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Effects of roads and motorized human access on grizzly bear populations in British Columbia and Alberta, Canada

Michael F. Proctor[1,6], Bruce N. McLellan[2], Gordon B. Stenhouse[3], Garth Mowat[4], Clayton T. Lamb[5], and Mark S. Boyce[5]

[1]*Birchdale Ecological, P.O. Box 606, Kaslo, British Columbia, V0G 1M0, Canada*
[2]*Ministry of Forest, Lands, & Natural Resource Operations, P.O. Box 1732, D'Arcy, British Columbia, V0N 1L0, Canada*
[3]*fRi Research, 1176b Switzer Drive, Hinton, Alberta, T7V 1V3, Canada*
[4]*Ministry of Forest, Lands, Natural Resource Operations & Rural Development, Nelson, British Columbia, V1L 4K3, Canada*
[5]*Department of Biological Sciences, University of Alberta, Edmonton, Alberta, T6G 2E9, Canada*

Abstract: The growing human footprint has placed unprecedented stressors on ecosystems in recent decades resulting in losses of biodiversity and ecosystem function around the world. Roads are influential through their direct footprint and facilitating human access; however, their influence can be mitigated. Here, we review the scientific literature on the relationship between grizzly bears (*Ursus arctos*), human motorized access, and the efficacy of motorized access control as a tool to benefit grizzly bear conservation in western Canada. We found that motorized access affected grizzly bears at the individual and population levels through effects on bears' habitat use, home range selection, movements, population fragmentation, survival, and reproductive rates that ultimately were reflected in population density, trend, and conservation status. Motorized access management was effective in mitigating these effects. Our review of the scientific literature suggests that industrial road management would be a useful tool if (a) roads exist in high-quality grizzly bear habitats with population-energy-rich food resources; (b) open road densities exceed 0.6 km/km^2; (c) less than at least 60% of the unit's area is $>$500 m from an open road in patch sizes of $\geq$10 km^2. Motorized access management would be most beneficial in threatened populations, in areas where roads occur in the highest quality habitats, within and adjacent to identified linkage areas between population units, and in areas that are expected to exceed motorized route thresholds as a result of resource extraction activities. Evidence suggests benefits of motorized access management are more likely to be realized if habitat quality is integrated and is best if managed at scales that optimize the benefit of distribution, survival, reproduction, and density of female grizzly bears. We encourage land use managers developing access rules to consider a wider spectrum of biodiversity and overall habitat conservation, and suggest landscape road targets that will benefit bear conservation.

Key words: access management, Alberta, British Columbia, grizzly bear, motorized access, review, roads, *Ursus arctos*

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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, van der Ree 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 (Secretariat 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 (Sanderson et al. 2002, Venter et al. 2016, Wilson 2016, Dinerstein et al. 2017). 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).

[6]email: mproctor@netidea.com

Table 1. A glossary of terms applicable to our review of the scientific literature on the relationship between grizzly bears (*Ursus arctos*), human motorized access, and the efficacy of motorized access control as a tool to benefit grizzly bear conservation in western Canada.

Term	Definition
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/km^2.
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 autumn berry season when bears feed intensively to store energy for hibernation.

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, Basille et al. 2013, Ibisch et al. 2016, Ceia-Hasse et al. 2017).

Although this document is focused on one large carnivore species, the grizzly bear (*Ursus arctos*) in British Columbia (BC) and Alberta, Canada, it also is a reflection of our modern world. We are not alone with the issues presented here. Although biodiversity loss in Canada is less than in many other parts of the world, we do have significant extinction risk for several endemic species and extirpation risk within BC and Alberta for several species with broader distributions (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 (MACs, on routes that include roads and Off Highway Vehicles [OHV] tracks; Table 1) have been the cornerstone of the recovery of threatened grizzly bear populations for the past 3 decades in the contiguous United States, where grizzly bears in the Yellowstone and Northern Continental Divide ecosystems have all but recovered (though legal debates are ongoing [Schwartz et al. 2006, Kendall et al. 2009, Mace et al. 2012]). Populations have increased significantly and geographic expansion has occurred in both ecosystems from historic lows prior to 1970 (Schwartz et al. 2006, Kendall et al. 2009). In the lower 48 states, mortality reduction has been implemented intensively, including motorized access management on public lands and mitigation efforts to reduce front-country (human-settled valleys), conflict-related deaths. These successes are lessons for grizzly bear management in Canada, where there is extensive 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 newest "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). British Columbia has no provincial-scale road management strategy and road building has been extensive, although some regional MAC 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 MACs as a tool in grizzly bear management to answer 3 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 natural systems. The goal of this report is to assess these costs and the tools that can help mitigate them.

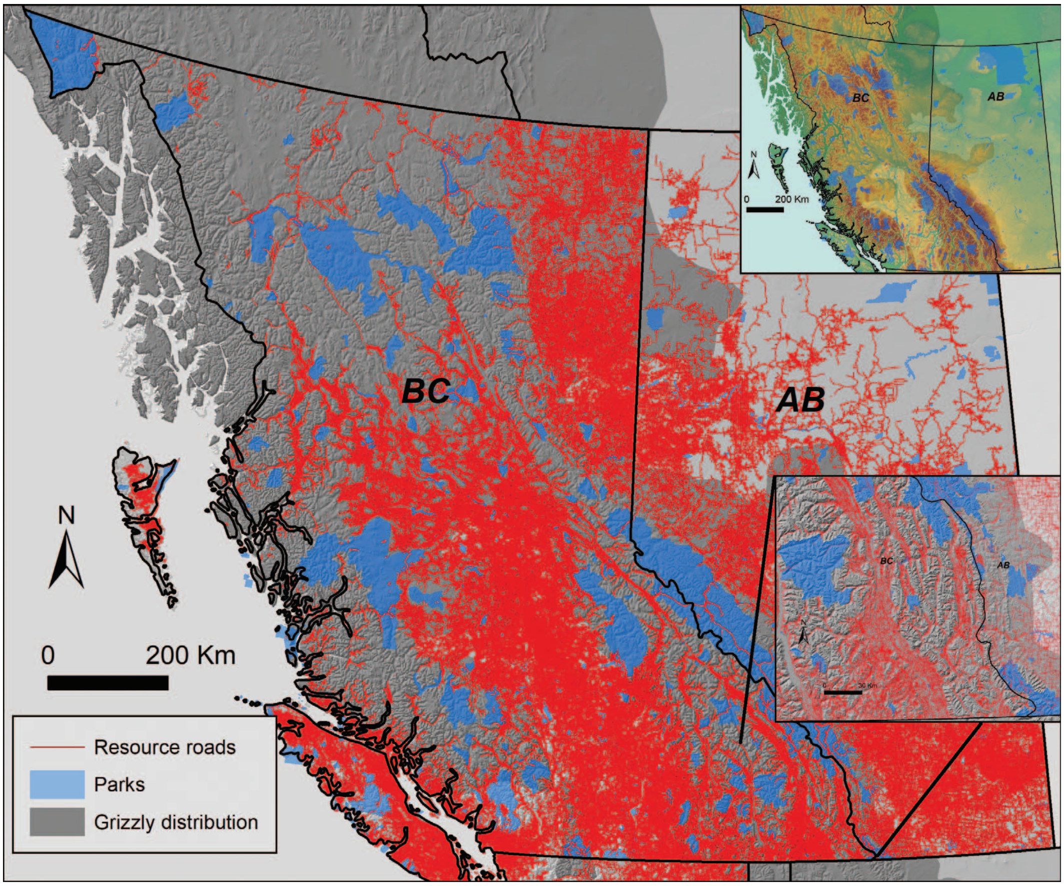

Fig. 1. Grizzly bear (*Ursus arctos*) distribution and resource roads across Alberta and British Columbia, Canada. Resource roads are non-highway, dirt or gravel roads used to access timber and mining resources. This map does not reflect all Off Highway Vehicle tracks. The upper right inset displays topographic relief and the lower left inset provides a close up to show variation in road densities within southeast British Columbia.

We begin by discussing some of the mechanisms involved between grizzly bears and motorized access with grizzly bear response to roads, mortality, displacement, habitat loss, and fragmentation. This is followed by an exploration into beneficial access controls for grizzly bear conservation, including what metrics (road density, secure habitat—habitat >500 m from an open road) and thresholds exist. We then look at where MACs are useful (i.e., in what types of populations and habitats are they beneficial). We finish with how they might be applied within Alberta and British Columbia.

Grizzly bear response to roads

Grizzly bear response to motorized human access generally occurs via 4 mechanisms. In the likely order of their influence on grizzly bear populations in Alberta and BC they are (1) increased human-caused mortality, (2) habitat displacement, (3) fragmentation, and (4) direct habitat loss (Fig. 2).

Mortality—top-down versus bottom-up influence

When trying to understand grizzly bear population dynamics and the role of mortality, it is useful to consider the relationship between food resources (bottom-up influence) and mortality (top-down influence). Food resources drive animal abundance (McLellan 1994, 2011, 2015; Hilderbrand et al. 1999; Carbone and Gittleman 2002; Sinclair and Krebs 2002; Brasher et al. 2007; Lamb et al. 2017, 2018b; Proctor et al. 2017). However, mortality rate can determine how close a population comes to its food-limited density and can have a significant influence on

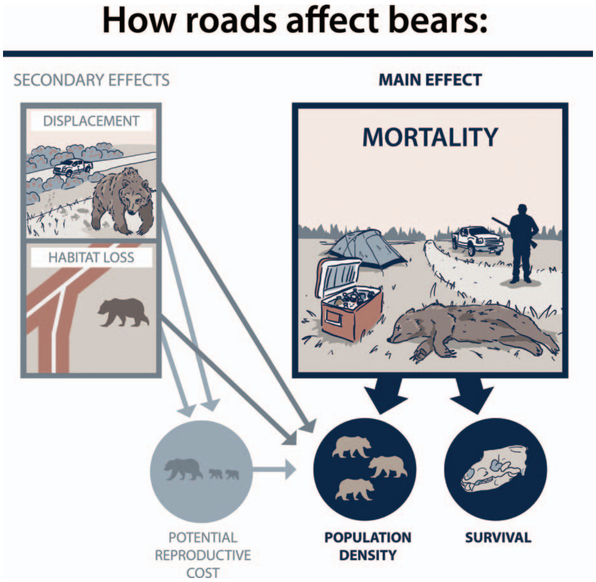

Fig. 2. Schematic of mechanisms of grizzly bear (*Ursus arctos*) response to roads. The main effect is mortality, which ultimately reduces density. Secondarily, displacement and direct habitat loss potentially affect reproductive output and density.

conservation status (Ciarniello et al. 2007a, Lamb et al. 2017, Proctor et al. 2017). Conservation status is not necessarily determined by bear density because it can naturally range by 2 orders of magnitude (100×) 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 population may be at low density because food is naturally limited, whereas a higher density population may be well below its potential because of human mortality, often as a result of high road densities (Mowat and Lamb 2016; Lamb et al. 2017, 2018b).

Top down—mortality and roads

In areas with human–bear overlap, a large majority of grizzly bears over the age of 2 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% and 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). Most bears are killed near a road (Benn and Herrero 2002, McLellan 2015); therefore, there is a strong positive association between motorized access into grizzly bear habitat and 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. 3; 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) demonstrated the link between road density, female survival, and the potential for population decline.

Excessive human-caused mortality is the main cause of current grizzly bear conservation issues in several, but not all, population units in Alberta and BC. 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. 2007a). Mortality was thought to be a major factor in a population decline in the South Rockies Grizzly Bear Population Unit (GBPU) of southeastern BC, which 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). Although food resources likely 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

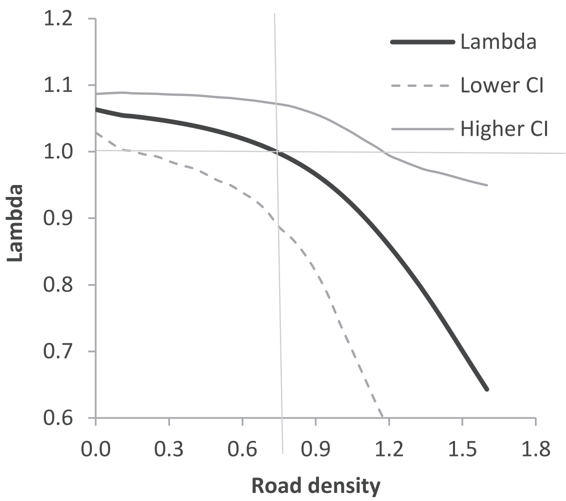

Fig. 3. Road density threshold for stable population growth relative to female grizzly bear (*Ursus arctos*) survival in western Alberta, Canada between 1999 and 2012. The reproductive state of females was considered as a variable when developing this curve. Females with dependent offspring had lower survival, relative to road density, than females without offspring. Adapted from Boulanger and Stenhouse (2014). Areas with road densities >0.75 km/km^2 correspondingly had Lambda (population growth), values <1.0, representing population decline. 'CI' is confidence interval.

(Nielsen et al. 2004a). A similar analysis in southeastern 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. 2018). Both these studies used mortality databases that were skewed toward 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 southeastern BC, McLellan (2015) found 86% of the 26 radiocollared bears killed by people were within 120 m of a backcountry road when killed. Similarly, 20 years of radiocollared bear data from across Alberta found 100% of all human-caused mortalities were within 100 m of all-weather gravel roads or highways (G.B. Stenhouse, unpublished data). The cumulative evidence is compelling; motorized road access into grizzly bear habitat does reduce grizzly bear survival, particularly of females, and will usually affect density and sometimes conservation status.

Bottom up—food resources, habitat quality, and roads

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?

As mentioned above, population dynamics of grizzly bears are driven by interrelated top-down and bottom-up forces. Food abundance and quality affect individual and population productivity (Carbone and Gittleman 2002, Sinclair and Krebs 2002, Mattson et al. 2004, Rode et al. 2006, McLellan 2015, Hertel et al. 2017, Proctor et al. 2017) and density (Hilderbrand et al. 1999, Mowat et al. 2013). Researchers brought these forces together to identity source and sink 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, 2010; Boulanger et al. 2018). In other 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 southeastern BC, higher grizzly bear densities occurred in an area with higher overall road density, but with large, unroaded huckleberry (*Vaccinium membranaceum*) fields (see Flathead example discussed below; McLellan 2015). These results showed that abundant and secure food in late summer–autumn habitats regulated this population.

Inspired by these insights, 2 efforts linked food and mortality risk in different analyses in southeastern 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 southern Selkirk and Purcell Mountains, researchers developed 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, whereas road density was also a significant and additive contributor to predicting realized habitat effectiveness, density, and fitness.

Although 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 that habitat quality was most important in the northern population units and mortality risk was the key driver in southern units. These results demonstrate that 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 relationships between food resources and mortality risk. Their relative influence varies spatially and temporally and suggests that to benefit bears, food and motorized access are better kept apart.

Although berries are important in many areas, various energy-rich foods drive the productivity of bears in other ecosystems across British Columbia and Alberta, including salmon (*Oncorynchus* spp.), 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 autumn, 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 as a result of human–bear conflict as were by grizzly bear hunters in the spring. Keeping roads away from important energy-rich food sources not only enables females to focus on getting fat for hibernation, but also reduces the number of ungulate hunters, who sometimes kill these bears as a result of real or perceived self-defense (McLellan 2015).

The proximity between humans and bears can also vary by season. For example, spring green-up, summer and autumn natural-food fluctuations, and autumn 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. 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).

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 (*U. arctos*) in Scandinavia decrease foraging on berries in response to hunting pressure, causing a measurable nutritional cost that likely results 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). Although 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, Ordiz et al. 2011, Northrup et al. 2012, Cristescu et al. 2013) or become habituated to nutritious food sources 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 (see below for more on this topic). Nevertheless, on average it appears that bears avoid roads with vehicular traffic, but exceptions exist to this rule.

Although grizzly bears tend to avoid roads at the individual level, especially those that receive moderate–high traffic volumes (Northrup et al. 2012), there are important caveats to road influence at the population level. Roadside habitats do not usually provide energy-rich food resources during some seasons (spring and late autumn) and bears may avoid roads more when their populations are below carrying capacity and 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.

In the literature, the spatial extent of road effects on female survival is variable. 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 behavior varies across studies, but is at a minimum 100 m (McLellan and Shackleton 1989), and extends up to 1,000 m (Kasworm and Manley 1990). Most commonly, researchers reported that 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, Benn and Herrero 2002, Schwartz et al. 2010, van Manen et al. 2016).

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 7,500 km^2 of vegetative habitat loss across BC due to road footprint (although some areas eventually re-vegetate). This represents approximately 1% of the 750,000 km^2 of occupied grizzly bear territory within BC. Likewise, in Alberta, the approximately 43,000 km of roads (not including all OHV tracks) in potential grizzly bear habitat (Boulanger and Stenhouse 2014) represents 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 greater than zero.

Fragmentation

Roads have been shown to disrupt bear movements, influencing natal dispersal and ultimately population-level fragmentation. In northwestern Montana, USA (Graves et al. 2014), and Scandinavia (Steyaert et al. 2016, Bischof et al. 2017), backcountry forestry 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 southeastern BC, western Alberta, and northwestern United States in occupied bear territory (Proctor et al. 2012): road densities were an influential variable in mortality risk of grizzly bears across their study area (Proctor et al. 2018). 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 (Mowat and Lamb 2016, Lamb et al. 2017); this corroborated and further explained population-level fragmentation caused by Highway 3 through the Canadian Rockies (Proctor et al. 2012). In other work, detailed analyses of movements of 38 Global Positioning System–collared grizzly bears in the BC Highway 3 area of the Rocky Mountains found that the main highway reduced the odds of crossing movements by 44%, whereas industrial main lines (forestry and energy sector roads) reduced the odds of crossing movements by 9–20% (Apps et al. 2013). Only the main highway (approx. 3,700 vehicles/day) blocked movements of about half the collared bears, although all bears crossed less busy roads (Apps et al. 2013). These examples reveal the link between excessive road densities and fragmentation.

When are access controls a beneficial tool for grizzly bear conservation?

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 MACs where road densities are high and grizzly bear conservation is a concern. There are large areas of grizzly bear distribution, particularly in northwestern BC, where motorized access management may not be necessary because of current low road densities; but, considering trends in resource extraction, road development, and increasing human populations, motorized access management should be considered by 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 MACs have been applied effectively in some areas of each province. However, whereas 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 United States has used MACs 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 (Mealey 1986, USFWS 1993) and is supported by a body of science (Mace et al. 1996, 2012; Kendall et al. 2009; Schwartz et al. 2010). Other mortality reduction actions also were undertaken, so it is difficult to tease apart the proportional influence of each concurrent action. Prior to 1993, there were ≥237 grizzly bears across 23,300 km^2 in the Greater Yellowstone Ecosystem (USFWS 1993, 136 in 1975, U.S. Fish and Wildlife Service [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 U.S. 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 DNA-derived estimate of 765 in 2004 across 33,480 km^2 (Kendall et al. 2009), and has been increasing at a rate of approximately 3% annually (Mace et al. 2012).

Managers in the United States 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/km^2), approximately 19–33% should have a road density of <0.6 km/km^2, and 19–26% may have >1.2 km/km^2 total road density (both closed and open roads; these percentages do not sum to 100 because their categories overlap). 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 to, and benefit from, secure habitat (W. Kasworm, USFWS Cabinet–Yaak Recovery Coordinator, personal communication). 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 northwestern Montana.

The 0.6-km/km^2 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 on what digitized roads layers were available, with several researchers including all motorized routes, which included roads traversable by pickup trucks and trails suitable for only OHVs, whereas 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/km^2. The surrounding landscape where females were not found had road densities of 1.1 km/km^2. Similarly, work in Alberta found lower female survival and population declines in areas with road densities >0.75 km/km^2 (Fig. 3; Boulanger and Stenhouse [2014]). In the BC Granby–Kettle population, researchers found that the optimal threshold road density was approximately 0.5 km/km^2 (range = 0.4–0.6) and that grizzly bear density was approximately 3–4 times higher in habitats with road densities <0.6 km/km^2 than in habitats with >0.6 km/km^2 (Fig. 4; Lamb et al. 2018b). Across the south Selkirk and Purcell Mountains of southeastern BC, researchers that found radiocollared females selected and survived in home ranges with average road densities of 0.5 km/km^2 (Proctor et al. 2017). Similar to Lamb et al. (2017), Proctor et al. (2017) also found grizzly bear densities to be approximately 3 times higher in habitats with road densities <0.6 km/km^2 relative to habitats with road densities of >0.6 km/km^2 (Fig. 5).

Female choice of home range, 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 higher survival rates 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 habitats with fewer roads. In a multi-scaled analysis, assessing daily use areas versus female home ranges, researchers found that bears used habitats with higher road densities on a daily basis, yet their home ranges contained lower road densities on average (Apps et al. 2013). These results suggested that survival was more important than avoiding roads. So rather than refer to this as "selection of home range," a more appropriately descriptive term might be "selection of home ranges considering survival."

Although road densities matter to grizzly bears, thresholds can be population-specific. For example, the threatened Stein–Nahatlatch population in southwestern BC—a small (≈10 adults), isolated, low-density, and threatened population—declined from 7.4 to 6.5 bears/1,000 km^2 between 2005 and 2015, even though there are only ≈0.2 km/km^2 of open roads (M. McLellan, Victoria University of Wellington, unpublished data). This area has generally poor habitat quality that limits bear reproduction to a level that only compensates for minimal human-caused mortality. Thus, 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–Nahatlatch bear population, even road

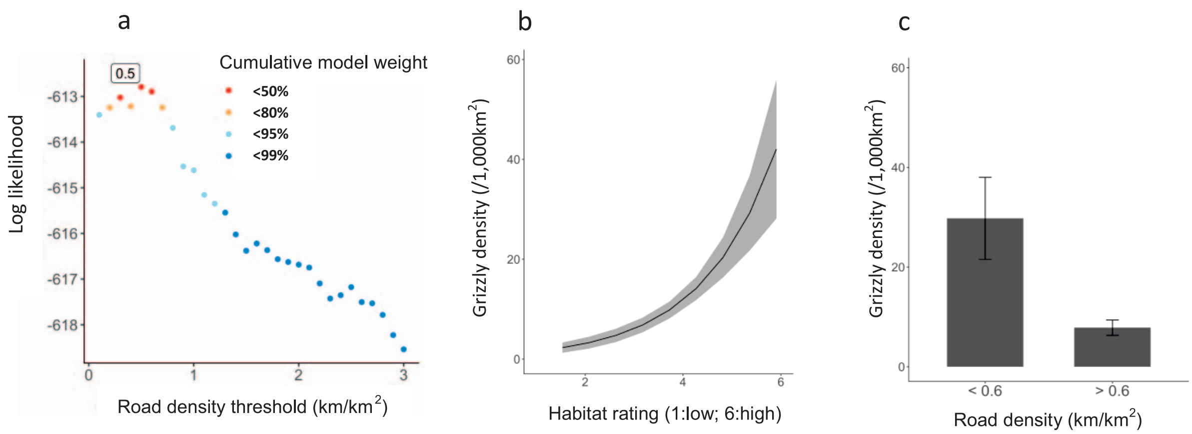

Fig. 4. (a) Optimal road density threshold (0.5 km/km^2) in the Kettle–Granby Grizzly Bear Population Unit of south-central British Columbia, Canada, in 2015. The threshold was derived from the distribution of log likelihood values and cumulative model weights used to find an optimal road-density breakpoint (best fit of the data when grizzly bear (*Ursus arctos*) density was classified into 2 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 > and <0.6 km/km^2. Adapted from Lamb et al. (2018b).

density of 0.6 km/km^2 may facilitate too much mortality risk for that population to recover or be sustainable until habitat management can yield a better food supply.

Another example is from the Flathead Valley (Wildlife Management Units 4-01) of southeastern BC. A DNA-based survey in 2007 yielded an estimated density of 65 bears/1,000 km^2 across the 1,585-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 ephemeral roads (McLellan 2015). This is a very productive area, and bear reproductive rates can compensate for a higher level of human-caused mortality than in most other areas; the Flathead population unit had the highest density of human-caused deaths of grizzly bears in BC between 1979 and 2010 (McLellan 2015).

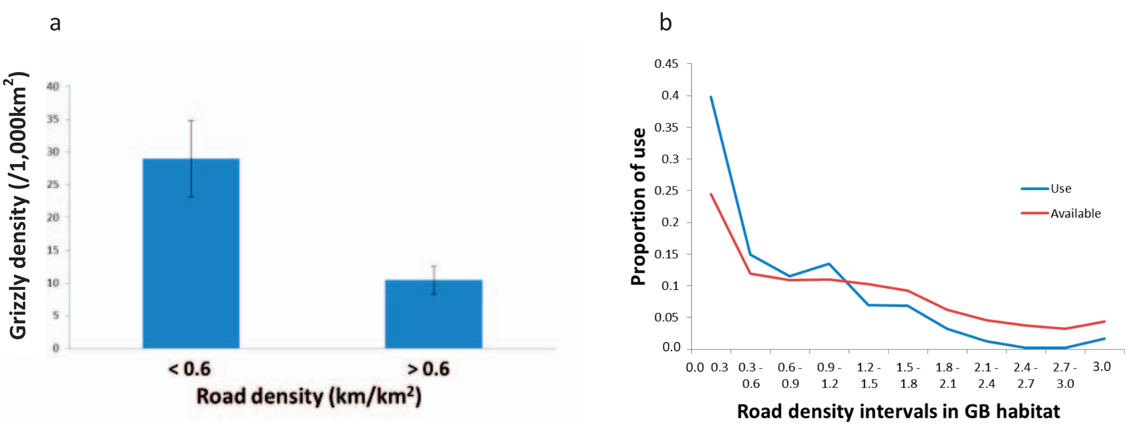

Fig. 5. (a) Differential grizzly bear (GB; *Ursus arctos*) density in the South Selkirk and Purcell Mountain habitats, British Columbia, Canada, between 2004 and 2017 with open road densities > and <0.6 km/km^2; and (b) Female grizzly response to open road density, used (telemetry locations of bears, blue line) versus available habitat (all habitat in area, red line). Adapted from Proctor et al. (2017).

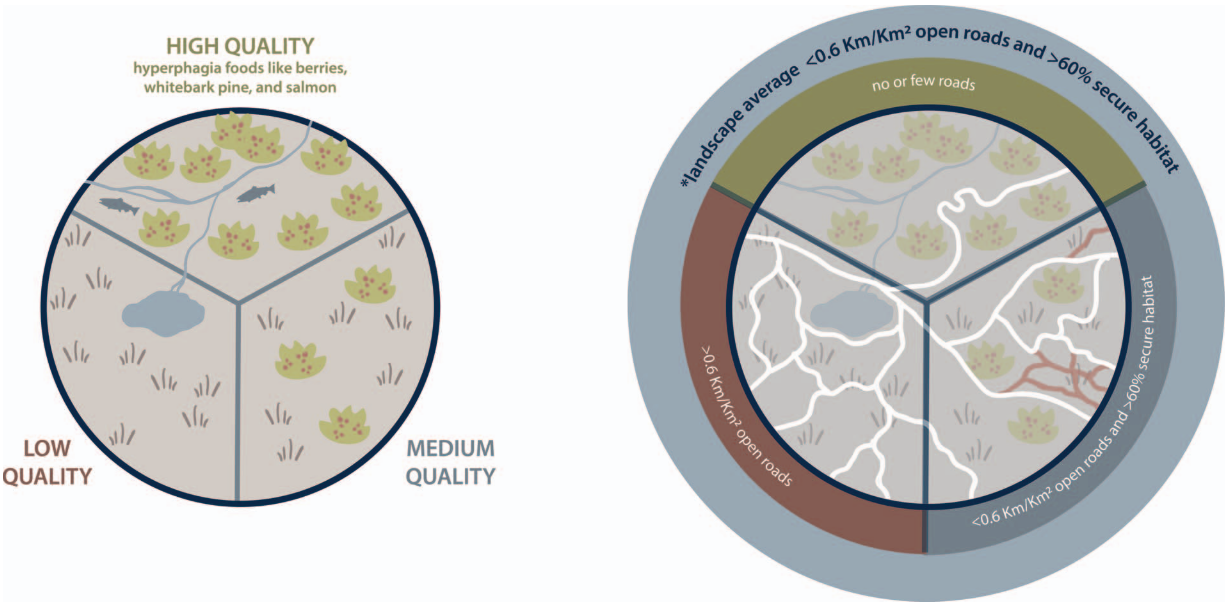

Fig. 6. Schematic of how landscape-level motorized-access controls might look when applied relative to grizzly bear (*Ursus arctos*) habitats. Berry fields and salmon streams represent important energy-rich hyperphagia food habitats, which contain very few or no roads. Areas of medium-quality habitat would be associated with $<$0.6 km/km^2 open road densities and $>$60% secure habitat $>$500 m from open roads wherein some roads might be 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 of $>$60% secure habitat and $<$0.6 km/km^2 road density.

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 autumn 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 (*Pinus contorta*) and clearcut-dominated valley bottom that is generally of less value to grizzly bears (McLellan 2015). Also of importance, the entire area is more than an hour's drive from the nearest permanent human settlement, so the roads see little public use except during the autumn hunting season.

The Flathead Valley is 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 autumn (i.e., ungulate hunting season) hyperphagia 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 MAC (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.

Grizzly bear response to secure habitat

In addition to road densities, female home-range selection and/or survival also has related to the proportion of habitat $>$500 m from an open road (Fig. 7; often

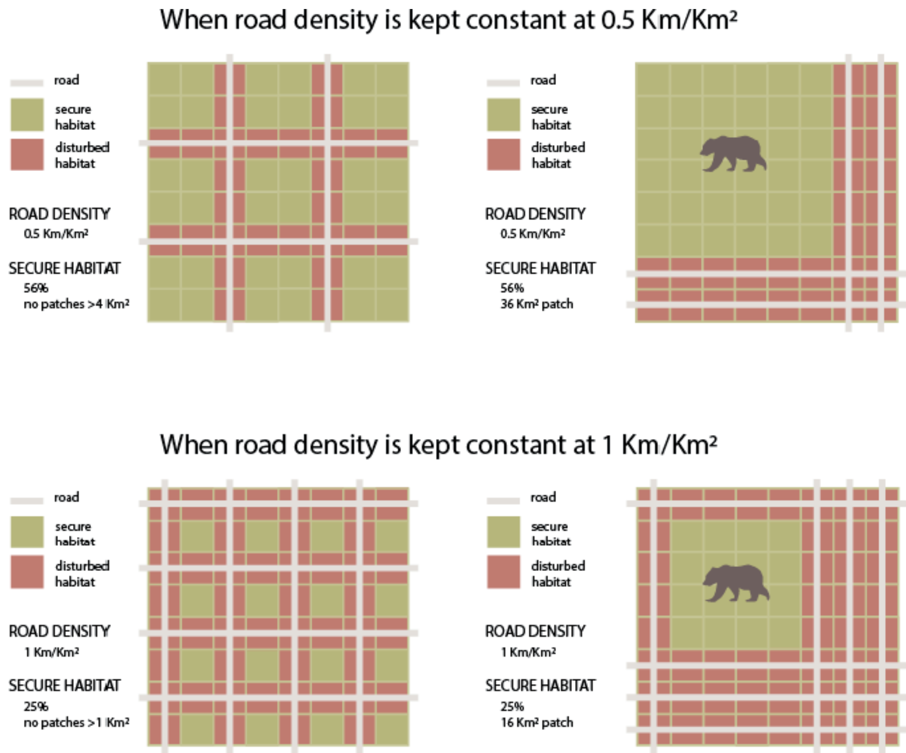

Fig. 7. Schematic of the relationship between road density and the proportion of secure grizzly bear (*Ursus arctos*) habitat. Evenly spaced roads across a unit can result in small patches of secure habitat (i.e., areas >500 m from an open road) that require female bears to cross roads often during a 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.

termed ‘secure habitat’). Studies in northwestern Montana’s Rocky Mountains found that female grizzly bears selected for, and survived better in, home ranges with 56% secure habitat as compared with 30% secure habitat outside the composite female home range (Mace et al. 1996). Female grizzly bears selected for, and survived better in, home ranges with 55% secure habitat, relative to 23–34% secure habitats, in the Yaak and Selkirk Mountains in Montana (Wakkinen and Kasworm 1997). Across the border in Canada, researchers found that female grizzly bears selected for, and survived better in, areas with 56% secure habitat as compared with available areas with 46% secure habitat (M. F. Proctor, unpublished data). The Canadian study measured secure habitats in patch sizes >9 km^2, as suggested by Gibeau et al. (2001) to provide females with lower mortality risk within their average daily movement areas. In the U.S. Greater 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 different, yet important, components influencing survival; road density had more influence on survival as the proportion of secure habitat within female home ranges decreased.

The distribution and configuration of roads can influence secure habitat patch sizes significantly (Fig. 7; Jaeger 2000, Jaeger et al. 2006). 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.

Restricted roads versus 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/km^2 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).

Where to apply motorized access controls

In this section we consider where MACs 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 MACs.

Conservation status

Although it is important to manage all population units for long-term sustainability, different ecological or anthropogenic factors influence conservation risks among populations. We therefore view threatened populations or those 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, backcountry-road–related mortality, and habitat security declines, or some combination of the four. When backcountry 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 >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 (Lamb et al. 2017), 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 neighboring populations should be candidates for MACs. 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 where significant resource extraction is planned, but that otherwise have a relatively robust wilderness character, would benefit from motorized access planning as resource industries develop. Public acceptance of MACs will be easier on new roads than those that have a tradition of use.

Scale of motorized access management

The scientific literature is less clear on which 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 United States have chosen to manage road density within geographic areas that approximate the size of several overlapping adult female home ranges (approx. 200–500 km^2; USFWS 1993, Alberta Environment and Parks 2016). Their 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 most females across the larger population unit. The U.S. example has the strength of a successful decades-long recovery program behind it.

British Columbia is not currently managing for road density across the province, but has several local initiatives. Within BC, several scales are typically used to manage wildlife and ecosystems. Grizzly Bear Population Units (GBPUs, average size approx. 13,500 km^2) are the legal units in which grizzly bears are assessed for conservation status. Although 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 MACs 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 3,800 km^2) may be more appropriately sized and in some cases the

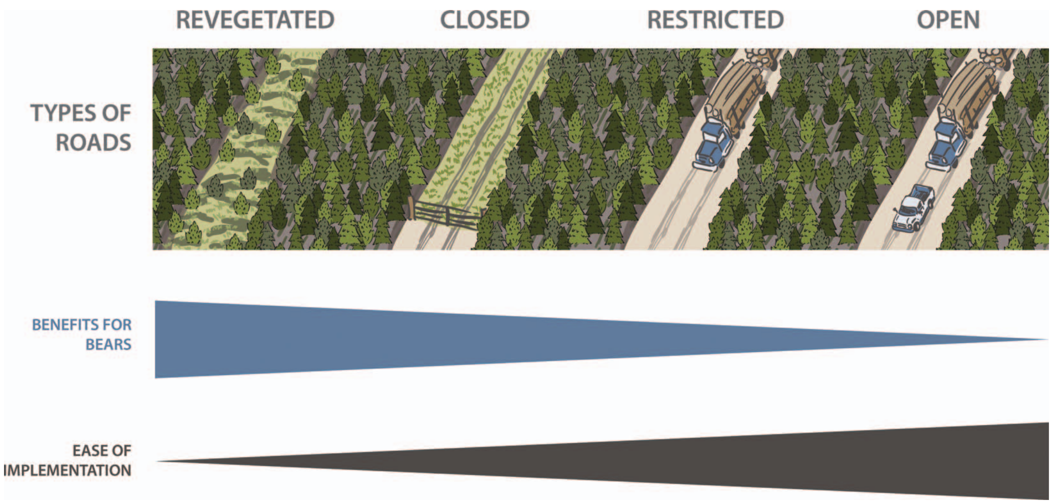

Fig. 8. Types of motorized access controls relative to ease of implementation and benefit to grizzly bears (*Ursus arctos*).

Landscape Unit scale (average size 800 km^2) may be best. This decision will depend on local conditions. Smaller geographic areas may benefit grizzly bears, as managers spread out MACs 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.

Prioritizing habitats for motorized access management across British Columbia 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), southeastern BC (McLellan and Hovey 2001; Proctor et al. 2015, 2017), southwestern BC (Apps et al. 2014; M. McLellan, Victoria University of Wellington, unpublished data); central BC (Ciarniello et al. 2007a,b), 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.

How might motorized access controls be applied?

Although 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 among political jurisdictions. There are several road-control designations that may be used in MAC 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, there is a balance between human use, ease of implementation, and what benefits grizzly bears (Fig. 8). Although 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 that 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 the roads were closed. We encourage land-use managers developing access rules to consider total roads (open, restricted, and closed), which includes the ecological needs of grizzly bears but also a wider spectrum of

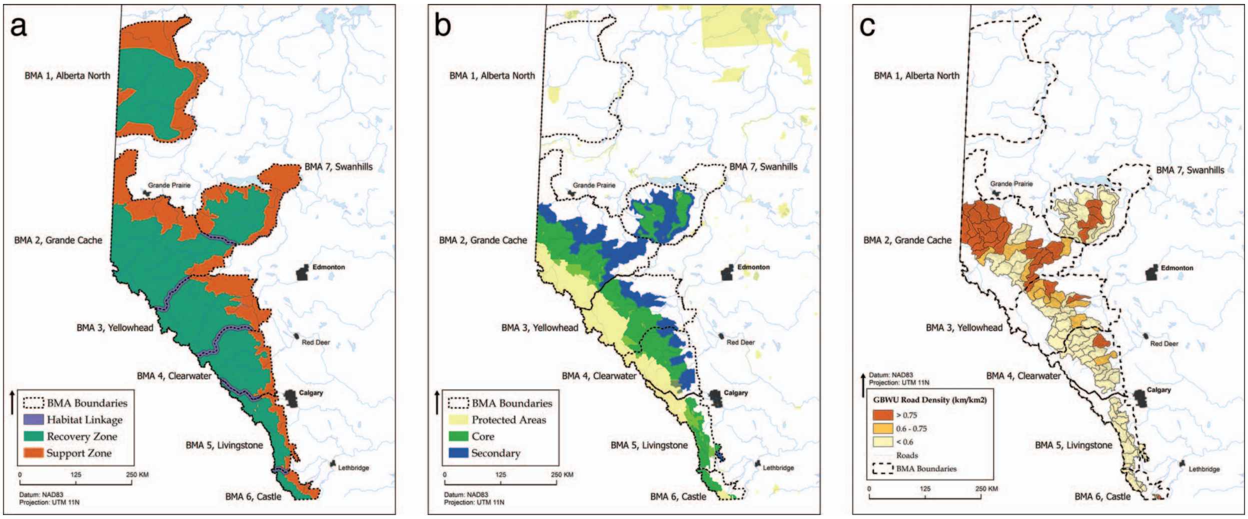

Fig. 9. (a) Grizzly Bear Management Areas (BMAs) across western Alberta, Canada (AEP 2016); (b) Core and Secondary habitats across grizzly bear distribution in western Alberta (adapted from Nielsen et al. 2009); and (c) Road density by Grizzly Bear Watershed Units across 7 BMAs in western Alberta (AEP 2016).

biodiversity (Trombulak and Frissell 2000, Ibisch et al. 2016), including amphibians and reptiles (Hels and Buchwald 2001, Fahrig and Rytwinski 2009), fish, birds and mammals (Fahrig and Rytwinski 2009, Beneitz-Lopez et al. 2010), and carnivores (Basille et al. 2013, Ceia-Hasse et al. 2017), in addition to overall habitat (erosion, terrain stability, water pollution, etc.) conservation (Forman and Alexander 1998, Diagle 2010).

Synthesis on how motorized access management could be improved in British Columbia and Alberta

In the following sections, we 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.

Alberta. Grizzly bears are considered threatened in Alberta, with an approximate estimate of <900 bears 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 approximately 4.3/1,000 km^2. The BMAs are separated by genetic discontinuities through Alberta mediated by major east–west highways (Proctor et al. 2012), but are all connected with populations in BC.

Road networks in Alberta grizzly bear habitat mainly exist outside the mountain parks along the east front of the Rocky Mountains (Fig. 1). Road management is applied in Alberta in response to, and accordance with, results of considerable province-wide 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. 9c: GBWUs, approx. 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. 9b; 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 (as 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 of <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-quality habitat (medium scores within ecological models) and somewhat higher open road densities. Recent work suggested that open road densities >0.75 km/km^2 were associated with sink habitats, the current target in Alberta's Draft Recovery Plan (AEP 2016). Currently, a large proportion of GBWUs exceed the new target road density of 0.75 km/km^2 (Boulanger and Stenhouse 2014; Fig. 9c). Grizzly bear population inventory data collected within the Alberta provincial BMAs (2004–2008 and 2014) have shown that the majority of grizzly bears were found within Core areas and lower numbers were found within Secondary areas (G.B. 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 pickup trucks and cars are on restricted roads). There also is a lack of clarity on what should 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 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 2 new conservation areas within BMA 6 in the southwestern 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 suggest a weak genetic break between these 2 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 >16 times as many bears across >4 times the occupied area of Alberta. The average grizzly bear density across BC is approximately 23 bears/1,000 km^2 (BC Ministry of Environment 2012), >5 times as high as Alberta bear densities. British Columbia's grizzly bears are managed within 55 diverse Grizzly Bear Population Units (GBPUs) that average approximately 13,500 km^2 in size. The GBPUs contain smaller designations, Wildlife Management Units (WMUs), of which there are 183 containing grizzly bears with an average area of approximately 3,800 km^2. Landscape Units are a yet smaller designation and the 940 in BC are approximately the size of several overlapping female home ranges (approx. 800 km^2), similar to Alberta's GBWUs. Although 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 northwestern BC are generally <0.6 km/km^2 (Fig. 10a), but the locations of critical food resources for grizzly bears are generally undocumented, and thus likely unprotected. Much of central, southern, and northeastern 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, the South Rockies, and the South Selkirk (Fig. 11). The Granby Kettle unit has an average road density of approximately 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, as a result of a recently created Provincial park that has no roads and includes an

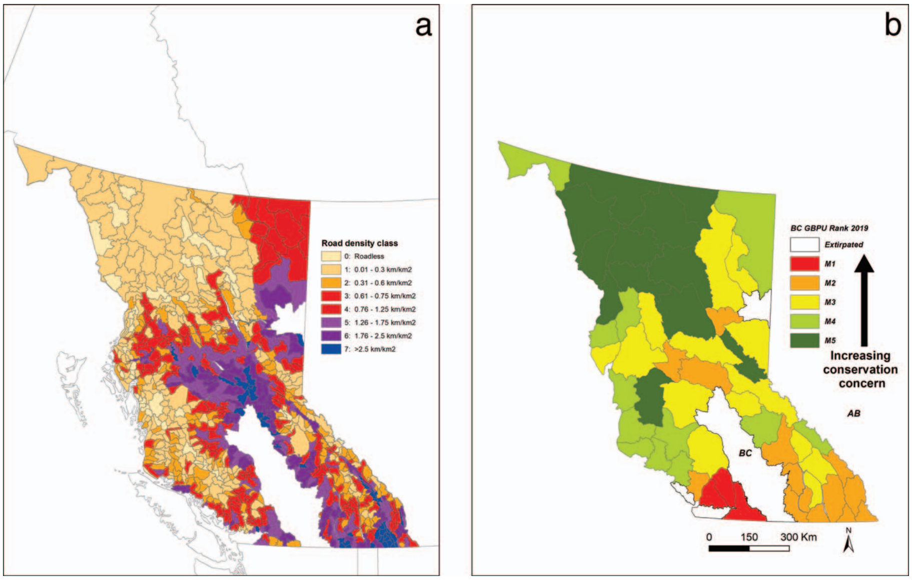

Fig. 10. (a) Road density across British Columbia (BC), Canada, by Landscape Unit (LU mean area approx. 800 km^2) adapted from a BC government initiative to assess Cumulative Effects in BC; and (b) Grizzly Bear Population Units (GBPU) in BC. Conservation status determined through NatureServe ranking by BC Ministry of Environment & Climate Change Strategy. Draft designations are ranked 1–5, with 1 being the highest conservation concern and 5 the least.

associated motorized-access management buffer (Lamb et al. 2018b). By far, the highest densities of bears in this unit are in areas of road densities <0.6 km/km^2 (Fig. 4b).

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 grizzly bears/1,000 km^2; Apps et al. 2016, Mowat and Lamb 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 an approximate 2% annual population decline over a recent 7-year period that was likely initiated by a multiple-year food shortage (Lamb et al. 2019), although it has been increasing for the past 3–4 years (C.T. Lamb, personal communication). The area has an average road density of 1.0 km/km^2, some of which are seasonally closed, and a relatively large human footprint. 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 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 MACs 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 become 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 energy-rich food resources for hyperphagia (salmon, berries, etc.); or,

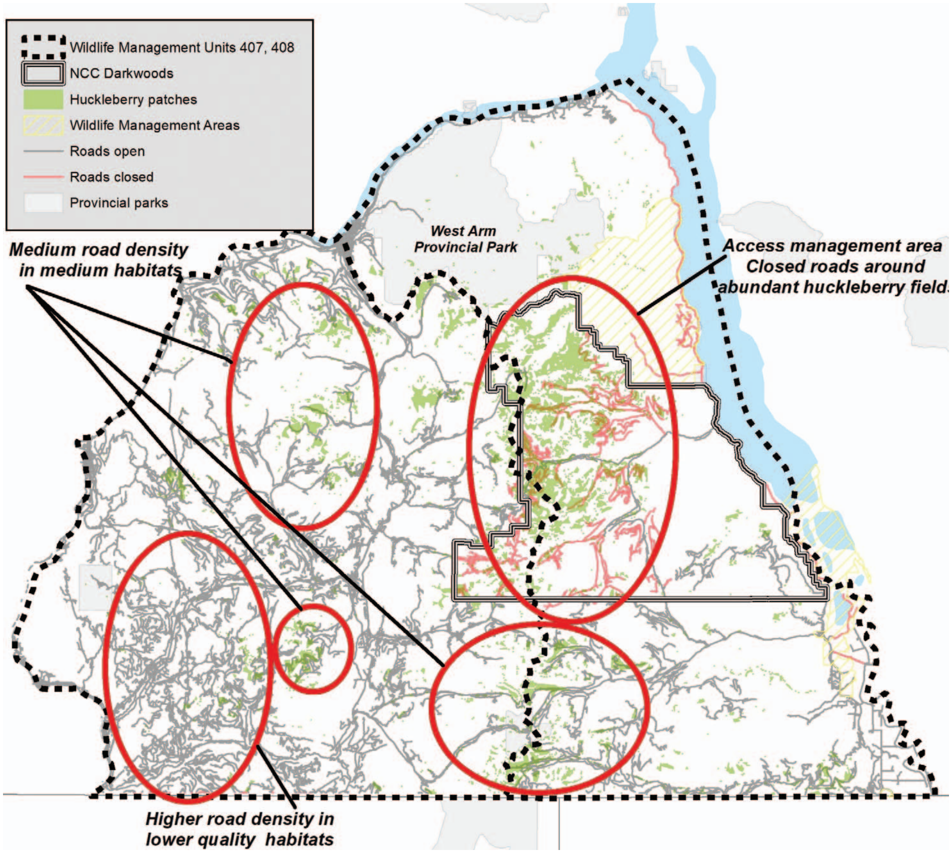

Fig. 11. Habitat-structured motorized-access management: an example in the South Selkirk population unit, southernmost British Columbia (BC), Canada, is an example of how motorized access management might work in BC. It contains 2 Wildlife Management Units, each approximately 2,000 km^2. The Nature Conservancy of Canada (NCC) owns a large parcel (550 km^2) that holds extensive huckleberry fields; and they continue a decades-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 radiocollaring 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 and 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 areas of higher road densities in lower quality habitats.

- $<$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 (BC 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 because many population units across BC and Alberta are at some level of risk, regardless of the hunt, as a result of habitat insecurity and mortality risk.

Within both BC and Alberta, non-usable land-cover types within broader bear 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 Ministry of Forests, Lands, Natural Resource Operations & Rural Development for a wildlife-ecosystem–oriented Cumulative Effects Analysis). We also realize these suggestions may not apply to some coastal road networks, where the general public has no ability to reach because 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 the development of a guidebook of motorized access management methods. Such a manual could be funded by government, nongovernmental organizations, or industry. However, after considering many years of voluntary closures and their ineffectiveness over time, we suggest that when MACs 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 to 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). There are also more research needs to fully understand the relationship between, and implement and monitor, MACs and grizzly bears (Table 2). This includes the need to integrate monitoring the efficacy of implementing MACs where they are applied to inform adaptive management strategies that improve optimization of landscape use for human endeavors and wildlife conservation (Robinson et al. 2010, van der Grift et al. 2013).

Table 2. Research needs for Alberta and British Columbia, Canada, relative to roads and grizzly bears (*Ursus arctos*).

Research topic
Improved digitized maps of usable roads across both provinces.
Updated unreported grizzly bear mortality estimates.
Assessment of habitat quality across much of the provinces.
Assessment of important energy-rich hyperphagia foods.
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.
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 behavior.
Studies on the link between people's attitudes toward bears and roads.

Conclusions

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 trends, 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 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, may allow female grizzly bears to 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.

Our consensus of prioritizing the use of motorized access management across occupied grizzly bear terrain was that "Threatened" populations, 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 responses to roads 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–autumn hyperphagia energy-rich food sources are used heavily. This could entail maintaining low road densities in currently 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 autumn 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 MACs 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 northeastern 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 approximately 500–800 km^2, 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, larger units may be more practical in some cases.

Final statement

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. (2006:62) discussing the approaching-recovered populations, at that time, in the lower 48 states of the United States.

"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 United States 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.

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