resolve itself, because habitat structured motorized access plans will require assessments at the scale of the drainage and many drainages make up a WMU, so ultimately managers must work at several scales.

Which habitats are best for motorized access controls?

To understand the relationship between human motorized access and grizzly bear habitat, it is useful to explore the relationship to habitat quality, important food resources, human motorized access, and the seasonality of human-caused mortality.

How are habitat and food resources related to road densities?

Where grizzly bears and humans overlap, population dynamics of grizzly bears are driven by interrelated forces. Food abundance and quality affects individual and population productivity (Sinclair and Krebs 2002, Carbone and Gittleman 2002, Mattson et al. 2004. Rode et al. 2006, McLellan 2015, Proctor et al 2017) and density (Hilderbrand et al. 1999, Mowat et al. 2013); human-caused mortality may also limit population growth (McLellan et al. 1999, Schwartz et al. 2010, Boulanger and Stenhouse 2014, Lamb et al. 2017). Researchers brought these forces together to identity source (bears are increasing) and sink (bears are declining) habitats across Alberta and eventually incorporated food resources and human-caused mortality risk into habitat models. They argued that understanding and integrating these functional drivers are required to better inform management (Nielsen et al. 2006, Nielsen et al. 2010, Boulanger et al. 2018). In other related Alberta research, grizzly bears in the foothills of central Alberta that used mixed ages of young regenerating forests were found to gain more weight than bears using older forests, but those advantages were offset by lower survival rates associated with higher road densities (Boulanger et al. 2013). In the southern Rocky Mountains of southeast BC, higher grizzly bear densities occurred in an area with higher overall road density but with large unroaded huckleberry fields (see Flathead example discussed in section 'Female home range selection, density, and the 0.6 km/km² threshold', McLellan 2015). These results showed that abundant and secure food in late summer/fall habitats regulated this population (McLellan 2015).

Inspired by these insights, two efforts linked food and mortality risk in different analyses in southeast BC. First, in the southern Rocky Mountains, researchers linked important foods with mortality risk and found that berry resources, kokanee salmon (*Oncorhynchus nerka*), and anthropogenic food sources (fruit trees, livestock, garbage and ungulate carcasses) likely acted to bring bears and humans into direct contact increasing bear mortality and contributing to a population decline (Lamb et al. 2017).

Second, in BC's south Selkirk and Purcell Mountains, researchers developed highly predictive models for grizzly bear seasonal habitat use, density, and fitness from a combination of a spatialized food patch layer using the region's primary hyperphagia food resource – huckleberry patches – and human motorized access layers (Proctor et al. 2017). They found that across all individual and population-level scales tested, food patch variables were the most influential predictors, while road density was also a significant and additive contributor to predicting realized habitat effectiveness. While not a direct assessment of foods and mortality risk, recent work in Alberta linked habitat quality (as a surrogate for food resources) to mortality risk. That pan-Alberta meta-analysis found habitat quality was most important in the northern population units and mortality risk was the key driver in southern units. These results demonstrate the spatial (and likely temporal) drivers of density differ by area and landscape conditions (Boulanger et al. 2018).

All the above studies reveal the complex and intertwined relationship between food resources and mortality risk. Their relative influence varies spatially and temporally and suggest that to benefit bears, food and motorized access are better kept apart.

While berries are important in many areas, various energy-rich foods drive the productivity of bears in other ecosystems across BC and Alberta, including salmon, ungulates, whitebark pine nuts (*Pinus albicaulis*), buffalo berries (*Shepherdia canadensis*), sweet vetch (*Hedysarum spp.*), and combinations of these and other important foods. To deposit fat needed for successful reproduction and hibernation, these foods are eaten in late summer and fall, concurrent with the ungulate hunting season. In the BC population unit with the highest legal hunter kill density in BC (Flathead), as many female grizzlies were killed in the autumn by ungulate hunters due to human-bear conflict as were in the spring by grizzly bear hunters. Keeping roads away from important energy-rich food sources not only enables females to focus on getting fat for hibernation but also keeps ungulate hunters away, who sometimes kill these bears due to perceived self-defence (McLellan 2015). From a management perspective, it would be most beneficial to maintain low or no road densities in areas with an abundance of important bear foods and allow more roads in lower-quality habitats.

The proximity between humans and bears can also vary by season. For example, spring green up, summer and fall natural food fluctuations, and fall ungulate hunting seasons can all bring bears to lower elevation valley bottoms where they are closer to people and roads resulting in high mortality rates. These spatial conflicts could be mitigated by seasonal road closures or by directly mitigating the cause of mortality, for example by electric-fencing hunting camps. Finally in some areas, timber harvest can improve foraging resources for bears, and may require post-harvest access management to realize this benefit for bears (Boulanger et al. 2013).

Current knowledge of quality habitats and foods across BC and Alberta

In parts of BC and Alberta, high quality habitats have been identified through telemetry studies and local knowledge, but mapping of specific food sources varies across these provinces. Habitat-quality maps have been created by several researchers for a variety of areas including Alberta (Nielsen et al. 2006, 2010), southeast BC (McLellan and Hovey 2001; Proctor et al. 2015, 2017), southwest BC, (Apps et al. 2014, McLellan (et al. submitted); Central BC (Ciarniello et al. 2007), northern BC (Milakovic et al. 2012), and the interior-side of the Coast Mountains (Iredale 2016). Food layers have been developed for portions of Alberta (Nielsen et al. 2010) and a small portion of BC (Lamb et al. 2017, Proctor et al. 2017). In large areas of BC these types of data are missing, although regional biologists and foresters often know the location of the major berry fields, salmon-spawning areas, whitebark pine stands, and/or areas of high ungulate density.

CONCLUSION 2

Our consensus of prioritizing the use of motorized access management across occupied grizzly bear terrain was that "Threatened", or populations of conservation concern (documented or suspected population declines, excessive reported mortality, and areas with high human footprints), were a first priority.

Next, we conclude that habitat quality is an integral part of understanding grizzly bear road responses and if integrated, will increase the efficiency and effectiveness of road management programs. Therefore, managers should allow for habitat security with zero or low road densities in high quality foraging habitats where major summer/fall hyperphagia energy-rich food sources are used heavily. This could entail maintaining low road densities in current safe habitats (where habitat quality is high and mortality risk is low) and applying motorized access controls in areas of sink habitats (where habitat quality and road densities are high). In some instances, when lower elevation spring or fall habitats have high mortality risk, access controls should be considered. Also, in some habitats, timber harvest can temporarily improve the foraging resources for bears. When this is the case, post-harvest motorized access controls may be necessary to provide habitat security for females to realize this benefit.

The third priority is protection for areas within and adjacent to identified linkage areas between population units to allow bears to move safely among occupied habitats, including connected sink habitats that may be affecting a larger area. Given that it is much easier to manage motorized access before the public begins using the road, the final priority is areas with increasing road densities due to recent or planned industrial activities such as increased resource extraction in northeast BC and portions of Alberta.

We conclude that motorized access is best monitored and applied across smaller geographic areas to optimize the protection of important habitats to benefit the distribution, survival, reproduction and density of females across a broad area. Most jurisdictions manage motorized access across areas ~500-800 km2, the approximate size of several overlapping female home ranges. Incorporating habitat quality into management strategies will require working at these smaller scales, but across BC, in some cases, larger units may be more practical.

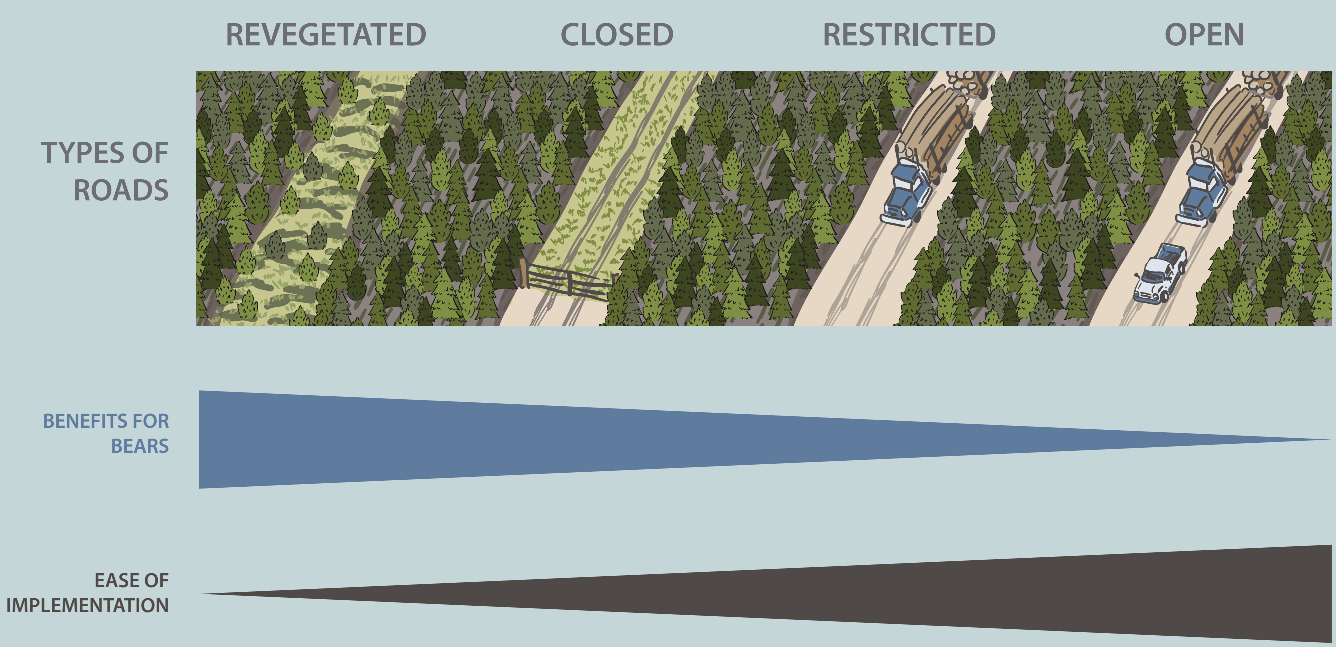
HOW MIGHT MOTORIZED ACCESS CONTROLS BE APPLIED?

While the relationship of grizzly bears to their basic food requirements and response to human pressures are similar across ecosystems, differences in ecology, natural resource industries, and land use decision traditions, make it inevitable that management approaches will differ between political jurisdictions.

There are several road control designations that may be used in motorized access control management systems. Roads may be revegetated, closed by a gate or their equivalent, restricted to certain segments of society (hunters, or the public, for example), or completely open. From a societal perspective,

FIGURE 8.

Types of motorized access controls relative to ease of implementation and benefit to grizzly bears.



there is a balance between human use, ease of implementation and what benefits grizzly bears (Fig. 8). While there is no consistent science-based estimate of what total road (open and closed) density might be conducive to grizzly bear, habitat, and biodiversity conservation, we suspect there is a threshold beyond which there are measurable negative impacts to grizzly bears (and other species) at both the individual and population level. A landscape saturated with roads would not be conductive to productive grizzly bear populations, even if they were closed. We encourage land use managers developing access rules to consider such a metric that includes the ecological needs of grizzly bears, but also a wider spectrum of biodiversity (amphibians, reptiles, fish, birds, small mammals, ungulates, carnivores, etc.) and overall habitat (erosion, terrain stability, water pollution, etc.) conservation.

Synthesis on how motorized access management could be improved in BC and Alberta.

In the following sections, we describe the situations, and discuss options for access management, in Alberta and BC separately while recognizing that both provinces have some level of motorized access management already in place. For this discussion, we intend road density to mean **open road density.** Restricted roads are not open to the public but may allow industrial access. Closed roads are closed to everyone. Roads may be open, restricted, or closed permanently or seasonally to use by motor vehicles.

Alberta

Grizzly bears are considered Threatened across Alberta with an estimated ~900 bears spread across 173,000 km^2 of occupied grizzly bear habitat (Festa-Bianchet 2010, Alberta Environment and Parks 2016). Alberta has developed a Province-wide Recovery Plan (Alberta Environment and Parks 2016) and manages grizzly bears within a series of 7 Grizzly Bear Management Areas (BMAs, Fig. 9a) with a mean size of 24,762 km^2. The average density of grizzly bears in Alberta is ~4.3/1000 km^2. BMAs are separated by genetic discontinuities through Alberta, mediated by major east-west highways but are each connected with populations in BC (Proctor et al. 2012).

Road networks in Alberta grizzly bear territory mainly exist outside the mountain parks along the east front of the Rocky Mountains (Fig. 1). Road management is being applied in Alberta in response to, and in accordance with, results of several province-wide studies that provided the best available science after considerable research into the relationship between road density, female survival, localized population trend, and source-sink population dynamics (Nielsen et al. 2004a, 2006, 2009, 2010, Boulanger et al. 2013, Boulanger and Stenhouse 2014).

Road density management is planned at the scale of Grizzly Bear Watershed Units (Fig. 9b, GBWUs, ~500 km^2, Alberta Environment and Parks 2016), the approximate size of several overlapping female home ranges, to partition road density management across the larger BMAs. Alberta has developed a habitat-structured access management system by delineating its provincial grizzly bear range into Core and Secondary areas (Fig. 9c, Nielsen et al. 2009) except in the northern BMA 1 where data were insufficient.

Core areas were identified within each BMA as areas of higher habitat quality, a indexed by high scores within ecological models, and security, as indexed by low road densities. Secondary areas were identified to connect or buffer Core areas. Road densities in identified Core area watersheds on provincial lands outside of National Parks have a target road density < 0.6 km/km^2 although several GBWUs exceed this target (Fig. 9b & c, Nielsen et al. 2009). Core grizzly bear areas are spatially linked and contiguous along the eastern slopes of the Rocky Mountains in Alberta. This system was designed so core areas maintained high quality grizzly bear habitats with lower human-caused mortality risk.

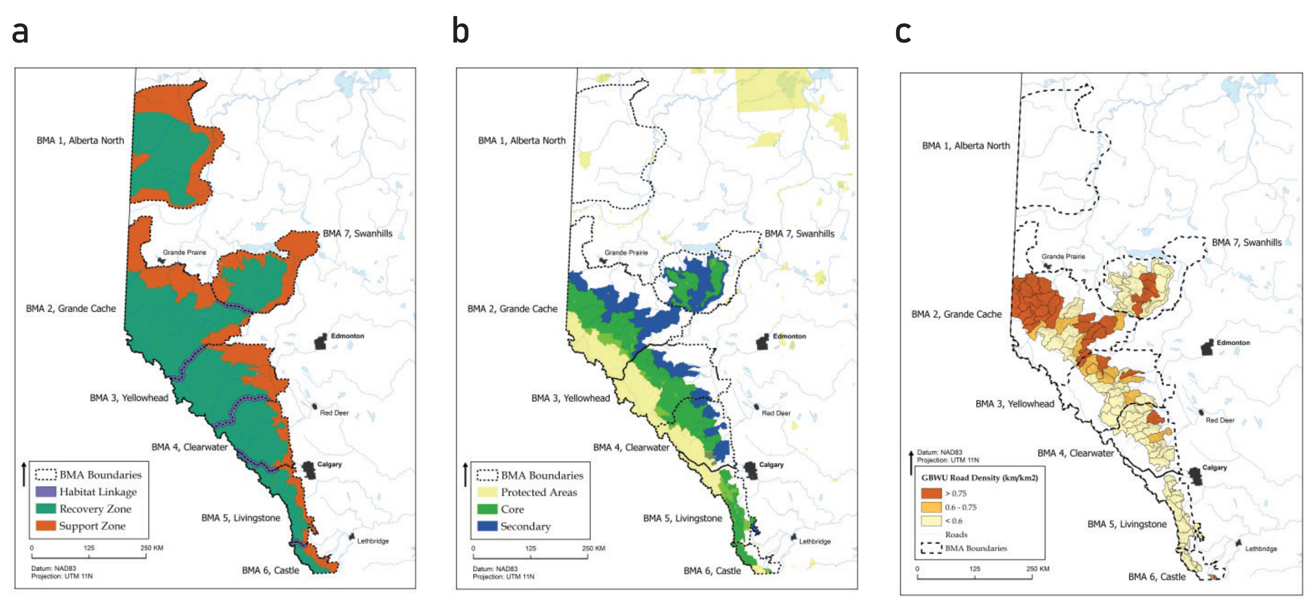
Secondary areas, generally to the east of Core areas, were also delineated using a combination of medium habitat quality (medium scores within ecological models) and somewhat higher open road densities. Recent work suggested open road densities > 0.75 km/km² were associated with sink habitats, the current target in Alberta's Draft Recovery Plan (Alberta Environment and Parks 2016). Currently, a large proportion of GBWUs exceed the new target road density of 0.75 km/km² (Boulanger and Stenhouse 2014, Fig. 9c).

Grizzly bear population inventory data collected within the Alberta provincial BMA's (2004-2008 and 2014), have shown the majority of grizzly bears were found within Core areas and lower numbers were found within Secondary areas. (Stenhouse, unpublished data).

Although there are open road density thresholds for grizzly bear conservation areas in Alberta, there are regional differences in how these are being implemented. Currently within Alberta, OHVs are not excluded as are pickup trucks and cars on restricted roads. There also is a lack of clarity on what will constitute a "closed or restricted" road that will not be counted within open road density calculations within watersheds inside each BMA. However, many resource extraction industries are changing access

FIGURE 9.

a) Grizzly Bear Management Areas across western Alberta (Alberta Environment & Parks 2016, b) Core and Secondary habitats across grizzly bear distribution in western Alberta (adapted from Nielsen et al. (2009), and c) Road density by Grizzly Bear Watershed Units across 7 BMAs in western Alberta (Alberta Environment & Parks 2016).



management practices related to road planning within grizzly bear conservation areas in the province. In addition to these challenges, there remains the need to develop and implement strategies to reduce current open road densities in identified watersheds (Boulanger and Stenhouse 2014) and this will be more challenging with the new open road density standard (0.75 km/km 2) in secondary conservation areas.

Examples of road management include units in southern and central Alberta. In 2017, the Alberta government announced the creation of two new conservation areas within BMA 6 in the south west corner of the province, the Castle Wildland Provincial Park and the Castle Provincial Park. A key element in the management of these areas is restrictions on motorized access to reduce open motorized road densities and thus human-caused mortality. The Swan Hills (BMA 7) population unit in central Alberta is geographically connected to BMA 2 (Fig. 9a) and current genetic data suggests a weak genetic break between these two management areas (Proctor et al. 2012). This is cause for concern and the current Secondary area, essentially a linkage between these 2 units, has open road densities that exceed the 0.75 km/km 2 target. Industrial development and associated road building continues in this linkage area and motorized access management planning is needed to reduce current open road densities and develop coordinated motorized access management plans with industry to ensure the BMA 7 grizzly bear population unit does not become an “island” population of bears.

British Columbia

The relationship between grizzly bear habitats and roads in BC is more complex than in Alberta. In BC there are an estimated 15,000 grizzly bears across an area of approximately 750,000 km^2, or more than 16 times as many bears across more than 4 times the occupied area of Alberta. The average grizzly bear density across BC is ~23 bears/1000 km^2 (BC Ministry of Environment 2012) more than 5 times as high as Alberta bear densities. BC’s grizzly bears are managed within 55 diverse Grizzly Bear Population Units (GBPUs) that average ~13,500 km^2 in size. GBPUs contain smaller designations, Wildlife Management Units (WMUs), of which there are 183 containing grizzly bears with an average area of ~3800 km^2. Landscape Units (LU) are a yet smaller designation and the 940 in BC are approximately the size of several overlapping female home ranges (~800 km^2), similar to Alberta’s GBWUs. While the greater spatial area and diversity of habitat types in BC mean that management also may be more variable than in Alberta, we expect that the response of female grizzly bear survival and displacement due to open roads to be similar in both provinces.

Road densities in north-central and northwest BC are generally below 0.6 km/km^2 (Fig. 10a), but the location of critical food resources for grizzly bears are generally undocumented, and thus likely unprotected. Much of central, southern, and northeast BC have road densities that exceed 0.6 km/km^2 (Fig. 10a) and critical food resources are mapped for only a small portion of these areas. There is no overarching grizzly bear management plan across BC that includes road densities and motorized access targets, however, there have been several regional initiatives.

Examples of “threatened” population units in BC include the Granby-Kettle and South Selkirk (see side bar). The Granby Kettle unit has an average road density of ~1.6 km/km^2 (Lamb et al. 2018b). This population has doubled in size over the past 20 years, likely influenced by reduced mortality rates due to a recently created provincial park that has no roads and includes an associated motorized access management buffer (Lamb et al. 2017). By far, the highest densities of bears in this unit are in areas of road densities < 0.6 km/km^2 (Fig. 4b).

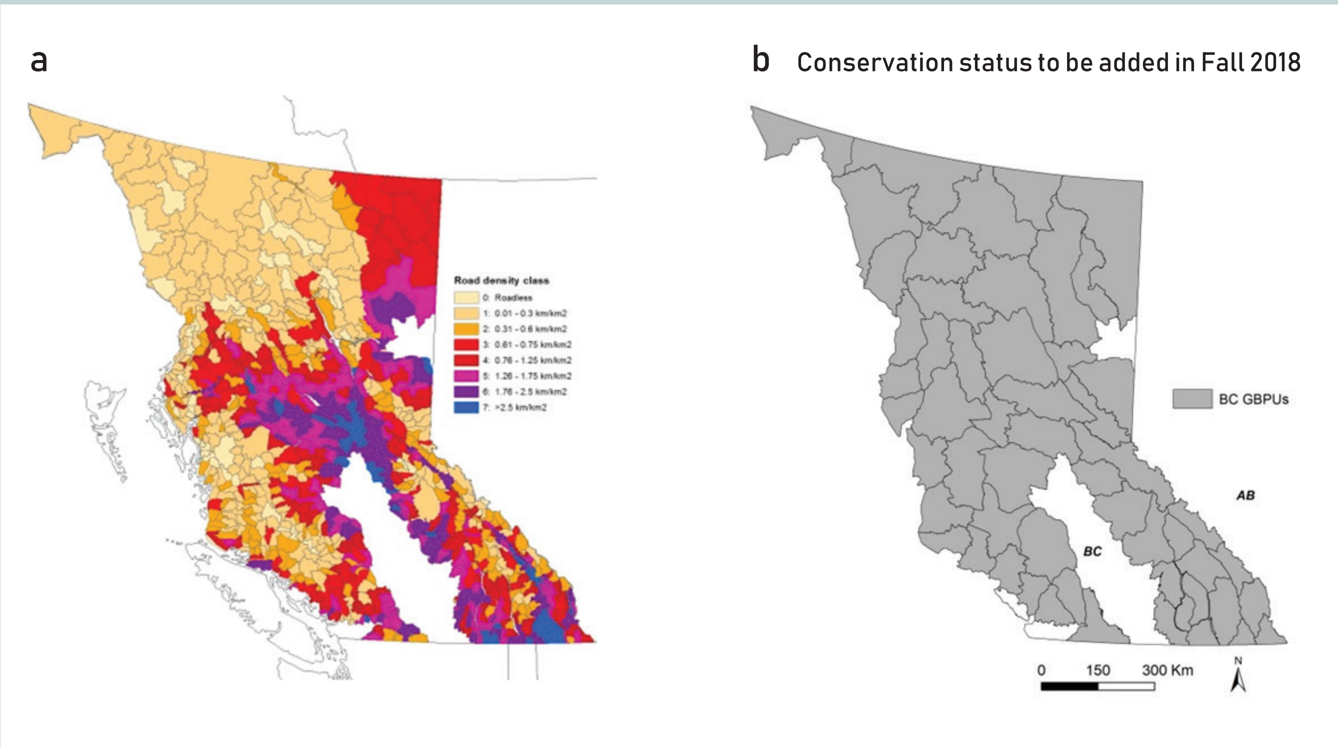
Although the South Rockies have been a focal - and often contentious - area for motorized access management for several decades, and until recently had a relatively high density of bears (35-50

GB/1000 km², Mowat and Lamb 2016, Apps et al. 2016). This is an example of a population unit in BC that is not threatened that could benefit from additional motorized access management. The unit experienced a 40% population decline over a recent 7 year period that was likely initiated be a multiple-year food shortage (Mowat and Lamb 2016) although it has been increasing for the past 3-4 years (C. Lamb pers. comm.). The area has an average road density of 1.0 km/km², some of which are seasonally closed and a relatively large human foot print. Unreported mortality from front and backcountry sources and highway and railway kills, all contributed to what may be a recent excessive unreported mortality issue (Mowat and Lamb 2016). The authors suggest motorized access management would be an appropriate management action to rebuild this population.

Central and northern BC are regions of the province that could benefit from motorized access management. Trends for resource extraction

FIGURE 10.

a) Road density across BC by Landscape Unit (LU mean area ~800 km2) adapted from a BC government initiative to asses Cumulative Effects in BC and b) Grizzly Bear Population Units (GBPU) in BC. Conservation status to be added in Fall of 2018. Status determined through NatureServe ranking by BC Forests Lands and Resource Operations. Designations are ranked 1-5 with 1 being the highest conservation concern and 5 the least. Units with M1-3 designations are populations of “conservation concern” while M4-5 designations are units of minimal concern.



expansion and the associated increase in road building in central and northern BC, is cause for concern. Road densities in areas are already high (many landscape units already exceed 0.6 km/km^2) and given the expected increase in resource extraction, we recommend increased consideration of motorized access controls be integrated into resource development activities in northern BC. Our experience has taught us that it is easier to manage motorized access before road densities get too high. Limiting motorized access to roads that have been traditionally used for recreation creates significant social challenges.

To meet the goals concerning grizzly bear conservation outlined in BC's Wildlife Program Plan (BC Ministry of Environment 2010) and the Grizzly Bear Conservation Strategy (BC Ministry of Environment 1995, see BC Auditor General Report 2017), our review of the scientific literature suggests that industrial road management would be a useful tool if:

- roads exist within 500 m of the highest quality habitats or hyperphagia energy-rich food resources (salmon, berries, etc.) or,
- < 60% of the vegetated land base in each Wildlife Management Unit (or Landscape Unit in some cases) is > 500 m from an open road with a minimum patch size of 10 km^2, or
- there is > 0.6 km/km^2 of open roads across the vegetated occupied habitat in the monitored unit (Fig. 10).

As a recent BC Auditor General Report (Auditor General 2017) concluded, habitat considerations are at the forefront of grizzly bear management and conservation, with or without a legal hunt. The grizzly bear hunt was closed in BC in November of 2017 and in Alberta in 2006. Motorized access management considerations are still relevant across grizzly bear distribution as many population units across BC and Alberta are at some level of risk regardless of the hunt due to habitat insecurity and mortality risk.

Within both BC and Alberta, non-usable habitat (rock, icefields, lakes, etc.) should be removed before calculating road density and the proportion of secure habitat. Both metrics should be standardized (e.g. recently developed methods by BC FLNRO for a wildlife-ecosystem-oriented Cumulative Effects Analysis). We also realize these suggestions may not apply to some coastal road networks where the public has no ability to reach as they are accessed through ocean travel.

Tools for managing motorized access

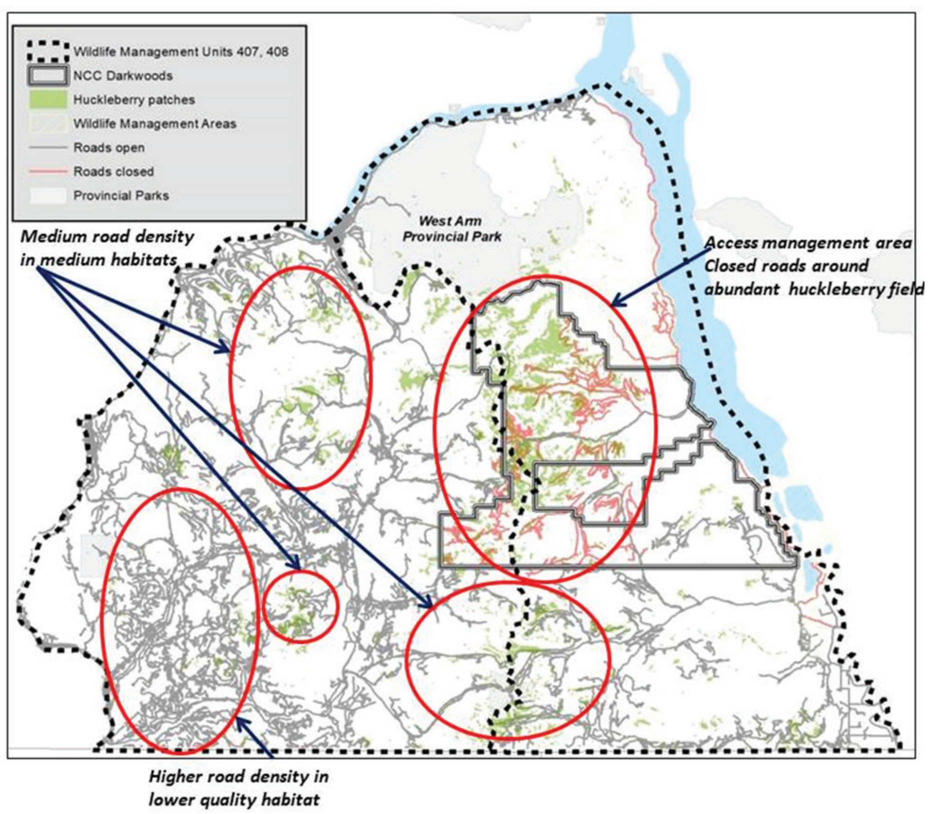
We will not make specific recommendations on methods for closing roads at this time, but suggest development of a guidebook of motorized access management methods. Such a manual could be funded by government, NGOs, or industry. However, after considering many years of voluntary closures and their ineffectiveness over time, we conclude that when motorized access controls are applied, that they be regulatory rather than voluntary. We also recognize that administrative use and some level of industrial use may be allowed on restricted roads (Wielgus et al. 2002, Northrup et al. 2012, Cristescu et al. 2016). We also note that managing motorized access for grizzly bears is but one environmental concern relative many other potential negative effects of roads faced by other species and habitats (runoff, pollution, disturbance, mortality, etc). For a more comprehensive assessment see Diagle (2010)

A short list of motorized access management options include, but are not limited to:

- Motorized hunting closures (gated or signed) where usually entire drainages (~100 km^2) are closed to hunters that use a motorized vehicle. These closures are common in the Kootenay region where they permit a more wilderness hunting experience.

HABITAT-STRUCTURED MOTORIZED ACCESS MANAGEMENT: AN EXAMPLE IN THE SOUTH SELKIRK POPULATION

The South Selkirk population unit is an example of how motorized access management might work in BC. It contains two Wildlife Management Units, each ~2000 km^2. The Nature Conservancy of Canada (NCC) owns a large parcel (550 km2) that holds extensive huckleberry fields and they continue a decade's long public motorized access management policy applied by the previous owners, a timber company. This "threatened" population unit has been increasing for a decade or more and is in slow recovery. The trans-border Grizzly Bear Project (Proctor et al. 2017) has been radio collaring and doing DNA-based population surveys in this unit for over a decade. Their research shows that the areas with low road densities and abundant huckleberry patches have provided well for female grizzly bears, being the best predictors of habitat use, reproductive success, and density. Some closed roads are being revegetated. Habitat quality is medium in other areas of the unit where road densities are correspondingly higher than in the NCC property. Areas of medium quality habitat (i.e. some huckleberry patches & other attractive attributes) have modest road densities. Another area of lower quality habitat for grizzly bears has high road densities. Although refinements may be necessary (application within smaller geographic units) this example has the components of an access management strategy that has worked reasonably well for industry, the public, and grizzly bears. It has allowed areas of very low road density in the highest quality food patches, areas of medium road densities in medium quality habitats, and higher road densities in lower quality habitats.



Because by far most grizzly bears are killed by black bear or ungulate hunters, these closures have been very effective at reducing mortality.

- Seasonal closures (gated or signed) to protect specific habitats during the season of use by bears or other species.
- Annual closures (gated or signed) to protect specific fish and wildlife resources over the entire year.
- Road deactivation to help terrain stability, including the use of deep water bars that make truck use prohibitive, reduced road maintenance, or bridge/culvert removal.
- Motorized access closures that still allow for non-motorized access such as equestrian users, cyclists, hikers, etc.

Research needs

Although much research has been completed to date, there are several arenas where additional motorized access related research would be useful.

- Improved digitized maps of usable roads across both provinces. This entails a database with roads useable by all types of motorized vehicles, roads grown over naturally, open roads, and closed roads.
- Updated unreported grizzly bear mortality estimates. This is particularly important given the recent hunt closures.
- Assessment of habitat quality across much of the provinces. Some regions of Alberta and BC have adequate habitat maps, but many do not.
- Assessment of important energy-rich hyperphagia foods. This would be region-specific and would include an examination of food types and their locations.
- Evaluation of road trends over time for both BC and Alberta. (i.e. roads layer map then vs now).
- Analysis of North America grizzly bear distribution patterns relative to road density patterns. For example, evaluating why some areas have so many bears and higher road densities, while others have few bears and lower road densities.
- Specific studies on the spatial extent of disturbance of open roads.
- Controlled studies that examine the effects of road traffic on both bear mortality and behaviour.
- Studies on the link between people's attitudes towards bears and roads.

SPECIAL ATTENTION REQUIRED FOR GRIZZLY BEAR MANAGEMENT AND CONSERVATION

In much of their range, particularly in southern BC and Alberta, grizzly bears live in close proximity to humans and are what Scott et al. (2005) refer to as a "conservation-reliant species," that is, a species that is at risk from threats so persistent that it requires continuous management to maintain population levels. This sentiment was echoed in Schwartz et al. (2006) discussing the approaching recovered populations, at that time, in the lower 48 states of the U.S.

*"We are optimistic that, with **continued vigilance,** these populations can persist indefinitely. But normal management, in the sense we have grown to expect from our experience with ungulate or black bear populations in the western U.S. over the past few decades, is not a term we associate with grizzly bear conservation."*

The point is that others have realized that grizzly bears have a special place in wildlife management. They require special attention and management to coexist with humans where they overlap significantly. That type of overlap is occurring in most of the Alberta grizzly bear distribution and in the southern, central, and northeastern distribution of BC.

LITERATURE CITED

Alberta Environment and Parks 2016. Alberta Grizzly Bear (*Ursus arctos*) DRAFT Recovery Plan. Alberta Environment and Parks. Alberta Species at Risk Recovery Plan 38. Edmonton, AB.

Apps, C., B. McLellan, and C. Servheen. 2013. Multi-scale population and behavioural responses by grizzly bears to habitat and human influence across the southern Canadian Rocky Mountains. Version 2.0. Aspen Wildlife Research in collaboration with Ministry of Forests, Lands and Natural Resource Operations, and the US Fish and Wildlife Service.

Apps, C. D., D. Paetkau, S. Rochetta, and B. McLellan. 2014. Grizzly bear population abundance, distribution, and connectivity across British Columbia's southern coast ranges. V. 2.2. Aspen Wildlife Research and Ministry of Environment, Victoria, BC.

Apps, C. D., B. N. McLellan, M. F. Proctor, G. B. Stenhouse, and C. Servheen. 2016. Predicting spatial variation in grizzly bear abundance to inform conservation. Journal of Wildlife Management. 80:396-413.

Barnosky, A. D., N. Matkze, S. T. Tomiya, G. O. U. Wogan, B. Swartz, T. B. Quental, C. Marshall, J. L. McGuire, E. L. Lindsey, K. C. Maguire, B, Mersey, and E. A. Ferrer. 2011. Has the Earth's sixth extinction already arrived? Nature 471:2-19.

Basille, M., B. Van Motter, I. Herfindal, J. Martin, J. D. C. Linnel, J. Odden, R. Andersen, and J-M. Gaillard. 2013. Selecting habitat to survive: the impact of road density on survival in a large carnivore. PLoS ONE 8:e65493.

BC Auditor General, 2017. An independent audit of grizzly bear management. Office of the Auditor General of BC. Victoria, BC. http://www.bcauditor.com/pubs/2017/independent-audit-grizzly-bear-management

BC Ministry of Environment. 1995. A Future for the Grizzly: British Columbia Grizzly Bear Conservation Strategy. BC Ministry of Environment Lands and Parks. Victoria BC. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/grizzly-bears/futureforgrizzly1995.pdf

BC Ministry of Environment. 2010. Wildlife Program Plan. BC Ministry of Environment. Victoria, BC. http://www.env.gov.bc.ca/fw/docs/WildlifeProgramPlan.pdf

BC Ministry of Environment 2012. British Columbia Populations Status. BC Ministry of Environment. http://www.env.gov.bc.ca/soe/indicators/plants-and-animals/print_ver/2012_Grizzly_Bear_Population_Status_BC.pdf

Beneitz-Lopez, A., R. Alkemade, and P. A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation 143:1307-1316.

Benn, B., and Herrero, S. 2002. Grizzly bear mortality and human access in Banff and Yoho

Berland, A., T. Nelson, G. Stenhouse, K. Graham, and J. Cranston. 2010. The impact of landscape disturbance on the grizzly bear habitat use in the Foothills Model Forest, Alberta, Canada. Forest Ecology and Management 256:1875-1883.

Bischof, R., S. J. G. Steyaert, and J. Kindberg. 2017. Caught in the mesh: roads and their network-scale impediment ot animal movement. Ecography 40: 1369-1380.

Boulanger, J., M. Cattet, S. E. Nielsen, G. Stenhouse, and J. Cranston. 2013. Use of multi-state models to explore relationships between changes in body condition, habitat and survival of grizzly bears *Ursus arctos horribilis*. Wildlife Biology 19: 274-288.

Boulanger, J., and G. B. Stenhouse. 2014. The impact of roads on the demography of grizzly bears in Alberta. PLoS ONE 9:e115535.

Boulanger, J., S. E. Nielsen, and G. Stenhouse. 2018. Using spatial mark-recapture for conservation monitoring of grizzly bear populations in Alberta. Scientific Reports. In review.

Brasher, M. G., J. D. Steckel, and R. J. Gates. 2007.Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71: 2532-2541.

Carbone, C. and J. L. Gittleman. 2002. A common rule for the scaling of carnivore density. Science 295:2273–2276.

Ceia-Hasse, A., L. Borda-de-Agua, C. Grillo, and H. M. Pereira. 2017. Global exposure of carnivores to roads. Global Ecology and biogeography 26:592-600.

Celabos, G., P. ER Ehrlich, A. D. Barnosky, A. Garcia, R. M. Pringle, and T. M. Palmer. 2015. Accelerated modern human-induced species losses: Entering the sixth mass extinction. Environmental Sciences 1:e1300253. http://advances.sciencemag.org/content/advances/1/5/e1400253.full.pdf

Ciarniello, L. M., M. S. Boyce, D. R Seip, and D. C. Heard. 2007. Grizzly bear habitat selection is scale dependent. Ecological Applications 17:1424-1440.

Ciarniello, L. M., M. S. Boyce, D. C. Heard, and D. R Seip. 2007. Components of grizzly bear habitat selection: density, habitats, roads, and mortality risk. Journal of Wildlife Management 71:1446-1457.

Cristescu, B., G. B. Stenhouse, and M. S. Boyce. 2013. Perception of human-derived risk influences choice at top of the food chain. PLoS ONE 8(12): e82738.

Cristescu, B., G. B. Stenhouse, M. C. Symbaluk, S. E. Nielsen, and M. S. Boyce. 2016. Wildlife habitat selection on landscapes with industrial disturbance. Environmental Conservation 43:327-336.

Diagle, P. 2010. A summary of the environmental impacts of roads, management responses, and research gaps: A literature review. BC Journal of Ecosystems and Management 10: 65-89.

Dinerstein, E. D. Olson, A. Joshi, C. Vynne, N. Burgess et al. (48 authors). 2017. An ecoregion-based approach to protecting half the terrestrial realm. Bioscience. 67:534-545.

Eberhardt, L. L., B. M. Blanchard, and R. R. Knight. 1994. Population trend of the Yellowstone grizzly bears as estimated from reproductive and survival rates. Canadian Journal of Zoology 72:360-363.

Fahrig, L. and T. Rytwinski. 2009. Effects of roads and traffic on wildlife populations and landscape function. Ecology and Society 14: 21. http://www.ecologyandsociety.org/vol14/iss1/art21/

Festa-Bianchet, M. 2010. Status of grizzly bear (Ursus arctos) in Alberta: Update 2010. Alberta Sustainable Resource Development, Alberta Conservation Association. Alberta Wildlife Status Report No. 37 (Update) 2010, Volume 37. http://aep.alberta.ca/fish-wildlife/species-at-risk/species-at-risk-publications-web-resources/mammals/documents/SAR-StatusGrizzlyBearAlbertaUpdate2010-Feb2010.pdf

Forman, R. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Garshelis, D.L., Gibeau, M.L., Herrero, S. 2005. Grizzly Bear Demongraphics in and Around Banff National Park and Kananaskis Country, Alberta. Journal of Wildlife Management 69(1): 277–297.

Gibeau, M. L., S. Herrero, B. N. McLellan, and J. G. Woods. 2001. Managing for grizzly bear security areas in Banff National Park and the central Canadian Rocky Mountains. Ursus 12:121-130.

Graves, T. T., R. B. Chandler, J. A. Royle, P. Beier, and K. C. Kendall. 2014. Estimating landscape resistance to dispersal. Landscape

Ecology 29:1201-1211.

Graham, K., J. Boulanger, J. Duval, and G. Stenhouse. 2010. Spatial and temporal use of roads by grizzly bears in west-central Alberta. Ursus 21:43-56.

Hamilton, A. N., and M. A. Austin. 2004. Grizzly bear harvest management in British Columbia: background report. BC Ministry of Environment. Victoria BC. http://www.env.gov.bc.ca/wld/documents/gbearbckgrdr.pdf

Harris, R.B., C.C. Schwartz, M.A. Haroldson, and G.C. White. 2006. Trajectory of the greater Yellowstone ecosystem grizzly bear population under alternative survival rates. Pages 45–56 in C.C. Schwartz, M.A. Haroldson, G.C. White, R.B. Harris, S. Cherry, K.A. Keating, D. Moody, and C. Servheen, editors. Temporal, spatial and environmental influences on the demographics of grizzly bears in the greater Yellowstone ecosystem. Wildlife Monographs 161.

Hels, T., and E. Buchwald. 2001. The effects of road kills of amphibian populations. International Conference on Ecology and Transportation. Eds. Irwin, C. L., Garrott, P., McDermott,K. P. Center for Transportation and the Environment, North Carolina State University Raleigh, BC. https://www.sciencedirect.com/science/article/pii/S0006320700002159

Hertel, A. G., A. Zedrosser, A. Mysterud. O. G. Stoen, S. M. J. G. Steyaert, and J. E. Swenson. 2016. Temporal effects of hunting on foraging behavior of an apex predator: do bears forego foraging when risk is high? Oecologia 182:1019-1029.

Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132–138.

Hooper, D. U., E. C. Adair, B. J. Cardinale, J. E. K. Byrnes, B. A. Hungate, K. L. Matulich, A. Gonzalez, J. E. Duffy, L. Gamfeldt, and M. I. O'Connor. 2012. A global synthesis reveals biodiversity loss as a major driver in ecosystem change. Nature 486:105-109.

Ibisch, P. L., M. T. Hoffmann, S. Kreft, G. Pe'er, V. Kati, L. Biber-Freudenberger, D. A. DellSala, M. M. Vale, P. R. Hobson, and N. Selva. 2016. A global map of roadless areas and their conservation status. Science 254: 1423-1427.

Iredale, F. 2016.. Final Report, FWCP Coastal Project & HCTF. Ministry of Forest Lands and Natural Resource Operations. Kamloops, BC.

Kasworm, W.F., and Manley, T.L. 1990. Road and trail influences on grizzly bears and black bears in northwest Montana. In Bears — Their Biology and Management: Proceedings of the 8th International Conference on Bear Research and Management, Feb. 1989, Victoria, B.C. Edited by L.M. Darling and W.R. Archibald. Bear Biology Association, University of Tennessee, Knoxville, Tenn. pp. 79–84.

Kendall, K. C., J. B. Stetz, J. Boulanger, A. C. MacLeod, D. Paetkau, and G. C. White. 2009. Demography and genetic structure of a recovering grizzly bear population. Journal of Wildlife Management 73:3-17.

Lamb, C. T., G. Mowat, B. N. McLellan, S. E. Nielsen, and S. Boutin. 2017. Forbidden fruit: human settlement and abundant fruit create an ecological trap for an apex predator. Journal of Animal Ecology 86:55-65.

Lamb, C.T., M. Festa-Bianchet, M. S. Boyce. 2018a. Invest long term in Canada's wilderness. Science 359(6379) pp. 1002.

Lamb, C. T., G. Mowat, A. Reid, L. Smit, M. Proctor, B. N. McLellan, S. E. Nielsen, and S. Boutin. 2018b. Effects of habitat quality and access management on the density of a recovering grizzly bear population. Journal of Applied Ecology 55:1406-1417.

Mace, R. D., J. S. Waller, T. L. Manley, L. J. Lyon, and H. Zuring. 1996. Relationships among grizzly bears, roads, and habitat use in the Swan Mountains, Montana. Journal of Applied Ecology 33:1395–1404.

Mace , R. D., D. W. Carney, T. Chilton-Radandt, S. A. Courville, M. A. Haroldson. R. B. Harris, J. Jonkel, B. McLellan, M. Madel, T. L.

Manley, C. C. Schwartz, C. Servheen, G. B. Stenhouse, J. S. Waller, and E. Wenum. 2012. Grizzly bear population vital rates and trend in the Northern Continental Divide Ecosystem. Journal of Wildlife Management 76:119-128.

Martin, J., M. Basille, B. Van Moorter, J.Kinsberg, D. Allaine and J. E. Swenson. 2010. Coping with human disturbance: spatial and temporal tactics of the brown bear (*Ursus arctos*). Journal of Canadian Zoology 88: 875-883.

Mattson, D.J., R.R. Knight, and B.M Blanchard. 1987. The effects of developments and primary roads on grizzly bear habitat use in Yellowstone National Park, Wyoming. International Conference on Bear Research and Management 7:259-273.

Mattson, D.J., K. Barber, R. Maw, and R. Renkin. 2004. Coefficients of productivity for Yellowstone's grizzly bear habitat. US Geological Survey, Biological Science Report USGS/BRD/BSR-2002-0007, 76pp. https://archive.usgs.gov/archive/sites/www.nwrc.usgs.gov/wdb/pub/others/grixzzly.pdf

McLellan, B. N. 1989. Dynamics of a grizzly bear population during a period of industrial resource extraction. III. Natality and rate of increase. Canadian Journal of Zoology 67:1865-1868.

McLellan, B.N. 1990. Relationships between human industrial activity and grizzly bears. International Conference on Bear Research and Management 8:57–64.

McLellan, B.N. 1994. Density-dependent population regulation of brown bears. In Density-dependent population regulation of brown, black, and polar bears. Edited by M. Taylor. Monogr. Ser. No. 3, International Association for Bear Research and Management. pp. 15–24.

McLellan, B.N. 2011. Implications of a high-energy and low-protein diet on the body composition, fitness, and competitive anilities of black (*Ursus americanus*) and grizzly (*Ursus arctos*) bears. Canadian Journal of Zoology 89:546-558.

McLellan, B.N. 2015. Some mechanisms underlying variation in vital rates of grizzly bear on a multiple use landscape. Journal of Wildlife Management 749-765.

McLellan, B. N., and D. M. Shackleton. 1988. Grizzly bears and resource-extraction industries: effects of roads on behavior, habitat use and demography. Journal of Applied Ecology 25:451-460.

McLellan, B. N., and F. W. Hovey. 2001. Habitats selected by grizzly bears in multiple use landscapes. Journal of Wildlife Management 65:92-99.

McLellan, B. N., F. W. Hovey, R. D. Mace, J. G. Woods, D. W. Carney, M. L. Gibeau, W. L. Wakkinen, and W. F. Kasworm. 1999. Rates and causes of grizzly bear mortality in the interior mountains of British Columbia, Alberta, Montana, Washington, and Idaho. Journal of Wildlife Management 63:911-920.

McLellan, B. N., Proctor, M. F., Huber, D. and S. Michel. (IUCN SSC Bear Specialist Group). 2016a. Ursus arctos. The IUCN Red List of Threatened Species 2016. IUCN website. http://www.iucnredlist.org/details/41688/0

McLellan, M.L., H.U. Wittmer, B.N. McLellan, R. Sollmann, C. Lamb, and C. Apps. (submitted). Divergent population trends ten years after ending the legal grizzly bear hunt in southwestern British Columbia, Canada.

Milakovic, B., K. A. Parker, D. D. Gustine, R. J. Lay, A. B. D. Walker, and M. P. Gillingham. 2012. Seasonal habitat use and selection by grizzly bears in northern British Columbia.Journal of Wildlife Management 76:170-180.

Mowat, G., and C. Lamb. 2016. Population status of the South Rockies and Flathead grizzly bear populations in British Columbia, 2006-2014. BC Ministry of Forests, Lands, and Natural Resource Operations, Nelson BC. http://wild49.biology.ualberta.ca/files/2016/05/Recent-status-of-the-South-Rockies_final.pdf

Mowat, G., D. C. Heard and C. J. Schwarz. 2013. Predicting grizzly bear density in western North America. PLoS One. 8(12): e82757.

Nielsen, S. E., S. Herrero, M. S. Boyce, R. D. Mace, B. Benn, M. L. Gibeau, and S. Jevons. 2004a. Modeling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation 120:101-113.

Nielsen. S., R. H. M. Munro, E. L. Bainbridge, G. B. Stenhouse, and M. S. Boyce. 2004b. Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Alberta. Forest Ecology and Management 199:67-82.

Nielsen, S., G. B. Stenhouse, and M. S. Boyce. 2006. A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation 30:217-229.

Nielsen, S. E., J. Cranston, and G. B. Stenhouse. 2009. Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada. Journal of Conservation Planning 5:38–60.

Nielsen, S. E., G. McDermid, G. B. Stenhouse, and M. S. Boyce. 2010. Dynamic wildlife habitat models: seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. Biological Conservation 143:1623-1634.

Northrup, J. M., J. Pitt, G. B. Stenhouse, M. Musiani, and M. S. Boyce. 2012. Vehicle traffic shapes grizzly bear behaviour on a multiple-use landscape. Journal of Applied Ecology 49:1159-1167.

Ordiz, A., O. Stoen, M. Delibes, and J. E. Swenson. 2011. Predators of prey? Spatio-temporal discrimination of human-derived risk by brown bears. Oecologia 166: 59-67.

Oriol-Cotterill. A., M. Valeix, L. G. Frank, C. Riginos, and D. W. MacDonald. 2015. Landscapes of coexistence for terrestrial carnivores: the ecological consequences of being downgraded from ultimate to penultimate predator by humans. Oikos 124:1263-1273.

Proctor, M. F., D. Paetkau, B. N. McLellan, G. B. Stenhouse, K. C. Kendall, R. D. Mace, W. F. Kasworm, C. Servheen, C. L. Lausen, M. L. Gibeau, W. L. Wakkinen, M. A. Haroldson, G. Mowat, C. D. Apps, L. M. Ciarniello, R. M. R. Barclay, M. S. Boyce, C. C. Schwartz, and C. Strobeck. 2012. Population fragmentation and inter-ecosystem movements of grizzly bears in Western Canada and the Northern United States. Wildlife Monographs 180:1-46.

Proctor, M. F., S. E. Nielsen, W. F. Kasworm, C. Servheen, T. G. Radandt, A. G. MacHutchon, and M. S. Boyce. 2015. Grizzly bear connectivity mapping in the Canada-US trans-border region. Journal of Wildlife Management 79:554-55.

Proctor, M. F., C. T. Lamb, and A G MacHutchon. 2017. The grizzly dance of berries and bullets: The relationship between bottom up food resources, huckleberries, and top down mortality risk on grizzly bear population processes in southeast British Columbia. Trans-border Grizzly Bear Project. Kaslo, BC, Canada. http://transbordergrizzlybearproject.ca/research/publications.html.

Rainer, R., Bennett, S. Blaney, A. Enns, P. Henry, E. Lofroth, and J. Mackenzie. 2017. On Guard for Them: Species of Global Conservation Concern in Canada—Summary Report. NatureServe Canada: Ottawa, ON. http://www.natureserve.org/sites/default/files/publications/files/on_guard_for_them_summary_report_natureserve_canada_2017_2_0.pdf

Rode, K.D., S. D. Farley, and C. T. Robbins. 2006. Sexual dimorphism, reproductive strategy, and human activities determine resource use by brown bears. Ecology 87:2636-2646.

Roever, C. L., M. S. Boyce, and G. B. Stenhouse. 2010. Grizzly bear movements relative to roads: application of step functions. Ecography 33:1113-1122.

Sala, O. E., F. S. Chapin, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, et al. (19 authors) . 2010. Global biodiversity scenario for the year 2100. Science 287:1770-1774.

Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G Wolmer. 2002. The human footprint and the last of the wild. Bioscience 52:891-904.

Schwartz, C. C., M. A. Haroldson, G. C White, R. B. Harris, S. Cherry, K. A. Keating, D. Moody, and C. Servheen. 2006. Temporal, spatial, and environmental influences on the demographics of grizzly bears in the Greater Yellowstone Ecosystem. Wildlife Monographs 161:1-68.

Schwartz, C. C., M. A. Haroldson, and G. C. White. 2010. Hazards affecting grizzly bear survival in the greater Yellowstone ecosystem. Journal of Wildlife Management 74:654–667.

Scott, J. M., D. D. Goble, J. A. Wiens, D. S. Wilcove, M. Bean, and T. Male. 2005. Recovery of imperiled species under the Endangered Species Act: the need to a new approach. Frontiers in Ecology and the Environment 3:383-389.

Secretariat of the Convention on Biological Diversity (2014) Global Biodiversity Outlook 4. Montréal, 155 pages.

Sinclair, A. R. E., and C. J. Krebs. 2002. Complex numerical responses to top-down and bottom-up processes in vertebrate populations. Philosophical Transactions of the Royal Society, London B 357:1221-1231.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodrigues, D. L. Fischman, and R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Sciencexpress 1103538. https://pdfs.semanticscholar.org/b4f0/5a1e0cbb12aa53e8a928d86fd1b05bd422ce.pdf

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

U.S. Fish and Wildlife Service. 1993. Grizzly bear recovery plan. Missoula, MT 181 pp. https://www.fws.gov/mountain-prairie/es/species/mammals/grizzly/2017-10-05_SIGNED_DRAFT_HBRC_RP_Supplement_for_NCDE_Grizzly_Bear.pdf

Van Manen, F. T., M. A. Harlodson, D. D. Bjornlie, M. E. Ebinger, D. J. Thompson, C. M. Costello, and G. C. White. 2016. Density dependence, whitebark pine, and vital rates of grizzly bears. Journal of Wildlife Management 80: 300-321.

Venter, O., E. W. Sanderson, A. Magrach, J. Allan, J. Beher, K. R. Jones, H. P. Possingham, W. F. Laurance, B. M. Fekete, M. A. Levy, and J. E. M. Watson. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications 7:12558.

Wakkinen, W. L., and W. F. Kasworm. 1997. Grizzly bear and road density relationships in the Selkirk and Cabinet–Yaak recovery zones. U.S. Fish and Wildlife Service, Missoula, Montana, USA. http://igbconline.org/wp-content/uploads/2016/02/Wakkinen_Kasworm_1997_Grizzly_bear_and_road_density_relation.pdf

Wielgus, R.B., P. R. Vernier, and T. Schivatcheva. 2002. Grizzly bear use of open, closed, and restricted forestry roads. Canadian Journal of Forest Research 32: 1597–1606.

Wilson, E. O. 2016. Half-Earth: our planets fight for life. W. W. Norton & Co. New York, New York, USA.