Ecological Indicators of Access and Access Management: A Wildlife Perspective

by

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Table of Contents

List of Tables

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Abstract

There is growing concern that human access into areas of wildlife habitat and the management of that access has become one of the most significant issues in sustaining wildlife populations worldwide. Although access management is recommended throughout primary wildlife research and provincial land management plans as a means of wildlife management, limited research has been conducted on measuring the status of access or on access management strategies. Based on a review of the literature on resource management plans and provincial management strategies, this thesis identifies and describes fifteen potential ecological indicators for measuring and monitoring access and access management. Five key findings are summarized from this review. (1) Meaning and implementation of the term ‘access management’ remains vague and ambiguous. (2) Measures of human access are often tied to large mammal management and studies. (3) Access management is a big question, encompassing cumulative impacts, and when viewed from a systems approach should consider ecological indicators across multiple levels of biological organization. (4) Attention is brought to two sub-types of indicators to monitor access management, land use indicators and wildlife use indicators. (5) Ecological indicators of access and access management share one similar data layer, GIS access infrastructure data.

Chapter 1: Human Access and Wildlife Management

Introduction

The growing concern about human access into areas of wildlife habitat and the management of that access has become one of the most significant issues in sustaining wildlife populations worldwide. In jurisdictions with a substantial amount of remote areas, such as British Columbia (BC), an increasing need exists for a unified access management approach as human access infrastructure, particularly the road network, expands into remote areas. A large body of scientific evidence indicates that expanding road networks, linear infrastructure, human settlements, resource extraction, and other encroachments on the landscape have negative impacts on wildlife and wildlife habitats. The effects are diverse and include loss and degradation of habitat, avoidance of habitat, wildlife mortality from increased human-wildlife interactions, and population fragmentation and isolation (Forman & Alexander, 1998).

Wildlife managers have identified the management and planning of human access and infrastructure development in remote areas as key elements in protecting wildlife species. For example, a recent global meta-analysis found mammal and bird population densities declined with proximity to development, and shows the “importance of minimizing infrastructure development for wildlife conservation in relatively undisturbed areas” (Benítez-López, Alkemade & Verweij, 2010, p. 1314). In Alberta, the Alberta Grizzly Bear Recovery Plan 2008-2013 identified human use of access as “one of the primary threats to grizzly bear persistence” (Alberta Sustainable Resource Development, 2008, p. 9). Based on these concerns, managing access and other land uses has become a primary strategy in the recovery plan to reduce human-caused mortality of grizzly bear. Similarly in BC, management of access comprises two of the four management recommendations aimed at maintaining viable, healthy, and productive populations of mountain goats throughout the province (Mountain Goat Management Team, 2010).

A provincial overview of access management in BC concluded that “access management is a high to very high priority throughout the province” (Hamilton & Wilson, 2001, p. 7). Efforts have been made to incorporate access management direction into provincial strategic land use plans and sustainable resource management plans (BC Ministry of Sustainable Resource Management, 2004a). Moreover, strategic land use plans and sustainable resource management plans can provide direction and guidance for access management for resource development, recreation access planning, and public access on Crown land, including provisions and restrictions on uses to protect wildlife and wildlife habitats or other sensitive values (BC Ministry of Sustainable Resource Management, 2004a; Forest Practices Board, 2005).

Unfortunately, natural resource management, and access management in particular, is seldom paired with effective monitoring to evaluate the efficacy of various management strategies. One of the reasons for this in BC has been uncertainty as there “exists varying interpretations within and between respective ministries regarding the regulatory and legislative mandates and participatory roles and responsibilities for access management” (Hamilton & Wilson, 2001, p. 7). Moreover, the effects of access on wildlife populations, such as land use by hunters, wildlife avoidance and barriers to movement, are difficult to monitor. In light of these challenges, the BC Ministry of Sustainable Resource Management (2004a) identified 'plan implementation and monitoring' as one of the four phases in the planning process. Implementation and effectiveness monitoring is recognized as "important steps for achieving continuous, adaptive improvement in [sustainable resource management plans]" (BC Ministry of Sustainable Resource Management, 2004a, p. 54).

Monitoring can be used to update existing land use conditions, confirm the application of land management strategies, and measure the effectiveness of management measures in meeting overall land management goals. Nevertheless, not everything in the environment can be measured, and monitoring a large suite of environmental variables is cost prohibitive. Once resource management plans are completed, monitoring of indicators is relied upon for evaluating the implementation progress and the effectiveness of plan objectives and strategies (BC Ministry of Sustainable Resource Management, 2004a). Indicators are tools used to gather and communicate information about the status, changes, or trends of a condition or process (National Academy of Sciences, 2000). An indicator can be defined as "a quantitative, qualitative, or descriptive attribute that, when measured or monitored periodically, indicates the direction of change in a criterion" (International Tropical Timber Organization, 2005, p. 9).

Since the 1980s, increasing efforts have been devoted to developing environmental indicators of natural resource management. One of the main drivers at the international level has been the United Nations Conference on Environment and Development in Rio de Janeiro, and the resulting Agenda 21, urging countries to manage forests sustainably (National Academy of Sciences, 2000; United Nations, 1992). Indicators subsequently emerged through numerous international workshops and processes as a key mechanism to characterize and measure progress towards forest sustainability (National Academy of Sciences, 2000; Wijewardana, 2008).

At the national level, beginning in the late-1980s, the Canadian government developed indicators to measure and monitor the state of the environment (Environment Canada, 1991). Canada and BC now report on national and regional environmental indicators in 'State of the Environment' reports (e.g., BC Ministry of Forests, Mines and Lands, 2010). Environmental indicators can include chemical indicators (e.g., atmospheric carbon dioxide), physical indicators (e.g., sea surface temperature), and ecological indicators[1] (e.g., species diversity). Ecological indicators are the primary focus of this thesis.

Ecological indicators are well researched and described in the literature for sustainable forest management (e.g., International Tropical Timber Organization, 2005), biodiversity and protected area management (e.g., Noss, 1990; Timko, 2008). Unfortunately, research is limited that has identified or described relevant ecological indicators for measuring and monitoring access and evaluating access management strategies on public lands, despite its importance for effective wildlife management. Instead, research on access management has typically focused on measures of access control, including road restrictions and closures to manage hunter access (e.g., Crichton, Barker & Schindler, 2004), and more recently, on the effects of road network design and road placement on wildlife (e.g., Frair, Merrill, Beyer, & Morales, 2008).

[1] Ecological indicators have been developed and used to measure ecological processes and conditions, specifically to "inform decision-makers about the status and trends in populations of particular species and small groups of species, and in particular ecosystems" (National Academy of Sciences, 2000, p. x).

With increased calls for access management in provincial wildlife management plans and resource management plans, a need exists to identify and describe ecological indicators as measurable attributes of access for use in environmental monitoring and evaluation of access management. This thesis identifies and describes potential ecological indicators of access and access management from a review of the available literature and relevant management plans in BC and Alberta. Understanding how access management at the level of land management can be effectively measured and monitored is becoming increasingly important as access for resource development and recreational activities on Crown land increase in intensity (Forest Practices Board, 2005; Hamilton & Wilson, 2001).

Research Purpose

This thesis reviews the types of human access and various metrics to measure the rates and characteristics of human access in remote areas and the resulting effects on wildlife populations. This is accomplished through a review of key literature, land management plans, and wildlife management plans. The fundamental question guiding this work is:

What ecological indicators can be used to measure and monitor human access and access management in British Columbia?

The specific objectives of the research are to:

1) Review the literature on the effects of increased human access into wildlife habitats and the consequent effects to wildlife species,

2) Identify 'ecological indicators' for measuring and monitoring the impacts of human access in relation to wildlife, from the literature review,

3) Examine landscape-level access management plans and management direction statements to identify other ecological indicators not mentioned in relevant literature, and

4) List and describe potential ecological indicators that can monitor and measure the status and trends in human access and the effectiveness of access management strategies.

In the context of this thesis, ‘ecological indicators’ refers to indicators of human land use and access, or wildlife and habitat health in relation to human land use and access.

Research Scope

This thesis is separated into six chapters. Chapter 1 is the introduction, and it presents background information and the rationale for the study, along with the research purpose and study objectives. Chapter 2 presents the review of the literature on human access effects on wildlife, from land, water, and air, with a focus on BC. This chapter also provides background on the use and meaning of the term ‘access management,’ and ‘ecological indicators’ for monitoring and evaluating resource management. Chapter 3 describes the methods for identifying the ecological indicators, including the review and analysis of the literature and the regional management plans from BC and Alberta. This chapter also describes limitations in the research methodology.

Chapter 4 presents the results of the literature review and management plan analysis and lists and describes potential ecological indicators that could be used to measure the extent and status of access and access management. Chapter 5 discusses the results in terms of key findings from the literature review and the criteria for selection of ecological indicators and makes recommendations for further study. Chapter 6 presents the summary and conclusion. This chapter presents a summary and the overall significance of the research to wildlife management, along with the potential applications of the research findings.

Chapter 2: Literature Review

Human Access Effects on Wildlife

The following sections review the effects of human access on wildlife in remote areas from land, air, and water, with specific reference to examples from BC. The term 'access' can be defined "as the ability to enter Crown land; the mode of travel may be motorized, which may include commercial vehicles, [4- or 2-wheel] drive vehicles, all terrain vehicles, snowmobiles, aircraft, and motorbikes, or may be non-motorized, such as travel by foot, horse, or mountain bike" (Government of BC, 2005, p. 69). In the context of this thesis, 'human access' broadly refers to any mode of travel into remote areas.

Land Access – Roads

The detrimental effects on wildlife populations in remote areas from road access are well documented. Roads in areas of wildlife habitats have two primary effects; effects related to the road infrastructure itself (e.g., Benítez-López et al., 2010; Coffin, 2007; Forman & Alexander, 1998; McGregor, Bender, & Fahrig, 2008) and effects of increased access that allow hunting, recreation, resource development, and other human activities (e.g., Ciarniello, Boyce, Heard, & Seip, 2007; Coffin, 2007; Nielsen et al., 2004). Road networks have dramatically expanded worldwide and in BC, road lengths have increased 82% from an estimated 387,000 km in 1988 to 702,574 km in 2005 (BC Ministry of Environment, 2007), with 76% of these roads classified as forest access roads (Austin et al., 2008). Provincial road length is likely an underestimate since, in 2005, the Forest Practices Board (2005) estimated an annual construction of approximately 20,000 to 30,000 km of new resource roads per year for the subsequent five to ten years.

New and existing forest roads or resource roads (generally characterized as gravel, narrow, lightly travelled, and remote) can have a major effect on wildlife populations by facilitating human access for resource extraction activities, hunting, and recreation activities into remote areas (Forman & Alexander, 1998). Once roads are established, they are often left for other users and activities. For example, Chomitz and Gray (1996) found new roads into forested areas offer market access for timber and “unambiguously increases in the incentives to log those territories or convert them to other uses” (p. 488).

The direct and indirect effects of roads on wildlife are extensive (Forman & Alexander, 1998). The following section briefly reviews the research on the effects to wildlife populations caused by access roads into remote areas for human activity; specifically, the effects of human-caused wildlife mortality through increased hunting and vehicle accidents, and the effect of indirect habitat loss via avoidance of roads.

In remote areas, the primary effect of roads on wildlife population is the facilitation of hunting over an increased area. Results of radiotelemetry studies on wolves (Person & Russell, 2008), elk (Stussy, Edge, & O’Neil, 1994), and moose (Rempel, Elkie, Rodgers, & Gluck, 1997) demonstrate that areas with extensive road systems have increased mortality risk associated with legal, and particularly, illegal hunting and trapping. The risk of grizzly bear mortality is also higher near roads. A study in the Central Rockies Ecosystem on grizzly bear reported that all 95 known human-caused grizzly bear mortalities occurred within 500 m of roads or within 200 m of trails (Benn & Herrero, 2002). Such results are reiterated in the Cabinet-Yaak and Selkirk grizzly bear recovery zones, where most of human-caused mortalities were within 500 m of open roads on public lands (Summerfield, Johnson, & Roberts, 2004).

As road development increases, the effects of human access on remote areas tend to increase and wildlife populations decline (Forman & Alexander, 1998). One of the most obvious reasons for the decline in wildlife population is human-caused wildlife mortality, as a direct result of vehicle collisions and an indirect result of increased hunting pressure. Vehicle mortality risk has been correlated to higher traffic volumes, increased speed limits, and landscape composition in the vicinity of the roads (e.g., Fahrig, Pedlar, Pope, Taylor, & Wegner, 1995; Seiler, 2005). Coffin (2007, p. 400) noted that wildlife-vehicle collisions are “driven mostly by the spatial arrangement of resources,” thus, wildlife are struck be vehicles when trying to access habitats, food sources, water, and other required resources. Areas of increased collision risk with wildlife occur where roads occur near or bisect preferred foraging and breeding habitats (Ashley & Robinson, 1996; Nystrom et al., 2007). Other areas of higher risk occur where linear landscape features act as wildlife movement corridors (e.g., riparian corridors, power lines, pipelines, and steep slopes) which funnel animals towards a road (Forman & Alexander, 1998; Seiler, 2005).

Forman and Alexander (1998) stated that “the ecological effect of road avoidance caused by traffic disturbance is probably much greater than that of roadkills” (p. 214). Avoidance of habitat near roads resulting from human-caused mortality and vehicle traffic has been reported for elk (Rowland, Wisdom, Johnson, & Kie, 2000), caribou (Dyer et al., 2001), and grizzly bear (Ciarniello et al., 2007; Gibeau, Clevenger, Herrero, & Wierchowski, 2002; McLellan & Shackleton, 1988; Wielgus, Vernier, & Schivatcheva, 2002). Wildlife avoidance of areas adjacent to roads combined with an expanding road network can greatly decrease the amount of available habitat. As road networks expand and interconnect, the landscape becomes more fragmented (Coffin, 2007) and even in moderately-roaded areas, road effects can saturate a landscape (Forman et al., 2003). For example, Frair et al. (2008) reported that road effects saturated a landscape (i.e., no refuges > 1 km from a road in a 100 km^2 area for elk), given a simulated road density model of 1.6 km/km^2.

Ecological effects of a road that extend beyond the road surface into adjacent non-road areas was initially described by Forman et al. (1997) as the 'road-effect zone'. These zones of influence are difficult to estimate for each species but can extend up to several kilometers from the road surface (Forman & Alexander, 1998; Ries, Fletcher, Battin, & Sisk, 2004). At a broad scale, a recent meta-analysis found the effects of infrastructure (mainly road infrastructure) to extend up to about 1 km for birds and up to about 5 km for mammals (Benítez-López et al., 2010). Such results are of concern for wildlife conservation, particularly in the context of Riiters and Wickman (2003) who estimated that approximately 83% of the total land area in the US was within slightly more than 1 km of a road, and only 3% was slightly more than 5 km away from a road.

It is well recognized that limiting both the level of traffic volume and human use of roads decreases the influence of road access on wildlife (e.g., Apps, McLellan, Woods, & Proctor, 2004; Ciarniello et al., 2007; Cole et al., 1997; Nielsen et al., 2004; Wielgus et al., 2002). In western Oregon, Cole et al. (1997) found that female elk survival rate increased following limited road closures. Similarly, in the Cabinet-Yaak and Selkirk Grizzly Bear

Recovery Zones, the grizzly bear security core habitat (i.e., area > 500 m from an open or gated road) increased as a result of road closures and road decommissioning efforts (Summerfield et al., 2004). Other studies on grizzly bear have shown bear use of high quality habitat near roads at night or when unoccupied or during low traffic levels (e.g., Gibeau et al., 2002; Mace, Waller, Manley, Lyon, & Zuuring, 1996). Such results have led to road management recommendations including reducing active road density, restricting human access or public use of open roads, seasonal area closures, day use only restrictions in areas of high quality habitat, and travel limitations and party size restrictions in national parks (Ciarniello et al., 2007; Gibeau et al., 2002; Mace et al., 1996; Wielgus et al., 2002).

Land Access – Off-Road and Rail

Off-road.

Access issues are not restricted to roads. Linear infrastructure such as seismic lines, transmission lines, and pipelines also provide access for off-road vehicles into backcountry areas. Once a tradition of access has been established via roads, trails, or linear access corridors; restricting or removing access is often difficult. For example, off-road vehicle users have opposed both temporary and permanent access restrictions in the Rocky Mountains of Alberta (McFarlane, Craig, Stumpf-Allen, & Watson, 2007).

Since the 1970s, the use and technological capabilities of off-road vehicles have dramatically increased, allowing access to high-elevation habitats and more isolated backcountry areas than ever before (Adams & McCool, 2009). New retail sales of all-terrain vehicles or ATVs and off-highway motorcycles in the US increased from 292,000 units in 1973 to over 1.1 million units in 2003, with 9.8 million total units (new and old) estimated to be operable during 2007 (Adams & McCool, 2009; Cordell, Betz, Green, & Stephens, 2005). Canada has seen similar increases in off-road vehicles, with new ATV retail sales estimated to range between CDN$ 588.3 million and $1,143.8 million per year over the last seven years (Motorcycle & Moped Industry Council and Canadian Off Highway Vehicle Distributors Council, 2011).

Increases in off-road vehicle use and access to increasingly remote areas have resulted in a variety of effects on wildlife, depending on species sensitivity, habitat quality, and the type of access and approach of vehicle. In controlled experiments, ATV use in off-road areas was reported to cause behavior change in elk (Naylor, Wisdom, & Anthony, 2009) at relatively large distances (> 1000 m) from ATVs (Preisler, Ager & Wisdom, 2006). Snowmobiles have been implicated in declines in mountain goat populations in Montana (McCarthy, 2008 as cited in Mountain Goat Management Team, 2010), and displacement of mountain caribou from high quality habitats in the Hart Ranges of BC (Seip, Johnson, & Watts, 2007). Off-road vehicle recreation effects extend to the coastal and desert environments as well, with ATV use resulting in habitat avoidance by both shorebirds and desert tortoises (Bury & Luckenbach, 2002; Tarr, Simons & Pollock, 2010).

Rail.

Railway access through remote areas has also led to effects on wildlife. A study conducted in northwest BC found 71 individual moose-train collisions along an approximate 200 km section of the CN rail during the winter of 2010-2011 (McElhanney Consulting Services Ltd., 2011). In Norway, moose-train collisions are a management concern with approximately 5,860 moose-train collisions reported nationally from 2006 to 2012

(Andreassen, Gundersen, & Storaas, 2005; Statistics Norway, 2012). Based on a review of video footage, Rea, Child, and Aitken (2010) reported that moose generally ran along snow-packed rail beds ahead of a locomotive. Moose are thought to use railways as movement corridors during the winter because of ease of mobility and the lower energetic cost; however, such behavior increases their risk of train collisions, particularly when high snow banks are beside the railway bed (Becker & Grauvogel, 1991; Gundersen & Andreassen, 1998). Ungulate mortality on railway tracks has also been reported for elk and deer (Statistics Norway, 2012; Rea et al., 2010).

Air Access

In BC, helicopters and fixed-wing aircrafts are commonly used to access backcountry areas for recreation (e.g., sightseeing, heli-skiing, and heli-hiking) and industrial development activities, particularly mineral exploration programs. These aircraft can access remote areas, where they can have negative effects on wildlife. The degree to which helicopter or fixed-wing aircraft overflights influence wildlife is thought to vary based on species sensitivity, habitat, topography, seasonal timing, the degree of prior exposure, aircraft type (Ward, Stehn, Erickson, & Derksen, 1999), aircraft angle of approach (Frid, 2003), and the distance between animals and aircraft (Goldstein et al., 2005; Krausman & Hervert, 1983; Ward et al., 1999). Mountain goats show high sensitivity to helicopter disturbance, with greater behavioral responses inversely related to helicopter distance (Côté, 1996; Goldstein et al., 2005). Other studies have documented aircraft disturbances on mountain sheep (Frid, 2003; Krausman & Hervert, 1983) and geese (Belanger & Bedard, 1989; Ward et al., 1999).

Water Access

Relatively few studies have addressed the effects of water-based access to in-land areas on wildlife populations. Overall, the effect of water-based access on wildlife appears to vary depending on the level of human use of a waterway (Rasmussen & Simpson, 2010), type of disturbance (Knapton, Petrie, & Herring, 2000), species variations in behavior, and the quality of habitat (Schummer & Eddleman, 2003; Velando & Munilla, 2011). Boat use has been a source of access for wildlife harvesting in southeast Alaska. For example, Person and Russell (2008) found that approximately half of the wolves killed by harvesters were taken by harvesters using boats to travel to remote islands along the coast of Alaska.

Some wildlife species are more susceptible to disturbance from boating activities. For example, in northwestern Iberia, European shags foraged in higher densities in areas of lower boat traffic and were excluded from high quality foraging habitat by high levels of tourism boats (Velando & Munilla, 2011). A study in the Tishomingo National Wildlife Refuge in Oklahoma reported that waterbirds are more sensitive to disturbance from boats than human presence at the shoreline (Schummer & Eddleman, 2003).

The effects of sea-based activities from tourism, recreation, and commercial fisheries on marine wildlife are extensive and well documented (e.g., Davenport & Davenport, 2006; Julian & Beeson, 1998). Although acknowledged that sea-based human activities are directly related to human access, marine environments are not part of the scope of this thesis.

Access Management

Concerns about access-related impacts on wildlife populations are not new. Since the 1980s, biologists have recommended access management in BC (e.g., Apps et al., 2004; Ciarniello et al., 2007; Hamilton & Wilson, 2001; McLellan & Shackleton, 1988). In general, the use of the term ‘access management’ has changed from a road-by-road approach to a more holistic landscape-level planning approach. The following sections provide a review of the evolution of access management in BC and summarize research on monitoring and evaluating access management.

Access Management – Then and Now

Early initiatives of access management in BC generally focused on road access control measures (i.e., gates, berms, bridge removal, and road deactivation) on a road-by-road basis (BC Ministry of Forests, 1989). This road-focused approach of access management was consistent with the Ministry of Forests and Lands definition of access management during the 1980s, which was: “the overall mandate for the administration of the planning, construction, maintenance, use and deactivation of Forest Service Roads, Operation roads and non-status roads on Crown Lands within or outside of Provincial Forests…” (BC Ministry of Forests, 1989, Appendix A, p. 3).

This road-by-road approach was rarely successful in the absence of any comprehensive plan (BC Ministry of Forests, 1989), and thus, the BC Forest Service initiated the Coordinated Access Management Planning Process in the early-1980s. Coordinated Access Management Planning involved a local resource use planning process intended to incorporate, at varying levels, industrial and public forest access requirements on existing and planned access roads. It was designed specifically to identify access requirements of all forest users and resolve any conflicts in an established forum led by the Province of BC (BC Ministry of Forests, 1989). The end result of the planning process was a Coordinated Access Management Plan, defined as: "a strategy, prepared through the coordinated involvement of government officials, resource users, recreationalists, and other interested parties, designed to manage access of all users into a specified area" (Government of BC, 1995, p. 131). This definition remains current as the *Sea-to-Sky Coordinated Access Management Plan*, which was developed in 2009, identified access management in terms of managing the use of existing and future road access to access-sensitive areas and by "maintaining road access to important recreational resources" (Rowe, 2009, p.5).

In 1994, BC initiated an Access Management Initiative comprised of government, industry, and a range of public interest groups (Access Management Initiative, 1995). The primary objective of the initiative was to improve the understanding about the management and control of access on public lands and to clarify issues and provide information to assist with the resolution of access-related problems in northeastern BC (Access Management Initiative, 1995). Through this initiative, reviews were completed on physical access control measures (Axys Environmental Consulting Ltd., 1995), the Coordinated Access Management Planning process (Carmanah Research Ltd., 1995), and legislative and administrative policies and procedures affecting access management (Downs, 1994). Although access management was not formally defined during this review, the term 'access management' was summarized by the Access Management Initiative (1995) as including the following factors:

> Ability to control the use of roads, trails, cut lines and rights-of-way; the control of both industrial and recreational uses at the time of construction and, subsequently, when secondary use develops; a decision process to determine where, when and how access controls should be applied; the incorporation of planning, construction, maintenance, deactivation, rehabilitation and reclamation in the decision process; and control of existing access as well as the planned control and/or deactivation of new access. (p. 2-3)

Since the 1990s, the Province of BC has developed and systematically applied a land use planning process throughout the province. This planning process has evolved from strategic land use plans, such as Land and Resource Management Plans (LRMP) that can provide high level strategic direction, to Sustainable Resource Management Plans (SRMP) that are designed to provide a consolidated approach to planning at the landscape level. As defined by the BC Ministry of Sustainable Resource Management (2002): "SRM Planning is a comprehensive, landscape-level approach to designing objectives and indicators that promotes sustainable economic development afforded by the province's wealth of Crown land, water, sub-surface and biological resources" (p. 4).

The term 'access management' has been readily used in some of the earlier LRMPs, but not explicitly defined. For example, the Kamloops LRMP (Government of BC, 1995) identified access management as an important strategy to maintain or enhance identified wildlife habitat areas through consideration of predator access to caribou habitat, maintenance of access, and human access allowances. Similarly, the Kispiox LRMP (Government of BC, 2001) included requirements towards access planning and access management with regards to grizzly bear habitat, motorized and non-motorized recreational access, zoning and designation of areas for specific uses, and road construction, maintenance, deactivation, and rehabilitation needs.

In more recent sustainable resource management planning, the need and general objective for access management was identified. For example, the 100 Mile House SRMP states access management as "necessary to minimize conflicts between industrial, commercial, and recreational user groups, while minimizing the negative impacts of access on fish, wildlife, and the environment" (Government of BC, 2005, p. 68). Within the Skeena Region of BC, access management is identified as a tool to minimize mortality and disturbance to moose, mountain goat, and grizzly bear (Government of BC, 2012).

Although access management is often referred to within resource management planning; unfortunately, the term 'access management' is largely undefined. So, what is 'access management'? To help answer this question in the context of this thesis, the Foothills Research Institute in Alberta; a partnership of government, industry, local communities, public interest groups, and academia; provides a broad definition of access management in their *Review of Access Management Strategies and Tools* (Eos Research and Consulting, 2009). The Institute defines access management as the "placement, management and reclamation of linear infrastructure and the associated impacts arising from the use of that infrastructure by industry and all other public users" (Eos Research and Consulting, 2009, p. 12).

In the context of this thesis, access management is similarly defined broadly, but with the inclusion of the *planning and management of motorized and non-motorized access*. Thus, access and access management in the context of this thesis is further defined by the following two definitions:

***Human access**:* *any mode of human travel into a remote area.*

Access management: *planning and management of motorized and non-motorized human access and linear infrastructure, and associated impacts arising from human access and linear infrastructure.*

Access Management – Monitoring and Evaluation

Although access management is recommended throughout primary wildlife research and provincial land management plans as a means of wildlife management, little research has measured the status of access or access management strategies. Most research on monitoring access initiatives has focused on evaluating access control measures for protecting wildlife and wildlife habitats, particularly from hunting activities (Crichton et al., 2004; Gratson & Whitman, 2000). These studies, along with others (e.g., Axys Environmental Consulting, 1995; Cole et al., 1997; Dunkley, Wise, Leslie, & Collins, 2004; Eos Research and Consulting, 2009), provide insight into the types, uses, and effectiveness of physical access control measures and road closures in decreasing hunter density and human use or increasing wildlife density in particular areas.

Unfortunately, wildlife are not affected by each road, access route, or individual user group independently but are subject to the cumulative influences of multiple land uses. As reviewed above, human access into remote areas is no longer just about roads but is occurring through other modes and at intensity levels that have shown effects on wildlife. Furthermore, access management is evolving from a road management or access control approach to more of a landscape planning management tool for conserving and sustaining wildlife populations and habitats. A road-by-road or access control approach to monitoring and evaluating access does not encompass the broader landscape-level conditions, context, or system. Consequently, a more holistic, big picture approach to measuring and monitoring access is needed – a landscape monitoring approach.

To define a landscape monitoring approach, details about the level of access, wildlife populations and their interactions must be understood. In order to quantify these variables, particularly between jurisdictions and ecozones, a standard set of access and wildlife indicators are needed.

Indicators in Natural Resource Management

The concept of ‘indicators’ has emerged over the last two decades as an important monitoring tool in natural resource management. Indicators have been the key mechanism for characterizing the essential components of sustainable forest management. In the context of sustainable forest management, an indicator is defined as a “quantitative, qualitative or descriptive attribute that, when measured or monitored periodically, indicates the direction of change in a criterion” (International Tropical Timber Organization, 2005, p. 9). From nine regional and international processes[2] some 150 countries, including Canada, have endorsed indicators as an effective means of monitoring, assessing, and reporting on the state and trends in a country's forest management (International Tropical Timber Organization, 2005; Wijewardana, 2008). Guided by these international processes, BC reported on 91 indicators in *The State of British Columbia's Forests* report (BC Ministry of Forests, Mines and Lands, 2010).

Indicators have also been used in protected area management, as part of a framework for measuring conservation effectiveness (Parrish, Braun, & Unnasch, 2003). Parks Canada identifies indicator monitoring and reporting as a crucial part of its management planning cycle (Parks Canada, 2008). Two types of monitoring are defined by Parks Canada: effectiveness and condition monitoring. Effectiveness monitoring is designed to answer 'what did we do and whether those actions accomplished what we set out to do'. Condition monitoring looks at what is the 'state of' through selecting and monitoring indicators, and comparing and reporting the results against pre-determined management targets every five years in 'State of the Park Reports' (Parks Canada, 2008). Indicators, as defined by Parks Canada, are

> a nationally or bio-regionally consistent summary reporting statement that provides a comprehensive synopsis of each element of the Agency mandate. [Their use] is based on a combination of data, measures and critical success factors that provide a clear

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[2] The nine regional and international processes include those of the African Timber Organization (ATO), the Dry Forest in Asia, the Dry-Zone Africa, the International Tropical Timber Organization (ITTO), the Lepaterique Process of Central America, the Montreal Process, the Near East Process, the Pan-European Process, and the Tarapoto Process for the Sustainability of the Amazon Forest.

message about current conditions and the change since the last measurement. (Parks Canada, 2008, p. 33)

BC's sustainable resource management planning also identifies indicators as primary tools through which the resource management direction can be communicated, though the terminology is different. The term 'goal' is typically used to refer to broad ideals, aspirations, or benefits pertaining to specific environmental, economic, or social issues (BC Ministry of Sustainable Resource Management, 2004c). The terms 'objective' and 'strategy' are often used to define what outcome is intended and how the desired outcome will be achieved. Indicator, in context of resource management plans, is defined as a "number or other descriptor, measured in real units, which is assumed to be representative of a larger set of conditions or values" (BC Ministry of Sustainable Resource Management, 2004a, p. 11) Once SRMPs are completed, the monitoring of indicators is used every five years to evaluate implementation progress and the effectiveness of plan objectives and strategies (BC Ministry of Sustainable Resource Management, 2004b).

Although the terminology varies across land management disciplines, one common theme is that indicators are considered a key mechanism not only in describing and assessing implementation of management direction, but also in measuring and monitoring the state of the environment. Environmental indicators may include physical, chemical, and ecological indicators. Ecological indicators, the focus of this thesis, are used to monitor ecological processes and conditions (National Academy of Sciences, 2000).

To date in the LRMP and SRMP process, indicators have not been universally identified or adopted to monitor human access. This thesis aims to identify and describe ecological indicators of human access and access management through a review of the relevant literature and resource management plans for BC.

Chapter 3: Methodology

Research Approach

A synthesis of ecological indicators was derived from a literature review. Data was collected and analysed in three stages. Initially, a broad list of indicators was developed from a review of the peer-reviewed literature on land management, conservation biology, road ecology, and wildlife management in relation to human disturbance, access, and wildlife. Second, an analysis was conducted of management plans and management direction statements to provide a list of other indicators that are important to wildlife management and human access that are not mentioned in the academic literature. This included a detailed review and document analysis of selected management plans and monitoring statements. Finally, indicators were broadly categorized and analysed based on Noss's (1990) four levels of biological organization: regional landscape, ecosystem-community, population-species, and individual-genetic. The methodology details of each of these three stages are described below.

Stage 1: Literature Review

In stage one, I developed a list of potential indicators and metrics (measurable qualities of an indicator) from a review of the primary academic literature on land management, conservation biology, road ecology, and wildlife management in relation to human disturbance, access, and wildlife. I selected studies for review that had titles and keywords associated with the objectives of this thesis. Subsequently, I examined information provided in article abstracts and in the full text to determine if the studies met the following conditions:

- Human access land use measure: provided or summarized a human access indicator, variable, or metric as a measure of human access impact on wildlife.
- Wildlife and wildlife habitat measure: provided or summarized a wildlife health or wildlife habitat indicator, metric, or variable as a measure of human access impact on wildlife.

I developed a database that listed each study and the associated human access land use indicator, metric or variable, wildlife species or group, wildlife and wildlife habitat measures, scale of the study, and relevant conclusions or research findings.

Stage 2: Management Plan Review

In stage two, I reviewed management plans and management direction statements from a sample of management plans in BC and Alberta. The analysis revealed additional indicators that are important to wildlife management and human access management, but not mentioned in the academic literature.

I selected to review management plans for BC and Alberta that had explicit access management objectives or strategies, or that identified indicators of human access and access management. Resource management plans often stated the direction and strategies for wildlife and wildlife habitats in the context of access. Thus, I reviewed the plans for access management strategies or indicators that pertained to wildlife components. I also reviewed supporting documents in the management plans, where available. I selected management plans with specific wildlife management plans, recreational access management plans, resource management plans, and cumulative effects management plans. The selected management plans varied greatly in size, scale, primary ecosystem type, management strategy and goal, and type and degree of human access. This variation increased the scope of the proposed list of ecological indicators.

I developed a database listing for each management plan and the associated access management goal, strategy, indicator, and metric. Wherever available, the standard, threshold, or target set by the management area was documented for each indicator.

Stage 3: Analysis Framework

I grouped the indicators, variables, and metrics into similar themes and then categorized them more broadly according to the potential indicators. The broader group of potential indicators were chosen to cover many of the variations of similar indicators in single categories. For example, road density, road and trail density, and corridor density were all identified as indicators of access in the literature, but represented slightly different measures. In this analysis, they were all placed within the ‘linear density’ category.

I categorized the broad potential indicators following the four levels of biological organization: regional landscape, community-ecosystem, population-species, and individual-genetic. Noss (1990) defined these as follows:

- Regional landscape level: includes “spatial complexity of regions” where the spatial scale can vary from the size of a park up to the size of a region or province (p. 358).

- Community-ecosystem level: "comprises the populations of some or all species at a site and includes abiotic aspects of the environment with which the biotic community is interdependent" (p. 360).
- Population-species level: includes "all populations of a species across its range, a metapopulation (populations of a species connected by dispersal), or a single, disjunct population" (p. 360).
- Genetic: includes the level of genes and genetic variation.

Potential indicators were grouped into the level of organization based on the context and spatial scale of the article or management plan in which the indicator was identified. The groupings are recognized to be somewhat arbitrary as many indicators can be measured at different scales, depending on the management question.

Challenges of the Research Methodology

The ecological indicator terminology used in the literature, resource management plans, and wildlife management plans is confused, does not follow standard terms, and definitions tend to overlap. The literature offers various ways to describe human access impacts and indicators, and indicators identified by some authors are considered subsets of indicators or metrics and variables by other authors. Similarly, in the management plans, indicators may not be explicitly listed, but only implied in the context of the management plan objectives, strategies, and targets. Moreover, when indicators are identified, some management plans are unclear about what they are intended to measure.

Chapter 4: Results

Review of the Literature and Management Plans

Table 1 list the studies reviewed that provided or summarized indicators or measurable attributes (variables or metrics) of human access and wildlife health as a measure of human access impact on wildlife. This review focuses on research of access and wildlife in remote areas, such as resource road networks and linear infrastructure into backcountry areas. In addition to the original research articles (Table 1), several review articles and books were reviewed, including Coffin (2007), Forman and Alexander (1998), and Forman et al. (2003). Table 2 lists the management plans that were reviewed that provided indicators, strategies, targets or measurable attributes of human access or wildlife health as a measure of human access impact on wildlife.

Ecological Indicators and Measures of Human Access and Access Management

Table 3 presents the list of ecological indicators and measurable attributes of human access and access management in relation to wildlife from the synthesized review of relevant literature and land management plans. For each potential ecological indicator, a literature reference example and/or a specific example of a management plan is provided. To a certain extent, one indicator could be used to measure human access and access management at different levels of organization; thus, some overlap exists in the indicators in the list (Table 3).

Table 1: Summary of the reviewed literature that provided potential ecological indicators or measurable attributes of human access impacts on wildlife.

Wildlife		**Human Access**		**Primary Literature Reference**
Group or Species	**Measurable Attribute**	**Access Component**	**Measurable Attribute**	
Grizzly bear	Mortality risk / human-caused mortality, population density, habitat selection, habitat avoidance, security core habitat, habitat use / distribution, movement	Roads, trails (including linear access features), railway lines, high human use features (campgrounds, picnic areas)	Distance to roads/linear access, density (road/route/trail/linear infrastructure), zones of influence (buffer widths around linear access), traffic volume, human access index (index of expected human access to the landscape)	Apps et al. (2004); Benn and Herrero (2002); Ciarniello et al. (2007); Gibeau et al. (2002); Mace et al. (1996); McLellan and Shackleton (1988); Nielsen et al. (2004); Roever, Boyce and Stenhouse (2010); Summerfield et al. (2004); Wielgus et al. (2002)
Mammal and bird populations	Diversity, abundance, species richness, population density (mean species abundance), distribution	Roads, infrastructure (linear and clustered), human settlements	Fragmentation rate, distance, density	Aubad, Aragón, and Rodríguez (2010); Benítez-López et al. (2010); Bowman, Ray, Magoun, Johnson, and Dawson (2010); Pattanvibool and Dearden (2002)
Moose	Density	Roads	Road closure	Crichton et al. (2004)
Elk	Abundance, survival rate, movement (core area and home range) and redistribution, mortality risk, habitat effectiveness / habitat selection	Roads, trails / pipelines, hunters	Road density, trail density, hunter density, road closure, distance to road, road network design	Cole et al. (1997); Frair et al. (2008); Gratson and Whitman (2000); Rowland et al. (2000)
Caribou	Habitat avoidance, caribou density, fragmentation, habitat modelling, mortality distribution	Roads, wells, seismic lines, powerlines, snowmobiles	Distance, snowmobile use	Dyer et al. (2001); James and Stuart-Smith (2000); Nellemann, Vistnes, Jordhøy, Strand, and Newton (2003); Seip et al. (2007)
Wolf	Mortality harvest / risk	Roads, boat access	Density, average distance	Person and Russell (2008)

Table 2: Provincial and regional management plans, access management plans, and wildlife management plans reviewed for potential ecological indicators and metrics to measure human access impacts on wildlife.

Province	Location	Management Plan
Alberta	Provincial	Alberta Grizzly Bear Provincial Recovery Plan 2008-2013 (Alberta Sustainable Resource Development, 2008)
BC	Skeena Region	Cranberry Sustainable Resource Management Plan (Government of BC, 2012)
BC	Northeast	Cumulative Effects Assessment and Management for Northeast BC: Vol. 2, Cumulative Effects Indicators, Thresholds, and Case Studies (Salmo Consulting Inc. and Diversified Environmental Services, 2003)
Alberta	Bighorn Backcountry	Bighorn Backcountry Access Management Plan (Alberta Sustainable Resource Development, 2002) and supporting monitoring documents (Alberta Wilderness Association, 2009; Nichols & Wilson, 2012)
BC	Cariboo Chilcotin	Chilcotin Sustainable Resource Management Plan (Government of BC, 2007), 100 Mile House Sustainable Resource Management Plan (Government of BC, 2005), Regional Access Management Strategy (Government of BC, 1996)
BC	Golden	Golden Backcountry Recreation Access Plan (Golden Interagency Technical Committee, 2002) and supporting Golden/Windy Creek LAC Pilot Project documents (Vold, Sranko, Johnsen, & Mitchell, 2008)
BC	Muskwa-Kechika	Muskwa-Kechika Management Area, and supporting Wildlife Management Plan (BC Ministry of Environment, 2009), annual reports (Government of BC, 2011), Conservation Area Design (Heinemeyer et al., 2004)

Table 3: Potential ecological indicators and measurable attributes of access and access management at multiple levels of biological organization

Ecological Indicator	Measurable attribute	Literature Example	Management Plan Example
Regional Landscape			
Human development rate	Grazing and agricultural intensity, number of industrial developments or camps, deforestation rate, number of land tenure permits and applications for development		The Muskwa-Kechika Management Area annually reports on human development activity, including mining activity, oil and gas activity, and land tenure activity (BC Government, 2011)
Linear density	Measured in km/km^2; change in open or total access corridor or linear density (e.g., roads, trails, and other linear corridors)	Apps et al. (2004); Gratson and Whitman (2000); Mace et al. (1996); Person and Russell (2008); Summerfield et al. (2004)	The Alberta Grizzly Bear Recovery Plan identified open route density as an indicator of human use of access and set a target of at or below 0.6 km/km^2 in Grizzly Bear Habitat Areas (Alberta Sustainable Resource Development, 2008)
Distance to development	Measured in linear distance or distance bands buffered from human access infrastructure	Benítez-López et al (2010); McLellan and Shackleton (1988); Nielsen et al. (2004); Rowland et al. (2000); Wielgus et al. (2002)	
Access network structure	Measures can include road pattern, route width or type, traffic density, road density, network connectivity, frequency of spur roads or roads, clear-cut associations	Forman and Alexander (1998); Frair et al. (2008); Rowland et al. (2000)	
Intact areas or no-access designation zones	Measures can include amount and change to intact areas or the number, location, amount and type of no-access designated areas	Crist, Wilmer, and Aplet (2005)	The Alberta Grizzly Bear Recovery Plan suggests managing access through the creation of priority habitat – Grizzly Bear Habitat Areas (Alberta Sustainable

			Resource Development, 2008)
Landscape structure	Landscape connectivity and fragmentation. Measures can include landscape metrics such as area, isolation, and aggregation	Crist et al. (2005); Leitao, Miller, Ahern, and McGarigal (2006); Pattanvibool and Dearden (2002)	In northeast BC, patch and corridor size recommended as a measure of cumulative access impacts on wildlife (Salmo Consulting Inc. and Diversified Environmental Services, 2003)
Community-Ecosystem			
Ecosystem network	Landscape corridors designated to protect hydroriparian ecosystems; measure change by proportion harvested, road length, total area		Cranberry SRMP identified a road length target of 0 km within ecosystem networks (Government of BC, 2012)
Species diversity / abundance	Mean species abundance	Benítez-López et al. (2010); National Academy of Sciences (2000)	
Access closure and restrictions	Number of trails, roads, and access routes defined as open and closed; number of roads deactivated or with motorized vehicle access restrictions	Crichton et al. (2004); Gratson and Whitman (2000); Summerfield et al. (2004)	The Cranberry SRMP identified number of deactivated roads as an indicator for maintenance of key resources such as wildlife habitat. Within moose habitat the target number of roads deactivated or have motorized access restrictions is all roads (Government of BC, 2012)
Rate of illegal or non-compliant activity	Change in number and species of illegally harvested wildlife, illegal activity of trails from motorized off-highway vehicles		Illegal activity of trails is an indicator of recreational access management success and measured by the amount of motorized off-highway vehicle traffic on non-designated trails, and on designated trails during non-designated times in Alberta's Bighorn Backcountry (Alberta Wilderness Association, 2009; Nichols & Wilson, 2012)
Rate of motorized	Measures of motorized vehicle, boat,	Seip et al. (2007)	The Golden Backcountry Recreation

vehicle activity	aircraft activity; total vehicle passes per day, number of helicopter sightings or landings per day		Access Plan identifies aerial access, measured by number of landings per day, as an indicator of recreational impacts on the natural environment (Golden Interagency Technical Committee, 2002)
Population-Species			
Focal species	Population size, abundance, density, distribution, productivity, survivorship, age-class and gender structure	Ciarniello et al. (2007); Crichton et al. (2004); Gratson and Whitman (2000)	
Habitat selection	Change or extent in habitat effectiveness or habitat selection	Ciarniello et al. (2007); Mace et al. (1996); Rowland et al. (2000)	
Core area	Measure of use distribution or the availability and location of areas where minimal human impacts have occurred	Cole et al. (1997); Summerfield et al. (2004)	In northeast BC, core habitat is recommended as a cumulative impact indicator to help describe and monitor environmental and land use conditions (Salmo Consulting Inc. and Diversified Environmental Services, 2003)
Rate of human-caused wildlife mortality	Total number of reported human-caused mortality, can include number or proportion of problem wildlife killed, vehicle-wildlife collisions, rail-wildlife collisions. Model mortality risk through distribution and concentration of known human-caused mortality	Benn and Herrero (2002); Ciarniello et al. (2007); Nielsen et al. (2004); Person and Russell (2008)	Alberta Grizzly Bear Recovery Plan identified human-caused mortality as an indicator of human use and access, and set a target of total number of known human-caused mortality per Bear Management Area per year to account for less than 4% of the provincial population per year (Alberta Sustainable Resource Development, 2008)

Ecological indicators were grouped according to the four levels of biological organization: 1) regional landscape, 2) communities-ecosystem, 3) population-species, and 4) genetic. While, genetics are directly linked to landscape; whereby human access changes to a landscape isolate or mix certain populations can change the natural distribution of genetic diversity among populations; genetic information is not the fundamental issue in habitat conversion (Meffe, Nielsen, Knight, & Schenborn, 2002). Genetic indicators have not yet been well-developed or applied in measuring human access impacts on wildlife. Thus, this review is focused on the first three levels of organization.

Regional Landscape

At the regional landscape level, human access can affect wildlife by three primary interrelated factors: “1) habitat loss from conversion of natural ecosystems to human uses; 2) habitat fragmentation, the dissection of natural habitat by human activities; and 3) matrix quality, the overall integrity of the landscape in which natural areas are embedded” (Meffe et al., 2002, p. 169). This is because as human access and use convert a landscape, the level of fragmentation increases, and the quality of surrounding landscapes decreases (Meffe et al., 2002).

Based on Noss’s (1990) definition of regional landscape and Meffe et al.’s (2002) description of human access impacts at the regional landscape level, the following ecological indicators of human access are assessed at the regional landscape level:

- human development rate,
- linear density,

- distance to development,
- access network structure,
- intact areas or no-access designated zones, and
- landscape structure.

Human development rate: measured at the regional landscape scale, can include deforestation rate, grazing or agricultural intensity, rate of housing development, number and location of industrial developments or camps, rate of oil and gas development, number or length of geophysical exploration (or seismic) lines, and number of pre-tenure applications and grants. Tracking the extent of change in the human footprint over time in an area can also provide a measure of the amount of human development, and indicate when habitat conservation and enhancement initiatives are needed (Alberta Sustainable Resource Development, 2008). Measures of the human development rate can include linear density (detailed below) or a count of the number of approved permits and development applications.

For example, the Muskwa-Kechika Management Area provides an annual activity report for the area, which includes an overview of development activity for mining activity (e.g., number of Notice of Works approved, mineral claims, and mineral exploration permits), oil and gas activity (e.g., number of granted lease parcels, new Crown sales, geophysical and well applications submitted and approved), and land activity (e.g., number of land tenures by type) (e.g., Government of BC, 2011).

Linear density: (expressed as km/km^2) is used to describe both road and other linear corridor densities and can be used as a land use indicator that integrates many ecological effects of habitat loss, alteration, barriers, mortality, and disturbance (Forman & Alexander, 1998). Measuring the change or extent of access density over time can inform land managers of the intensity of human use (existing access) and broad area development (new access). Road density is commonly considered as a “useful, broad index of several ecological effects of roads in the landscape,” including human access (Forman & Alexander, 1998, p. 222), and it continues to be used as a proxy for human footprint extent (e.g., Bowman et al., 2010) since resource development is generally accompanied by a transportation network. Increases in road density have been negatively correlated to reductions in species abundance and positively correlated to mortality rates (Mace et al., 1996; Person & Russel, 2008). Thus, some wildlife studies have identified road density thresholds for specific species (e.g., Person & Russel, 2008).

Measures of linear density can include different combinations of access corridors depending on the type and level of human activities in a given area and the wildlife species or habitats of concern. Studies have suggested road density, road and trail density, road, trail and seismic line density, and total corridor or route density as a measure of human access (e.g., Bowman et al., 2010; Gratson & Whitman, 2000; Salmo Consulting Inc. and Diversified Environmental Services, 2003). In northeast BC, total access corridor density was identified as a useful land use indicator for analysing designated woodland caribou habitat (Salmo Consulting Inc. and Diversified Environmental Services, 2003).

Linear density can also include measures of open linear density (access is open to the public/motorized use), closed linear density (access is closed to the public/motorized use) and total linear density (access is open and closed) (Gratson & Whitman, 2000; Summerfield et al., 2004). For example, the Alberta Grizzly Bear Recovery Plan (2008) identifies open route density (i.e., roads, trails, and seismic lines on which motorized travel is possible and permissible) as an indicator of the amount of human use of access, and sets a target of at or below 0.6 km/km^2 for designated Grizzly Bear Priority Areas.

Distance to development: (expressed as distance bands buffered from human infrastructure, such as roads, trails, seismic lines, petroleum wells, etc., or distance in km to nearest linear human use feature) can provide a measure of change in the spatial distribution and extent of developments in relation to wildlife and wildlife habitats. For example, in northeast Oregon, Rowland et al. (2000) found a strong relationship between elk selection and distance from open roads, rather than road density alone. In Alberta, Nielsen et al. (2004) modelled human-caused grizzly bear mortality risk and found the distance to linear human access feature (roads and trails) to be an effective predictor for determining risk. Other researchers have also shown distance to developments to be an effective predictor in modelling wildlife habitat avoidance, or conversely, wildlife habitat selection, though the type and level of human activity is suggested to determine the potential zone of influence (area of avoidance) from development and wildlife density (e.g., Dyer et al., 2001; Ciarniello et al., 2007; Gibeau et al., 2002; Wielgus et al., 2002).

Access network structure: Variations in access network structure and design can produce differing effects on indirect habitat loss for wildlife. For example, research on road patterns found that roads clumped together in an area can lead to large continuous blocks of habitat unaffected by roads, even in higher road density areas; whereas, a regular pattern of roads (i.e., evenly spaced) can influence greater amounts of habitat (Rowland et al., 2000). Similarly, a model simulation study using elk found that the design of the road network accounted for up to 60 to 80% of the difference in the density of roads (Frair et al., 2008). In the study, network structure considered the location of other human impacts (i.e., clear-cuts) in association with, or independent of, resource roads (Frair et al., 2008). In addition to road pattern, other metrics of access network structure can include linear width or type, traffic density, network connectivity, frequency of spur roads or routes (e.g., trails, and right-of-ways from transmission lines and seismic lines) into remote areas, and location (Forman & Alexander, 1998).

In terms of access network connectivity, Apps et al. (2004) developed an index of expected human access to the landscape, called a 'human access index,' by calculating the time required to access existing road networks from human population centers. The study viewed human access "as a function of road networks, temporal proximity to human settlements, and the population of those settlements" (Apps et al., 2004, p. 146).

Intact areas or no-access designation zones: In contrast to the presence of linear infrastructure, the lack of linear infrastructure can be used as an indicator of the absence of human use and can represent the amount of land intact or available as habitat. In BC, the

Ministry of Environment (2007) identified the amount of intact land area in the province as an indicator of human impact on ecosystems. In provincial state of the environment reports, intact areas were defined as “areas of at least 2,000 ha that are more than 5 km away from roads,” with road data including paved and dirt roads, railways, runways used by vehicle traffic, and seismic lines (BC Ministry of Environment, 2007, p. 260). Similarly, a study in central US, on the value of road-less areas in protected area management, included intact areas that are greater than 2,000 ha in size (Crist et al., 2005). Measuring the amount and change in intact areas can provide a measure of human land use and access within an area, as well as an indication of wildlife habitat security.

Resource management plans, access management plans, and wildlife management plans often designate areas or zones with differing levels of access and resource use. Designated zones for the protection of wildlife habitat are generally more stringent with access restrictions and management strategies to minimize human presence and development. For example, one key concept in reducing unregulated mortality of grizzly bear in the Alberta Grizzly Bear Recovery Plan 2008-2013 is managing access through the creation of priority habitat (i.e., Grizzly Bear Habitat Areas) (Alberta Sustainable Resource Development, 2008). Measures of the extent or change to special designated zones can include the number, type (zoning), and amount of area designated. Measures of the level of access within designated zones may include other measures (depending on the objectives of the zone), such as linear density, core area, rate of illegal or non-compliant activity, and rate of motorized activity.

Landscape structure: refers to the “description of the spatial relationships among ecosystems” (Leitao et al., 2006, p. 5). A common broad indicator of landscape structure is connectivity, the “degree to which the landscape facilitates or impedes movement of individuals among habitat patches” (Leitao et al., 2006, p. 12). Crist et al. (2005) used three landscape metrics to measure landscape connectivity, including area (size of habitat patches), isolation (distance between habitat patches), and aggregation (spatial arrangement of patches). Other landscape metrics used to measure landscape configuration can include number of patches, patch shape, patch extensiveness, contagion (spatial arrangement of patches), and edge contrast (amount of contrast between adjacent land cover patches) (Leitao et al., 2006). In northeast BC, patch and corridor size was recommended as an indicator to measure cumulative human land use impacts on wildlife habitat across the landscape (Salmo Consulting Inc. and Diversified Environmental Services, 2003).

Landscape connectivity has also been studied extensively as the degree of fragmentation of a landscape; which could also be thought of as the inverse of ‘connectivity’. Fragmentation occurs when “continuous natural areas are broken up or subdivided into disjunct fragments as development progresses” (Leitao et al., 2006, p. 17). The expansion and intensification of human land use is the main cause of habitat fragmentation (Andrén, 1994). Landscape can be fragmented by the construction of roads, power lines, corridors, or other linear features, as well as through other human activities such as resource development, forest harvesting, agriculture, and urban development. Pattanavibool and Dearden (2002) used rate and extent of fragmentation, measured by spatial configuration of habitat patches, as in indicator of human access and settlement impacts on wildlife in Northern Thailand.

Community-Ecosystem

Ecological indicators of human access at the community-ecosystem level can include:

- ecosystem networks,
- species diversity/abundance,
- access closure and restrictions,
- rate of illegal or non-compliant activity, and
- rate of motorized activity.

Ecosystem networks: are landscape corridors that protect hydroriparian ecosystems, such as streams, lakes, and wetlands. Ecosystem networks generally include the hydroriparian zone and a buffer, with the intention to provide interior, old forest conditions throughout the ecosystem network corridor (Government of BC, 2012). Ecosystem networks, as landscape corridors, serve many functions including habitat for wildlife, and can either facilitate or act as a barrier to the movement of plants, animals, nutrients, water, and wind (Leitao et al., 2006). Measures of the extent or change to ecosystem networks can include total area, proportion harvested, and road length. For example, the Cranberry SRMP identified a target of 0 km for road length within ecosystem networks (Government of BC, 2012).

Species diversity/abundance: measured by species richness, was selected by the National Academy of Sciences (2000) as an indicator of land transformation and human use. Measures of species diversity can include total species diversity, native species diversity, and ratio of native to non-native or invasive species. Species abundance can also be used as an indicator of wildlife health in relation to human access impacts. For example, Benítez-López et al. (2010) used mean species abundance, defined as the "mean abundance of (remaining) original species in an area related to an undisturbed situation" (p. 1308), as an indicator of the effect of infrastructure proximity on mammal and bird populations.

Access closures and restrictions: have been found to decrease human access into an area (Crichton et al., 2004; Gratson & Whitman, 2000). Access restrictions can include physical access control measures to prevent motorized access, as well as administrative seasonal or timing restrictions for access. Roads, trails and other access routes can be classified by human use categories, such as open (open to public), closed (no known vehicle use or physically barricaded), restricted (administratively restricted vehicle use through signage, not open to public), and deactivated or decommissioned (Summerfield et al., 2004). Measures of the extent or change in access closures and restrictions can include monitoring the number, location, and length (km) of access routes per classification against set targets. For example, the Cranberry SRMP identified road deactivation as an indicator of access and set a target of 100% of roads within 500 m of mountain goat winter range to be deactivated (Government of BC, 2012).

Rate of illegal or non-compliant activity: can include illegal hunting, illegal use of access routes (use during restricted periods), or cutting of new trails in areas with prohibited access. In Alberta's Bighorn Backcountry, illegal activity on trails is an indicator of access management success and measured by the number of passes of motorized off-highway vehicle traffic on non-designated trails, and on designated trails during non-designated times (Alberta Wilderness Association, 2009; Nichols & Wilson, 2012).

Rate of motorized activity: along access routes can provide an indicator of the level of human use of an area. This can include measures of motorized vehicle, boat, and aircraft activity. Measures of motorized vehicle activity can include total number of vehicle passes and can be separated by vehicle type, such as off-highway vehicle and highway vehicle. For example, off-highway motorized vehicle activity was identified as an indicator of access management success for Alberta's Bighorn Backcountry and measured using digital traffic counters (Alberta Wilderness Association, 2009; Nichols & Wilson, 2012). In the Hart Ranges of BC, Seip et al. (2007) recorded snowmobile activity (sightings and tracks) to determine the location and intensity of snowmobile use in relation to caribou winter habitat.

Helicopter activity into an area is considered an access management concern in BC (Hamilton & Wilson, 2001; Mountain Goat Management Team, 2010). In the Golden Backcountry Recreation Access Plan and Pilot Project, aerial access (measured by number of sightings or landings per day) was identified as an indicator to measure recreational impacts on the natural physical environment (Golden Interagency Technical Committee, 2002; Vold et al., 2008).

Population-Species

Monitoring at the population-species level can be directed at the population itself or at habitat variables that are important to the species (Noss, 1990). The population-species level receives the most attention of wildlife research and monitoring, mainly for two reasons: "(1) species are often more tangible and easy to study than communities, landscape, or genes; and (2) laws…mandate attention to species but not to other levels of organization" (Noss, 1990, p. 360).

Potential ecological indicators of human access at the population-species level included those identified by researchers or management plans for addressing specific wildlife species, populations, or their habitats, can include:

- focal species,
- habitat selection,
- core habitat, and
- rate of human-caused wildlife mortality.

Focal species: are often selected for one or more of the following reasons: keystone species (addition or removal of this species has a disproportionate effect on other species), indicator species (indicative of particular conditions in a system), umbrella species (protective of many other species due to its requirements for large expanses of habitat), charismatic species (elicits emotional feelings from individuals), vulnerable species (species at risk), and socially or economically important species (positive or negative consequences for the local, regional, or national community or economy) (Meffe et al., 2002). For example, grizzly bear are considered a premier indicator of terrestrial ecosystem health, a species of conservation concern, and since this species has broad habitat requirements, the protection or management of grizzly bear can be protective of many other species. Such considerations are reflected in the literature as numerous studies on the effects of human access have focused on grizzly bear (Table 1).

Measures of focal species can include population size, abundance, density (Crichton et al, 2004), distribution (Mace et al., 1996), productivity, survivorship (Cole et al., 1997), and age-class and gender structure (Table 1). For example, Crichton et al. (2004) estimated moose density over two time periods to determine population effects from road closures in Manitoba.

Habitat selection: or conversely, habitat avoidance, can express the continued use of a habitat by the species that historically used it (Government of BC, 2012). Models developed for predicting changes in habitat selection or avoidance of a focal species in relation to access corridors or infrastructure can be useful in analysing the effects of management strategies (Rowland et al., 2000). Measures of habitat selection can be developed with tools such as radio-telemetry and geographic information system data, and road density as in the study by Mace et al. (1996) that assessed grizzly bear habitat use near roads. Instead of road density, measures of the amount of habitat within distance bands from open roads and active development sites (e.g., well sites, and exploration camps) along with radio-telemetry data can also provide an estimate of habitat effectiveness for focal species monitoring (Rowland et al., 2000). A more recent study in the Parsnip River area of BC linked population assessment tools, such as radio-telemetry, with habitat modelling techniques (resource selection functions) to assess habitat selection of grizzly bear in the context of habitat, distance to roads, and human-caused mortality risk (Ciarniello et al., 2007).

Core area: can be a measure of use distribution of core activity areas (Cole et al., 1997) or the availability and location of areas where minimal human impacts have occurred. In northeast BC, core habitat is recommended as a cumulative impact indicator to help describe and monitor environmental and land use conditions (Salmo Consulting Inc. and Diversified Environmental Services, 2003). Different core area calculations have arisen but the common approach is to include a buffer zone of influence around all potential high use features, such as primary and secondary roads, truck and ATV trails, wellsites, industrial, commercial, and recreational facilities, communities and permanent residences (Salmo Consulting Inc. and Diversified Environmental Services, 2003). For example, Summerfield et al. (2004) used grizzly bear security core habitat, defined as “area greater than 500 m from an open or gated road” (p. 117), along with open and total route density, to measure the effects of motorized access on grizzly bears in the Cabinet-Yaak and Selkirk Grizzly Bear Recovery Zones. Other techniques to measure core area can include habitat models. For example, the Muskwa-Kechika Conservation Area Design determined the primary core area and connectivity-secondary core area for select focal species through habitat suitability modelling (Heinemeyer et al., 2004).

Rate of human-caused wildlife mortality: can be indicative of human use of access and the effectiveness of management decisions with respect to access and development, particularly for those wildlife species associated with more remote areas such as grizzly bear (Benn & Herrero, 2002; Alberta Sustainable Resource Development, 2008). Measures of human-caused mortality can include total number of known human-caused mortality, with data collected on species, sex, location, season, and type of mortality. Within the Central Rockies Ecosystem of Alberta, Nielsen et al. (2004) modelled grizzly bear mortality risk based on the spatial patterns of known human-caused grizzly bear mortalities, animal use locations, and land cover. The study, along with others (Person & Russell, 2008; Summerfield et al., 2004), found a higher wildlife mortality risk near areas of human use and access (Nielsen et al., 2004). Since humans are the main source of known grizzly bear mortality in Alberta, the Alberta Grizzly Bear Recovery Plan 2008-2013 identified total number of human-caused mortality as an indicator and set a target of human-caused mortality per Bear Management Area to account for less than 4% of the provincial population per year (Alberta Sustainable Resource Development, 2008).

Chapter 5: Discussion

Ecological Indicators of Access and Access Management

The central purpose of this thesis was to undertake a literature review of human access and access management to identify potential ecological indicators for measuring the extent and status of access and access management. My results suggest 15 potential ecological indicators of access and access management at multiple levels of organization. From the review and synthesis of the literature on human access, access management, and wildlife management, the following key findings emerge from this study.

Vagueness of Access Management

One unanticipated finding of this review is the prominent use of the term ‘access management’ in the literature and in management plans, without a clear definition or characterization. Use of the term is similar to Noss’s (1990) explanation of biodiversity, prior to its characterization: “means different things to different people….no wonder agencies are having difficulty in defining and implementing this new buzzword in a way that satisfies policy-makers, scientists, and public user groups alike” (p. 356). Access management is currently undergoing a similar phenomenon, whereby the term is referred to as a ‘silver-bullet’ for solving wildlife management concerns in remote areas, particularly in relation to access control measures, but the meaning and implementation of access management remains vague and ambiguous.

Two fundamental changes seem to be occurring in the views of wildlife biologists and land management planners with regards to access management. First, human access into remote areas no longer considers only roads, and now includes access from other linear features, water-way access, and air access. Second, access management is evolving from an access control measure to a more holistic landscape-level or systems approach. Thus, in context of this thesis, access management is defined as: *planning and management of motorized and non-motorized human access and linear infrastructure, and associated impacts arising from human access and linear infrastructure*. As Noss (1990) suggests for "escap[ing] the vagueness associated with the biodiversity issue" (p. 356), one way to further characterize access management is by identifying indicators or measurable attributes of access management.

Access Management in Terms of Large Mammal Management

The scope of this review was intended to cover different types of wildlife and habitats; however, wildlife grouping bias is present. Most of the reviewed studies with measureable attributes for human access or with recommendations for access management were on large mammals (Table 1). Thus, the applicability of the results and the suggested list of potential ecological indicators to other wildlife groups is unknown.

The large mammal bias is likely due to a combination of the study focus on remote areas and human use of roads (not the road infrastructure itself), the requirements for remote areas for habitats and security for large mammals, the sensitivities of large mammals to human use, and a publication and conservation bias toward large mammals that have large territories, are of interest to the public, and have legislative protection. Based on the amounts of published research, both grizzly bear and caribou would be wildlife species or ‘focal species’ that could be considered as sufficiently sensitive to provide a measure of stress or warning of change, in terms of human access in remote areas. ‘Sensitivity to stresses on a system’ is considered as one of many criteria for selecting ecological indicators (Dale & Beyeler, 2001).

Ecological Indicators across Multiple Levels of Organization

The ecological indicators identified in this review were categorized by biological organization, based on the context and scale in which they were represented in the literature or in management plans. This categorizing is somewhat arbitrary as many of the indicators can represent other levels of organization depending on the specific research or monitoring question. For example, linear density can be a human access indicator at the level of landscape, community-ecosystem or population-species, depending on the management question and the spatial scale of study.

The intent of the categorization was not to suggest that each indicator represents only one level of biological organization; instead, it is to highlight how human access and land use impacts can change landscape patterns, and thus, have impacts on wildlife and wildlife habitats that extend through other levels of organization, including communities and ecosystems, species composition and abundance, and gene flow (Noss & Cooperrider, 1994). “Big questions require answers from several scales” (Noss, 1990, p. 357). Human access and access management is a big question, encompassing cumulative impacts, and it should be viewed from a systems approach. Measuring and monitoring access and access management in an area should therefore consider multiple levels of organization, particularly since "effects of environmental stresses will be expressed in different ways at different levels of biological organization" (Noss, 1990, p. 357).

Integration of Ecological Indicators of Human Access

Although each indicator is listed separately in the results section, a single indicator cannot tell the whole picture. As stated by Noss (1990), "a complementary set of indicators is required" (p. 358). Much of the reviewed research that was selected offers many different indicators to assess and explore the effects and relationship of human access and wildlife. Two sub-types of ecological indicators could be categorized from the synthesis of the literature: a 'human land use' indicator and a 'wildlife use' indicator.

Human land use indicators, representing the extent and status of human stressors or impacts, can include the following eight indicators from the resulting list: human development rate, linear density, distance to development, access network structure, access closures and restrictions, rate of illegal or non-compliant activity, rate of motorized activity, and rate of human-caused wildlife mortality. Wildlife use indicators that represent wildlife or wildlife habitat health can include the remaining seven indicators from the results list: intact areas of no-access designation zones, landscape structure, ecosystem networks, species diversity/abundance, focal species, habitat effectiveness, and core areas. In general, at least one indicator of human land use and one indicator of wildlife use were paired together in reviewed research on human access and wildlife.

Building Block for Ecological Indicators of Human Access

Each of the fifteen indicators identified through this review requires different levels, complexity and sources of information; however, there is one similar data requirement or 'building block' for most of the identified indicators – GIS access infrastructure data (Table 4). This includes roads, trails, seismic lines, power lines, and railways.

Table 4: Selected ecological indicators by GIS access infrastructure data requirement.

Indicator	Access Infrastructure GIS Data
Human development rate	Yes
Linear density	Yes
Distance to development	Yes
Access network structure	Yes
Intact areas or no-access designated zones	Yes
Landscape structure	Yes
Ecosystem network	Yes
Species diversity/abundance	No
Access closure and restrictions	Yes
Rate of illegal or non-compliant activity	Yes
Rate of motorized vehicle activity	Yes
Focal species	No
Habitat selection	Yes
Core area	Yes
Rate of human-caused wildlife mortality	Yes

Selection of the Ecological Indicators

In general, ecological indicators are good tools for describing and monitoring land use and environmental conditions simply and quickly. This is because indicators can simplify complex issues by focusing on certain relevant aspects of a condition or process, for which data is available (Stanners et al., 2007). As a component of a management system, indicators can provide many benefits, as described by Raison, Flinn, and Brown (2001), International Tropical Timber Organization (2005), and Dale and Beyeler (2001) indicators can:

- communicate the status of efforts and provide a way to assess progress towards management objectives,
- focus research efforts where knowledge is still deficient to identify weakness,
- through continual re-valuation and review, indicators can account for evolving knowledge about human access impacts on wildlife, wildlife populations, and status of access,
- provide a tool for reporting, at a range of levels, on the state and trend in a condition over time,
- provide an early warning signal of changes in the environment, and can be used to diagnose the cause and quantify the magnitude of a stress.

In addition to the benefits, Dale and Beyeler (2001) identified three main concerns in using ecological indicators as resource management tools. First, selecting only one or a few indicators may oversimplify the ecological management program, leading to poorly informed decisions. Second, selection of indicators may not coincide with long-term goals, particularly in management programs with vague long-term goals and objectives. Third, scientific rigor is lacking in the selection of ecological indicators.

The results of this thesis suggest 15 different ecological indicators of access and access management. Moreover, not all indicators are recognized as being relevant or applicable to each management plan area or access management initiative. Nor can just one indicator represent the entire picture. Thus, as recommended by Noss (1990), a complementary set of ecological indicators across multiple levels of biological organization should be selected that are specific to the question or management objective to be answered in the monitoring process, and the set should meet the following criteria (Dale & Beyeler, 2001, p. 6):

- easily measured,
- sensitive to stresses on the system,
- respond to stress in a predictable manner,
- are anticipatory,
- predict changes that can be averted by management actions,
- are integrative,
- have a known response to natural disturbances, anthropogenic stresses, and changes over time,
- have low variability in response.

Recommendations for Land Managers and Further Study

Based on the results of this study, the following general recommendations for land managers and further study include:

- Terminology and frameworks for access management planning should be further characterized, developed, and operationalized.

- Land managers should require industry and government agencies to submit GIS access infrastructure data for use in assessing ecological indicators of access and access management
- The results section lists potential ecological indicators but does not compare, rate, or assess the effectiveness of the indicators. Further study is recommended to assess the indicators, and other ecological indicators for measuring and monitoring the extent and status of human access and whether or not the achievements of the access management direction and strategies are actually as expected or planned.
- Guidance for sustainable resource management planning outlines indicator monitoring as a Guidance Standard, which should occur every five years. Further development and support in ecological indicator monitoring frameworks and monitoring programs are recommended for assessing implementation and effectiveness of sustainable resource management plans, with a particular focus on human access.
- The components of access management, presented here, focus on potential ecological indicators of access and access management from a wildlife management perspective. This thesis does not cover other important types of environmental values (e.g., soil, erosion, water, and vegetation) as ecological indicators or the many equally important social, economic, cultural, and human health indicators of access and access management. Further studies are recommended for the development of environmental, as well as social, economic, and cultural indicators and measures of access and access management for use in inventory, monitoring, and assessment programs.

Chapter 6: Summary and Conclusions

Summary of Research Outcomes

Human access into remote areas is occurring through many modes at varying intensity levels that have shown effects on wildlife. Access management continues to be the 'silver bullet' for minimizing and managing potential human access effects on wildlife. Unfortunately, research on the status of access, implementation of access management, and/or measures of progress of whether an area is achieving the goals of access management are limited. One way to measure access and access management is to identify measurable attributes or indicators of access for use in environmental inventory, monitoring, assessment, and evaluation programs.

Based on the review of relevant literature, resource management plans, and provincial wildlife management strategies, this research identified and described the following ecological indicators for measuring and monitoring access and access management:

- As indicators of the extent and status of land use and wildlife habitat at the regional landscape level: *human development rate, linear density, distance to development, access network structure, intact areas or no-access designation zones, and landscape structure*.

- As indicators of the extent and status of human intrusion rates and intensities, and wildlife habitat and populations at the community-ecosystem level: *ecosystem networks, species diversity/abundance, access closures and restrictions, rate of illegal or non-compliant activity, and rate of motorized activity*.

- As indicators of the extent and status of human access and wildlife at the population-species level: *focal species, habitat effectiveness, core areas, and rate of human-caused wildlife mortality*.

Indicators can be applied at multiple levels of organization depending on the research or management question. In addition, not all of these indicators are applicable or relevant to each management plan area. Selection of ecological indicators for measuring the status and extent of access and access management should be specific to the question or management objectives to be answered in the monitoring process, meet criteria or selection frameworks, and include a complimentary set of indicators across multiple levels of biological organization.

Overall Significance of the Research to the Field of Study

While the individual indicators discussed in this paper are from a review and synthesis of the literature and management plans, I believe this is the first attempt to develop a list of ecological indicators at multiple levels of biological organization for use in measuring and monitoring access and access management. Because of the pilot nature of this effort, many of the suggested indicators require further calibration.

Measures of the status of access and the success of access management strategies are weak, making it difficult to determine whether or not land and resources are being managed in an ecologically sustainable way. Government resource management agencies should be expected to define, manage for, and evaluate the success with which an area manages access. This list of ecological indicators can provide a starting point for: 1) further characterizing access management, 2) measuring and monitoring the state of access, and 3) measuring and evaluating progress towards access management objectives and targets.

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