Linear Disturbances in the Livingstone-Porcupine Hills of Alberta: Review of Potential Ecological Responses

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Peer review

To ensure the accuracy and objectivity of the information, analyses, and conclusions contained in this report peer review has been conducted by independent and external professionals who are experts in the subject matter contained herein. Feedback received from reviewers has been considered and incorporated to enhance this work.

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Abstract

A considerable body of information is available in the scientific literature to evaluate potential ecological responses to linear disturbances in the eastern slopes of the Rocky Mountains. Drawing from a previous assessment of biological and ecological responses to a range of human activities in the Castle area of southwestern Alberta, this report provides a supplementary analysis specific to the Livingstone-Porcupine Hills, located just north of the Castle area. This report focuses on information related to linear disturbances to inform ongoing dialogue on managing land use and human activities. We provide an overview of relevant evidence from the Castle regional assessment, summarize relevant published case studies, and document the current extent of linear disturbances in the Livingstone-Porcupine Hills region.

Government records supplemented by non-government sources indicate that there are over 4,000 kilometers of roads and trails in the Livingstone-Porcupine Hills region. While comprehensive data on the use of these linear features by people are not available, the region is a popular destination for recreational use of off-highway vehicles, and anecdotal observations indicate high levels of motorized use in certain parts of the region.

Estimates of linear disturbance density, which range from 0.9 to 5.9 km/km^2 among the 20 watersheds in the region, exceed those recently calculated for the Castle Parks area to the south, in which densities ranged from 0.5 to 3.4 km/km^2. An extensive network of intermittent and continuously-flowing streams in the region is estimated to cross these linear disturbances more than 3,000 times, with potential consequences for stream-dwelling species.

Based on an existing body of published research, linear disturbances have the potential to cause a range of ecological responses including stream sedimentation, vegetation disturbance, spread and establishment of invasive species, and a range of behavioural and population-level responses of grizzly bears and other wildlife. Additional focused monitoring and research is needed to further understand the extent and magnitude of these and other potential responses in the Livingstone-Porcupine Hills region. Because variability in the volume, timing and type of off-highway vehicle affects the manner in which terrestrial and aquatic ecosystem attributes may respond, an adaptive monitoring program to characterize vehicle use and related responses of relevant biological and ecological parameters would inform future assessments of the efficacy of actions to achieve management objectives in the area.

Contents

Figures

1 Introduction

The Livingstone-Porcupine Hills region of southwestern Alberta supports a variety of recreational and industrial activities. Along with natural environmental drivers such as wildfire and climate, human activities have the potential to affect species and ecosystem attributes in the region. Understanding the relationships between human activities and ecosystem attributes is necessary to inform land use planning and related decision-making processes.

Drawing from a previous assessment of ecological response to a range of land uses and human activities in the Castle region of southwestern Alberta (Farr et al. 2017), this is a supplementary report focused on linear disturbances in the Livingstone-Porcupine Hills region. Linear disturbances are defined as straight or curvilinear movement corridors that usually contrast with the adjacent landscape.

The purpose of this report is to support informed dialogue on motorized recreation in the region. We provide an assessment of the current linear disturbance density and distribution in the region, and highlight the need for additional adaptive monitoring information on their use by people to better understand the responses of relevant biological and ecological parameters related to achieving regional conservation objectives.

2 Study area

The study area is delineated by several public land use zones identified in the Livingstone-Porcupine Hills Land Footprint Management Plan (Alberta Environment and Parks 2018), which cover a combined area of 1,779 km^2 (Figure 1). The region extends from the northern boundary of the Castle Wildland Provincial Park approximately 60 kilometers along the eastern slopes of the Rocky Mountains and intersects with 20 watersheds (Figure 2).

The complex topography in this mountainous landscape, dominated by slopes greater than 20%, supports a dense network of intermittent and continuous-flowing streams and rivers. A temperate climate, ongoing erosion, and redistribution of weathered rock and soil, create challenging environments for vegetation, which consists of montane forest and shrubland, with subalpine vegetation at higher elevations.

The region accommodates a variety of land uses, including forestry, oil and gas, agriculture, and a range of recreational activities such as camping, hiking, and motorized recreation. While quantitative measures of motorized recreation are not available, the region is a popular destination for recreational use of off-highway vehicles, and anecdotal observations indicate high levels of motorized use in parts of the region. The region is also valued for the conservation of wilderness and ecological integrity, and is adjacent to several provincial protected areas.

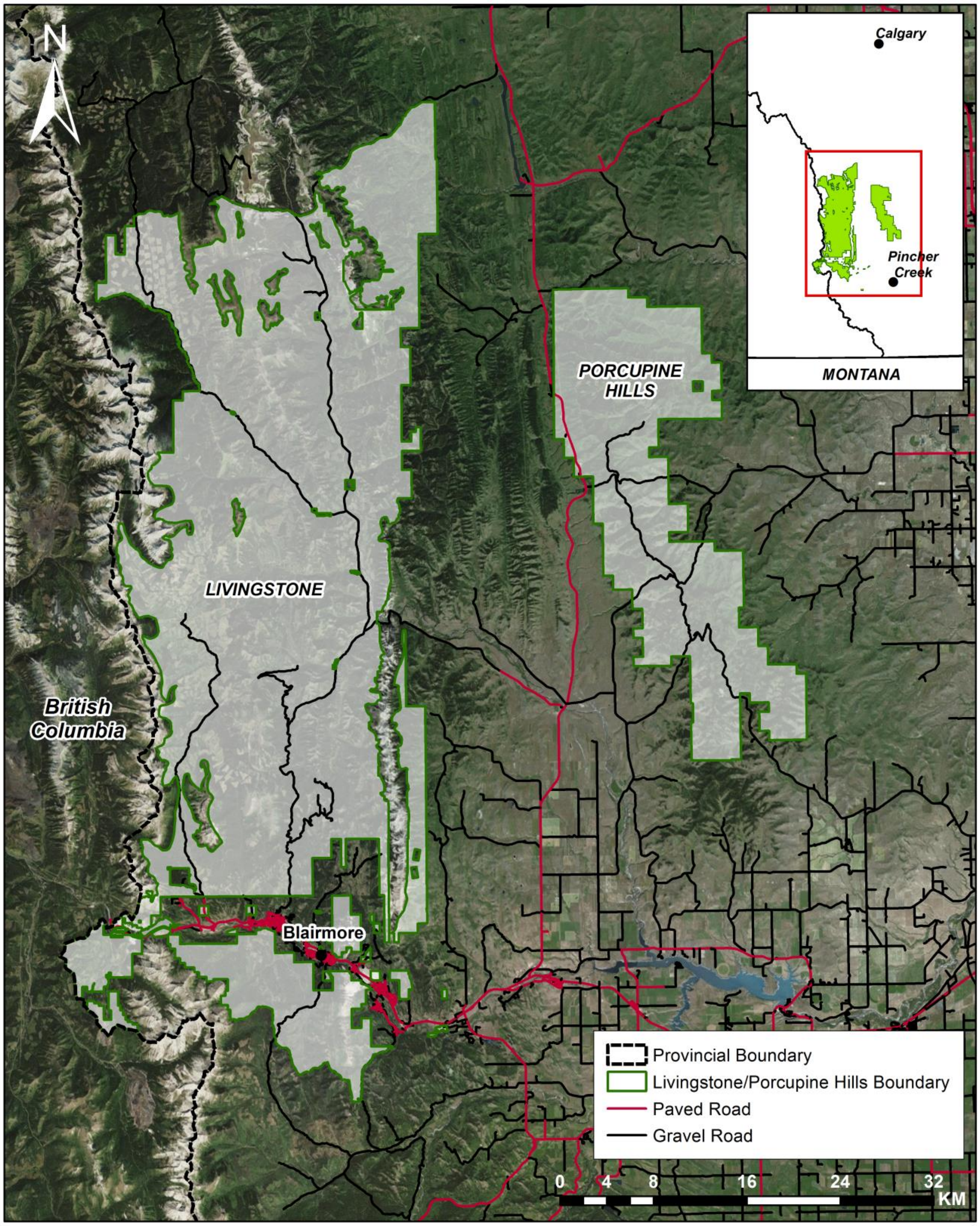

Figure 1. Map of the Livingstone-Porcupine Hills region. Data sources: Appendix A.

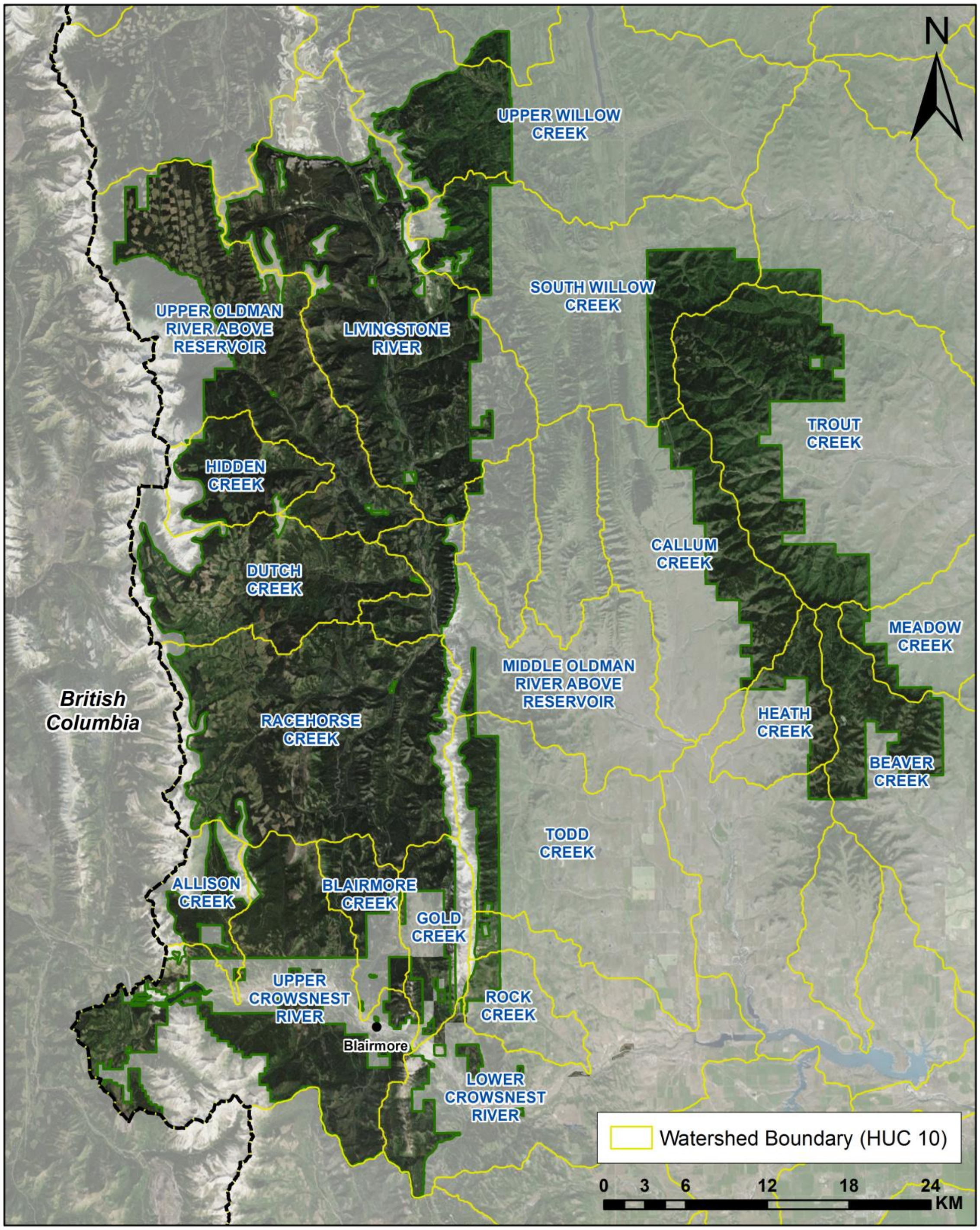

Figure 2. Watersheds of the Livingstone-Porcupine Hills region. Data sources: Appendix A.

3 Literature review

Farr et al. (2017) reviewed published information on the potential impacts of land use and human activity on soil, vegetation, streams and three key wildlife species. Peer-reviewed research articles referenced in that previous report, that specifically addressed linear disturbances, are summarized in Appendix B of this report. In addition, review articles that summarized multiple studies of ecological response to motorized use of linear disturbances are summarized in Appendix C.

4 Geospatial methods

Data sources used to create maps and to conduct spatial summaries are listed in the Literature Cited section, and key spatial data sources used in maps are listed in Appendix A. Esri's world imagery was used for visual reference in maps (Esri World Imagery WGS84 2017), and all maps were created using ArcMap (Esri 2015).

The location and type of linear disturbances such as roads and trails were based on a linear disturbance inventory compiled to inform the Livingstone-Porcupine Hills Land Footprint Management Plan (Linear disturbances in the Livingstone-Porcupine Hills region 2017), which included data from several Government of Alberta and public data sources. The primary data sources used in this inventory came from the Government of Alberta's 1:20,000 base features datasets, including roads, pipelines, powerlines, cutlines created to delineate underground petroleum reserves, and trails (Alberta Base Features 2017). These were supplemented with additional data from several other sources, including Alberta Agriculture and Forestry Timber Operations, TrailNet, the Quad Squad, and the Great Divide Trail.

Once compiled, a topology check was conducted on the linear disturbance inventory to remove duplicate entries. Attribution from input data sources was used to categorize linear disturbances into one of the following five categories:

- paved roads;
- gravel roads;
- unimproved roads, unclassified roads, and truck trails;
- pipelines and powerlines;
- cutlines and trails.

Unimproved roads, unclassified roads, and truck trails were combined into a single category because they are defined as “minor access routes” but have the potential to facilitate the use of motorized vehicles, particularly for recreational purposes. Timber operations roads without base features attribution were also included in this category.

In the case of cutlines and trails, the majority were identified by attributions in the base features dataset. Additional linear disturbances were identified as trails in other attribute fields and were therefore categorized as cutlines and trails. This category also included features that had some indication that they were trails but lacked sufficient attribution to be grouped into any other category. Lastly, timber operations roads classified as partially or fully reclaimed were included in this category.

Four features identified as railway lines (with a combined length of 0.23 km), as well as several features identified as planned timber roads with no visible disturbance on 150 cm SPOT imagery (Alberta SPOT Imagery 2016), were excluded from spatial summaries.

The total length of each linear disturbance category in the study area was calculated using ArcMap (Esri 2015). To calculate the density of linear disturbances in each watershed, we intersected watersheds (Hydrologic unit code watersheds of Alberta 2017) with linear disturbances and calculated the density of linear disturbances for watersheds in which at least 10% of the watershed area overlapped with the study area.

Stream crossings were identified by intersecting watercourses (FWMIS Hydrology Arcs 2017) with linear disturbances. Crossings were then categorized by stream order (Strahler 1952) and by linear disturbance type. Density of stream crossings was calculated by dividing the total number of stream crossings on each watercourse by the total length of the watercourse.

5 Linear disturbances in the Livingstone-Porcupine Hills region

Our compilation of linear disturbances in the region found a total of 4,209 km of linear disturbances (Figure 3) consisting primarily of trails (3,248 km), followed by unimproved roads and truck trails (556 km), gravel roads (250 km), pipelines and powerlines (144 km), and paved roads (10 km; Figure 4).

The overall density of linear disturbances in the region is 2.4 km/km^2. At the watershed scale, the density of linear disturbances ranges from 0.9 km/km^2 to 5.9 km/km^2 in the 20 watersheds with at least 10% of their area within the region (Figures 5, 6, 7). This is considerably greater than the Castle Parks area to the south, for which recent estimates ranged from 0.5 to 3.4 km/km^2 (Farr et al. 2017).

The overall density of roads (paved, gravel, unimproved, and truck trails) in the region is 0.5 km/km^2. Road densities range from 0.0 km/km^2 to 0.9 km/km^2 in the region's 20 watersheds (Figure 8).

There is limited information on the frequency and types of vehicle use in the Livingstone-Porcupine Hills region; however, many linear disturbances in the area are trails that are inaccessible to on-highway vehicles. As noted previously, the region is a popular destination for recreational use of off-highway vehicles, with anecdotal observations indicating high levels of motorized use in parts of the region.

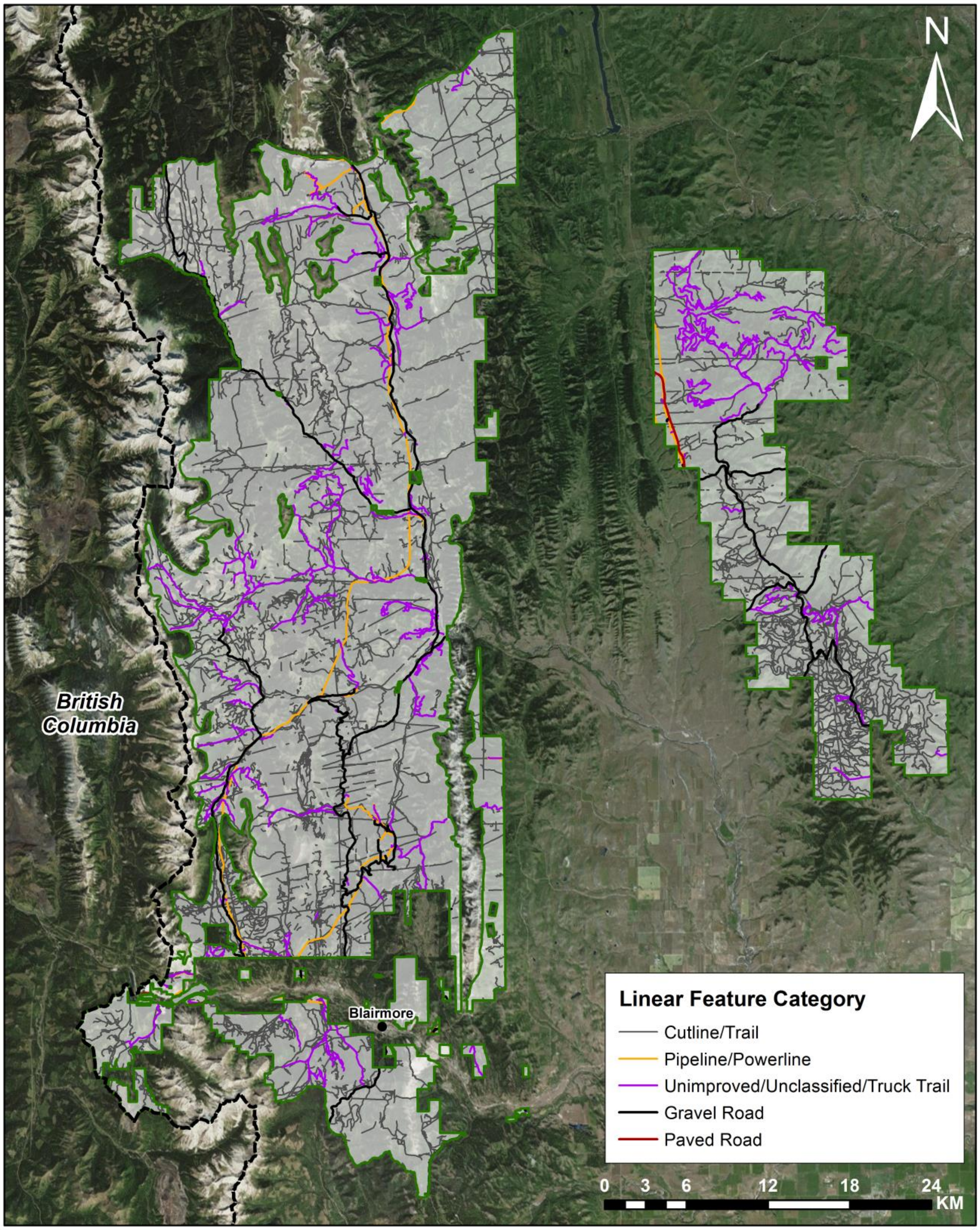

Figure 3. Linear disturbances in the Livingstone-Porcupine Hills region. Data sources: Appendix A.

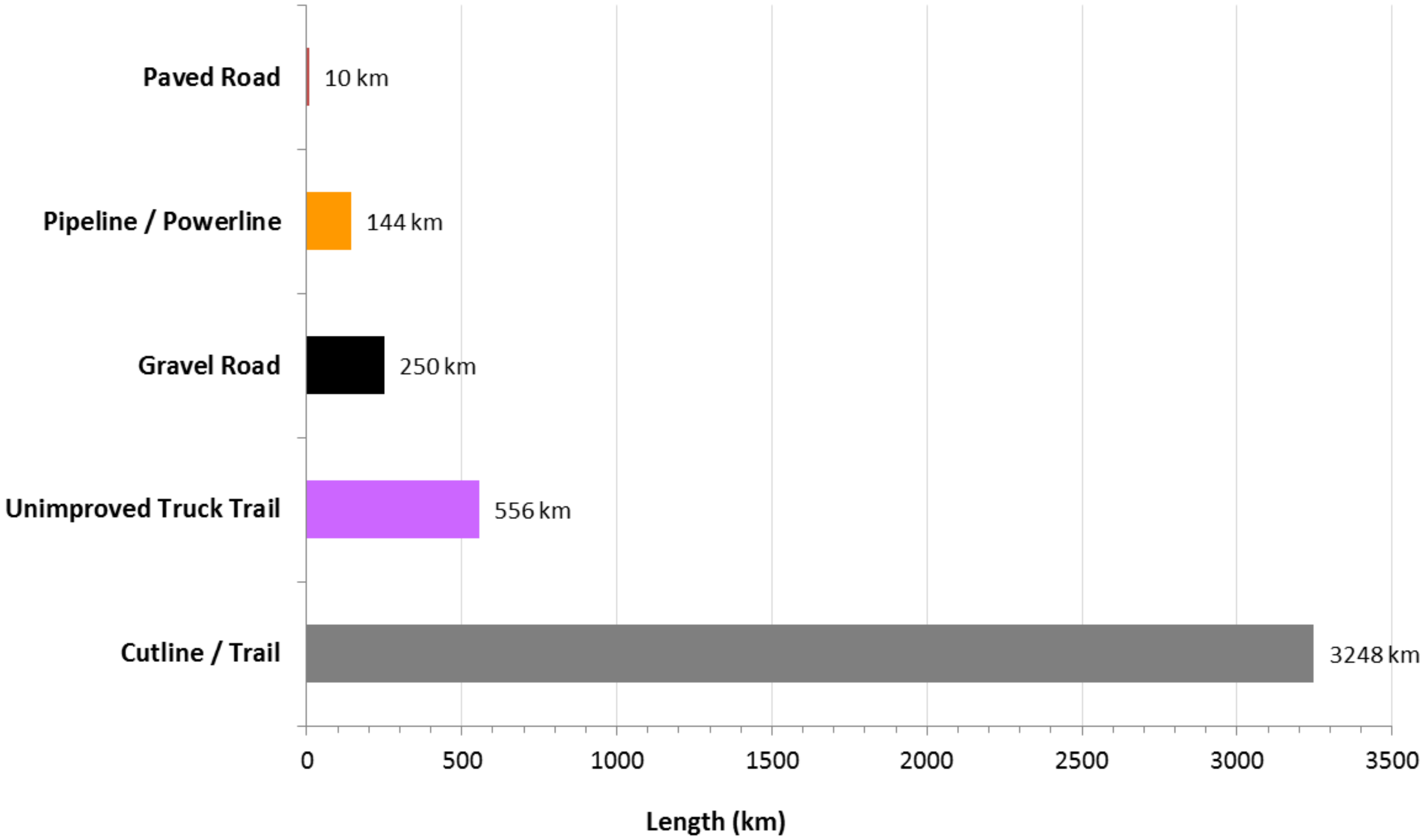

Figure 4. Summary of the cumulative linear disturbance (km) by category in the Livingstone-Porcupine Hills region. Data sources: Appendix A.

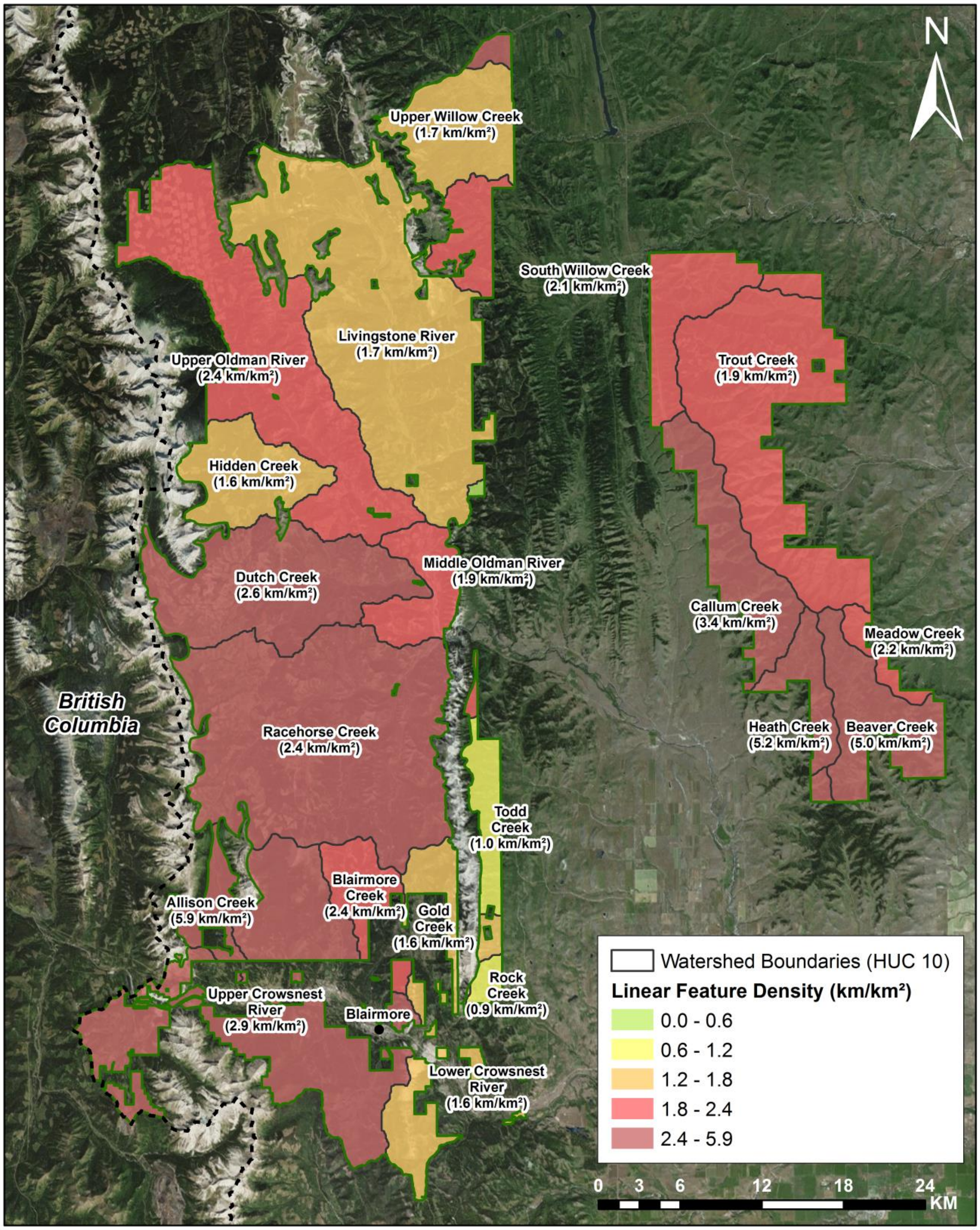

Figure 5. Linear disturbance densities in 20 watersheds in the Livingstone-Porcupine Hills region. Densities were calculated for watersheds with >10% overlap with the region, and only for the overlapping portion of each watershed. Data sources: Appendix A.

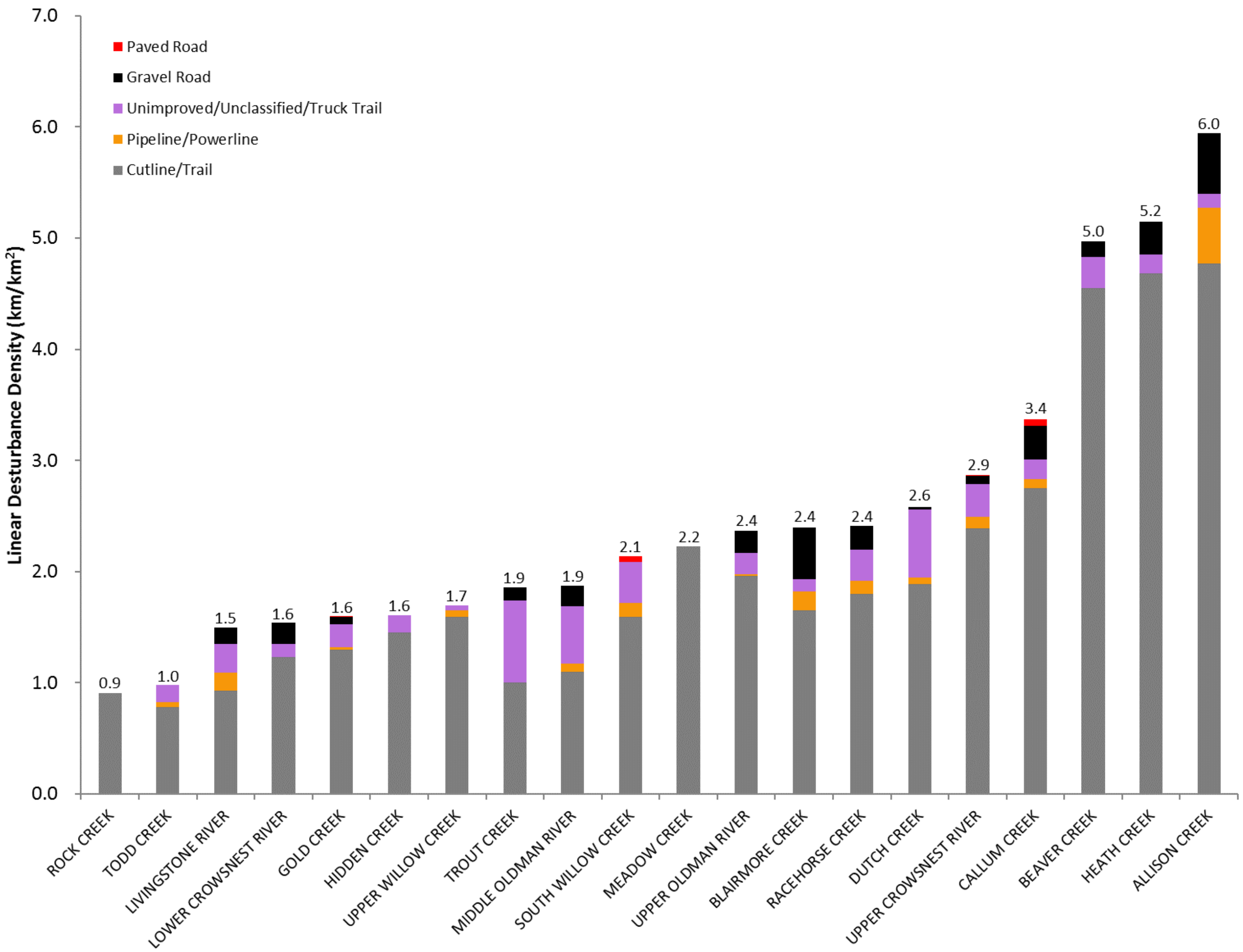

Figure 6. Linear disturbance density in the Livingstone-Porcupine Hills region by watershed. Data sources: Appendix A.

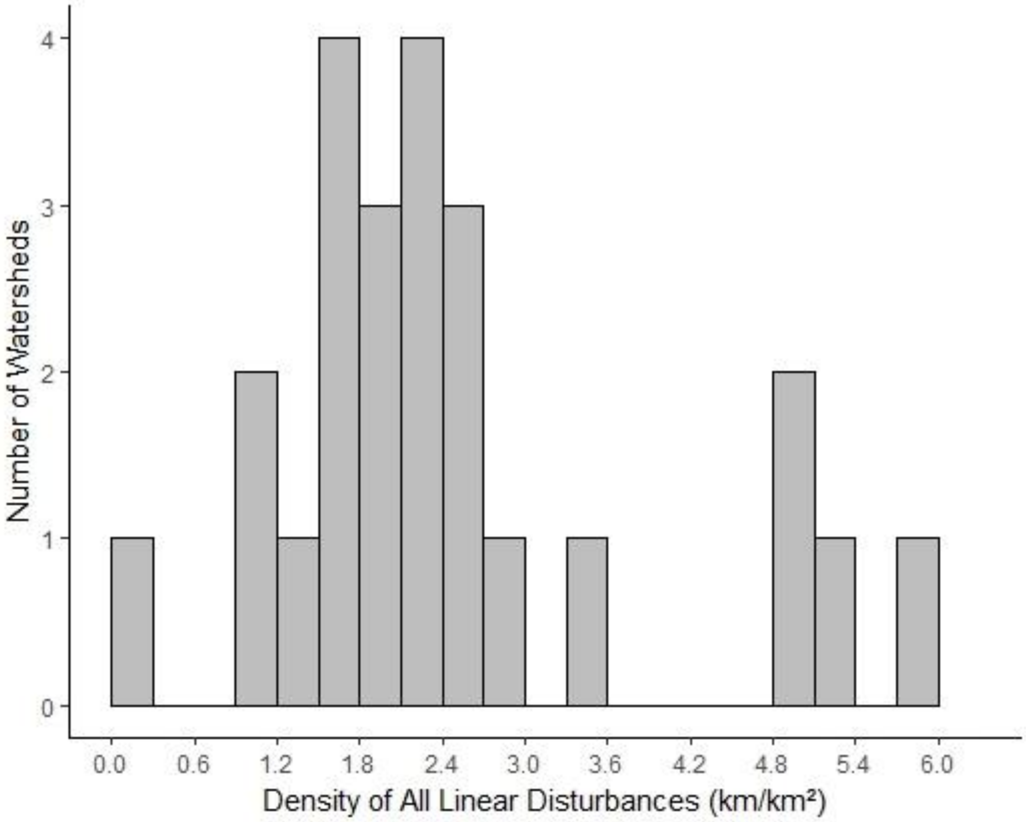

Figure 7. Histogram of the frequency of watersheds in relation to the density of linear disturbances in the Livingstone-Porcupine Hills region. Data sources: Appendix A.

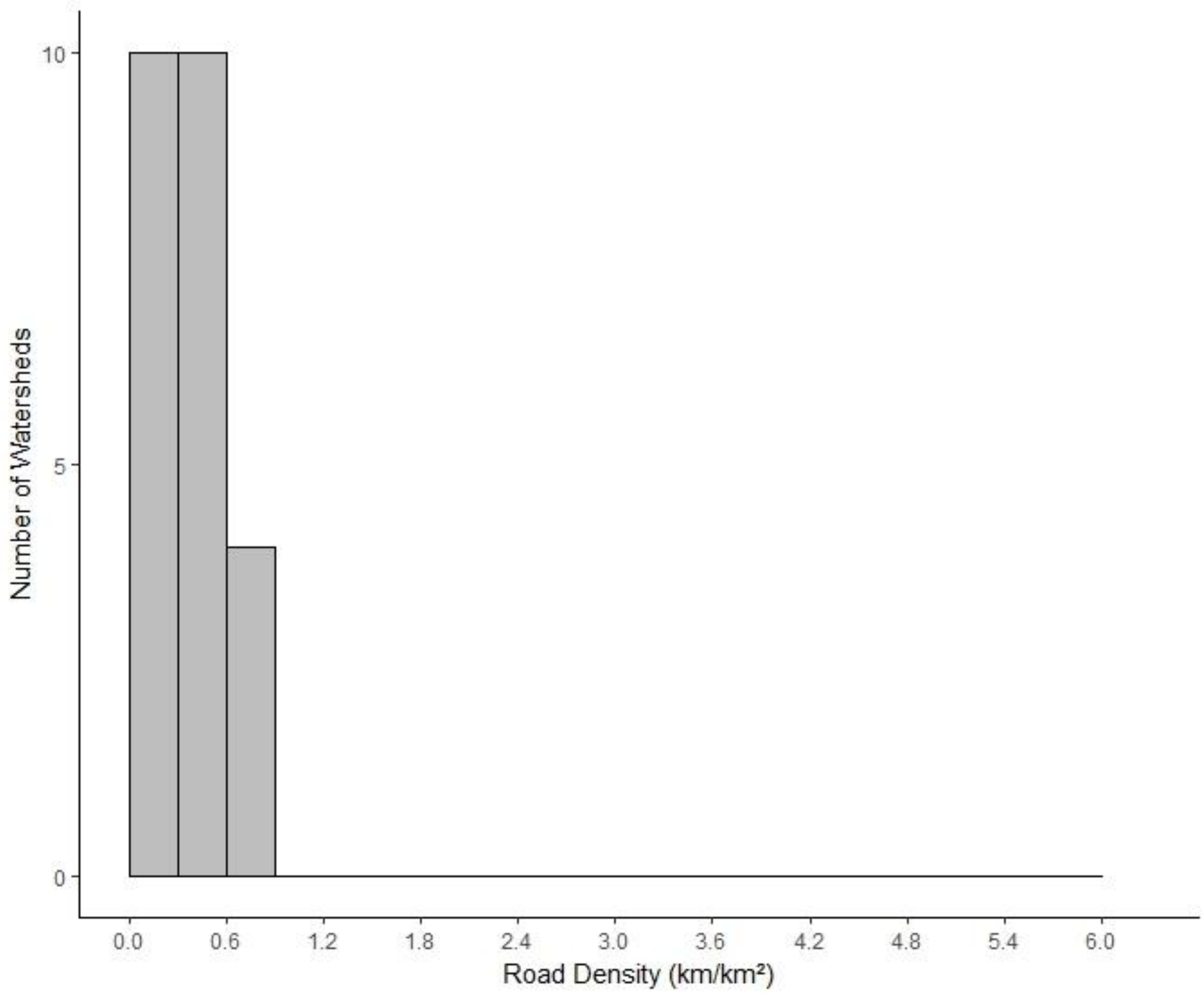

Figure 8. Histogram of the frequency of watersheds in relation to the density of roads in the Livingstone-Porcupine Hills region. Data sources: Appendix A.

5.1 Stream crossings

Intersections of mapped linear disturbances and watercourses indicate that there are approximately 3,800 stream crossings in the Livingstone-Porcupine Hills region (Figure 9). Most (91%) of these crossings occur on small headwater streams (i.e., stream orders 1 to 3). Some streams are crossed more than 10 times per kilometer, and 28% of streams have crossing densities greater than one crossing per kilometer of stream.

Headwater streams may have intermittent flows or be difficult to observe depending on the season and the amount of recent precipitation. Thus, in some cases motorized users may not be aware that they are crossing a stream channel. Surficial materials loosened by vehicles crossing a dry streambed may enter the aquatic environment during the next streamflow event, such as after rainfall. The cumulative sedimentation generated by numerous crossings in a watershed may affect water quality but this parameter is not monitored in the region.

There are several additional considerations when interpreting the stream crossing estimates. Firstly, not all linear disturbances in the region are mapped, and some linear disturbances may be incorrectly mapped (i.e., they are natural features or they are not accessible to motorized users). Secondly, intensity of use (i.e., how many times each motorized users actually cross each watercourse) plays a key role in determining the magnitude of sedimentation, but cannot be evaluated because data are unavailable. Lastly, crossings at some larger watercourses are facilitated by bridges or culverts, which would likely reduce sedimentation and other impacts compared to crossings without such structures. Despite the uncertainty caused by these considerations, the large number of crossings in the region indicate the potential for downstream impacts on aquatic systems caused by sediment input.

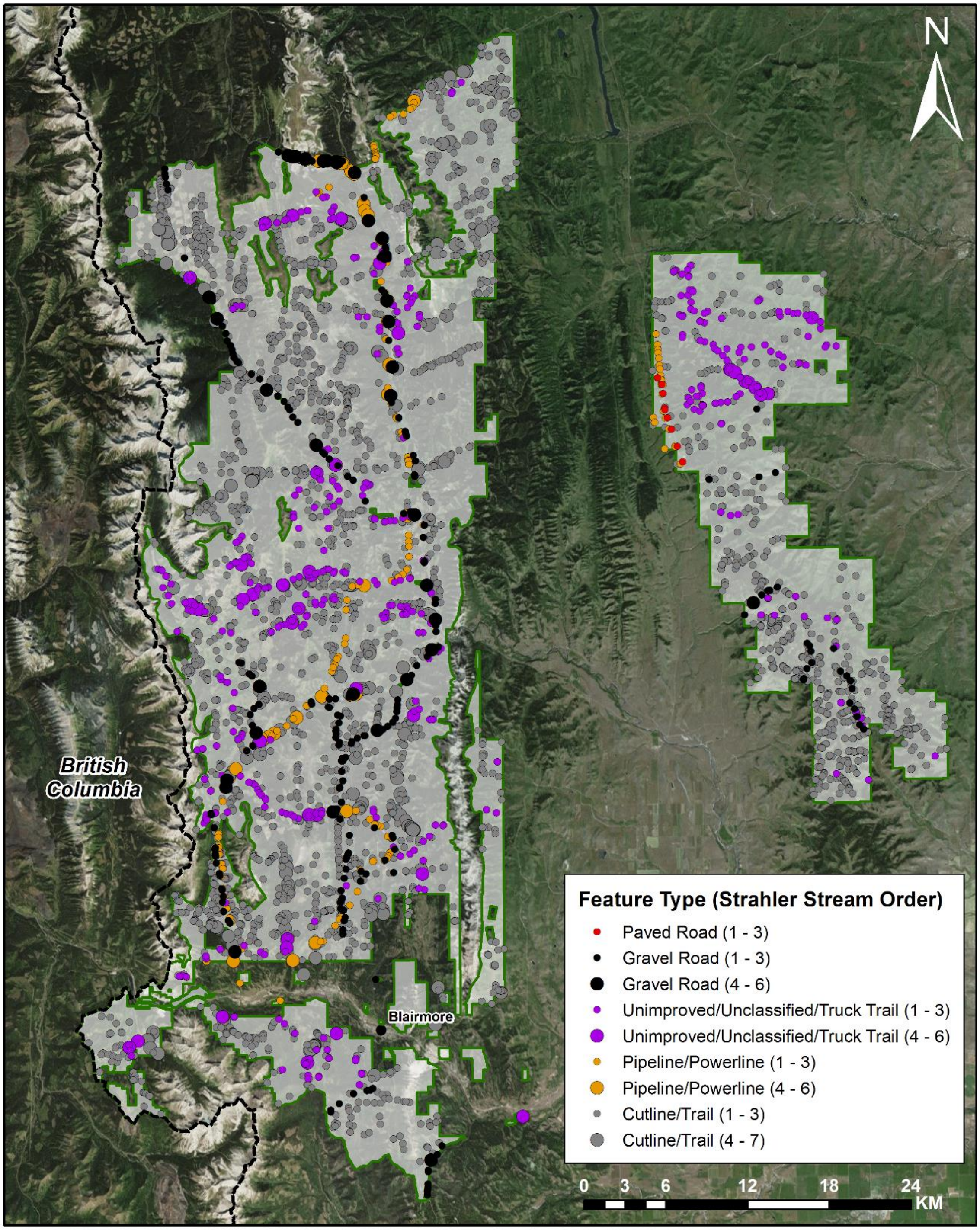

Figure 9. Stream crossings in the Livingstone-Porcupine Hills region. Data sources: Appendix A.

6 Ecological response to motorized use of linear disturbances

6.1 Soil and vegetation

The general effects of motorized use of linear disturbances on soils and vegetation are well-documented in the scientific literature. These include: increased rates of soil erosion and compaction; destruction and loss of vegetation cover; loss of species richness and shifts in species composition; and habitat fragmentation (Weaver and Dale 1978, Kay 1981, Forman and Alexander 1998, Stokowski and LaPointe 2000, Kelleway 2005, Arocena et al. 2006, Nepal and Way 2007, Ouren et al. 2007, Pickering and Hills 2007, Dickson et al. 2008, Geneletti and Dawa 2009, Burgin and Hardiman 2012, Farr et al. 2017).

Observed effects on soil and vegetation vary among different environments (Olive and Marion 2009). For example, in treeless environments at higher elevations, damage to poorly developed soils and sparse, fragile vegetation can persist far longer than in treed or lower elevation areas (Crisfield et al. 2012). Soils within the Livingstone-Porcupine Hills region consist mainly (90%) of Brunisols (Derived Ecosite Phase 2017) which are subject to erosion, particularly in areas of moderate to steep terrain.

Vegetation loss and soil compaction also create favourable conditions for the establishment of invasive plant species (Stokowski and LaPointe 2000, Havlick 2002, Foltz 2006, Goossens and Buck 2009, Hermanutz and Stavne 2009). Motorized vehicles can also facilitate the transport of seeds and vegetative structures of invasive and non-native species (Adams 1998, Rooney 2005, Hermanutz and Stavne 2009).

Together, these processes of vegetation loss, soil compaction and erosion, and the spread of invasive species can create positive feedbacks that continually degrade habitat and natural plant communities (Crisfield et al. 2012, van Vierssen Trip and Wiersma 2015). Additional research is needed to clarify how variation in the type and frequency of human activity along linear disturbances affects these responses.

Case Study: Effects of Motorized Trail Use on Soils

Sediment flux and compaction trends on off-road vehicle (ORV) and other trails in an Appalachian Forest setting

Sack and da Luz (2003)

Sack and da Luz (2003) surveyed trail segments from ORV, horse-riding, and hiking trails in Ohio’s Wayne National Forest. Repeated measurements of topographic profiles and soil compaction were taken at cross-trail transect sites on each trail segment, as well as adjacent forest land. Field data were collected over three time periods, including peak ORV season, end of ORV season, and at the end of the ORV off-season. Empirical measurements were compared between trails and adjacent forests, between ORV and non-ORV sites, and between observation periods.

Changes in mean ground height on ORV trails were indicative of net deposition in the trail-adjacent forest zones, particularly during the ORV season. Net trail erosion was observed during the ORV season, whereas net deposition occurred during the off-season. Penetrometer measurements indicated that horse-riding and hiking trails were more compacted than ORV trails, but that maximum compaction occurred farther below the ground surface than on ORV trials. Penetrometer resistance was higher on trails than in adjacent forest soils in all cases (regardless of type of recreational use), and depth of maximum penetrometer resistance was higher in forest soils in almost every case.

Measurements of detailed topographic profiles on ORV trails revealed substantial sediment flux. Aggradation in adjacent forest zones, along with field observations, suggested that some of the eroded sediment was deposited in areas adjacent to the ORV trails. The authors suggested that sediment-splash caused by ORVs and downslope fluvial translocation of sediment over compacted trails were responsible for the sediment flux from trails to adjacent forest zones. Non-ORV trails did not follow the same pattern of trail erosion and forest deposition, and while compaction was higher on non-ORV trails, less surface compaction was observed compared to ORV trails.

Physical impacts of ORV use on soils included significant surface compaction and sediment flux. The authors also highlighted the concern that the sediment flux observed on ORV trails could contribute to higher sediment yields in perennial stream channels in the study area, which can adversely affect lotic ecosystems.

Case Study: Effects of Motorized Use on Vegetation

The effects of vehicular and pedestrian traffic on dune vegetation in South Africa

Rickard, McLachlan and Kerley (1994)

Rickard et al. (1994) measured vegetation responses (height and percent cover) of pioneer and climax dune shrubland communities to varied intensities of off-road vehicle (ORV) and pedestrian traffic in South Africa. Treatments included repeated low- and medium-intensity applications of ORV and pedestrian traffic, as well as single event, high intensity applications.

The climax community demonstrated greater resistance to both ORV and pedestrian traffic relative to the pioneer community. Repeated low- and medium-intensity trampling of vegetation had cumulative effects on both height and cover. High-intensity traffic caused a lag response with immediate decreases in height and percent cover which were followed by additional decreases over time. Over the full 10-month observation period, continued declines in both height and cover were observed at the low- and medium-intensity sites, whereas minimal recovery was observed following the high-intensity treatments. Recovery was more pronounced in the pioneer community, demonstrating that while the shrubland community was more resistant to disturbance, it was less resilient.

Overall, damage to vegetation was proportional to the level of impact. Repeated disturbance generated cumulative impacts (reduced height and cover), whereas single, high-intensity disturbance caused both initial damage and additional damage over time. Recovery was observed in both plant communities after single, high-intensity disturbance treatments, but was much less pronounced in the climax shrubland community relative to the pioneer community. Though vehicular and pedestrian traffic generated similar negative vegetation responses, the treatments were not directly comparable and the authors suggested that both communities were less resistant to ORV traffic than to pedestrian traffic.

6.2 Water quality and trout

As described above, the intersection of linear disturbances with watercourses in this hydrologically complex region creates the potential for sediment inputs to the aquatic environment. Each of these crossings provides a potential pathway for sedimentation (Chin et al. 2004, Ouren et al. 2007, Welsh 20080 and negative impacts on water quality (Arp and Simmons 2012, Kidd et al. 2014, Marion et al. 2014).

Motorized vehicle crossings of streams, particularly at unimproved crossings, is a concern for threatened populations of westslope cutthroat trout (*Oncorhynchus clarki lewisi*) and bull trout (*Salvelinus confluentus*) (Al-Chokhachy et al. 2016), along with other aquatic species that are adapted to clean, cool, structurally complex habitats, and connected watercourses (Farr et al. 2017). Studies throughout the range of both trout species in western North America have documented negative relationships between stream trout and linear disturbances (Rieman et al. 1997, Dunham and Rieman 1999, Ripley et al. 2005, Valdal and Quinn 2011). Increased sedimentation from bank erosion and streambed disturbance may negatively impact spawning (Magee et al. 1996, Greig et al. 2005, Julien and Bergeron 2006, Sear et al. 2008, Bowerman et al. 2014), and other life stages (Watson and Hillman 1997, Quigley and Arbelbide 1997, Reid et al. 2003). Sedimentation in watercourses can also have indirect impacts on stream trout by disrupting primary production (Henley et al. 2010) and other aquatic food web components (Weigelhofer and Waringer 2003).

Case Study: Effects of Roads on Westslope Cutthroat Trout Abundance

Spatial analysis of forestry-related disturbance on westslope cutthroat trout (*Oncorhynchus clarkii lewisi*): Implications for policy and management

Valdal and Quinn (2011)

Valdal and Quinn (2011) explored relationships between cutthroat trout abundance and landscape-level variables (including natural and anthropogenic factors) in six watersheds in British Columbia's Kootenay River watershed. Univariate regression models were used to explore single-variable relationships, and multiple regression was used to develop a cutthroat trout abundance model.

Univariate analysis revealed significant negative relationships between cutthroat abundance and several metrics of road density, as well as proportions of streams that were logged. The most-supported multiple regression model included density of roads within 100 m of streams and proportion of streams that were recently logged.

Road systems had significant negative effects on cutthroat trout abundance. While the relationship between road density and abundance was significant, road density on erodible soils within 100 m of streams was the factor that was most strongly related to cutthroat abundance. The authors stressed that in addition to road density, the spatial arrangement of roads – particularly relative to erodible soils and stream networks – played a large role in influencing cutthroat trout abundance. Roads that cut through erodible soils in close proximity to streams are primary pathways of sediment input into streams, which in turn has detrimental effects on cutthroat trout habitat. Logging on fish-bearing streams was not significantly related to cutthroat trout abundance, likely because of riparian setback regulations. However, logging of all streams (i.e., perennial and ephemeral streams regardless of fish occupancy) had a significant negative effect on cutthroat trout abundance. The authors concluded that land use disturbance in upstream reaches, regardless of westslope cutthroat trout occupancy, has significant ramifications for downstream channel morphology and salmonid habitat. The most-supported multivariate model included road density within 100 m of streams and proportion of streams that were recently logged, which illustrates the negative cumulative effects of roads and forest harvesting on cutthroat trout abundance.

Case Study: Effects of Roads on Bull Trout Occurrence and Abundance

Bull trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative developments in a Canadian boreal forest watershed

Ripley, Scrimgeour, and Boyce (2005)

Ripley et al. (2005) used logistic regression and zero-inflated Poisson models to relate bull trout occurrence and abundance in Alberta's Kakwa River watershed to a number of environmental variables focused on capturing the effects of various stream reach characteristics and levels of industrial disturbance from forestry and hydrocarbon extraction. They then used data from logistic regression models to forecast local extirpation of bull trout from stream reaches due to increases in forest harvesting.

Bull trout occurrence was positively related to stream wetted width and negatively related to percent fines, reach slope, and percent forest harvesting. Across several well-supported models, bull trout occurrence was consistently negatively related to forest harvesting and road density. Bull trout occurred in sub-basins containing 2.5 times fewer roads and three times less forest harvesting than sub-basins where bull trout did not occur. Using logistic regression models, predicted probability of bull trout occurrence sharply declined with increasing road density until ~0.7 km/km^2, and reached zero at ~1.6 km/km^2. The authors predicted the local extirpation of bull trout in 24-43% of stream reaches in the study area once 35% of individual sub-basins are harvested, depending on the current bull trout abundance in a given stream reach.

Though road density for the Kakwa River watershed was relatively low overall (0.2 km/km^2), road densities were often higher than 1.0 km/km^2 in sub-basins where commercial forest harvesting occurred. Industrial disturbance variables were important predictors in many of their models, but generally explained less variance in bull trout occurrence than environmental variables. The authors suggested that this can be interpreted as portending more serious impacts to bull trout (including local extirpations) in the region if industrial activity and associated disturbance continues to increase under status quo watershed management. Accordingly, they recommended that land managers protect and maintain large, interconnected cold-water habitats such as the Kakwa River watershed because of their critical importance to bull trout conservation in Alberta.

6.3 Grizzly bears

Negative interactions with people are a major threat to the persistence of grizzly bear populations in most jurisdictions across their North American range (Benn and Herrero 2002, Nielsen et al. 2004, Schwartz et al. 2006, McLellan 2015). Over the past 10 years in Alberta, most mortalities of grizzly bears over the age of 2 years old were caused by people (Alberta Environment and Parks 2017a). Several studies suggest that grizzly bear mortalities predominantly occur in close proximity to roads (within 500 m; Benn and Herrero 2002, Boulanger and Stenhouse 2014, McLellan 2015) and trails (within 200 m; Benn and Herrero 2002). Grizzly bear survival is reduced in areas of high road density (Schwartz et al. 2010, Boulanger et al. 2013). Females with cubs are particularly vulnerable (Boulanger and Stenhouse 2014), likely because they may select habitats near roads (McLellan and Shackleton 1988, Graham et al. 2010). Unsurprisingly, grizzly bear survival is positively associated with the availability of secure habitat distant from roads (i.e., where the risk of mortality is low; Schwartz et al. 2010). Accordingly, the area of roadless habitat has been used as a measure of habitat security for grizzly bears in several jurisdictions (Interagency Grizzly Bear Committee 1998, United States Fish and Wildlife Service 2003, Schwartz et al. 2010).

Aside from the direct consequences of human activity along linear disturbances, a suite of indirect effects have also been well documented, including behavioural and distributional responses (McLellan and Shackleton 1988, Mace and Manley 1993, Mace et al. 1996, Gibeau et al. 2002, Roever et al. 2008, Graham et al. 2010, Northrup et al. 2012, Fortin et al. 2016). Spatiotemporal displacement and behavioural alteration can disrupt nutritional intake and increase energetic costs, both of which can decrease the likelihood of reproduction by reducing the body condition of female grizzly bears (Boulanger et al. 2013, Fortin et al. 2016). The direct and indirect impacts of human activity along linear disturbances, particularly with respect to mature females, can impose negative long-term effects on population viability, particularly in areas with moderate habitat quality where population density is low such as the Livingstone-Porcupine Hills region.

Multiple studies suggest that grizzly bear populations may not be viable in areas where linear disturbance density exceeds approximately 0.6 km/km^2 (Mace et al. 1996, Boulanger and Stenhouse 2014, Lamb et al. 2018). Within the Livingstone-Porcupine Hills region, all but one watershed exceed this ecological threshold when all linear disturbances are included in the calculation (Fig. 7). Previous studies have also assessed the potential effectiveness of access management (either closures or restrictions) to establish and maintain viable grizzly bear populations by enhancing survival rates (e.g., Mace et al. 1996, Nielsen et al. 2004, Roever et al. 2010, Schwartz et al. 2010, Northrup et al. 2012, Boulanger and Stenhouse 2014).

Case Study: Effects of Road Density and Grizzly Bear Demography

The impact of roads on the demography of grizzly bears in Alberta

Boulanger and Stenhouse (2014)

Boulanger and Stenhouse (2014) examined the direct demographic impact of roads on grizzly bears. They used known fate survival models to quantify relationships between survival rates and road density, and developed multi-reproductive state models to explore factors influencing mortality risk for female bears. Demographic models were then used to estimate threshold road densities where population rate of change became negative.

Known fate survival models suggested that roads contribute to a greater reduction in survival of sub-adult bears (and particularly sub-adult males) than for adult bears. Multi-reproductive state models indicated that while all female classes were vulnerable to being killed near roads, females with young cubs (young of the year or yearlings) had higher mortality risk associated with roads than females with older cubs (2 years or older) or no cubs. Results of demographic models were highly dependent on assumptions about effects of road density on female survival in the context of reproductive state. If reproductive state was not considered, population rate of change became negative at a road density of 1.25 km/km^2. Demographic models that considered reproductive state specific survival rates estimated a negative population rate of change at road densities greater than 0.75 km/km^2.

The findings of Boulanger and Stenhouse (2014) illustrate how road density is related to the demography and population trends of grizzly bear populations, and also confers additional risk to reproduction and recruitment. Sub-adult females, as well as females with young cubs, had higher risk of mortality associated with roads than other population cohorts. The authors suggest that the road density limit of 0.75 km/km^2 is most appropriate for fostering viable grizzly bear populations in Alberta, but also suggested that maintaining even lower road densities is a preferable conservation strategy given the uncertainty around the relationship between road density and population viability.

Case Study: Human Use of Roads and Grizzly Bear Behaviour

Vehicle traffic shapes grizzly bear behaviour on a multiple-use landscape

Northrup, Pitt, Muhly, Stenhouse, Musiani, and Boyce (2012)

Northrup et al. (2012) modeled traffic volume for a network of roads in southwestern Alberta that included both private and public land and used step-selection and resource selection functions to model behavioural responses of grizzly bears to traffic levels.

Bears selected areas near roads and crossed roads at night when traffic volumes were low. Similarly, they preferred areas near low-use roads that were travelled by less than 20 vehicles per day.

While grizzly bears are naturally diurnal, individuals observed in this study demonstrated a departure from normal behavioural patterns. Bears also preferred to utilize habitats on private agricultural land with low traffic levels and substantially higher road density than on multi-use public land (1.30 km/km^2 vs. 0.55 km/km^2). The authors also inferred that traffic type may have contributed to avoidance of public land by bears; based on unpublished data, the predominant uses of roads and trails on public land in their study area were recreational (off-highway vehicles and hunting).

The findings of Northup et al. (2012) highlight the complex relationship between grizzly bears and roads. To date, most research has focused on spatial relationships between bears and roads irrespective of traffic volume, and a road density threshold of 0.6 km/km^2 suggested by Mace et al. (1996) has formed the basis of management targets in many jurisdictions. The authors suggested a multi-pronged approach to managing human access in important grizzly bear habitat that considers not only the spatial distribution of roads (i.e., density), but also the type and volume of human use.

6.4 Other wildlife

The effects of motorized use of linear disturbances on wildlife vary based on a number of factors, including species, habitat, and seasonality. However, the weight of scientific evidence suggests that motorized use of linear disturbances has predominantly negative effects on wildlife (e.g., Frair et al. 2008, Quinn and Chernoff 2010, Ciuti et al. 2012, Hebblewhite and Merrill 2008, Muhly et al. 2013, Gaines et al. 2003, Farr et al. 2017). These impacts include:

- Physical disturbance and habitat degradation;
- Behavioural alteration and associated nutritional costs and stress; and
- Lower reproduction and lower population densities

Case Study: Modelling Elk Response to Changing Road Networks

Thresholds in landscape connectivity and mortality risks in response to growing road networks

Frair, Merrill, Beyer, and Morales (2008)

Frair et al. (2008) used a random walk framework to explore interacting effects of road density and design, amount of critical habitat, and animal behaviour on distributional changes of non-dispersing animals due to expanding road networks. They used elk (*Cervus canadensis*) as their model species because roads confer mortality risk and illicit distributional responses throughout their geographic range. Additionally, elk distributions vary depending on the interaction of road density and different ecological settings.

The results of their simulation revealed that refugia from road effects (i.e., habitat greater than 1 km from any road) disappeared at road densities exceeding 1.6 km/km^2. Overall, mortality risk increased with road density, but was dependent on prevalence of clearcuts and road network design. Habitat accessibility dropped significantly in simulations when initial access routes were developed and bisected the landscape, then decreased linearly with increasing road density.

For each response variable (elk distribution, mortality hazard, habitat accessibility, and home range fidelity), the most rapid changes were observed at low road densities, suggesting a possible threshold between 0.25 and 0.50 km/km^2. In the surrounding region, 90% of cow elk home ranges occurred in areas where road densities were less than 0.5 kmkm^2, and no cow elk occupied areas where road densities exceeded 1.08 km/km^2.The low tolerance of elk to increasing road densities was likely attributable to hunting pressure in the area, because elk have been observed tolerating much higher road densities in other regions (ex. Banff National Park).

The approach taken by Frair et al. (2008) allowed them to analyze population-level redistribution of elk while separating confounding effects of landscape context from road effects. Their model results suggested that road densities below 0.5 km/km^2 conferred the highest probability of elk occurrence in a hunted landscape where elk tolerance to roads was low. However, they stress that managing road network design could maintain effective elk habitat at far higher road densities, and that ultimately the type of human activity tied to roads plays a significant role in determining behavioural responses.

7 Conclusion

As summarized in this report, and reviewed in greater detail in a previous report (Farr et al. 2017), numerous studies have documented negative relationships between linear disturbances and a range of ecosystem attributes. Human use of linear disturbances, in particular motorized use, potentially contributes to the following ecological responses:

- Increased soil erosion, loss of vegetation cover, and shifts in plant species composition;
- Increased sediment input to aquatic ecosystems and decreased habitat quality in watercourses used by fish for spawning, rearing, and other life stages;
- Increased likelihood of negative encounters between grizzly bears and people, with an increased risk of grizzly bear mortality;
- Modified behaviour and distributional responses of grizzly bears and other wildlife, and corresponding effects on body condition and reproduction.

Because variability in the volume, timing and type of off-highway vehicle use may affect ecological response, studies of vehicle use patterns and ecological response would enable a more detailed assessment of potential impacts. In particular, while many studies report ecological responses to linear disturbances accessible to on-highway vehicles (i.e., roads), fewer studies have focused on trails that are accessible only to off-highway vehicles (e.g., Ladle 2017, Olson et al. 2017). Given recreational use of off-highway vehicles is expanding in many regions of North America, including Alberta, this is an important area for future ecological research and monitoring.

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Appendix A Summary of data sources used in report figures.

See Literature Cited for full reference.

Figure	Title	Data sources
1	Map of the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Roads of Alberta (2016)
2	Watersheds in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Hydrologic unit code watersheds of Alberta (2017)
3	Linear disturbances in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)
4	Summary of linear disturbance lengths by disturbance category in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)

Figure	Title	Data sources
5	Linear disturbance density in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Hydrologic unit code watersheds of Alberta (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)
6	Summary of linear disturbance density in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Hydrologic unit code watersheds of Alberta (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)
7	Density of roads and trails in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Hydrologic unit code watersheds of Alberta (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)
8	Density of roads in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Hydrologic unit code watersheds of Alberta (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017)
9	Stream crossings in the Livingstone-Porcupine Hills region.	Livingstone Public Land Use Zone (2017) Porcupine Hills Public Land Use Zone (2017) Linear disturbances in the Livingstone-Porcupine Hills region (2017) FWMIS Hydrology Arcs (2017)

Appendix B Summary of key literature

Ecological response to motorized use of linear disturbances (sorted by stressor type then reverse chronological order).

Linear disturbance (Type / Use / Density)	**Stressor**	**Ecosystem attribute**	**Key finding**	**Location**	**Source**
Trails Motorized	Soil removal	Soil parameter	Greater dust throw measured in silt soils.	Nevada, USA	Goossens and Buck 2009
Trails Motorized	Soil removal	Soil parameter, vegetation parameter	OHVs are a significant source of soil erosion from aeolian displacement.	Western Kentucky, USA	Padgett et al. 2008
Road and trail Motorized Road: 0.6 km/km^2 Trail: 0.2 km/km^2	Sediment runoff	Habitat quality	OHV trails produced 6 times sediment amount than greater number of road segments; 24% of OHV trails connected to and influencing stream water quality.	South Platte River Watershed, Colorado, USA	Welsh 2008
Other – pipeline crossing	Sediment runoff	Aquatic invertebrate community composition and fish abundance	Changes in invertebrate community composition and decrease in fish abundance downstream of pipeline creek crossing.	N/A - Review article	Lévesque and Dubé 2007

Linear disturbance	**Stressor**	**Ecosystem attribute**	**Key finding**	**Location**	**Source**
Road Motorized	Sediment runoff	Water quality	Road construction increased sediment load in drainage basin by 7 times.	Missoula, Montana, USA	Anderson and Potts 1987
Trails Motorized	Soil removal, sediment runoff	Habitat quality	All stream crossings evaluated had soil loss; downstream of OHV stream crossing, river substrate has increased mud coating.	Western Arkansas, USA	Marion et al. 2014
Trails Motorized and non-motorized	Soil removal, sediment runoff	Soil parameter / habitat quality	Mean soil loss on OHV trails was significantly higher than other forms of recreational use; horse trails still had large amount of soil loss whereas hiking and biking trails had minimal.	North Central Tennessee, USA	Olive and Marion 2009
Trails Motorized and non-motorized Trail use	Soil removal, sediment runoff	Soils	OHVs compact soil and have increase erosion rates compared to hiking and equestrian trails.	Wayne National Forest, Ohio, USA	Sack and da Luz 2003
Road Motorized 0 – 1.2 km/km^2	Soil removal, sediment runoff	Bull trout reproduction	Negative relationship between bull trout redd abundance and road density.	Swan Basin Montana, USA	Baxter et al. 1999
Roads Motorized	Soil removal, sediment runoff	Bull trout occurrence	Negative relationship between bull trout occurrence and density of roads within stream basins.	Boise River Basin, Idaho, USA	Dunham and Rieman 1999

Linear disturbance	Stressor	Ecosystem attribute	Key finding	Location	Source
Trails Motorized	Soil removal, hydrological changes, permafrost alteration	Vegetation and organic soil loss	OHVs are altering headwater hydrology (drainage density); increased mean active layer depth.	Wrangell-St. Elias National Park, USA	Arp and Simmons 2012
Trails Motorized	Animal disturbance	Kit fox space use	Negative correlation between winter OHV trail density and kit fox space use.	Sonoran Desert, Arizona, USA	Jones et al. 2017
Multi-use trails Motorized, non-motorized 0.7-7.8 km/km^2	Animal disturbance	Golden eagle territory occupancy and productivity	Negative relationship between occupancy and off-road vehicle use; negative relationship between productivity and off-road vehicle use.	Idaho, USA	Spaul and Heath 2016
Winter snowmobile trails Snowmobiles 0 -100% coverage by snowmobile tracks	Animal disturbance	Moose habitat use measured from radiotelemetry	Avoidance by moose of areas of high snowmobile trail density.	Kenai Peninsula, south-central Alaska, USA	Harris et al. 2014
Off-road Motorized, non-motorized	Animal disturbance	Waterbird flight response	Flight response to non-motorized use greater than motorized use.	Victoria, Australia	McLeod et al. 2013
Paved road Motorized, non-motorized	Animal disturbance	Ungulate behaviour (vigilance, defensive, flee, travel)	Behavioural response was variable to motorized and non-motorized use along paved road.	Grand Teton National Park, Wyoming, USA	Brown et al. 2012

Linear disturbance	Stressor	Ecosystem attribute	Key finding	Location	Source
Road Motorized Vehicle use	Animal disturbance	Grizzly bear behaviour (movement)	Negative relationship between habitat use and moderate and high traffic roads.	Southwestern Alberta	Northrup et al. 2012
Human disturbance (Roads/Settlements)	Animal disturbance	Grizzly bear population fragmentation	Females have lower habitat disturbance thresholds.	Western Canada, Northwest USA and SE Alaska, USA	Proctor et al. 2012
Roads Motorized 0.0 – 2.5 km/km^2	Animal disturbance	Elk habitat use and mortality risk	Negative relationship between habitat use and road density; Positive relationship between mortality risk and road density. Road densities ≤ 0.5 km/km^2 yielded the high probability of elk occurrence.	West-central Alberta	Frair et al. 2008
Trails Motorized	Animal disturbance	Animal behaviour	Increased nest desertion and abandonment rates by songbirds <100m from an OHV trail than those >100m from trail.	Northeast California, USA	Barton and Holmes 2007
Roads, trails and off-road/trail Motorized and non-motorized	Animal disturbance	Spanish imperial eagle flight response	No response to passing surface vehicles; flight response to overhead aircraft and passing pedestrians.	Central Spain	González et al. 2006

Linear disturbance	Stressor	Ecosystem attribute	Key finding	Location	Source
Off-trail Motorized and non-motorized Vehicle use	Animal disturbance	American oystercatcher incubation behaviour	Negative relationship between incubation duration and all-terrain vehicle traffic.	Coastal North Carolina, USA	McGowan and Simons 2006
Road/trail Motorized and non-motorized OHV use	Animal disturbance	Ungulate behaviour (flight/avoidance)	Elk respond negatively (with flight/avoidance) to OHV use (> 1 km).	Starkey Experimental Forest and Range, Oregon, USA	Preisler et al. 2006
Road Motorized 0 – 1.6 km/km^2	Animal disturbance	Bull trout occurrence	Negative relationship between bull trout occurrence and road density. Compared to roadless areas, bull trout were 50% less likely to be found where road density was greater than 0.4 km/km2, and were predicted to be absent where road density exceeded 1.6 km/km^2.	Kakwa River basin, west-central Alberta	Ripley et al. 2005
Roads Motorized 0.0 – 2.5 km/km^2	Animal disturbance	Carnivore occurrence (fisher, lynx, wolverine, grizzly bear)	Varying response to road density. Higher road density at sites with fisher (1.3 km/km^2); lower road density at sites with wolverine (0.7 km/km^2).	Rocky Mountains, northern USA and southern Canada	Carroll et al. 2001

Linear disturbance	Stressor	Ecosystem attribute	Key finding	Location	Source
Roads Motorized	Animal disturbance	Bull trout occurrence	Negative relationship between bull trout occurrence and road density.	Columbia River and Klamath River Basins: Idaho, Montana, Nevada, Oregon, Washington and Wyoming, USA	Rieman et al. 1997
Road Motorized	Animal disturbance	Salmonid spawning and rearing success	Negative relationship between the proportion of a watershed supporting strong salmonid populations (spawning and rearing) and road density.	Columbia River and Klamath River Basins: Idaho, Montana, Nevada, Oregon, Washington and Wyoming, USA	Quigley and Arbelbide 1997
Road Motorized	Animal disturbance	Grizzly bear habitat use	Most of the 23 grizzly bears used areas within 250 m of open roads significantly less than expected; equivalent to 8% loss of available habitat.	Flathead Valley, southeastern BC, northern Montana, USA	McLellan and Shackleton 1988
Road Motorized	Human-caused mortality	Grizzly bear mortality rate	Positive relationship between grizzly bear mortality and road density.	Greater Yellowstone Ecosystem, USA	Schwartz et al. 2010

Linear disturbance	**Stressor**	**Ecosystem attribute**	**Key finding**	**Location**	**Source**
Road Motorized 0 – 2.5 km/km^2	Human-caused mortality	Grizzly bear mortality rate	Positive relationship between grizzly bear mortality and road density from 1999 to 2012.	Central Rockies of Alberta	Boulanger and Stenhouse 2014
Roads Motorized 0-1.05 km/km^2 (E. Valdal 2006)	Human-caused mortality	Westslope cutthroat trout abundance	Negative relationship between trout abundance and road density within 100 m of streams.	Southeastern British Columbia	Valdal 2006
Road and trail Motorized Distance to disturbance	Human-caused mortality	Grizzly bear mortality rate	Greater mortality near linear footprints.	Southwestern Alberta	Nielsen et al. 2004
Road Motorized 0 – 6.3 km/km^2	Human-caused mortality	Grizzly bear habitat use	When traffic, road densities and human access increases, bears avoid these areas and survival rates decline.	Swan Mountain Range, Montana, USA	Mace et al. 1996
Off-trail Motorized	Human-caused mortality	Hooded plover nesting success	Loss of 81% of nests (average 6% per day).	South Australia	Buick and Paton 1989
Human disturbance Motorized, non-motorized Distance to disturbance	Hybridization	Westslope cutthroat/ Rainbow trout Hybridization	Human disturbance may have direct and indirect effects on the spread of non-native species and hybridization in stream fish.	SW Alberta, SE British Columbia	Yau and Taylor 2013

Linear disturbance	Stressor	Ecosystem attribute	Key finding	Location	Source
Roads/Trails Motorized	OHV effects on soils, vegetation, wildlife and habitats, water quality and air quality	Terrestrial and aquatic communities	Soil compaction negatively impacts vegetation growth which leads to a decrease in plant diversity. OHV use also increases sedimentation and pollutants in water and air.	Bureau of Land Management areas, USA	Ouren et al. 2007
Roads All	Sediment dynamics, soil compaction, animal disturbance, human-caused mortality	Terrestrial and aquatic communities	Review the ecological effects of roads on terrestrial and aquatic communities.	N/A - Review synthesis	Trombulak and Frissell 2000
Trails Motorized and non-motorized Trail use	Species richness, non-native plants	Vegetation community	OHV use results in more areas being accessed, and spread of non-native plants 4x the amount when compared with non-motorized users.	Montana and northern Idaho, USA	Adams 1998

Appendix C Summary of literature reviews

Ecological response to motorized use of linear disturbances (sorted in reverse chronological order).

Source	Title	Studies Reviewed	Key Findings
Switalski 2016	Snowmobile best management practices for Forest Service travel planning: A comprehensive literature review and recommendations for management. Four articles: 1. Introduction 2. winter recreation use conflict 3. Wildlife and 4. water quality, soils, vegetation	Series of articles – 90 references	Alpine environments are particularly sensitive to disturbance, snowmobiles can pollute waterways, cause soil erosion, damage vegetation. Snowmobiles can impact sensitive and hunted wildlife species, from energy expenditures, denning disruption, to physiological and behavioural responses.
Marzano and Dandy 2012	Recreational use of forest and disturbance of wildlife. A literature review.	450 references	Review the impact of recreational activities on the flora, fauna and habitat in UK forests. Non-motorized trail use such as hiking, biking, and horse riding have been shown to cause less impact on soil and vegetation than motorized uses by off-highway vehicles.
Switalski and Jones 2012	Off-road vehicle best management practices for forestlands: A review of scientific literature and guidance for managers.	70 references	Document how compaction from OHV traffic increases surface flow, soil erosion and sedimentation. Loss of vegetation following OHV use, leaves plants that do survive along trails weakened, malformed, and more susceptible to disease/insect predation. Vegetation trampling by OHVs can damage germinating seeds, and OHVs are a major vector for non-native invasive plant species.

Source	Title	Studies Reviewed	Key Findings
Backcountry Hunters and Anglers 2011	Cumulative and universal: ATV impacts on the landscape and wildlife	92 references	Impacts of OHV use are cumulative, universal and can be achieved by low intensity traffic over short time periods. OHV use affects soil and hydrologic function. OHV travel can disproportionately alter animal behaviour relative to traditional forms of recreation due to the distances motorized vehicles can travel in a day.
Daigle 2010	A summary of the environmental impacts of roads, management responses, and research gaps: A literature review.	160 references	Overview of potential environmental impacts of resource roads including effects on terrestrial and aquatic wildlife, plant communities, and physical elements found across landscapes in British Columbia. Effects may be local or may apply to large areas. Road effects can occur during construction or with subsequent road presence, upkeep, and use.
Stankowich 2008	Ungulate flight responses to human disturbance: A review and meta-analysis.	59 studies used for meta-analysis	Evidence shows ungulates pay attention to approacher behavior, have greater perceptions of risk when disturbed in open habitats. Females or groups with young offspring show greater flight responses than adult groups. Populations in areas with higher human traffic showed reduced wariness. Hunted populations showed significantly greater flight responses than non-hunted populations.

Source	Title	Studies Reviewed	Key Findings
Ouren et al. 2007	Environmental effects of off-highway vehicles on Bureau of Land Management lands: A literature synthesis, annotated bibliographies, extensive bibliographies, and internet resources.	700 references	Summary of OHV effects: Soils and watersheds (loss of soil structure, soil compaction, runoff); Vegetation (size and abundance of native plants reduced, dust effects, photosynthetic processes); Wildlife and habitats (both noise and presence of OHVs effectively reduced habitat connectivity, changed animal movements, altered population, recolonization dynamics); Water quality (increased sedimentation, turbidity, pollutants); Air quality (fugitive dust, by product of combustion).
Gaines et al. 2003	Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests.	238 references	Common impacts on wildlife species include altered habitat use from human caused displacement and avoidance and disturbance at a specific site during a critical life history stage. They found negative impacts arose from both motorized and non-motorized activities, the severity of which was contingent on the wildlife species.
Stokowski and LaPointe 2000	Environmental and social effects of ATVs and ORVs: an annotated bibliography and research assessment.	59 references	Concluded that soil compaction caused by OHVs, and shear forces of wheel acceleration create channeling that alters water flow, which intensifies soil erosion and compaction. In turn, this compaction exacerbates runoff and reduces water infiltration, causing a reduction of soil moisture and organic carbon content, which both prevent surface revegetation.

Source	Title	Studies Reviewed	Key Findings
Trombulak and Frissell 2000	Review of ecological effects of roads on terrestrial and aquatic communities.	179 references	Concluded that linear disturbance impacts on terrestrial ecosystems are generally negative, with impacts that include an increase in mortality rates, vehicle collisions, human-wildlife conflict, hunting and fishing pressure, as well as alterations of animal behaviours and chemical and physical environments.
Canfield et al. 1999	Ungulates. Effects of recreation on Rocky Mountain wildlife: A review for Montana	205 references	Suggest recreational activities have the potential to displace ungulates to private land and have negative direct and indirect effects on the populations. Big game hunting has more immediate effects on population densities and structures than any other recreational activity.
Forman and Alexander 1998	Roads and their major ecological effects.	139 references	Concluded that increased runoff associated with roads results in increased rate and extent of soil erosion, a reduction in soil percolation, aquifer recharge rates, and alteration of stream-channel morphology. Report road densities of approximately 0.6 km/km^2 appear to be the maximum for a naturally functioning landscape containing sustained populations of large predators (wolf, cougar).
Reid 1993	Research and Cumulative Watershed Effects	800+ references	Cumulative watershed effects (CWEs) include changes that involve watershed processes and influenced by multiple land-use activities. Land-use activities can directly affect vegetation, soil properties, topography, and can import or remove water, chemicals, pathogens, and fauna. Land-use activities reviewed include: roads, dams, forestry, grazing, mining, agriculture, urbanization, recreation and fishing.

Source	Title	Studies Reviewed	Key Findings
Boyle and Samson 1985	Effects of non-consumptive recreation on wildlife: A review	166 references	A rapid increase in recreation is increasing impacts on wildlife and wildlife habitat. Recreationists can affect wildlife through habitat alteration, disturbance, or direct mortality. Mechanized forms of recreation present the greatest impacts. Important to recognize that individuals, populations and species vary in their sensitivity to disturbance.