Analysis of Habitat Fragmentation and Ecosystem Connectivity within The Castle Parks, Alberta, Canada

by

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Abstract

Habitat fragmentation is an important subject of research needed by park management planners, particularly for conservation management. The Castle Parks, in southwest Alberta, Canada, exhibit extensive habitat fragmentation from recreational and resource use activities. Umbrella and keystone species within The Castle Parks include grizzly bears, wolverines, cougars, and elk which are important animals used for conservation agendas to help protect the matrix of the ecosystem. This study identified and analyzed the nature of habitat fragmentation within The Castle Parks for these species, and has identified geographic areas of habitat fragmentation concern. This was accomplished using remote sensing, ArcGIS, and statistical analyses, to develop models of fragmentation for ecosystem cover type and Digital Elevation Models of slope, which acted as proxies for species habitat suitability. Data indicated that the primary threat to the study species was increased habitat fragmentation caused by an increase in dirt roads and lightly-used trails. Identifying each species' habitat needs, alongside considerable fragmentation areas allowed for the development of recommendations to mitigate the negative effects of fragmentation, and thus better conserve the ecosystem in these provincial parks.

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Chapter 1 Introduction

1.1 Overview of Project

In southwest Alberta lies a small strip of land with significant biodiversity called The Castle Parks. This area is referred to by many names including The Castle Crown, The Castle Wilderness, The Castle Carbondale, and The Castle Region. In this document the term "The Castle Parks" will be used to describe this area. This region represents an important ecological area, as it includes four ecoregions, which are home to a variety of plant and animal species. A healthy ecosystem provides services to both humans and wildlife including fresh air, water, and various resources. Resource use in the area has become a threat to the wildlife and the services provided.

Despite many conservation efforts over the last century, The Castle Parks' biodiversity has never been fully protected, until 2015 when plans were made to convert this region into a Wildland and Provincial Park (Chaney 2015). Resource use and extraction have left the land fragmented (Leckie, 2002), from road construction, trail use, and industrial development, which is negatively affecting umbrella and keystone species (Arc Wildlife Services, 2004). To protect the new parks, the volume and type of land use changes that have occurred must be geospatially modeled in context within bioregions to understand the potential or actual threat they pose, and offer recommendations to minimize negative effects, while maximizing ecological function. With this new information, management plans may better protect and preserve the wildlife and resources in The Castle Parks.

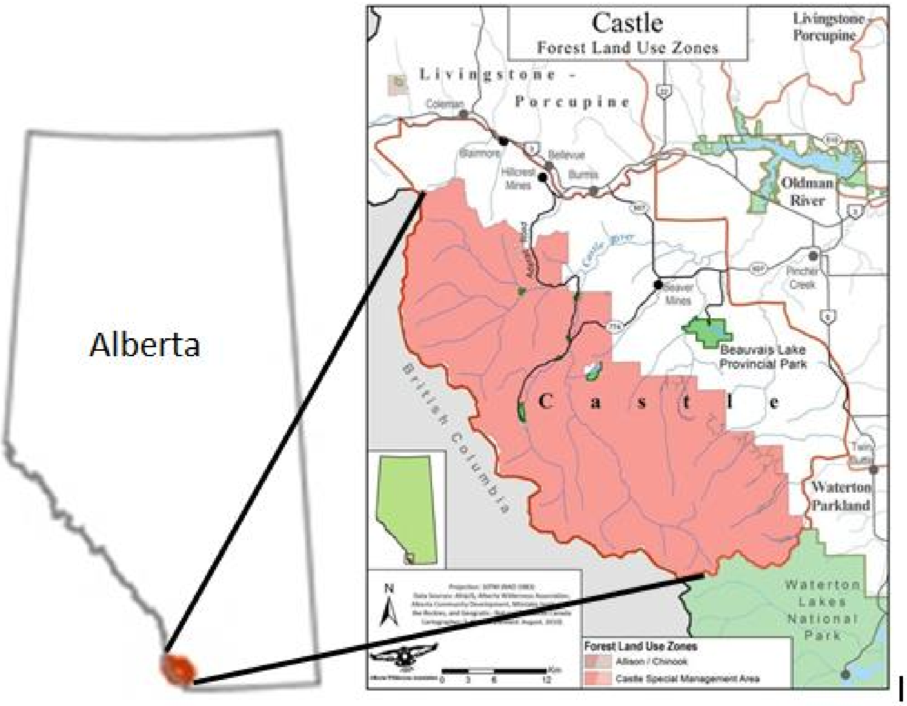
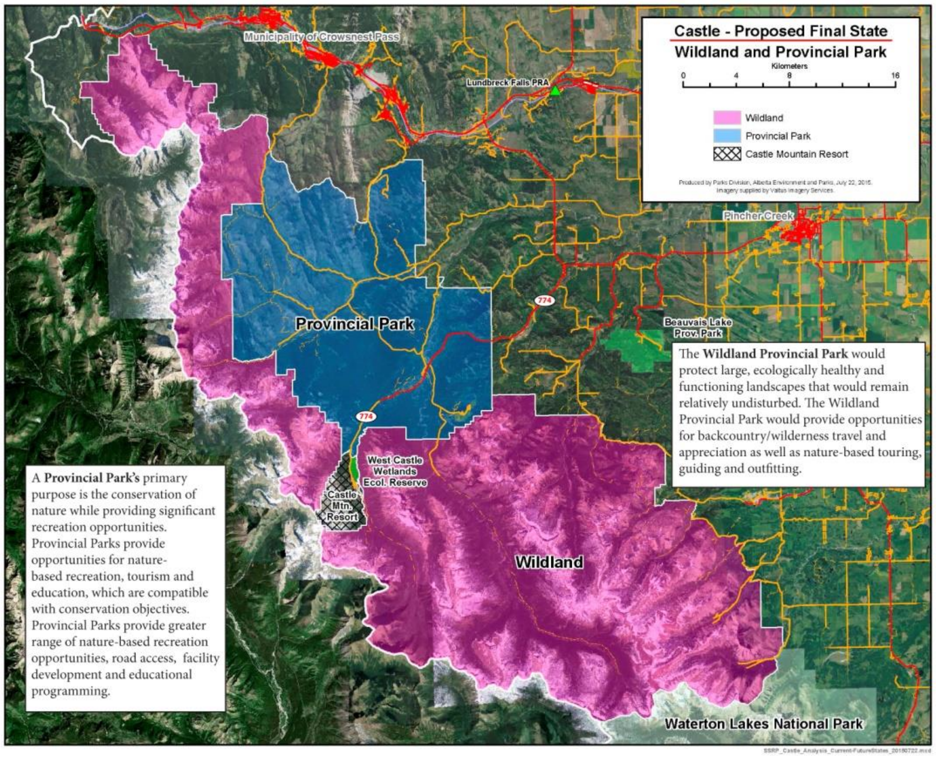


Figure 1.1 –The Castle Parks in Southwest Alberta (Castle Wilderness Coalition, 1985).

Chapter 2 Literature Review

2.1 Study Area

The Castle Parks are currently provincial public land, which lie on the eastern border of British Columbia and the northern border of Waterton Lakes National Park (Figure 1.1) (Kershaw, 2008). The Alberta Government is establishing this land as a proposed protected Provincial and Wildland Park (Figure 2.1), which will encompass an area of approximately 1040km^2. The parks' location, southwest of Pincher Creek municipality, will protect the headwaters of the Oldman River Basin (Pachal, 2006), offering downstream benefits to ecology, industry, and society.



The **Wildland Provincial Park** would protect large, ecologically healthy and functioning landscapes that would remain relatively undisturbed. The Wildland Provincial Park would provide opportunities for backcountry/wilderness travel and appreciation as well as nature-based touring, guiding and outfitting.

A **Provincial Park's** primary purpose is the conservation of nature while providing significant recreation opportunities. Provincial Parks provide opportunities for nature-based recreation, tourism and education, which are compatible with conservation objectives. Provincial Parks provide greater range of nature-based recreation opportunities, road access, facility development and educational programming.

Figure 2.1 The Castle Parks' Proposed Provincial and Wildlands Park. Provincial Park indicated in blue and Wildland Park indicated in purple (Castle-Crown Wilderness Coalition, Produced by Park Division, Alberta Environment and Parks, 2015).

2.1.1 Climate

The regional climate, with short summers followed by long, snowy winters, allowed for high biodiversity. Two influencing air masses in the region are the Pacific Maritime and the Arctic Continental which, when they collide, bring precipitation. There is variability in precipitation, where the further from the Continental Divide, the less precipitation (Kershaw, 2008). Average summer temperatures for Crowsnest Pass, just north of The Castle Parks, range from 11 to 16 degrees Celsius and winter temperatures average between -4 to 0 degrees Celsius, with 102 cm of average annual precipitation (Farmzone, 2016; Kershaw, 2008). Winter snow accumulates on mountaintops which melts during the spring and summer, and supplies rivers with water (Anderson, 2014). Wind plays an important part of the climate in The Castle

Parks as wind blows from both the west and southwest, having a significant desiccation effect on the environment (Kershaw, 2008) and winter Chinook winds bring warm air through the region, removing the snow cover to expose plants (Arc Wildlife Services, 2004).

2.1.2 Geology

The Castle Parks' topography includes hills, mountains, and steep cliffs, having elevations between 1220 to 2755 m above sea level (Arc Wildlife Services, 2004). According to the Atlas of the Western Canada Sedimentary Basin (1994), The Castle Parks is composed of three different rock ages (Figure 2.2). To the west, exposed rocks are from the middle Proterozoic eon (dating 542 to 2500 million years ago (mya). The Midwest region consists of Paleozoic rocks (252 to 542 mya) and to the east, Mesozoic (66 to 252 mya) (Mossop and Shetsen, 1994).

During the Cretaceous Period, collision between the North American Pacific Plates uplifted western Canada and formed the Southern Canadian Rockies. Throughout the Quaternary, glaciers morphed Alberta's Rockies into their current form (Timoney, 1998) as alpine ice carved the park areas' west and south valleys (Kershaw, 2008), and transported sediment into valleys and adjacent plains. As the glaciers retreated, meltwater transported alpine material, including rich montane tills, to the foothill area (Ehlers and Gibbard, 2004) which created a complex topography, which contribute to the regions high biodiversity.

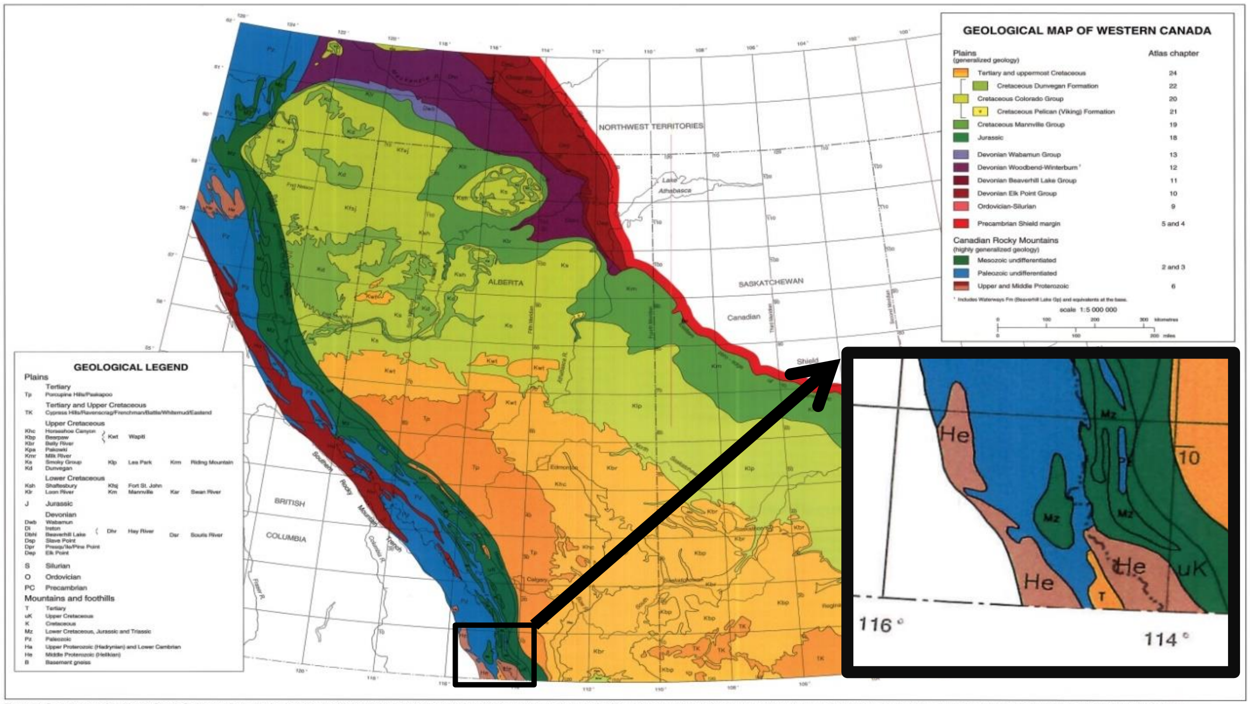


Figure 1.1 Geological map of the Western Canada Sedimentary Basin, showing the regionally and stratigraphically generalized distribution of Phanerozoic rocks in the Interior Plains (commonly mantled by Quaternary cover) and the schematic distribution of major Proterozoic and Phanerozoic tectonic wedges in the Canadian Rocky Mountains.

Figure 2.2 Geological map of western Canada Castle Region showing areas of Paleozoic (Blue), Middle Proterozoic (Beige) and Mesozoic (Dark Green) rock (Atlas of Western Canada Sedimentary Basin, Mossop, 1994).

2.1.3 Historic Land Use: First Nations People

The first nation to call The Castle Parks area home was the Kutenai and Piikani people, known today commonly as the Peigan. They referred to this area as “A’sanni” which means sacred paint (Leckie, 2002) for when they practiced spiritual ceremonies they would seek out a special paint, found within The Castle (Kershaw, 2008). For more than 10,000 years the Peigan have relied on the land for resources and managed it as a sacred place. They used the resources in the region for hunting, gathering, fishing, and ceremonies (Leckie, 2002).

The Kainai First Nation, commonly referred to as the Blood Nation, also called The Castle Parks area their home. Together with the Peigan they became part of the Blackfoot Confederacy (Colpitts, 2015). During the 18th century the Blackfoot controlled half of Alberta, including The Castle Parks. During this time, they traded with other native groups and restricted outsider travel into the region. The Piikani’s isolated, mountainous location and resistance to intruders made them one of the last groups of Blackfoot Indians to regularly trade with Europeans. In the mid-1800s, trading continued, drawing Europeans closer to The Castle Parks region (Kershaw, 2008), initiating resource extraction and fragmentation.

2.1.4 Historic Land Use: European Occupation of Western North America

In 1801, Blackfoot chief, Ac ko Mok ki, drew a map in the dirt for Peter Fidler, a Welsh surveyor. The map portrayed a land area of 320,000 km^2, which included the Yellowstone River and Missouri River junction west to the Pacific Ocean. The map encouraged the British and American governments to stake claims to what is now the northern United States and western Canada (Kershaw, 2008). In 1858, Thomas Blakiston, a British government surveyor, became the first known European to travel into The Castle Parks region, naming a local peak Castle Mountain. The region and river would later take on the name of Castle. During this expedition Blakiston mapped the territory and took magnetic readings. His findings were sent to the United Kingdom's Royal Geographic Society and were used to illustrate potential agricultural land and resources available in Southern Alberta, such as lumber and minerals (Leckie, 2002). Encouraged by the potential the region held, the British Government initiated the Dominion Lands Act in 1872. The Act gifted land to anyone who settled in Saskatchewan, Manitoba, and Alberta, encouraging hundreds of thousands of people to relocate to Alberta (Rollings-Magnusson, 2014). By this time, the Blackfoot Indians offered little resistance to European settlement, having suffered a smallpox epidemic that reduced their numbers. With the arrival of European settlement, bison populations, which the Indians depended on, began to diminish in appreciable numbers, further compromising the Blackfoot society (Kershaw, 2008).

As time passed, disputes over territory increased between the Europeans and Blackfoot, causing the British government to establish Treaty Seven, in September 1877. The treaty gave land to the British while starting to provide aid to the Blackfoot Indians in the form of money, supplies, guns for hunting, and a reserve on which to live. The Blackfoot Indians were divided into their original tribes and given separate reserves, outside of The Castle. Europeans took control of The Castle region and its resources and the Indians were no longer permitted to access the area, for which they had come to depend on for their livelihood and independence (Kershaw, 2008).

Throughout the 20th century, Europeans continued to settle in western Canada. Many immigrants discovered that arid conditions on the prairie were not suitable for farming and turned to cattle ranching in the foothills and lower-mountain slopes. Ranching became profitable and allowed the introduction of the railroad. The railway also brought more eager settlers, most of whom received land through the Dominion Lands Act. As time passed, settlers received land increasingly farther from town and the number of settlers with diverse skills increased, such as miners, developers, farmers, and hunters, some of whom would seek opportunity in The Castle region and surrounding mountains (Kershaw, 2008).

2.1.5 Contemporary Land Use History

The Castle Parks region has been used for a variety of land uses throughout the last century, with recreation being a substantial use of land. The region has offered both high and low environmental impact recreational activities across its landscapes. Some low impact activities include hiking, cross-country skiing, hunting, horseback riding, and fishing. Higher impact recreation includes mountain biking, snowmobiling, use of off-highway vehicles (OHV), downhill skiing, and intensive festivals such as the Annual Castle Mountain Huckleberry Festival (Leckie, 2002). The proposed 2015 protection plan for the new parks will continue to provide many recreational activities to its residents and visitors, although some activities may be modified to better protect the environment (Pachal, 2006).

The Castle Mountain Resort, the area's only ski hill, has been operational since 1965. Throughout the 1990s, the skiing area was quadrupled and in 2006, Mount Haig was added to the resort, further expanding its footprint. This provided an opportunity for intermediate skiers, as well as professionals and advanced skiers, to enjoy the resort. The resort also hosts many other events such as bridal exhibitions, sport festivals, and live music during non-peak season, and the Huckleberry Festival each year, which draws in hundreds of people (Castle Mountain Resort, 2016a; Labbe, 2012).

Other high impact activities in The Castle Parks include petroleum extraction, which began in 1957 with the drilling of natural gas wells, and logging beginning in the 1800s. Drilling has culminated into more than fifty established wells throughout the area, while logging is estimated to have clear-cut fifteen percent of the area's total forests and has reduced the remaining old growth to less than ten percent of remaining forests (Leckie, 2002). Both logging and petroleum extraction fragments the landscape, which displaces wildlife and allows recreational users greater access to isolated wilderness areas. Promoters of sustainable forests suggest that at least twenty-five percent of forested areas should be composed of old growths trees, particularly as certain species, such as elk, rely on old growth forests for cover (Leckie, 2002). In 2010, the Canadian government established a C5 Forest Management Plan, which includes The Castle Parks, (Figure 2.3) after recognizing the negative effects produced from logging and the need for forest conservation in the area. A forest management plan aids in sustainable management by identifying a specific area's harvest and reforestation needs. The management plan states that trees will be harvested in small clusters of approximately 6.5 hectares in size. This strategy allows a forest structure where a small amount of trees will be left uncut in each section. To help promote forest re-growth, logging companies are required to replant areas within two years of harvest (Alberta Government, 2016).

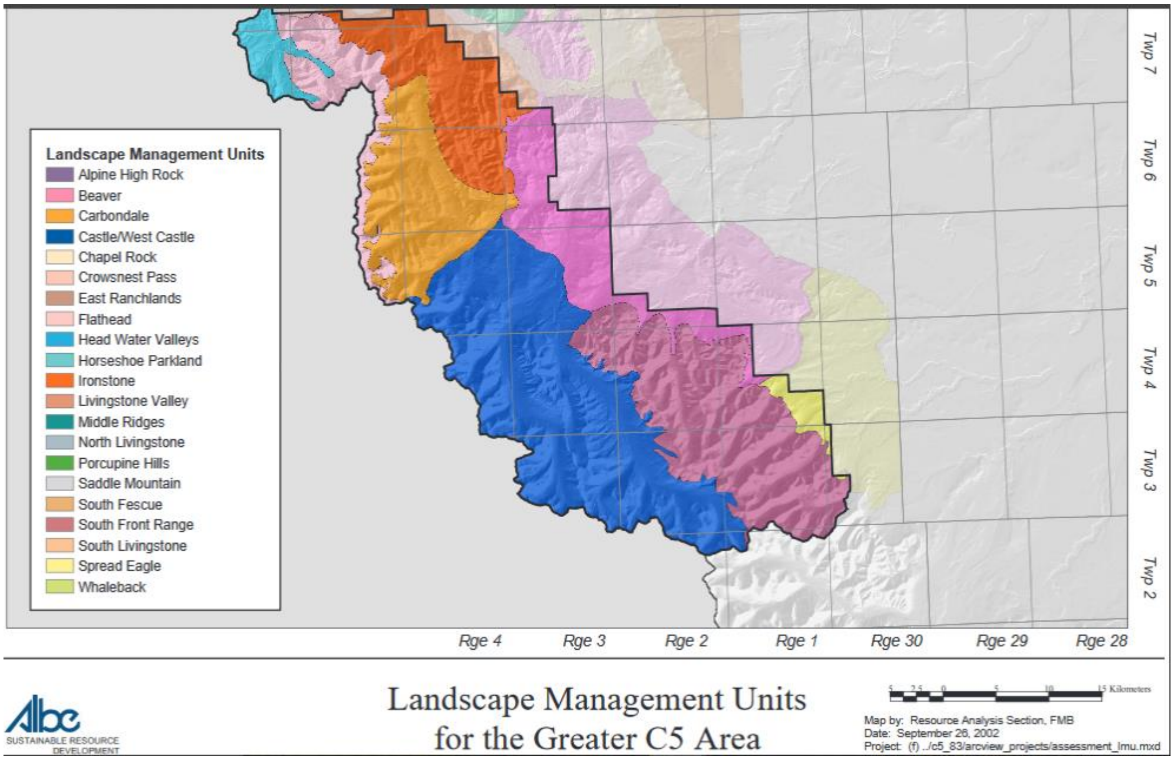


Figure 2.3 Part of Alberta's C5 Forest Management Plan Area, where dark blue represents The Castle Parks region. Scale bar is 20km (Alberta Agriculture and Forestry, Map of Landscape Management Units, 2010).

2.1.6 Political History of The Castle Parks Region

Over the last 150 years The Castle Parks region has changed mandates on land use, yet has never fully been protected. In 1908, The Castle Parks area was included in the revised Dominion Lands Act, which made it part of the Rocky Mountain Forest Reserve. The Canadian government established Waterton Forest Park in 1911, later renamed Waterton Lakes National Park (Kershaw, 2008). The government expanded this Waterton Lakes National Park in 1914 to include the Rocky Mountain Forest Reserve (Kershaw, 2008). However, only seven years later, in 1921 the region was cut off from the park so that it could become a game preserve for Alberta's provincial government (Chaney, 2015). In 1954, the status of game preserve was revoked, allowing hunting within the region. In 1986, The Castle River Sub-Regional Integrated Resource Plan began to manage The Castle Parks region (Leckie, 2002). It should be noted that in 1932, Waterton Lakes National Park, together with Glacier National Park, make up the world's first International Peace Park and UNESCO World Heritage Site (UNESCO, 1995). This designation makes protecting The Castle Parks even more critical, as the Heritage site will directly benefit from The Castle's preservation, by helping to conserve species that may utilize both park systems.

Throughout The Castle's history, many different groups have recognized the ecological importance of the region and have lobbied for its protection. In 1968, residents, along with the Pincher Creek Fish and Game Association, saw the need for protection of The Castle Parks region and requested the provincial government protect the land. The Alberta Wilderness Association, a society dedicated to conservation, requested legislative protection in 1973, and in an additional recommendation in 1974, from Alberta's Recreation, Parks and Wildlife, suggested the area be reclassified to a Provincial park. Despite these efforts, protection from resource use had not been established in the area (Leckie, 2002).

The Castle-Crown Wilderness Coalition was formed in 1989 by a group of local Southern Alberta citizens. They recognized the ecological value of The Castle Parks region, understanding that it is important grizzly bear habitat, encompasses the headwater for the Oldman River Basin, and contains historic Blackfoot cultural sites. Their main goal was to restore and maintain environmental protection for this area (CCWA, 2016a). In 1996, the group submitted a document titled, "Proposal to Protect The Castle Wilderness" to the Alberta Government. The government approved the plan which regulated off-road vehicles, yet enforcement has been minimal (Leckie, 2002).

In 1997, The Castle Parks region was considered for Alberta's Special Places 2000 Program. This program was designed to protect biodiversity in different ecoregions throughout Alberta. A committee suggested the region become a special management area which would be used for commercial and recreational activities, with no real environmental protection (Fluker, 2015). A 2009 report titled, "Castle Special Place, Conceptual Proposal for Legislated Protected Areas" was created to request protection of the land. This proposal was created by The Castle Special Place Working Group, which included citizens and organizations across Alberta. The proposal recommended the region be converted into a Wildland and Provincial Park (CCWA, 2016a).

After years of conservation debate, on September 4, 2015, the newly elected New Democratic Party (NDP) at the provincial level announced the plan to protect The Castle Parks region by creating Provincial and Wildland parks (CCWC, 2016c). The New Democratic Party ran on a platform which supported protection of the area, for they saw the importance of the region to the community and that biodiversity needed protection (Lambert, 2016). About sixty percent of The Castle Parks will be designated as a Wildland Park dedicated to back-country experiences, and remain an undeveloped area. The remaining land will become a Provincial Park for front-country experiences, a more accessible and developed area (Chaney, 2015). Canadian Wildland Parks provide hiking and camping in undeveloped regions and trails for OHVs, mountain climbing, and wildlife viewing. Canadian Provincial Parks support a variety of outdoor recreation in more developed lands, as well as facilities for recreation and education (Pachal, 2006).

2.1.7 Castle Parks Management Plan

The Castle Management Plan was drafted in January 2017 by the Alberta government, with aims to protect The Castle Parks area by creating both a Provincial and Wildland Park which will value conservation practices, Indigenous rights, and recreational experiences. The conservation values proposed in the document address local biodiversity, protection of headwaters, ecological health, and habitat needs for grizzly bears, wolverine, and westslope cutthroat trout. Protection of water resources in the area, including headwaters of the Oldman basin, aid in creating healthy habitats and clean water needed for both humans and animals. The Castle Parks are further identified as a corridor linking Waterton National Park, The Flathead River basin, and Crowsnest Pass. Successful management of this corridor will allow animals to move freely between areas and extend their ranges (Alberta Government, 2017).

With the addition of both Castle Provincial Park (255.01km^2) and Castle Wildland Provincial Park (796.78km^2), there will be a total of 1051.79km^2 of newly protected land. The Provincial Park will offer services, such as visitor support and educational programs. Priorities will consist of front-country experiences in nature, including camping, hiking, boating, skiing, and fishing. The Wildland Provincial Park will provide managed access into the park. Priorities will include access to low-impact backcountry experiences, such as hiking trails developed around the Alberta Government's conservation standards (Alberta Government, 2017).

2.1.8 Climate Change

The Alberta Government discusses climate change in the Castle Management Plan draft, because climate change directly affects the species and ecosystem structure within The Castle Parks. To address climate change the government plans to protect ecosystem services, protect current habitats which will act as future refugia, and aid in increasing resiliency of the ecosystem. The Castle Parks will have management practices based on province-wide climate change strategies. These strategies include reducing environmental impacts by using sustainable practices within the park, incorporating green building, being energy efficient where practical, and minimizing vehicle traffic. The Castle Parks will also incorporate climate change modeling into management decisions by maintaining connectivity of habitats to allow species to move to new regions as climate changes (Alberta Government, 2017).

2.2 Ecological Review

The Castle Parks is the second most biologically diverse area in Alberta. With more than 200 rare or at-risk species, protection of The Castle Parks is vital (CCWC, 2016b). Ecosystems in this region include alpine meadows, grassy slopes, and forests. The biodiversity here is critical, as it is located in such a small geographic area. An estimated 824 plant species grow within the region (Arc Wildlife Services, 2004), of which 120 are provincially rare and 38 are nationally rare (Leckie, 2002). The richness of vegetation in southwest Alberta is important to ecosystem stability. Some plants and animals, such as the Canadian Lynx, are reported to live only within patches of old growth forest. These forests contain rich soils, fallen logs, and a range of plants that support a diversity of species (Leckie, 2002). The Castle Parks contain over half of the vascular plant species found in Alberta while occupying only 0.16% of the province's landmass. This area is home to 59 species of mammals including ungulates such as elk, moose, and bighorn sheep and small fauna such as the wandering shrew and red-tailed chipmunk. Nesting habitats are a home for 105 bird species, including the bald eagle. Currently, little is known about the full array of insects found in the region, apart from The Castle River having a variety of butterfly species, found nowhere else in Alberta (Leckie, 2002). There are a variety of reptiles and amphibians including garter snakes, long-toed salamanders, and western toads, many of which are considered at-risk. The Castle Parks contains 34 lakes and 26 streams supporting a variety of trout, such as the bull trout and native cutthroat trout (Pachal, 2006; Kershaw, 2008; Leckie, 2002).

2.2.1 Ecoregions

There are four dominant ecoregions in The Castle Parks, each with their own structure and function, producing unique ecological compositions. Each ecoregion differs in precipitation, temperature, topography, vegetation, and wildlife, although there are overlaps in characteristics between them. The Castle Parks is one of few areas in Alberta containing four out of the five different ecoregions found within the province (Kershaw, 2008).

The lowest elevation ecoregion is the foothills; located at elevations between 1250 and 1500m, which receives 500-650 mm of annual precipitation. This area has nutrient-poor soil, resulting in the foothills being used widely for ranching. This region is characterized by rough fescue (*Festuca scabrella*), trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*). The fescue lives through the winter, providing important forage for ungulates. The aspen understory includes flowers and bushes, such as glacier lilies (*Erythronium grandiflorum*) (Kershaw, 2008).

The next ecoregion increasing in elevation is the montane, which consists of forests and grasslands. It is located between 1000-1900m overlapping some of the foothills areas. There is no defined rainfall range for the montane in this area, however Bellevue, a town within the montane region, recorded a total of 375 mm of precipitation in 2016 (world weather online, 2016). Although a small area, the montane contains the greatest amount of biodiversity. Characteristic species include Douglas fir (*Pseudotsuga menziesii*), limber pine (*Pinus flexilis*), subalpine fir(*Abies lasiocarpa*), Engelmann spruce (*Picea engelmanni*), and rough fescue (Kershaw, 2008).

Above the montane is the subalpine, covering over thirty percent of The Castle Parks and is the prevailing ecoregion in the Rocky Mountain Cordillera. The subalpine ranges between 1650-2250 m in elevation and has the highest precipitation (460– 1400 mm). The lower alpine ranges from 1650-1950 m in elevation and includes Engelmann spruce and subalpine fir forests. Trees here hold and accumulate snow throughout the winter. Moisture held in the region allows for growth of mosses and mushrooms. The additional precipitation enhances wildflower forb growth and supports downstream ecosystems, farming, and urban life. Some vegetation species do not occur north of The Castle Parks, which include beargrass (*Xerophyllum tenax*), thimbleberry (*Rubus parviforus*), and mountain boxwood (*Buxus x*). The upper alpine elevation ranges from 1950-2250 m and contains fewer trees, with species including whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*) (Kershaw, 2008).

The last ecoregion found in The Castle Parks is the alpine. This ecoregion located above 2250 m, is above the treeline. Between May and September the average temperature is six degrees Celsius, which makes it the coldest ecoregion. This rocky area has little soil and an annual precipitation of 420 to 850 mm. Plants found in the alpine include bluebells (*hyacinthoides non-scripta*), black alpine sedge (*Carex nigricans*) and beargrass (Kershaw, 2008).

2.2.2 Structure and Function

The region's overall ecological structure can be defined by alpine, subalpine, montane, and foothill plant communities. The structure of the ecosystem, which changes over time, provides functions for humans and wildlife to utilize. Functions may include, but are not limited to, travel by animals between each subsystem, water movement, and hazards such as fire and avalanches. The ecosystem provides services to both wildlife and humans including clean water, nutrients, and energy. These allow plants and animals to grow thus, providing resources such as medicine, timber for building, and food (Forman, 1995).

Generally, structure consists of energy, material, and species. Energy and material are represented by biomass, which is separated into producers, herbivores, predators (omnivores and carnivores), top predators (carnivores), and decomposers. This distribution is represented by a pyramid, where mass decreases from the bottom producers to the top predators. Species may be represented in a vertical or horizontal distribution. A vertical stratification describes the spatial arrangement of species in a vertical facet, above soil, in the soil, or in water. A horizontal distribution of species is described as an environmental gradient that changes across landscape (Forman, 1995).

Fragmentation, the breakup of land into smaller pieces, plays a major role in disrupting structure and function, as fragmentation of the landscape inhibits or stops energy and matter from moving through historic pathways. Fragmentation could be natural, as caused by a landslide, or human induced in the form of roads or agricultural land use. The outcome of fragmentation is the breakup of land into smaller, primarily homogeneous patches. The various types of fragmentation include, dissection which subdivides landscapes with equal-width features, such as roads, perforation which creates holes in a landscape, shrinkage which decreases the overall size of a landscape, and attrition which is the disappearance of sections of the landscape, such as patches. Each of these features increase habitat loss and isolation (Forman, 1995).

Patches may be detrimental to the surrounding ecosystem. A study conducted in the upper Midwest, compared an undisturbed old-growth forest to a nearby harvested forest. The harvested forest had smaller patches of old growth trees scattered throughout, which caused a loss in associated vegetation (Turner et al., 2001). Fragmentation also creates edges when a border separates two landscapes. This creates an “edge effect” where the habitat edges often contain high population density, but tends to eliminate species that require core forest or habitat away from edges (Forman, 1995).

Connectivity is an important element between ecosystems. Connectivity refers to how connected the patches are within the landscape. The more disturbance patches in a landscape, the lower the connectivity will be between similar patches of isolated ecosystems. Connectivity is a reflection of energy pathways (Forman, 1995). The Yellowstone to Yukon Conservation Initiative (Y2Y) has created plans to reconnect wildlife corridors to ensure wildlife movement, conserve biodiversity, and thus increase connectivity (Blatter and Ingram, 2001). This initiative aims to protect land and water resources, stretching 3200 km from Yellowstone National Park to northern Canada, along the Rocky Mountain Corridor (Figure 2.4) (Yellowstone to Yukon Conservation Initiative, n.d.). The southern reaches of this area are highly fragmented by human land use and connectivity needs restoration. For this project to be a success, communication and mutual agreements need to exist between multiple groups and organizations, ranging from small local groups to national parks (Blatter and Ingram, 2001). The Castle Parks is central to this initiative because of the important wildlife corridor it offers within the southern portion cordillera. However, the region's fragmentation is of concern as it disrupts connectivity. Reconstruction of the regions' ecological structure needs to be established to allow for the flow of energy and matter along the corridor.

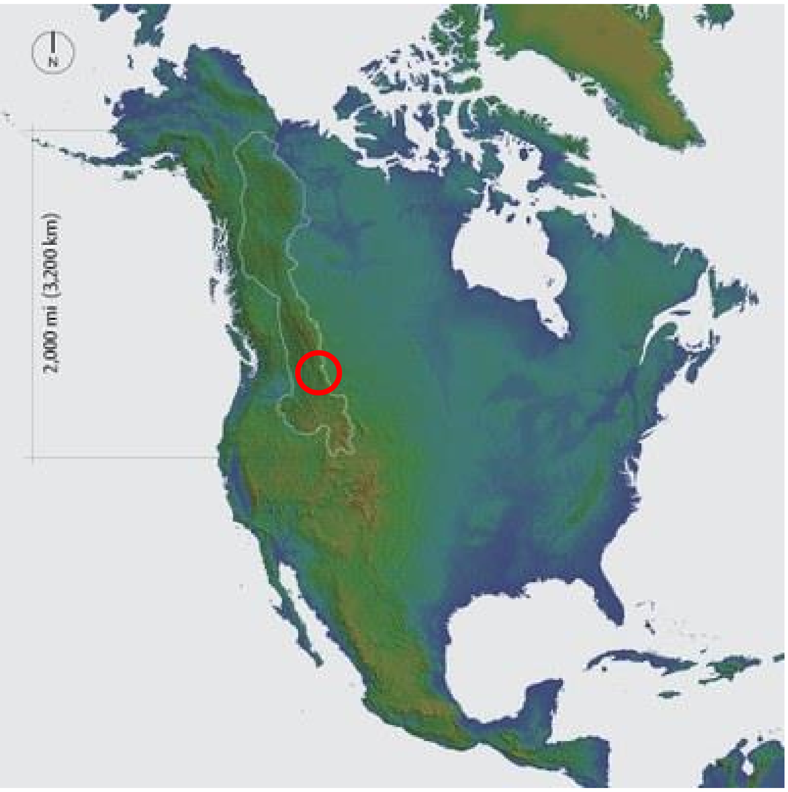


Figure 2.4 Map of North America showing the region of Yellowstone to Yukon Conservation Plan. The Castle Parks region is circled in red. (Yellowstone to Yukon Conservation Initiative, n.d.)

2.2.3 Species Ecology

An ecological investigation of the complex ecosystem structures is beyond the scope of this study. However, umbrella and keystone species are commonly used in wildlife conservation plans to estimate ecosystem health, and will be used as a proxy for ecosystem structure health and needs. Umbrella species are typically large animals with geographically extensive home ranges, such as grizzly bears, which range through multiple ecoregions in an area up to 3000 km^2 (Roberge and Angelstam, 2002). The overall health of umbrella species in an area indicates the general health of other species in the same ecosystem (Turner, Gardner and O'Neil, 2001). By conserving a large region used by umbrella species, the habitat of species requiring smaller size areas are also conserved. As a single umbrella species may not use the whole ecosystem, multiple focal species should be considered. It is suggested that focal species should represent limited areas, limited resources, and limited dispersal. By selecting focal species that are amongst the most sensitive in the ecosystem, their requirements can be used to guide conservation management strategies that will also cover animals who are less environmental sensitive (Roberge and Angelstam, 2002).

Keystone species can be plants or animals, typically at the top of the food chain, that help regulate the ecosystem (Forman, 1995). If they are removed, the ecosystem will change substantially through a cascading effect. With the top predators removed, the preceding organisms in the food chain are affected either by overpopulation, displacement, or extirpation/extinction (Arc Wildlife Services Ltd., 2004). For instance, in 1927, wolves were absent from Yellowstone National Park causing an increase in elk population. The increased elk population was free to consume aspen, and thus significantly decreased the abundance of aspen, reducing the songbirds (Fortin et al., 2005). By studying both keystone and umbrella species in The Castle Parks, the ecosystem requirements for a wide range of species can be established (Arc Wildlife Services Ltd., 2004). Although elk are not an umbrella or keystone species, they will be included in this study because they directly affect the keystone and umbrella species. Table 2-1 summarizes the needs of the study species.

2.2.4 Grizzly Bear

Grizzly bears are an umbrella species in The Castle Parks. Grizzlies were abundant until the 1950s when industrialization reduced local grizzly habitat by 75 percent (Leckie, 2002). Land in The Castle Parks is essential for grizzly bear survival, as it is used as a corridor between Glacier National Park in Montana, Kananaskis, and Banff National Park (Leckie, 2002). Even with dwindling numbers, this region has some of the largest populations of non-coastal grizzly bears in North America. However, the existing area is considered insufficient to sustain grizzly populations without connectivity to neighboring parks (Kershaw, 2008). Although the exact number of grizzly bears currently in The Castle Parks is unknown, a 2007 study used scent lures to obtain grizzly bear hairs in order to analyze DNA. This study identified 27 bears in the region and estimated a population of 51 bears (Festa-Bianchet, 2010).

Grizzly bears residing in The Castle Parks require large home ranges of 200-3000km^2 (Leckie, 2002). Their habitat includes meadows, avalanche slopes, and riparian areas. Meadows may be used in the spring and fall when grizzlies dig hedysarum *(sweetvetch),* avalanche slopes are used in the spring, when grizzlies are looking for food sources, such as glacier lilies, and riparian sites are utilized in the spring and fall. In the summer and fall, grizzlies look for berries in low density canopy areas, which may include avalanche slopes, riparian sites, fire-successional communities, clear-cut logged areas, and open forests (Munro, et. al. 2006; McLellan and Hovey, 2001; Arc Wildlife Services, 2004). Across seasons, bears use forest areas for bedding (Munro, et. al. 2006). Typically, due to breeding activities, males require larger home ranges than females, with males typically traveling 1000-2000km^2 and females traveling 200-500km^2 (Parks

Canada, 2014). In their ranges, grizzlies prefer low and mid-elevation sites, although they do access higher elevations when lower elevations are not available because of human development. At lower elevation, shrub sites are well used throughout the year (Arc Wildlife Services, 2004). High elevations are also utilized to consume food sources such as army cutworm moths (French, French, and Knight, 1994). Their ideal habitat is away from humans with access to a food, shelter, dens, and mates (Parks Canada, 2014).

Being omnivores, grizzlies rely on vegetation, carrion, and prey for their diet (Arc Wildlife Services, 2004). The availability of vegetation is important as it accounts for approximately 85% of their diet. Grizzly bears selectively eat different plants throughout the seasons, traveling great distances to access them. When bears come out of hibernation, March through May, they need nutrition and their diet consists of roots, bulbs, and carrion. In the spring grizzlies eat in the valleys and move to higher elevations as the snow melts. In the summer, berries such as, blueberries, huckleberries, and buffaloberries become an important food source. When the annual berry crops fail, bears spend significant energy forging which causes stress, making them more likely to seek out food in human-occupied areas, such as garbage. During the fall, bears begin to store fat for hibernation and may eat for over 20 hours a day. If females do not store enough fat while pregnant, they may produce fewer or smaller cubs (Parks Canada, 2014).

Grizzly bears have one of the lowest reproductive rates of North American mammals (Parks Canada, 2014). Female grizzlies begin reproducing at age four and can remain fertile into their twenties (Arc Wildlife Services, 2004). A typical female only reproduces every three to five years (Parks Canada, 2014). Cubs often stay close to their mothers, having a shorter dispersal distance than other large carnivores (Arc Wildlife Services, 2004). Because cubs cannot travel as far as their mother, a safe habitat with an adequate food supply must be available for a mother to raise her cubs (Parks Canada, 2014).

2.2.5 Wolverine

Considered one of the rarest carnivores in Alberta, and an umbrella species, is the wolverine. Wolverines prefer to live in remote, old growth/mature forests, with medium canopy cover. Consequently, a well-suited habitat includes dispersed timber and areas to form dens, such as ravines, snow-covered fallen trees, and rocky peat bogs (Arc Wildlife Services, 2004). Home ranges average 400 km^2 for females and 1400 km^2 for males (LoFroth, 2001). Ranges typically include higher elevations (alpine) during the summer and lower elevations (the montane) during the winter (Carroll, Paquet, and Noss, 1999). The use of higher elevations in the summer may be due to rodent availability and the use of lower elevations in the winter may be a function of carrion availability and avoidance of heat (Arc Wildlife Services, 2004).

Wolverines require undisturbed habitat to survive and try to avoid humans. Off-road vehicles and snowmobiles are particularly significant threats to the wolverine, as they bring people into secluded wilderness areas (Leckie, 2002). Although rarely seen in The Castle Parks, wolverines have been sighted in Glacier National Park (Montana), Waterton National Park, as well as areas north of The Castle Parks, suggesting this region is used as a corridor. The exact number of wolverines in this area is unknown. However, a four-month study, conducted in 2013-2014, which utilized wildlife cameras and non-invasive DNA sampling, determined the area contained 20 individuals (Clevenger, 2014).

Wolverines are typically solitary, except when mating and caring for young. Mating normally occurs between May and August, when females are at least two years of age. Females give birth to kits, which they nurture for a seven to eight week period (Arc Wildlife Services, 2004). During this time it is crucial to have available resources for mothers to care for their young, which includes canopy coverage.

2.2.6 Cougars

Documented cougar sightings near The Castle Parks have occurred in Pincher Creek and Crowsnest Pass between 1999 and 2011 (Urmson and Morehouse, n.d.). Little is known about the current number of cougars living in the region, although 170 total cougars were estimated to be in the province's National Parks, Provincial Parks, and Wilderness Areas (Alberta Government, 2012). Fifty to 100 cougar sightings were reported in the front range south of Calgary, Alberta to the international border (Morehouse and Boyce, 2017).

Since 2008, the number of human-cougar conflicts has increased through human expansion and cougars being drawn into residential areas that have livestock and household pets. They are also attracted by dead stock disposal areas, where many ranchers leave dead livestock on their property. These attractants may be a function of compromised habitat at higher elevations. Most conflicts result in the cougar being killed by legal hunting or defending of property (Urmson and Morehouse, n.d.).

Cougars are carnivores, which stalk and hunt prey such as deer, elk, and sheep (Alberta Government, 2012). As a predator, cougars act as a keystone species, partially controlling the prey populations within their ranges (Kunkel et al., 2012). Female cougars have home ranges from 30-300km^2, whereas males have home ranges of 100 – 1000km^2 (Ross and Jalkotzy, 1992). Cougars thrive in mountain and forest ecosystems that provide cover, and avoid open landscapes. Adequate cover is important for both hunting and kitten security. Vegetation is an important aspect of cougar habitat, as it is used for hunting, to stalk and find prey. Edges are especially important, as prey often reside at forest edges, where a forest cover meets an open land cover. Cougars avoid large areas of forests that do not provide edges. A cougar also requires a habitat with limited human disturbance and will avoid areas with roads, buildings, and wellheads (Alberta Government, 2012). The addition of fragmented and developed regions in The Castle Parks makes it difficult for cougars to avoid humans and find premium forested mountain regions.

Female cougars give birth at approximately 20 months of age to litters of two or three kittens. These kittens are born at nursery sites, which contain heavy tree cover, vegetation, and/or rocks. When first born, kittens cannot hear or see and must rely on their mother for food until eight weeks, when they learn to hunt with their mother (Alberta Government, 2012). It is important that The Castle Parks have adequate resources for hunting, nursery sites, and ultimate survival of cougars.

2.2.7 Elk

The Castle Parks are home to a variety of ungulates, including elk. Although elk are not umbrella or keystone species, they are included in evaluation of ecosystem quality because grizzly bears, wolverines, and cougars rely on them as prey. Thus, the umbrella and keystone species are directly connected to the elk population (Proulx, 2003). Elk once lived in front range canyons, but abandoned these areas after road and development construction. The elk population in The Castle Parks has been in decline since the 1950s. Once estimated at 3,000 individuals, elk numbers have declined to about 1,000 in The Castle Parks region. Together, construction and hunting have caused elk to relocate to secluded areas within The Castle (Leckie, 2002).

Elk are herbivores whose diet consists of various plants. They are found in forested habitats in the montane and foothills, where site occupation is chosen based on available seasonal vegetation. As a result, they spend their summer at higher elevations between meadows and forested slopes, and in the winter they migrate to mature forests at lower elevations, with a winter home range measuring about 60 to 70 square kilometers. High cover areas are used for bedding sites, while low cover areas are used for foraging. Elk begin breeding around age two, normally giving birth to a single calf annually. Female elk need optimal forging conditions to breed successfully. When there is an inadequate food supply, females will not breed, but instead recuperate from the demands of birthing and raising calves from the previous season (Arc Wildlife Services, 2004).

Summary of Keystone and Umbrella Species Within The Castle Parks

Table 2-1 Overview of Umbrella and Keystone Species

Animal	**Umbrella/ Keystone**	**Home Range (sq km)**	**Habitat**	**Diet**	**Status**
Grizzly Bear	Umbrella (Leckie, 2002)	200-3000 (Leckie, 2002)	Meadows, avalanche slopes, riparian sites (Arc Wildlife Services, 2004)	Omnivores: vegetation, carrion and prey (Arc Wildlife Services, 2004)	Threatened (Alberta Government, 2014)
Wolverine	Umbrella (Leckie, 2002)	400-1400 (LoFroth, 2001)	Old growth forests (Arc Wildlife Services, 2004)	Carnivores: carrion and prey 58.8 and 71.3 km2	Data Deficient Species (Alberta Government, 2014)
Cougars	Keystone (Kunkel et al., 2012).	30-1000 (Ross and Jalkotzy, 1992)	Forested mountain (Alberta Government, 2012)	Carnivores: prey (Alberta Government, 2012)	Not Threatened (Alberta Government, 2014)
Elk	Neither	60-70 (Arc Wildlife Services, 2004)	Meadows and forests (Arc Wildlife Services, 2004)	Omnivores: vegetation (Arc Wildlife Services, 2004)	Not Threatened (Alberta Government, 2014)

2.3 Habitat Fragmentation

The process of fragmentation dissects land, separating parcels which become considerably different than the surrounding landscapes. Patches are created by, but not limited to, features such as roads, railroads, pastures and housing developments. With progressive fragmentation the number of patches increases, while individual patch volume decreases. Also, the total area of interior habitat drops, as well as habitat connectivity (Forman, 1995). This leads to animals expending more energy to find proper resources needed for survival (Alberta Government, 2012).

In the 1900s, roads began segmenting The Castle Parks' landscapes. Original roads designed for logging and oil use continue to be used for non-industrial purposes. The road density throughout The Castle Parks has continued to increase since the 1950s through urbanization and industrialization (Arc Wildlife Services, 2004), acting as a barrier to various species (Forman, 1995). Having a significantly large fragment effect, Highway 3, which runs east to west in the land north of The Castle Parks, impedes geosystem and biologic system access, such as water ways and migration. This highway, paved in the 1960s, brings a high volume of cars through the area (Proctor, McLellan, and Strobeck, 2002). The stress of this obstacle limits wildlife from accessing resources back and forth (Forman, 1995) from The Castle Parks. Specifically, migrating bears are separated from nearby populations. Many bears will not attempt to cross the highway, and female bears are less likely than males to attempt the crossing (Proctor, McLellan, and Strobeck, 2002).

It has been noted that the width of a road corridor directly affects the movement of a wide range of animals. The road width is typically a proxy for vehicle volume, where wider roads have a greater volume of traffic than more narrow roads. In a German study, beetles and spiders very rarely crossed a 6m road and even avoided the side vegetation (Mader, 1988). Small mammals are seen crossing roads 6-15m wide, yet rarely cross a road 15-30m wide. Large mammals, such as elk and goats, will cross varying roads, but at a less freqyency than movement within their natural habitat. Other large mammals, such as wolves, use unpaved roads primarily at night (Forman, 1995). The widest roads, found in a study in Ontario and Quebec, roads that are 118-137m in width, had no sightings of animal crossings. This was observed even with low vehicle movement, suggesting that vehicle density alone does not influence animal crossings. The study concluded that a four-lane highway created a barrier similar to a body of water, for small mammals (Oxley, Fenton, and Carmody, 1974).

2.3.1 Fragmentation Elements in The Castle Parks

Off-road vehicles create trails that bring users deep into the wilderness. Previously undisturbed areas can now be accessed, which may create various degrees of fragmentation for different species. Provincial government plans have been in place to regulate what areas can be used for off-highway vehicles (OHV); however enforcement has been minimal. Restricted areas are found to have (OHV) use with damaged habitats (Leckie, 2002).

Castle Mountain Resort, located in the Midwest region of The Castle Parks (Figure 2.5), occupies land both owned and leased for development (Castle Mountain Resort, 2016b). In 2004 the attraction consisted of a ski resort with 88 surrounding residential lots. Castle Mountain management created a 10-20 year plan to add additional housing units, a lodge, and a hostel (Arc Wildlife Services, 2004). Currently, the resort is under development and covers 14.6km^2 (Castle Mountain Resort, 2016c). In the next five years, the current owners plan to add more commercial and housing development to the area (Castle Mountain Resort, 2016b). This plan would increase recreation activities and the human population, thus increasing road traffic, potentially widening the current roads. This growth may negatively affect the surrounding ecosystem by further fragmenting the land. The Castle Parks are already fragmented, so it is important to understand the direct impact of current fragmentation on crucial indicator species. By understanding how species react to fragmentation, a plan can be formulated for better ecological conservation.

2.3.2 Grizzly Bears

Maintaining habitat connectivity for wide-ranging animals, like the grizzly bear, is difficult to do in a fragmented landscape (Proctor, McLellan, and Stroneck, 2002). Roads associated with grizzly bear habitat affect the bear's movement through fragmentation and are one of the leading causes of mortality. A recent Alberta study examined the mortality rate of grizzly bears associated with roads. Methods consisted of monitoring bears with GPS collars; to determine road densities, remotely sensed images were used to ascertain the area of roads throughout the grizzly bear habitat. The study found that between 1999 and 2012, out of 51 bears traced, 19 (37%) bear mortalities occurred less than 500m from a road (Boulanger and Stenhouse, 2014).

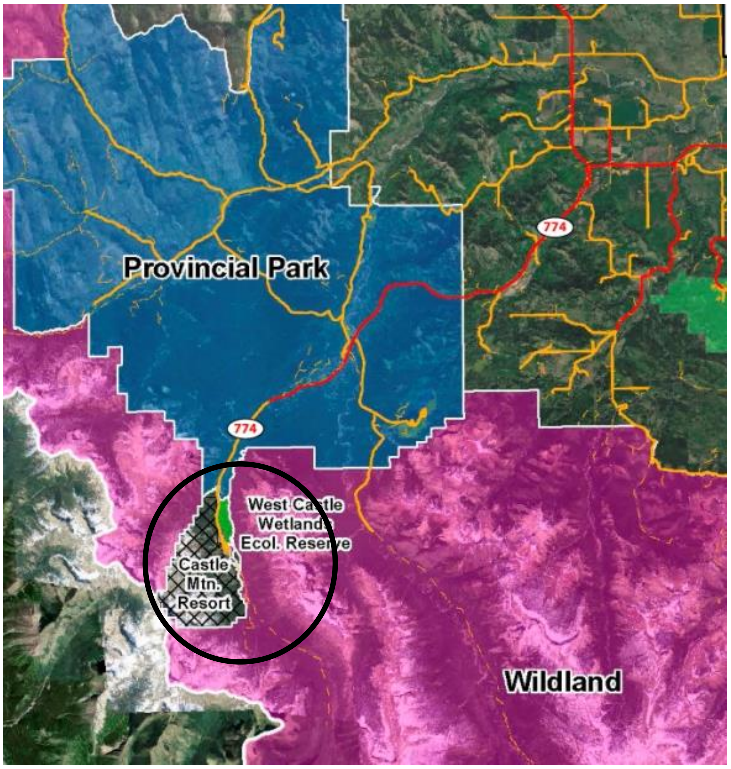


Figure 2.5 Enlarged map of proposed parks shows Castle Mountain Resort location along with major roads (2015). (The Castle-Crown Wilderness Coalition Maps)

Trails used by off-highway vehicles have a similar effect. A study conducted in northwest Montana showed that most grizzly bears avoid areas within 914m of roads. In the same study, most grizzly bears avoided areas within 122m of trails or closed roads. The avoidance of resources near roads and trails reduces the bears' ability to find food. This study supports closing old research roads for conservation management (Kasworm and Manley, 1990). Another Montana study recommended that management strategies for grizzly bear conservation should focus on restoring seasonal habitats, by reducing road density (Mace, Waller, Manley, Ake, and Wittinger, 1999).

Fragmentation in The Castle Parks area, caused by recreational and residential development, has increased grizzly bear mortality rates and prevented bears from accessing riparian sites (Arc Wildlife Services, 2004). A study conducted in Yellowstone National Park examined how grizzly bears adapt to high and low yielding whitebark pine seed crops. When comparing high to low yield seasons, bears used areas within 8km of developed areas twice as often during low yielding seasons, because fewer available food sources caused bears to venture closer to humans. When bears had to roam closer to developed areas their mortality rate increased 2-3 times and they were more likely to be habituated to humans. Human-habituated bears were almost 3 times as likely to come within 4km of developed areas and were 3 times as likely to be killed by humans (Mattson, Blanchard, and Knight, 1992).

2.3.3 Wolverine

Fragmented landscapes result in a loss of some ungulates, such as elk, which wolverines depend on as a food source. When wolverines must roam further for food, they are using valuable energy resulting in compromising reproduction and other health success. Like grizzly bears, wolverines also relocate to various habitats throughout each season, based on resource availability. Wide home ranges and use of multiple sites cause wolverines to be vulnerable to fragmentation (Carroll, Paquet and Noss, 1999). Increased road density has a negative effect on wolverines. A study completed in the Rocky Mountain region of northern United States and southern Canada, including Jasper National Park and the Greater Yellowstone Ecosystem, used a generalized additive model to predict the effect of road densities for various carnivores. The model showed that when road densities were above 1.7 km/km^2 the occurrence of wolverines declined (Carroll, Noss and Paquet, 2001).

Wolverine populations have been declining in the United States since the early 1900s. This decrease is caused, in part by trapping, habitat loss, and fragmentation. The estimated population of wolverines in the lower 48 states was 250-300 in 2014. Climate change has become an added threat to wolverines. Wolverines require snow to birth and train their young. Global warming is causing snow to melt earlier in the year (Maestas, 2013), as a result less habitat is suitable for wolverines. While currently living on about only 40% of their former historical range, additional loss of habitat due to climate change can have a severe impact on wolverines (Heim et.al. 2017). This means that locations in Canada that still have adequate volumes of snow are critical remnant habitats to their sustainability.

2.3.4 Cougars

Fragmentation reduces habitat quality, reducing adequate area available for cougars. Cougars normally will not occupy agricultural sites and urban areas. When cougars lack resources they normally will establish larger home ranges to meet their survival and reproduction needs (Alberta Government, 2012), bringing them into human populated areas (Morehouse and Boyce, 2017).

A study conducted in the San Andres Mountains, New Mexico monitored cougar movement using radio-collars to determine the effects of a 1993, US Highway 70 expansion from four to six lanes. Before the expansion, at least seven cougars were recorded crossing the highway. After the expansion two cougars were reported killed by highway vehicles. None of the collared cougars were monitored crossing the widened highway, restricting their land use, and separating the individuals from the population who crossed prior to the addition. This separation can cause reduced breeding and result in genetic limitations in the smaller population of cougars (Sweanor, Logan and Hornocker, 2000).

A study completed in Zion National Park (Utah), observed a trophic cascade, resulting from increased human interaction. The study found that an increase in visitors to Zion caused a decrease in cougars. This decrease allowed the mule deer population to increase, which reduced the abundancy of cottonwood trees. Without cottonwood trees along the rivers, there was an increase in stream erosion, which resulted in a decrease of aquatic species (Ripple and Beschta, 2006).

2.3.5 Elk

According to Lydon (1979), elk avoid areas fragmented by roads, by 400 to 800 m, limiting the habitat available to them. An additional study, conducted in northeast Oregon, further found that female elk consistently avoid areas with open roads (Rowland, Wisdom, Johnson, and Kie, 2000). A Wyoming study, observed the effect of natural gas development on elk populations. Using GPS data collected from female elk before and after natural gas development, elk were seen occupying areas further from the resource roads during gas well development. By avoiding these roads, elk lost 43 percent of summer habitat and 50 percent of winter habitat, which was listed as high use areas prior to development. To provide elk with sufficient habitat, the study suggested reducing traffic and protecting wooded areas near energy development (Buchanan, Beck, Bills, and Miller, 2014).

2.3.6 Lost Creek Fire

In 2003, Crowsnest Pass, which included the now Castle Parks, experienced the Lost Creek Fire, which burned about 20,000 hectares of forested area. This fire burned from July to September, consuming forest and organic matter in its path (Alberta Fire, 2017). The burned area included part of the headwater regions in The Castle area. After the fire, watersheds showed an increase in suspended sediment, which was six times higher than non-burned areas (Uldis, Stone, Emelko, and Bladon, 2008). The burned area within The Castle Parks is still undergoing primary succession. This makes the need for conservation greater, as post fire areas are critical habitat for grizzly bears and other species (Freeman et. al., 2017).

2.4 Geographic Information Science

2.4.1 Land Cover and Land Use

Land cover represents a specific habitat, such as forests or meadows, whereas land use represents the way humans use the landscape, such as agriculture or housing. Therefore, land cover can characterize multiple land uses and include human features. For example, a forest can be used for both recreation and housing. Land use change documents how humans have used a landscape over time and shows apparent changes to the land cover. Land cover is often altered by human use through urbanization, agriculture, recreation, and industrialization. Land use activities alter landscapes by reducing natural habitats and creating new land covers, and may cause fragmentation by varying spatial patterns. To understand landscape change, remote sensing and GIS models are often used to observe and measure the nature of landscape transitions over time and predict future landscapes. These models can show land cover changes and the spatial arrangement of the landscape (Turner et al., 2001).

2.4.2 Remote Sensing

Remote sensing is the process of acquiring information about Earth's surface from a distance using an airborne or space borne sensor. Once obtained, remote sensing data can be analyzed with geospatial technologies (Weng, 2012). Landsat satellites, which were first launched in 1972, are especially useful as they provide current, worldwide coverage free to users (Turner et al., 2001).

Remote sensors can document more than a human eye can discern, as they can detect wavelengths on the electromagnetic spectrum from microwave to ultraviolet. Each sensor is unique to the wavelengths it can detect (Weng, 2012). For example, healthy vegetation reflects a large amount of near infrared radiation, unhealthy vegetation will reflect less near infrared radiation. Thus, infrared is often used in environmental research to quantify the health of vegetation. A spectral signature, of various wavelengths, can be created to identify unique features and distinguish these features in an image, such as plant species or plant community age (Shellito, 2016).

Advances in technology have produced sensors which enable higher spatial resolution, producing better resolution images. For example, the IKONOS sensor can produce images with a spatial resolution of 4m and panchromatic imagery at 1m. With resolutions this high, direct identification of certain vegetation types is possible through unique spectral signatures. Sensors also have higher spectral resolution, allowing for improved land cover classification. These hyperspectral sensors, sense hundreds of bands of energy at once, allowing for finer differences between vegetation and soil to be determined (Woody et al., 2003).

2.4.3 Geographic Information Systems and Habitat Fragmentation

Geographic Information Systems (GIS), refers to a computer application of visualizing and analyzing geospatial information (Shellito, 2016). GIS technology allows for analyzing, managing, and displaying remotely sensed information. A useful analytical function of GIS is the use of overlays, which layers of various properties such as land use, vegetation, and aquatic systems are combined to assess the spatial relationships between the properties (Weng, 2012). Overlays may be used to identify current landscape conditions and can be used to conduct analysis of optimum locations for future land use (Forman, 1995).

GIS is proven to be useful in landscape ecology and has been used to record and identify habitat fragmentation (Crooks et al., 2017). GIS models allow designation of specific features, such as ecoregions, and can be used to compare an area over time, to reveal correlations and make predictions. The software also makes it easy to visualize spatial data, permitting effective communication of management plans to policy makers (Forman, 1995)

The range of applications for remote sensing and GIS permits multiple scale maps of land cover and use. For instance, a study conducted on global forest change used satellite data to map global forest loss and gain between 2000 and 2012, at a spatial resolution of 30m. The study determined that 2.3 million km^2 of forest were lost, while 800,000 km^2 were gained (Hansen et al., 2013). An Italian study examined the available habitat for the Apennine brown bear, within a 22,000 km region of Italy corresponding to the bear's historic range, by using a distribution model to compare land cover suitability in 1960, 1990 and 2000. A map also displayed land cover suitability for the bear in 2020, which was created from a Markov-chain land-transition model. The study found high and medium suitable habitats to be in the mountains, while low and unsuitable habitats were in the lowlands (Falcucci et al., 2008).

2.4.4 Density Ratios

Density ratios may be used to show the percentage of individual land covers within an area. By understanding individual species needs, specific ecotypes may be identified as suitable or unsuitable. For example, foothills are a suitable habitat for white-tailed deer, while the alpine is unsuitable (Kershaw, 2008). Determining the density of land covers throughout The Castle Parks can illustrate which ecotypes are lacking coverage and/or which are sufficient.

A study conducted throughout the United States analyzed fragmentation by determining road density in km/km^2. Ecoregions were used to determine fragmentation so that ecology and forest type could be discussed at a smaller scale (Heilman et al., 2002). The length of a road network within a region (density), is critical to address management practices (Colin et al., 2017).

2.4.5 Landscape Change

A land use and cover study examining the area of forest change evaluated three regions in Brazil between 1960 and 1980 and then from 1980 to 2000. It was concluded that in 1960 the three areas contained 10%, 30% and 50% forest cover respectively. Over the forty-year period, forest cover increased in two of the forests and declined in the study area having an original forest volume of 30%. Over the study period, the forest decline exhibited an increase in patch isolation. The investigated areas that had an increase in forest area exhibited an increase in connectivity between forest patches. The regenerated forests contained a span of forest community ages, which positively effects biodiversity (Lira, Tambosi, Ewers and Metzger, 2012).

Resource development has led to an increase in landscape disturbance. The Allegheny Plateau, within the states of West Virginia, Pennsylvania, Ohio, and Kentucky, has undergone shale-gas development. A study used the state of Pennsylvania as a proxy to represent the Plateau, to examine forest fragmentation through land cover change, caused by shale-gas extraction. Within the study area, land cover was classified for wells, which found 45-62% of well pads were located within agricultural land and 38-54% within forest land. Permits were expected to convert about 600-1100 ha of agricultural land and about 500-900 ha of forest land to resource extraction. With this development, about 650km of new roads were expected along with new pipelines. This would further change the land cover to classify more forest and agriculture land as wells (Drohan, Brittingham, Bishop and Yoder, 2012).

2.5 Resilience Theory

Resilience theory seeks to explain the dynamics of natural systems. Typically, resilience includes the capacity of a system to absorb disturbance and re-organize to maintain the original identity (Folke, 2006). The ball and cup model (Figure 2.6) used to represent the resilience theory, shows dips which represent stability, the ball represents the system, and arrows show ecological disturbance. The ball starts off steady in the cup, and loses stability after ecological disturbances. The adaptive capacity of a system is the ability of a system to remain stable as the ecosystem changes (Gunderson, 2000).

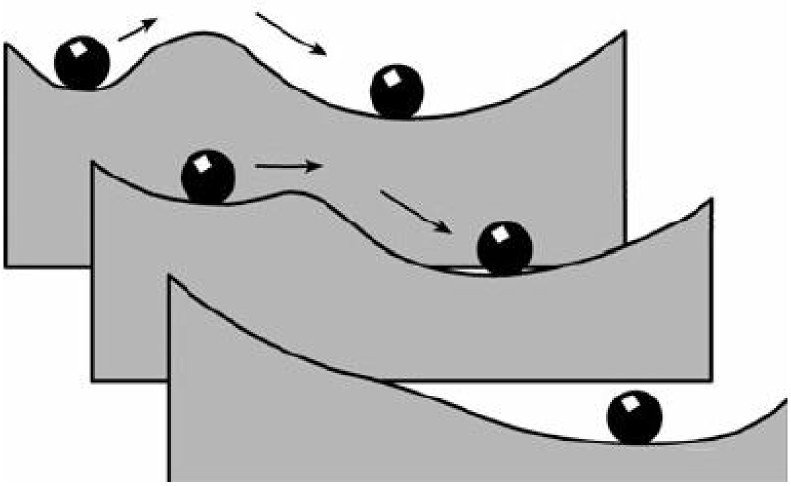


Figure 2.6: Ball and Cup Model Representing Ecological Resiliency.

Vegetation populations are not steady, but oscillate over time, creating a degree of persistence according to Holling (1973). Holling described the relationship and sequence between boreal forest trees and spruce budworms, which ate balsam fir. In this sequence, fir canopy would dominate until there was a budworm outbreak, followed by a decline in firs and then a collapse of budworm. After an outbreak, fir would regrow, become dominant again and initiate another budworm outbreak, starting again the “predator-prey” cycle. The changes in species abundance over time would then promote resilience in the system (Stallins, Mast, and Parker, 2013).

Ecological resilience explains how the system responds to changing structures and processes within the ecosystem to yield multiple functions. For example, organisms may regulate biogeochemical cycles, modify their environment, or control trophic levels through predation. To enhance function in the ecosystem, ecological diversity is generated by multiple species which have overlapping functions. The distribution of species across an ecosystem helps regenerate an area after an ecological disruption (Gunderson, Allen, and Holling, 2010).

Spatial resilience may be used to understand the effects of habitat fragmentation on an ecosystem, in which structure and connectivity of habitats affect system resilience (Cumming, 2011; Thrush, Halliday, Hewitt and Lohrer, 2007). Within spatial resilience, species respond differently to changes in spatial patterns (Cumming, 2011), so fragmentation effects should be studied for each individual species (Fischer and Lindenmayer, 2007). It is crucial to study fragmentation for a long period of time in order to observe the effects on different species, as some species are more sensitive to fragmentation and species loss occurs at different rates. When a habitat becomes smaller through fragmentation, ecological interactions become amplified. For example, if predators rely on a single food source, which becomes depleted, local extinction and/or extirpation may take place, further altering the food web (Cumming, 2011). Extinctions are more likely to occur in altered habitats with low native vegetation cover, poor connectivity, and intensive land use (Fischer and Lindenmayer, 2007). Conservation management strategies are needed to improve ecosystem connectivity, to reduce extinction rates, and preserve ecosystem services (Haddad et al., 2015).

2.6 Fire Ecology

A forest fire could represent resiliency, where the original forest structure is resilient and will return overtime. There are several stages of forest development following a fire. The first stage is stand initiation, where open landscapes allow for a regeneration of a variety of species, not restricted to conifer/forest species. The second stage, stem exclusion, is a period of low biodiversity, where the canopy becomes too dense to allow other species to grow. This is followed by understory reinitiation, where gaps in the canopy allow new species to establish. The last stage, termed old-growth, allows younger trees to grow into the canopy, creating discontinuous and irregular canopy ages and plant species structures (DeYoung, 2016).

Fires are an important aspect in ecology, as they shape the sequence of future forest structure patterns. In many landscapes without fires, trees encroach into the upper grasslands, reducing forging areas, and low-severity forest fires are responsible for the maintenance of forest-grassland ecotones. Mixed severity fires influence the long term ecology of similar forest-grassland ecotones in western North America. Severe fires clear away overstory trees, allowing a mix of other species to grow below. The consequent new heterogeneous forest structure supports diverse species and is argued to be more resilient to disturbances (Harvey, Smith and Veblen, 2017). Fires are especially important for the growth of berry crops, need by grizzlies, which require an open canopy cover to thrive (Munro et. al., 2006; Arc Wildlife Services, 2004). A study conducted in southeastern British Columbia, found that in the summer, grizzly bears preferred a landscape that had seen a forest fire 50 to 70 years prior (McLellan and Hovey, 2001). Fire creates heterogeneous landscapes and consequently forest edges, which are an important component of forest ecosystems (Hanson and Stuart, 2005). The mixed ecosystem structures produced benefit a wide range of species, such as cougars which utilize edge habitats to hunt for prey, like deer and elk (Alberta Government, 2012).

Chapter 3 Methods

3.1 Introduction

Methods were developed for site selection, image and road acquisition, supervised and unsupervised classification analysis, digitizing, identification of land use change, and digital elevation model development of the study area. Methods included GIS and remote sensing analysis and statistical analyses. This chapter begins with an overview of the remote sensing methods used for site selection, image acquisition, and land cover classification development. ArcGIS was then utilized to develop models by first digitizing points of interest, roads, and trails. Google Earth was used to identify digitized features and to compare land use change over time. This chapter ends by describing the methods used to create digital elevation model.

3.2 Site Selection

The site selection began during the fall of 2016 and image and shapefile acquisition during the spring of 2017. The Castle Parks region was selected for this study because the site became a new, government-operated park system creating protected and recreational zones. The area had been intensively and extensively used for non-regulated and regulated recreational activities, such as camping, off-road vehicle use, and resource extraction, such as logging and gas extraction. The Castle Parks provide critical habitat, and if they are altered substantially by recreational and industrial activities, ecological function may be altered. Additionally, the area contains important head water sources for ecosystems and downstream human activities, and fragmentation may alter water quality. Although, there could be additional aquatic issues, this study will focus on terrestrial ecosystems.

3.3 Image and Roads Acquisition

A single satellite image of The Castle Parks was acquired from Earth Explorer. The dataset from Landsat Archive, Pre-Collection, L8 OLI/TIRS was chosen as Landsat 8 images had cloud cover less than 20 percent. An image from 17 June 2015 was downloaded as a level 1 GeoTiff. The June dataset was specifically selected as it had few shadows, limiting analysis errors which occur in complex mountain topography. This image (figure 3.1), which portrays The Castle Parks in the upper right corner, is from UTM zone 11, path 42 row 26. To access the image in programs, such as ArcGIS, the data were formatted using ENVI and saved as a multispectral image in TIFF format. All seven bands were subsequently stacked together, allowing a normal color display to be produced using band four (red), band three (green) and band two (blue).

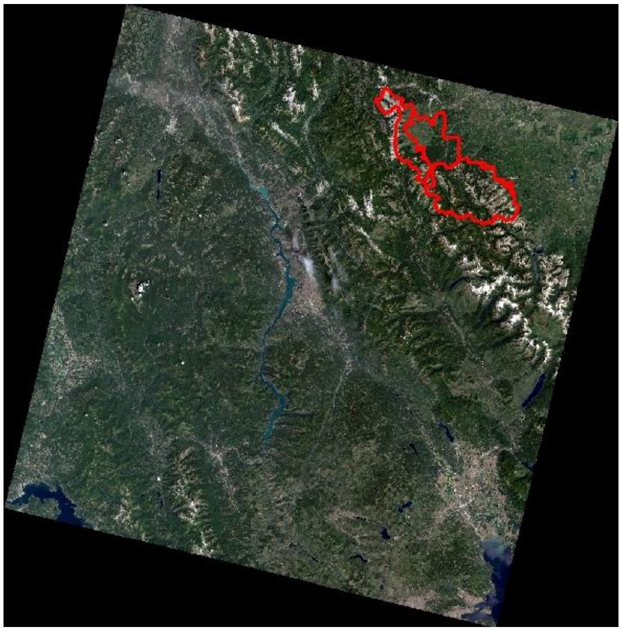


Figure 3.1 Satellite image of The Castle Parks, acquired from Earth Explorer from June 2015. The Castle Parks boarder is seen in red.

The shapefile of The Castle Parks was downloaded from the Alberta Environment and Parks website (http://aep.alberta.ca/). The shapefile, SSRP 2014-2024 Amended Conservation and Recreation Areas - 2017-02-16, included additional parks not associated with The Castle Parks.

This shapefile delineated the Provincial and Wildland Provincial Parks' border on the Landsat image. The Landsat image and park border were overlaid (placed on top of each other) and clipped (cut) using ENVI to limit the dataset to the area of interest (Figure 3.2). Excluding the data external to the study area is necessary for accurate statistical and visual analysis.

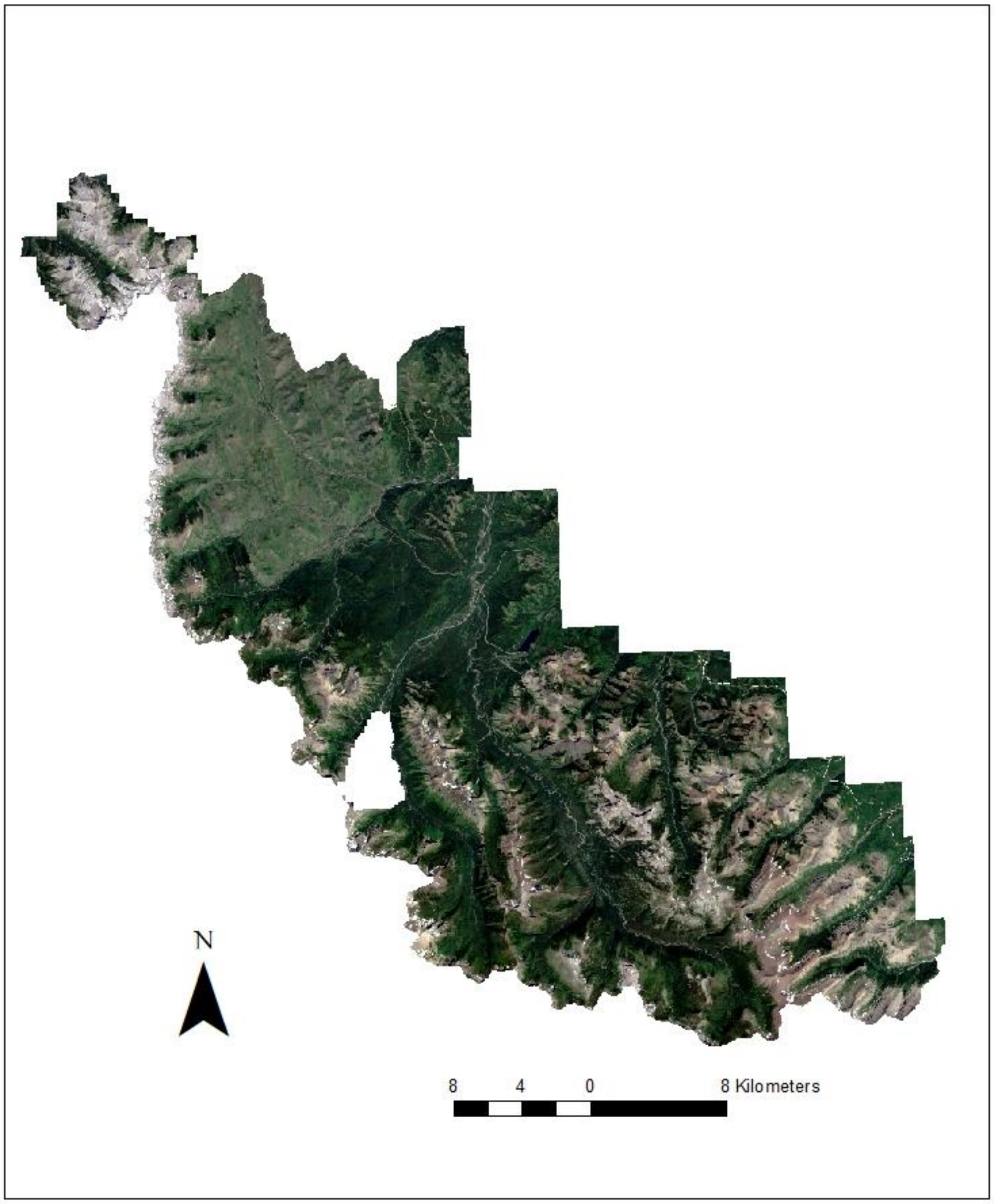


Figure 3.2: Landsat Image of the Clipped Castle Parks.

3.4 Supervised and Unsupervised Classification

Both supervised and unsupervised classifications were completed. An unsupervised classification conducted on the clipped Castle Parks Landsat dataset through ArcMap 10.4 was used to determine land cover type. Initial classifications produced classification confusion, due to the area of the 2003 Lost Creek Fire within the area of interest. When fewer classes were chosen, burned areas were being paired with inaccurate unburned areas. To correct for this confusion, The Castle Parks were divided into a forest fire region (Figure 3.3) and a non-forest fire region (Figure 3.4) each requiring separate analysis. For both regions an unsupervised classification was run using 8, 10 and 15 classes. Ten classes were selected as the best fit for the fire region and 15 classes were selected as the best fit for the non-fire region, based on the visual clarification of the classes produced. Identification of land cover type for each class was aided by visually examining the original Landsat Image, as well as Google Earth images, to accurately label vegetation structure. While naming cover types, immature described dense young tree growth, mid-aged described many and frequent large canopy gaps between trees, mature described tall trees with few canopy gaps, and conifer residual described small strands of mature conifer remaining within the forest bur area. Unsupervised classification categories used are found in Table 3.1 and 3.2, for the fire region and non-fire region respectively.

Table 3.1 Unsupervised classification for the fire region within The Castle Parks. Ten classes created from an unsupervised classification analysis for the fire region in The Castle Parks. The cover types were determined using Google Earth and the 2015 Landsat Image.

Created Class	**Cover Types**
1	Mature Conifer
2	Mid-aged Conifer
3	Mature Conifer
4	Mixed Shrubs
5	Revegetated Shrubs
6	Burned Meadow Regrowth
7	Burned Meadow Regrowth
8	Burned Meadow Regrowth
9	Burned Meadow Regrowth
10	Conifer Residual

Table 3.2 Unsupervised classification for the non-fire region within The Castle Parks. Fifteen classes were created from an unsupervised classification analysis for the non-fire region in The Castle Parks. The cover types were determined using Google Earth and the 2015 Landsat Image.

Created Class	**Cover Type**
1	Water/Shadow
2	Dense Conifer
3	Medium Dense Conifer
4	Medium Dense Conifer
5	Dense Conifer
6	Low Dense Conifer
7	Exposed Geology
8	Mixed Woods
9	Exposed Geology
10	Meadow With Tree Encroachment
11	Medium Dense Conifer
12	Mixed Woods
13	Slope With Tree Encroachment
14	Exposed Geology
15	Ridges

Supervised classifications were conducted using Arc Map 10.4. Revised classes were created based on knowledge gained from the unsupervised classifications and remote sensing visual analysis. Many classes from the unsupervised classification were aggregated, or combined, as they yielded the same cover type. The final supervised classification established six classes in the fire region (Table 3.3) (Figure 3.3), and eight classes in the non-fire region (Table 3.4) (Figure 3.4).

Table 3.3 Supervised classification for fire region within The Castle Parks. Six classes were created from a supervised classification analysis for the fire region in The Castle Parks. The cover types were determined using Google Earth and the 2015 Landsat Image.

Created Class	Cover Type
1	Mature Conifer
2	Mid-aged Conifer
3	Mixed Shrubs
4	Revegetated Shrubs
5	Burned Meadow Regrowth
6	Conifer Residual

Table 3.4 Supervised classification for the non-fire region within The Castle Parks. Eight classes were created from a supervised classification analysis for the non-fire region in The Castle Parks. The cover types were determined using Google Earth and the 2015 Landsat Image.

Created Class	Description
1	Lakes/ Ponds
2	Dense Mature Conifer (100%)
3	Dense Conifer (80-90%)
4	Medium Dense Mature Conifer (70%)
5	Medium Dense Conifer (30-70%)
6	Exposed Geology/Slopes
7	Mixed Woods
8	Meadow With Tree Encroachment

3.5 Digitizing

Digitizing and land use change were completed during the fall of 2017. To assess habitat fragmentation, roads and trails were digitized using Arc Map 10.4. Digitization was conducted within the parks on a 2012 image of Southern Alberta (Figure 3.4). The Alberta image had a resolution of 50 cm, offering exceptional visual clarity of the site. From this image, roads and trails were digitized manually. Manual digitizing does not permit lines to be perfectly aligned atop the roads/trails, but sufficiently accurate to capture the amount of fragmentation within The Castle Parks. It is important to note that because the 2012 image is a single point in time, current conditions will vary from the image used, resulting in additional or reduced fragmentation in certain areas. Heavily used trails may have turned into roads, and retired roads may have transformed into trails or become revegetated.

To accurately and consistently distinguish between roads and trails formal definitions were created as rules to follow when digitizing. Roads within The Castle Parks were defined as paths on which four-wheel vehicles, the size of cars and larger (2 m), can travel. Roads were typically more clearly defined than trails and lead to a discernible destination. Trails were defined as paths that show signs of being used by, hiking, or mountain biking and potentially all-terrain vehicles. Three categories of roads were digitized: paved, gravel, and dirt. Paved roads were identified from their straight margins created by the paving process, dark color and clear traffic lines were apparent in the center of the road. Gravel roads were identified from their straight margins created by grading and maintenance processes, a lighter color than paved roads, and nearby identified human activities. Dirt roads were identified by tread marks, visible vegetation adjacent to the tracks, lighter color, and having no clear edge margins. Trucks and cars would not be found on trails as the trails are generally too narrow for travel. Trails were typically narrower, had poorer definition than roads, could be found on steep slopes and did not always lead to a destination. Two categories of trails were identified: heavy use and light use trails. Heavy use trails could clearly be seen from a 1:10,000 scale image, had clear erosion characteristics and were often transitioning from a road. Light trails were not visible from a 1:10,000 scale image and required a larger scale image to accurately observe and document, were often narrower than heavy trails and did not always show clear erosion characteristics.

Before digitizing, key features were mapped as separate layers on top of The Castle Parks image. These features were identified using both the 2012 Alberta Image, and Google Earth, which allowed recognition of the features across multiple years and, in some cases, provided an indication of when the object or feature first appeared thereby documenting land cover and or land use change. Key features mapped as separate layers included: water bodies, logging sites, gas wellheads, various unknown human disturbances, parking areas, and campsites. Mapping known features before roads and trails were digitized facilitated the creation of road and trail networks connecting these features. These features are a component of fragmentation and helped identify the nature and extent of fragmentation on the landscape, by displaying camping, parking and industry locations and geographic extents. This information allows identification of areas no longer suitable for wildlife, based on the intrinsic characteristics of the feature, the location of features, and density of features. For example, Figure 3.6a and 3.6b shows a landscape heavily fragmented by gas wells, which may not be suitable for some wildlife sensitive to this land use (high road density and land obstruction). Each layer of features was continuously updated as new points of interest were identified. The entire study area was observed visually from the Landsat data and Google Earth images available to accurately document all landscape features. Accuracy of features was limited by the resolution of the images and the individual dates of the image. For example, some campsites were only identified on one Google Earth Image resulting in the area being suspect for such feature activity.

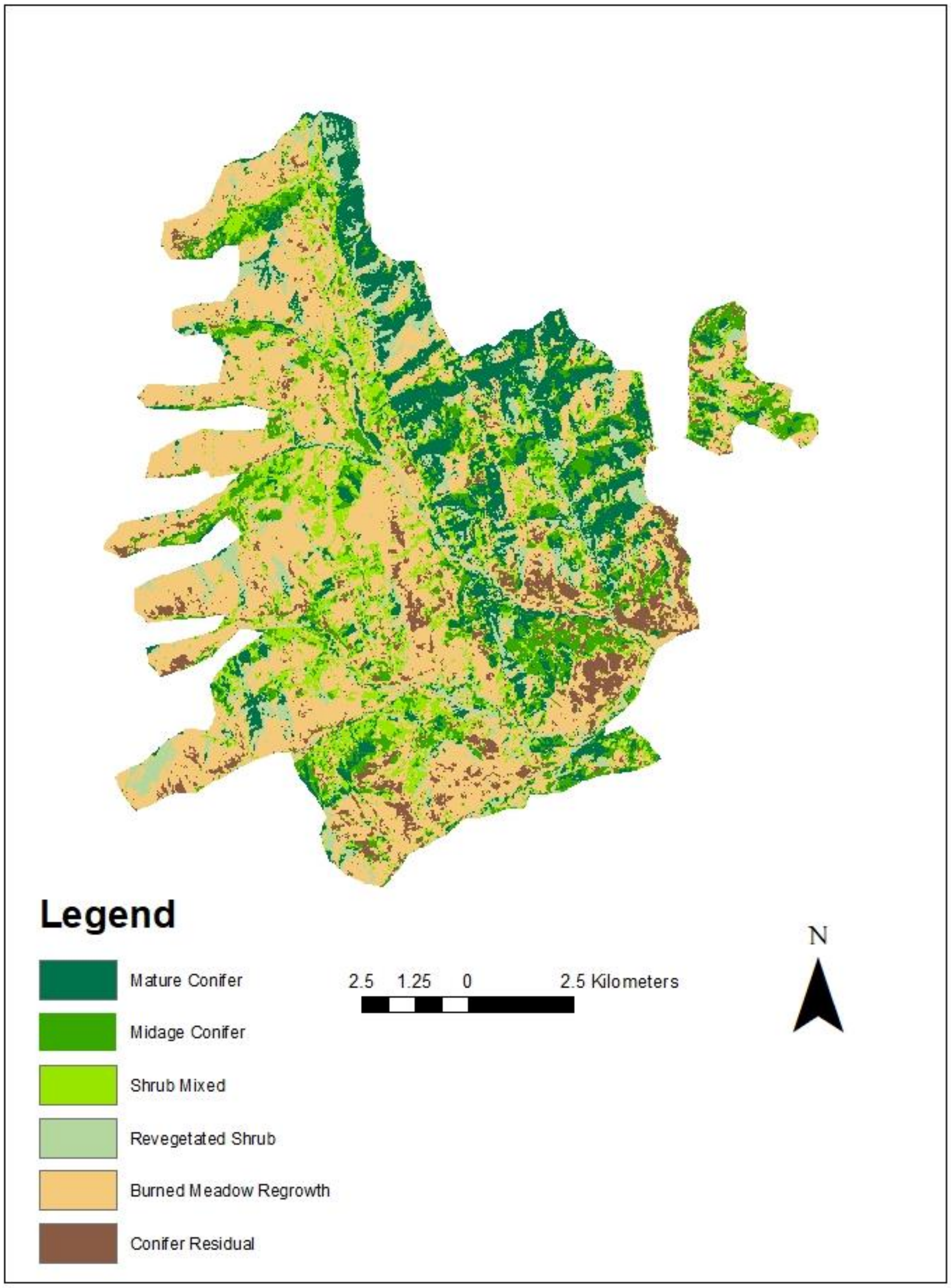


Figure 3.3 Supervised classification of the fire region of The Castle Parks: Six cover types were created from the supervised classification of the fire region of The Castle Parks.

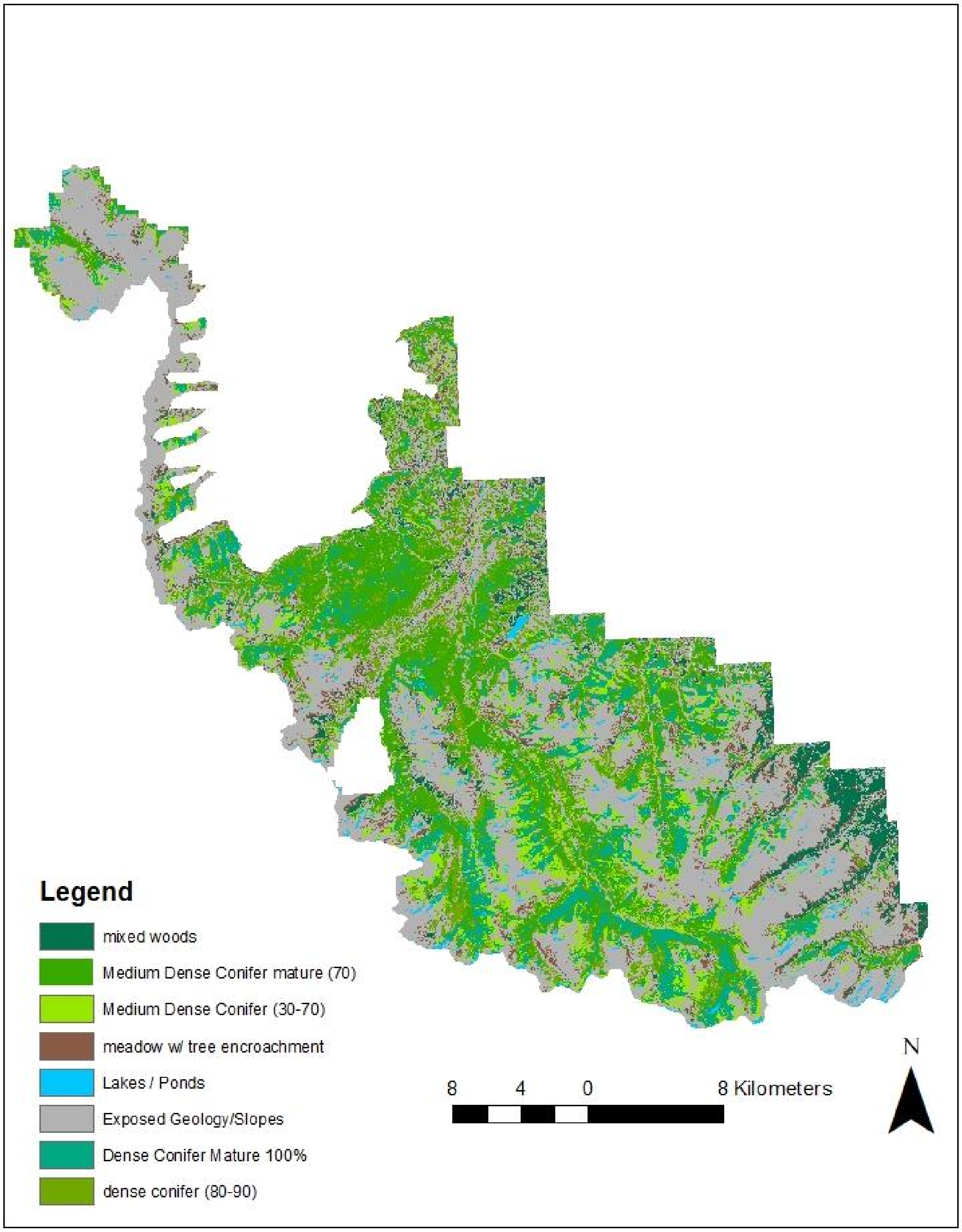


Figure 3.4 Supervised classification of the non-fire region of The Castle Parks: Eight cover types were created from the supervised classification of the non-fire region of The Castle Parks.

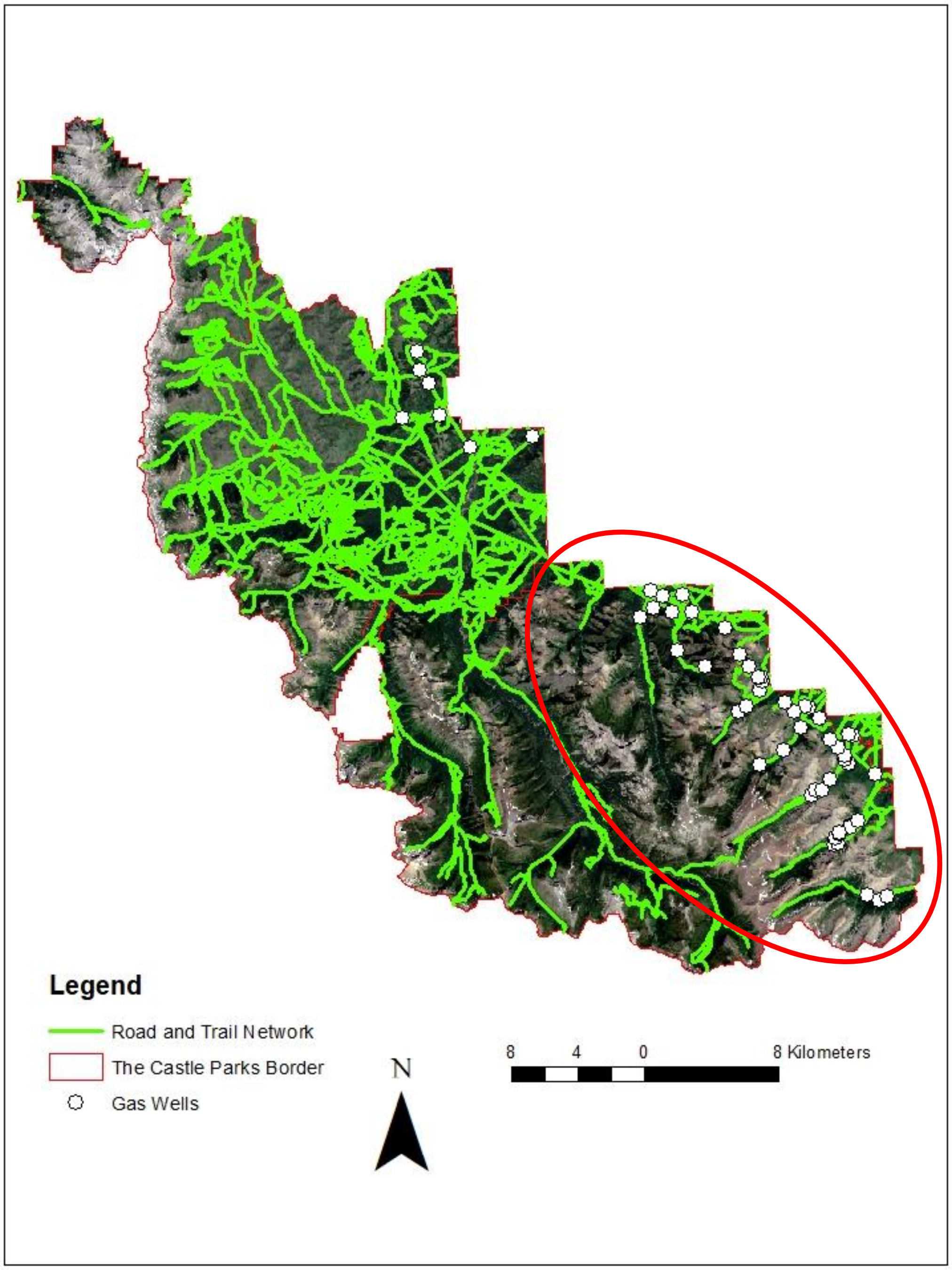
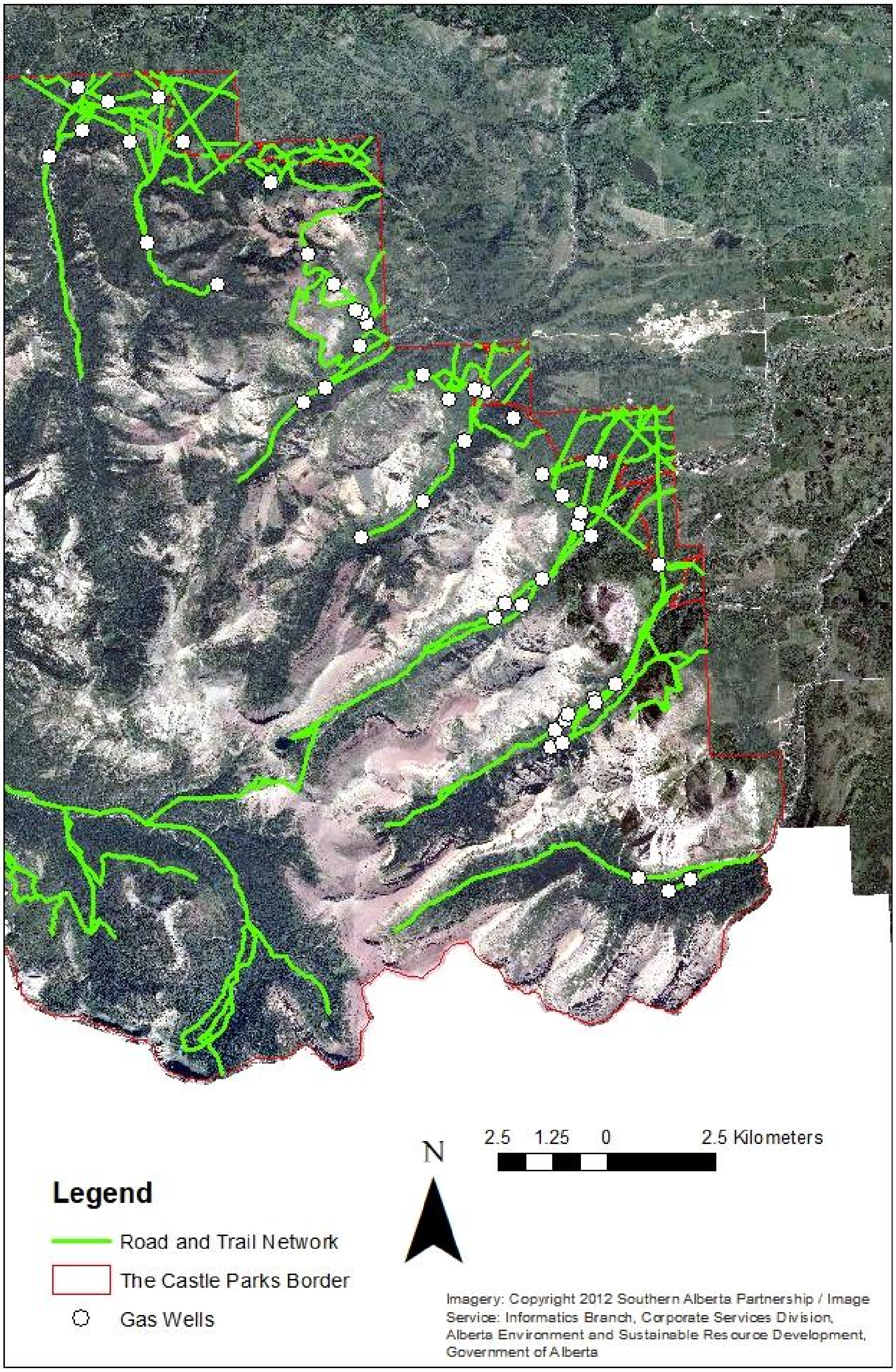


Figure 3.6a Primary location of gas wells within The Castle Parks. Roads and trails = green, gas wells = white, and primary gas well location = red. Figure 3.6b shows close up of circled region.



Imagery: Copyright 2012 Southern Alberta Partnership / Image Service: Informatics Branch, Corporate Services Division, Alberta Environment and Sustainable Resource Development, Government of Alberta

Figure 3.6b Fragmentation produced by road network between gas wells in the southern end of The Castle Parks. Road and trail network = green, gas wells = white, and The Castle Parks Border = red. The land in the southern end of The Castle Parks is very fragmented and may be unsuitable for some wildlife.

The total length (km) of trails and roads were calculated from the attribute tables of each digitized image. Data of the lengths of each road/trail type within each park and for each land cover type was acquired as well. Each road and trail type was converted to raster format, with a 30m resolution to match the Landsat image, and then reclassified with “one” representing cells containing a portion of road and “zero” representing cells not having a road. The supervised images of the fire region and non-fire region of The Castle Parks were reclassified, with each land cover type receiving a unique code number and zero representing all other features. Using the raster calculator, the supervised classification cells were multiplied with the road cells. When multiplied together, any overlap of a road and land cover were grouped together, with the attribute table for the calculations exhibiting the number of cells that included both the land cover type and road type. To calculate a relative road or trail distance, the number of cells containing a road or trail type were multiplied by 30m and divided by 1000 to get a measurement in km. The total road distance found in the fire region was 400.14 km and the total road distance found in the non-fire region was 1388.64 km. These numbers do not sum up to equal the total amount of road distance due to an intrinsic error with the raster calculator. When a road would cross a 30m cell, the raster calculator would assign the road section to that cell, assigning it to be 30m long, even if it the road only slightly crossed the cell and was much shorter. However, the data quality are accurate enough to provide comparative road distance across each land cover type. To find the length of a road using a raster calculator, the resolution (30m) is multiplied by number of cells that were assigned to be a road (DeMers, 2005). The same processes were used to calculate distance for each road and trail type. Road and trail densities were calculated for each land cover type in kilometers per square kilometer.

3.6 Land Use Change

To provide examples of how industry and recreation have changed the landscape in The Castle Parks, paired images showing change over time have been included. For instance, Figure 3.7a and Figure 3.7b show how logging increased between 2012 and 2015. Additionally, older logging shows evidence of forest return. Unfortunately, satellite evidence of early, peak harvesting predate existing Google Earth and high resolution Landsat images.

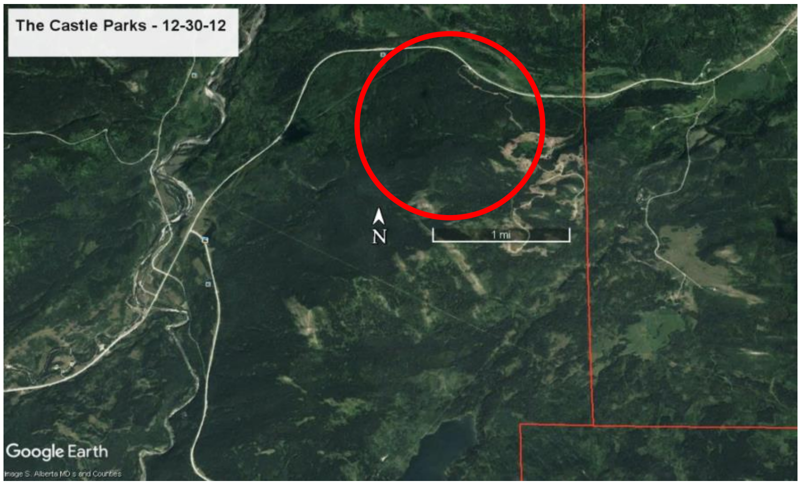


Figure 3.7a The Castle Parks, December of 2012, red shows the park boundaries. The lighter areas to the left of the perpendicular boundary are indicative of logging.

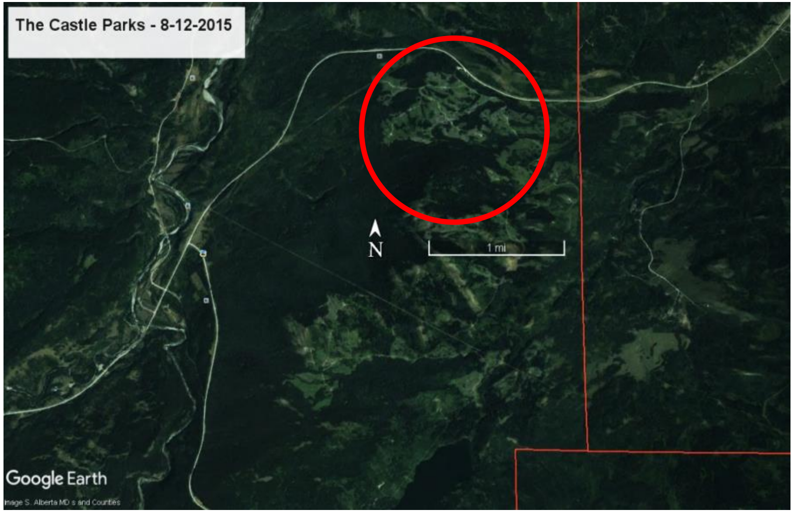


Figure 3.7b The Castle Parks, August of 2015 after logging, red showing the park boundaries. The lighter, logged, area to the right of the perpendicular boundary line has increased significantly over a 32 month period = circled in red.

3.7 Digital Elevation Model

A digital elevation model (DEM) of the region was downloaded from maps.canada.ca. The DEM cell size was resized to a 30m resolution, allowing for congruent analyses with the 30m road and trail models. Once resized it was clipped with The Castle Parks border. The DEM was reclassified to 7 slope classes. Slopes of 0-10 degrees (lowest slope), 10.1-20 degrees, 20.1-30 degrees, 30.1-40 degrees, 40.1-50 degrees, 50.1-60 degrees, and 60.1-71.6 degrees (steepest slope) (Figure 3.8).

Area was calculated for each DEM class within The Castle Parks by multiplying the number of cells in each class by 900m and dividing by 1,000,000 m to produce data area in square kilometers. Road and trail lengths were calculated for each DEM class (Figure 3.9 and 3.10) by using the raster calculator and multiplying the DEM cells with the road or trail cells to determine coincidence. From this data, road and trail density was calculated by comparing km of road or trail to square kilometers of each slope class. The area of each land cover occurring on each slope classification was also calculated using the raster calculator to multiply DEM class by land cover. The cells of each land cover slope occurrence were multiplied by 900m and divided by 1,000,000 to get the area total in square kilometers.

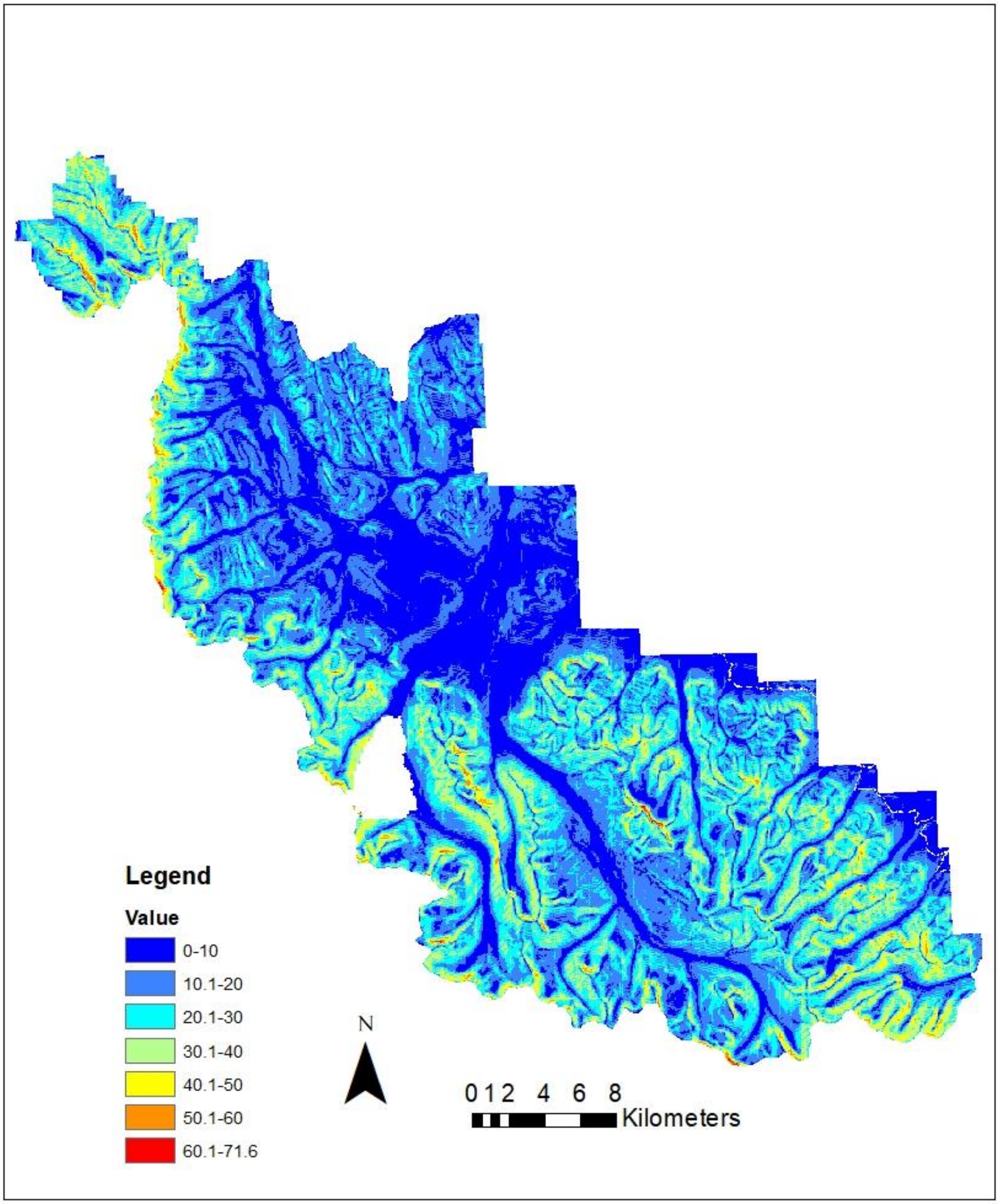


Figure 3.8 Slope degrees in The Castle Parks. Dark blue = 0-10.1 degrees, blue = 10.1-20 degrees, light blue = 20.1-30 degrees, green = 30.1-40 degrees, yellow = 40.1-50 degrees, orange = 50.1-60 degrees, and red = 60.1-71.6 degrees. The large blue clump in the center represents a shallow slope of 0-10 degrees. The steepest slopes are seen among the mountain ridges in yellow, orange, and red.

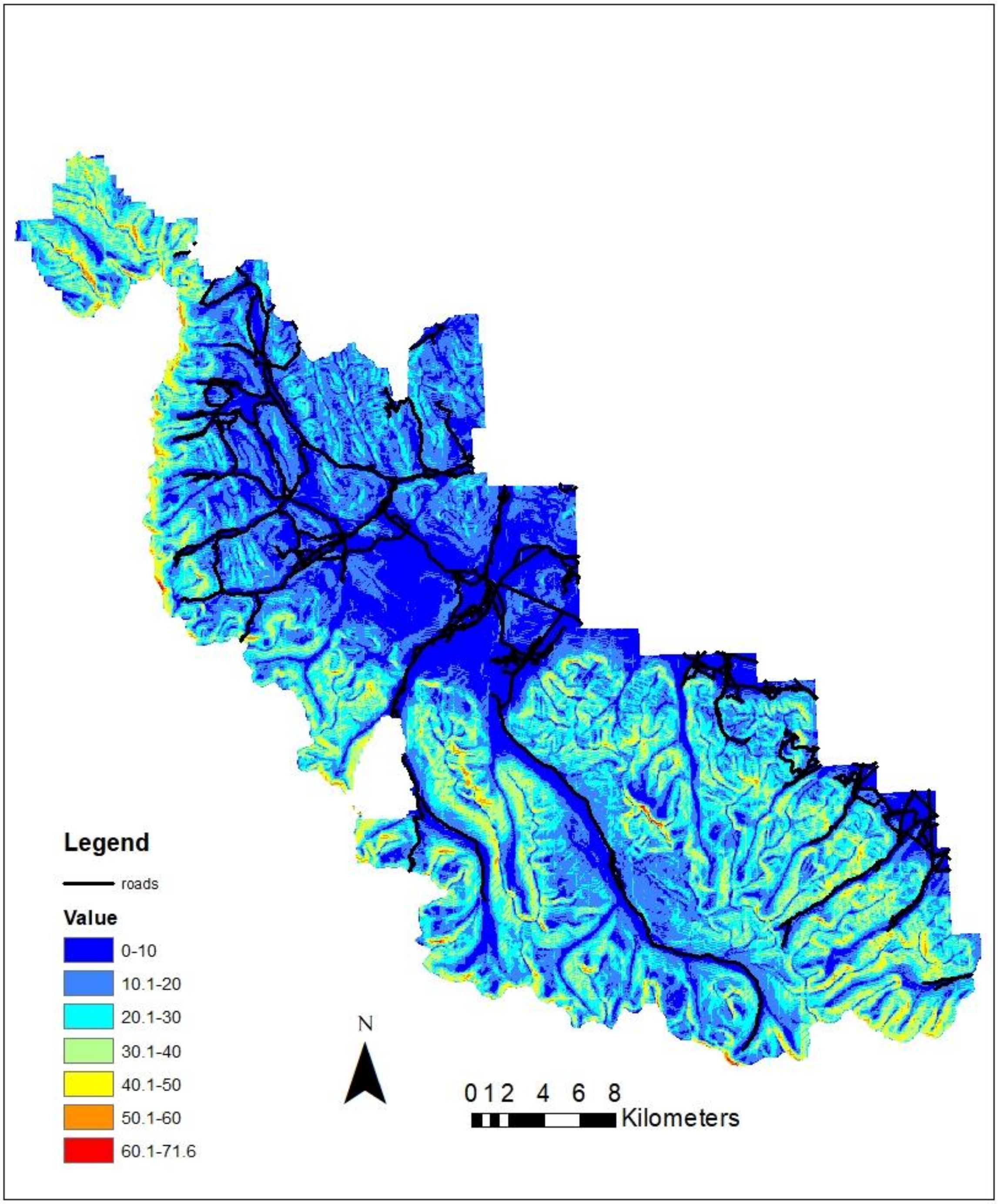


Figure 3.9 Road Network over DEM in The Castle Parks. Slope degree in The Castle Parks: Red = 0-10 degrees, orange = 10.1-20 degrees, yellow = 20.1-30 degrees, green = 30.1-40 degrees, light blue = 40.1-50 degrees, blue = 50.1-60 degrees, and dark blue = 60.1-71.6 degrees. Road networks are seen in black. Most of the roads occupy low angle slopes.

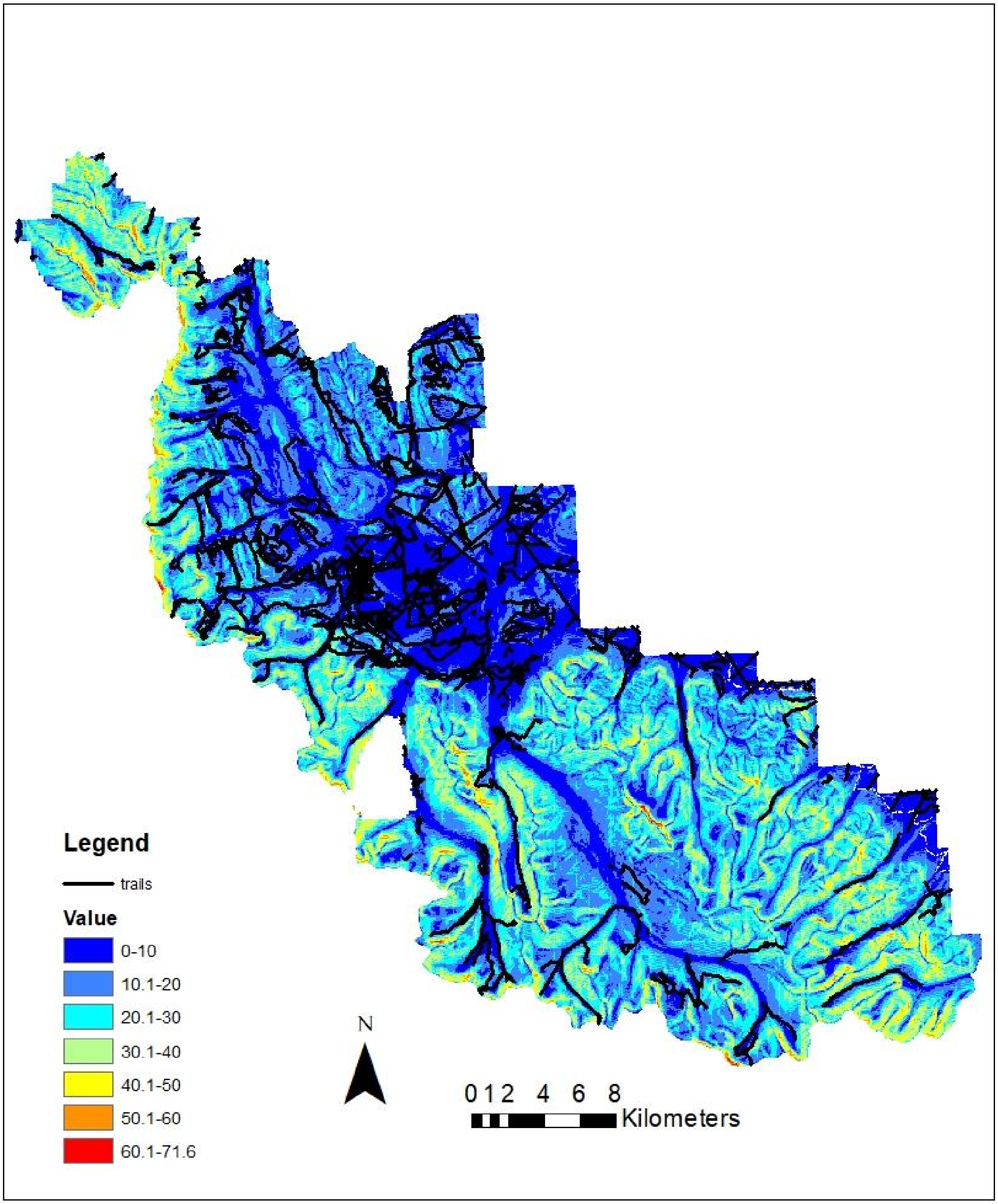


Figure 3.10 Trail network over DEM in The Castle Parks. Slope degree in The Castle Parks: Red = 0-10 degrees, orange = 10.1-20 degrees, yellow = 20.1-30 degrees, green = 30.1-40 degrees, light blue = 40.1-50 degrees, blue = 50.1-60 degrees, and dark blue = 60.1-71.6 degrees. Trail networks are seen in black. Trails generally occupy slopes between 0-30 degrees.

Chapter 4 Results

4.1 Introduction

Results from remote sensing, GIS, and statistical analyses are found in this chapter. The summations of points of interest are found in section 4.2. Section 4.3 includes both road and trail length and density within each land cover type. Finally, section 4.4 includes both road and trail length and density within each DEM class, in addition to total area of land cover type within each DEM class.

4.2 Points of Interest

Data collected from each layer of features identified 218 campsites, 64 water bodies, 63 wellheads, 43 logged sites, 18 areas with unknown human disturbance, and 55 parking areas (Figure 4.1). These points are often connected to roads and trails.

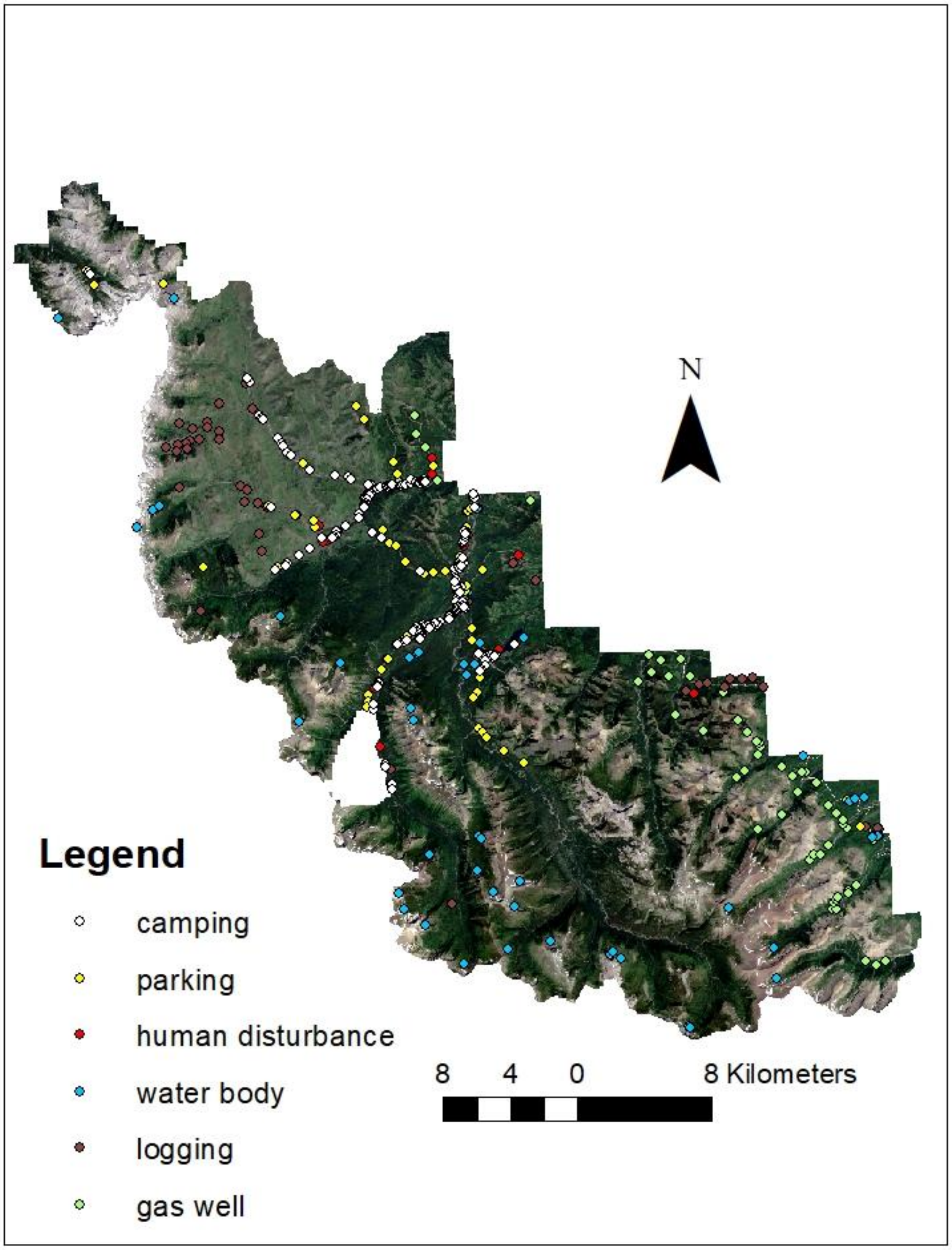


Figure 4.1: Points of interest found within The Castle Parks. Camping points = white, parking = yellow, human activity = red, water bodies = blue, logging = brown, and gas wells = green. At the northern end of The Castle Parks there are little features, in the middle there are predominantly camping, parking and logging features, and at the southern end there are predominantly well and water body features.

4.3 Road/Trail Length and Density

Within The Castle Parks there were 1628.86 km of total roads and trails (Figure 4.3); the Castle Provincial Park had a total combined road/trail network of 858.91 km (Table 4.1, Figure 4.2), and the Castle Wildland Provincial Park had a total combined road/trail network of 769.95 km (Table 4.2, Figure 4.2). In addition, width was determined by using the measuring tool from ArcGIS with the Landsat image. In The Castle Parks area the concrete road is widest (10.5m), followed by gravel (9m), dirt (4m), heavy trails (2.5m), and the narrowest is light trails (1.8m).

Table 4.1 Length of roads and trails within The Castle Provincial Park

Road/Trail Type	**Length in km**
Paved Roads	13.30 (1.55%)
Gravel Roads	95.12 (11.07%)
Dirt Roads	**212.88 (24.78%)**
Heavy Trails	87.89 (10.23%)
Light Trails	**449.72 (52.36 %)**

Table 4.2 Length of roads and trails within The Castle Wildland Provincial Park

Road/Trail Type	**Length in km**
Paved Roads	0
Gravel Roads	67.94 (8.82%)
Dirt Roads	**215.00 (27.92%)**
Heavy Trails	49.7 (6.45%)
Light Trails	**437.30 (56.80%)**

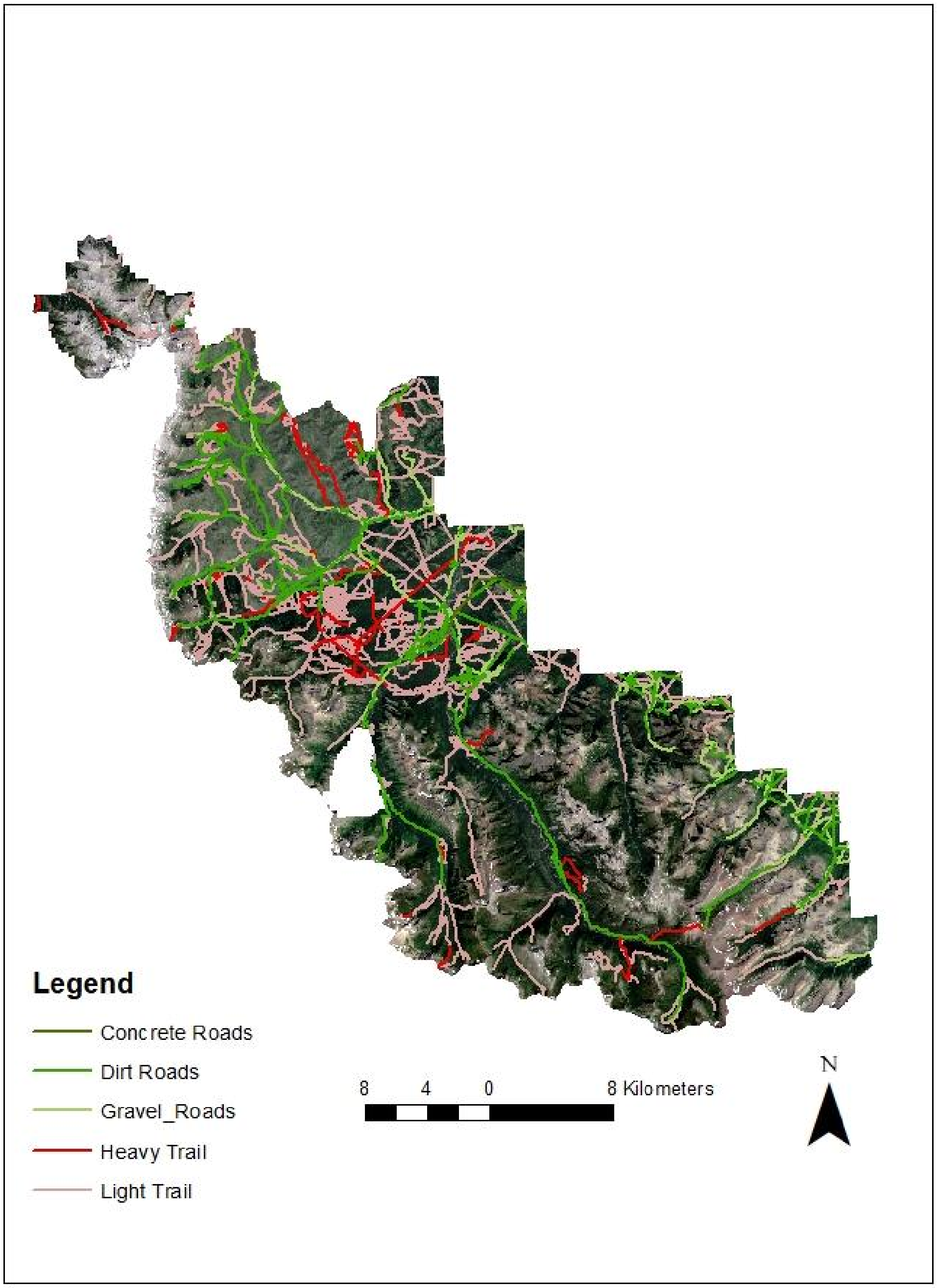


Figure 4.2 The Castle Parks with identified road and trail networks.

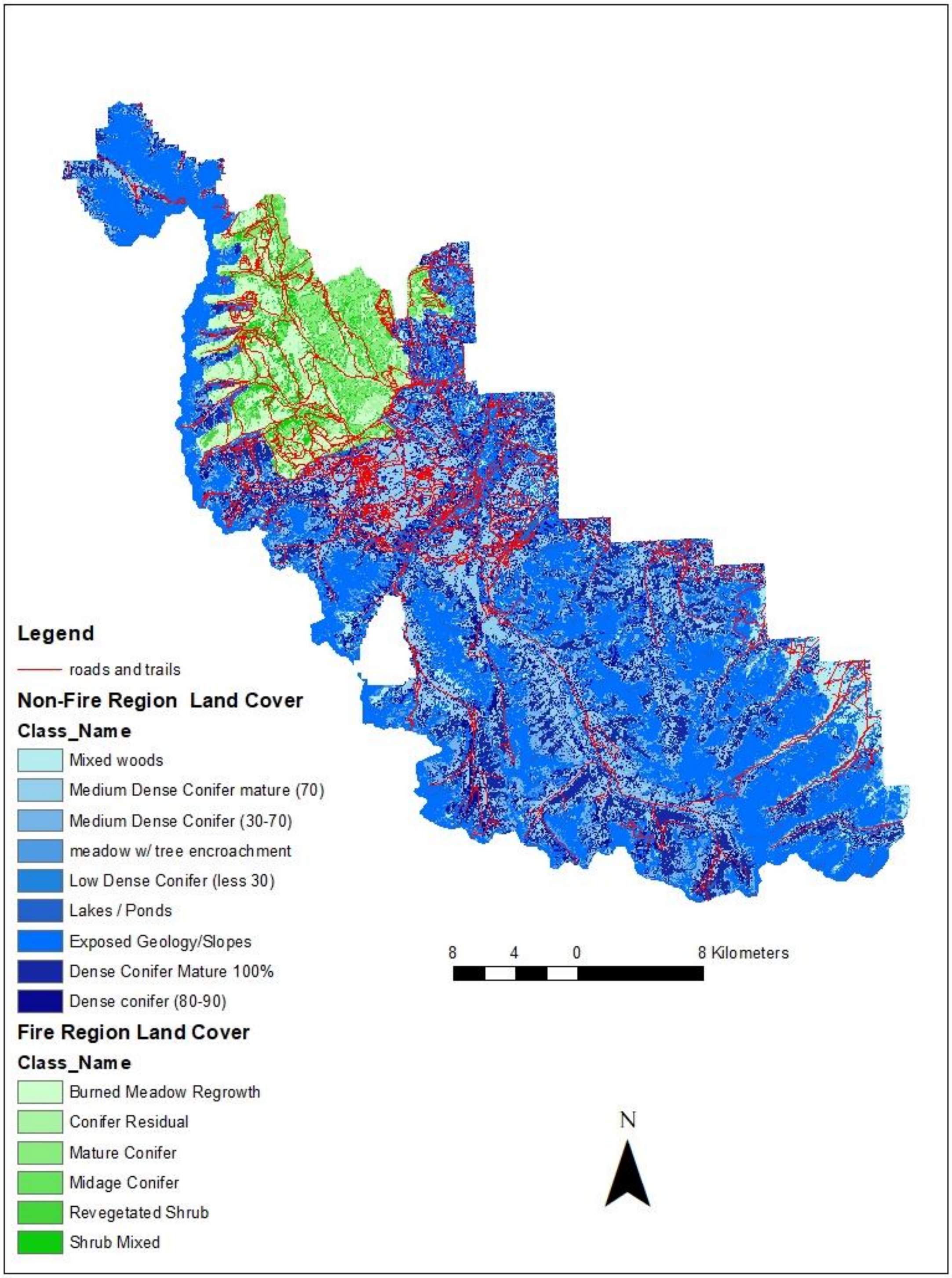


Figure 4.3 This image of The Castle Parks illustrates the locations of roads and trails in red, over the land cover for both the fire region and non-fire region.

Within the fire region of The Castle Parks there was a total combined road and trail length of 400.14 km, light trails and dirt roads dominated the fire region compared to other road and trail types (Table 4-3). Within the non-fire region of The Castle Parks there was a total combined road and trail length of 1388.64 km with (Table 4-4). Light use trails were predominantly longer than other road or trail types.

Within the fire region, the highest densities of linear features were found to be light trails within conifer residual (1.79 km/km^2), mid-age conifer (1.50 km/km^2, shrub mix (1.50 km/km^2), and burned meadow regrowth (1.49 km/km^2) (Table 4.5). Within the non-fire region, the highest densities were found to be light trails within medium dense conifer residual (1.70 km/km^2), dense conifer (1.66 km/km^2), and mixed woods (1.21 km/km^2) (Table 4.6).

Table 4.3 Road and trail linear kilometer associated with each cover type from the fire region of The Castle Parks. The Burned Meadow Regrowth classification had the greatest linear kilometers of trail and roads. Light trails occurred in greatest amounts in all cover classes.

Land Cover	**Concrete Road (km)**	**Gravel Road (km)**	**Dirt Road (km)**	**Heavy Trails (km)**	**Light Trails (km)**	**Total (km)**
Mature Conifer	0	1.83 (0.05%)	5.85 (1.46%)	5.37 (1.34%)	18.81 (4.70%)	31.86
Midaged Conifer	0	0.87 (0.02%)	13.62 (3.40%)	1.83 (0.46%)	22.83 (5.71%)	39.15
Shrub Mix	0	1.47 (0.04%)	21.6 (5.40%)	4.2 (1.05%)	31.56 (7.89%)	58.83
Revegetated Shrub	0	7.65 (0.19%)	9.84 (2.46%)	5.46 (1.36%)	14.61 (3.66%)	37.56
Burned Meadow Regrowth	0	15.12 (0.38%)	**72.42** **(18.91%)**	19.8 (4.95%)	**96.78** **(24.19%)**	**204.12** **(51.01%)**
Conifer Residual	0	0.66 (0.16%)	6.84 (1.71%)	1.8 (0.45%)	19.32 (4.83%)	28.62
Total	**0**	**27.6**	**130.17**	**38.46**	**203.91** **(50.96%)**	**400.14**

Table 4.4 Road and trail linear kilometer associated with each cover type from the non-fire region of the Castle Parks. The Medium Dense Conifer classification had the highest light trail use and generally exhibited long linear transportation networks second to the exposed geology classification. Light trails occurred in greatest amounts in all cover classes except where there was tree encroachment into meadows.

Land Cover	**Concrete Road(km)**	**Gravel Road(km)**	**Dirt Road(km)**	**Heavy Trails(km)**	**Light Trails (km)**	**Total (Km)**
Dense Conifer Mature	0.15 (0.01%)	2.4 (0.17%)	6.66 (0.48%)	7.14 (0.51%)	69.42 (5.00%)	85.77
Medium Dense Conifer Mature	0.45 (0.03%)	7.56 (0.54%)	48.57 (3.50%)	37.17 (2.68%)	**258.81 (18.64%)**	**352.56 (25.39%)**
Medium Dense Conifer	0.15 (0.01%)	7.11 (0.51%)	13.92 (1.00%)	5.4 (0.39%)	25.68 (1.85%)	52.26
Dense Conifer	0.72 (0.05%)	9.51 (0.68%)	37.53 (2.70%)	23.19 (1.67%)	**165.24 (11.90%)**	236.19
Exposed Geology	4.62 (0.33%)	63.75 (4.59%)	**111.21 (8.00%)**	31.11 (2.24%)	**236.34 (17.01%)**	**447.03 (32.19%)**
Mixed Woods	1.35 (0.10%)	15.87 (1.14%)	36.96 (2.66%)	3.57 (0.26%)	45.9 (3.31%)	103.65
Meadow with tree encroachment	1.71 (0.12%)	35.88 (2.58%)	36.06 (2.60%)	7.47 (0.54%)	30.03 (2.16%)	111.15
Total	**9.15**	**142.08**	**290.91 (20.95%)**	**115.05**	**831.42 (59.87%)**	**1388.61**

Table 4-5: Road and trail density associated with each cover type from the fire region of. The Castle Parks. This data table is color coded to show greatest trail density in dark blue, followed by medium blue, and then grey-blue. Due to canopy density the trail volumes may not have been completely observable, thus some trails may not have been mapped, resulting in potentially higher densities in these forested areas.

Land Cover	**Concrete Road km/km^2**	**Gravel Road km/km^2**	**Dirt Road km/km^2**	**Heavy Trails km/km^2**	**Light Trails km/km^2**	**Total km/km^2**
mature conifer	0	0.0743	0.238	0.218	0.764	1.29
midage conifer	0	0.0573	0.897	0.121	1.50	2.58
shrub mix	0	0.070	1.024	0.199	1.50	2.79
revegetated shrub	0	0.533	0.686	0.381	1.02	2.62
burned meadow regrowth	0	0.232	1.11	0.304	1.49	3.14
conifer residual	0	0.0613	0.635	0.167	1.79	2.65

Table 4-6: Road and trail density associated with each cover type from the non-fire region of The Castle Parks. This data table is color coded to show greatest trail density in dark blue, followed by medium blue, and then grey-blue.

Land Cover	**Concrete Road km/km^2**	**Gravel Road km/km^2**	**Dirt Road km/km^2**	**Heavy Trails km/km^2**	**Light Trails km/km^2**	**Total km/km^2**
Dense Conifer Mature	0.00162	0.0260	0.0721	0.0773	0.751	0.928
Medium Dense Conifer Mature	0.00295	0.0495	0.318	0.244	1.70	2.13
Medium Dense Conifer	0.00216	0.102	0.200	0.0777	0.369	0.751
Dense Conifer	0.00725	0.0957	0.378	0.233	1.66	2.37
Exposed Geology	0.0118	0.162	0.283	0.0792	0.602	1.14
Mixed Woods	0.0355	0.417	0.971	0.0938	1.21	2.73
Meadow with tree encroachment	0.0380	0.798	0.802	0.166	0.668	2.47

4.4 Digital Elevation Model

The total square kilometers for each DEM class within The Castle Parks are summarized in Table 4.7. Slopes of 10.1-20 degrees were the most predominate hillslopes in the study area, followed by 0-10 degrees slopes, 20.1-30 degrees slopes, and the remaining about 4% of the land area had greater than 40 degrees slopes. Total road and trail lengths for each DEM slope class with The Castle Parks are summarized in Table 4.8a, b and c. Total road and trail densities for each DEM slope class are summarized in Table 4.9a, b and c. The total area of land cover type in each DEM slope class is summarized in table 4.10 for the fire region and table 4.11 for the non-fire region.

Table 4.7 Total square kilometers of roads and trials combined for each DEM slope class within The Castle Parks. The greatest volume of total roads and trails are found between slope angles of 0 – 40 degrees.

Slope Class	**Square km**
0-10 degrees	271.40 (25.96%)
10-20 degrees	348.46 (33.33%)
20-30 degrees	248.60 (23.78%)
30-40 degrees	**139.31 (13.33%)**
40-50 degrees	32.16 (3.08%)
50-60 degrees	5.10 (0.49%)
60-71.6 degrees	0.45 (0.43%)

Table 4.8a Total road and trail lengths for each DEM slope class within The Castle Parks. This data table is color coded to show greatest trail density in dark blue, followed by medium blue, and then grey-blue. Light trails had the greatest overall length of travel corridors at slopes between 0-20 degrees of slope. Dirt roads also exhibited multiple kilometers of length between 0-20 degrees of slope.

Slope Class	**Concrete Road km**	**Gravel Road km**	**Dirt Road km**	**Heavy Trail km**	**Light Trail km**
0-10 degrees	8.94 (0.50%)	117.63 (6.61%)	292.38 (16.42%)	**75.84 (4.26%)**	520.38 (29.23%)
10.1-20 degrees	0.15 (0.01%)	45.48 (2.55%)	114.75 (6.45%)	**62.7 (3.52%)**	431.46 (24.23%)
20.1-30 degrees	0	4.95 (0.28%)	10.14 (0.57%)	13.29 (0.75%)	**71.88 (4.08%)**
30.1-40 degrees	0	0.42 (0.02%)	0.60 (0.03%)	1.11 (0.06%)	7.5 (0.42%)
40.1-50 degrees	0	0	0	0	0.51 (0.03%)
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4.8b Total road and trail lengths for each DEM slope class within The Castle Provincial Park. This data table is color coded to show greatest trail density in dark blue, followed by medium blue. Light trails had the greatest overall length of travel corridors at slopes between 0-20 degrees of slope. Dirt roads also exhibited multiple kilometers of length between 0-10 degrees of slope.

Slope Class	**Concrete Road km**	**Gravel Road km**	**Dirt Road km**	**Heavy Trail km**	**Light Trail km**
0-10 degrees	8.94 (1.05%)	8.34 (0.98%)	164.07 (19.36%)	57 (6.73%)	293.61 (35.65%)
10.1-20 degrees	0.15 (0.02%)	19.5 (2.30%)	38.67 (4.56%)	33.93 (4.00%)	190.77 (22.51%)
20.1-30 degrees	0	1.59 (0.19%)	1.38 (0.16%)	7.32 (0.86%)	21.03 (2.48%)
30.1-40 degrees	0	0	0.12 (0.16%)	0.39 (0.05%)	0.66 (0.78%)
40.1-50 degrees	0	0	0	0	0
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4.8c Total road and trail lengths for each DEM slope class within The Castle Wildland Provincial Park. This data table is color coded to show greatest trail density in dark blue and bold. Light trails and roads had the greatest overall length of travel corridors at slopes between 0-20 degrees of slope. Dirt and gravel roads also exhibited multiple kilometers of length between 0-10 degrees of slope

Slope Class	**Concrete Road km**	**Gravel Road km**	**Dirt Road km**	**Heavy Trail km**	**Light Trail km**
0-10 degrees	0	**109.26 (11.72%)**	**128.31 (13.78%)**	18.84 (2.02%)	226.77 (24.32%)
10.1-20 degrees	0	25.98 (2.79%)	76.08 (8.16%)	28.77 (3.08%)	240.69 (25.81%)
20.1-30 degrees	0	3.36 (0.36%)	8.76 (0.94%)	5.97 (0.64%)	50.85 (5.45%)
30.1-40 degrees	0	0.42 (0.05%)	0.48 (0.05%)	0.72 (0.08%)	6.84 (0.73%)
40.1-50 degrees	0	0	0	0	0.51 (0.54%)
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4.9a Total road and trail density for each DEM slope class within The Castle Parks. This data table is color coded to show slopes with greatest density of linear features in blue. Light trails had high corridor densities between 0 -20 degrees of slope. Dirt road densities were substantial on 0-10 degree slopes.

Class	**Concrete Road km/km^2**	**Gravel Road km/km^2**	**Dirt Road km/km^2**	**Heavy Trail km/km^2**	**Light Trail km/km^2**
0-10 degrees	0.03	0.43	1.08	0.28	1.92
10.1-20 degrees	0	0.13	0.33	0.18	1.24
20.1-30 degrees	0	0.02	0.04	0.05	0.29
30.1-40 degrees	0	0	0	0.01	0.05
40.1-50 degrees	0	0	0	0	0.02
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4.9b Total road and trail density for each DEM slope class within The Castle Provincial Park. This data table is color coded to show slopes with greatest density of linear features in blue. Light trails had high corridor densities between 0 -20 degrees of slope. Dirt road densities were substantial on 0-10 degree slopes.

Class	Concrete Road km/km^2	Gravel Road km/km^2	Dirt Road km/km^2	Heavy Trail km/km^2	Light Trail km/km^2
0-10 degrees	0.07	0.06	1.23	0.43	2.20
10.1-20 degrees	0	0.20	0.39	0.34	1.93
20.1-30 degrees	0	0.08	0.07	0.35	1.02
30.1-40 degrees	0	0	0.14	0.45	0.76
40.1-50 degrees	0	0	0	0	0
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4.9c Total road and trail density for each DEM slope class within The Castle Wildland Provincial Park. This data table is color coded to show slopes with greatest density of linear features in blue. Light trails had high corridor densities between 0 -20 degrees of slope. Dirt road densities were substantial on 0-10 degree slopes.

Class	Concrete Road km/km^2	Gravel Road km/km^2	Dirt Road km/km^2	Heavy Trail km/km^2	Light Trail km/km^2
0-10 degrees	0	0.80	0.93	0.14	1.65
10.1-20 degrees	0	0.10	0.31	0.12	0.97
20.1-30 degrees	0	0.01	0.04	0.03	0.22
30.1-40 degrees	0	0	0	0.01	0.05
40.1-50 degrees	0	0	0	0	0.02
50.1-60 degrees	0	0	0	0	0
60.1-71.6 degrees	0	0	0	0	0

Table 4-10: Area of land cover and DEM slope class in square kilometers within the fire region of The Castle Parks. This data table is color coded to show greatest land cover type in dark blue, followed by medium blue. Burned Meadows exhibited the greatest amount of total cover occurring on 0-20 degree slopes. Mature conifer exhibited 13.03 km^2 on 10-20 degree slopes.

Land Cover	**0-10 degrees km^2**	**10.1-20 degrees km^2**	**20.1-30 degrees km^2**	**30.1-40 degrees km^2**	**40.1-50 degrees km^2**	**50.1-60 degrees km^2**	**60.1-71.6 degrees km^2**
mature conifer	5.4 (3.59%)	13.03 (8.66%)	5.62 (3.74%)	0.24 (0.16%)	0	0	0
Midage conifer	5.5 (3.66%)	8.00 (5.32%)	1.61 (1.07%)	0.05 (0.03%)	0	0	0
shrub mixed	9.4 (6.25%)	9.87 (6.57%)	1.73 (1.15%)	0.04 (0.03%)	0	0	0
revegetated shrub	4.9 (3.26%)	5.84 (3.89%)	3.02 (2.01%)	0.45 (0.30%)	0.05 (0.03%)	0	0
burned meadow	22.7 (15.09%)	30.79 (20.47%)	9.87 (6.57%)	1.45 (0.96%)	0.09 (0.06%)	0	0
conifer residual	3.1 (2.06%)	6.46 (4.29%)	1.12 (0.75%)	0.07 (0.05%)	0	0	0

Table 4-11: Area of land cover and DEM slope class in square kilometers within the non-fire region of The Castle Parks. This data table is color coded to show greatest land cover type in dark blue, followed by medium blue, and then grey-blue. Exposed geology had the greatest volume area (360 km^2) occurring between 0-40 degree slopes with 112.8 km^2 on 10-20 degree slopes. Medium dense mature conifer exhibited 64.4 km^2 on 0-10 degree slopes.

Land Cover	**0-10 degrees km^2**	**10.1-20 degrees km^2**	**20.1-30 degrees km^2**	**30.1-40 degrees km^2**	**40.1-50 degrees km^2**	**50.1-60 degrees km^2**	**60.1-71.6 degrees km^2**
Lakes/ponds	1.2 (0.13%)	0.9 (0.10%)	2.0 (0.22%)	3.8 (0.43%)	2.9 (0.32%)	0.81 (0.09%)	0.11 (0.01%)
dense conifer mature	16.6 (1.86%)	**37.7 (4.22%)**	**27.6 (3.10%)**	8.9 (1.00%)	1.0 (0.11%)	0.09 (0.01%)	0.00
Medium dense conifer mature	64.4 (7.21%)	**58.5 (6.55%)**	23.1 (2.59%)	5.3 (0.59%)	0.4 (0.04%)	0.01 (0.00%)	0.00
Medium dense conifer	12.4 (1.39%)	24.9 (2.79%)	20.2 (2.26%)	9.7 (1.00%)	1.6 (0.18%)	0.13 (0.01%)	0.01 (0.00%)
Dense conifer	36.6 (4.10%)	38.1 (4.27%)	18.6 (2.08%)	4.9 (0.55%)	0.4 (0.04%)	0.02 (0.00%)	0.00
Exposed geology	63.9 (7.16%)	88.1 (9.87%)	112.8 (12.63%)	94.7 (10.61%)	24.8 (2.78%)	3.98 (0.45%)	0.34 (0.04%)
Mixed woods	14.6 (1.63%)	14.1 (1.58%)	6.7 (0.75%)	1.6 (0.18%)	0.1 (0.00%)	0.00	0.00
Meadow with tree encroachment	8.8 (1.00%)	**11.9 (1.33%)**	**14.7 (1.65%)**	8.1 (0.91%)	0.7 (0.08%)	0.05 (0.01%)	0.00

Chapter 5 Findings and Recommendations

5.1 Introduction

Analysis and discussion of results from the remote sensing and GIS are presented in this chapter. This chapter begins with a discussion of the impact points of interests have on The Castle Parks and study species. Section 5.3 then discusses the effects of fragmentation, followed by section 5.4 which discusses how slope and elevation affect the keystone and umbrella species investigated in this region.

5.2 Points of Interest

A visual assessment of human impact points and the trail network, primarily in areas of high trail density, indicate a strong relationship between the trails and roads and specific human points of interest (Figure 5.1). The greatest volume of both human land use points of interest and transportation network is found within the Provincial Park region. Consequently, designating this area as a traditional Provincial Park was a prudent decision. However, the combined dense human activities that include, camping, hiking, OHV use, fishing, Castle Resort use, and other actions, create a bottleneck for animal movement north and south along the cordillera as well as east and west migration to and from the foothills at lower elevations. Logging and gas well sites often exhibit a heavy network of roads and trails surrounding them, indicating that established roads allow back country users deeper access to the forest than areas where these formal road networks are absent. Specifically, light trails and dirt roads were seen surrounding logging sites (Figure 5.2) and camping sites; light trails and gravel roads were seen surrounding gas well sites; gravel roads were seen near random parking spots; light trails were seen leading to water bodies; and both gravel and dirt roads were observed and documented surrounding unknown human disturbances. Light trails within logged areas could influence revegetation and inhibit some species occupation (Ouren et al., 2007). The land near the southwestern corner of The Castle Parks is so heavily fragmented by gas wellheads and associated roads/trails (Figure 5.3) that the suitability of this location for some species may be compromised in the valleys by the activities taking place here, particularly if the animals need to migrate into the foothills. Further, study in this area is needed to determine the sensitivity of species to the fragmentation in this area.

Initial analysis indicated that the gravel roads have encouraged heavy trail use, trials that could clearly be seen from a 1:10,000 scale image and had clear erosion characteristics. It also appears that one particular road in the south end of the Wildland Park allows access to the inner valley as evidenced by a connecting heavy use trial. Studies on trail use and animal use should be undertaken to determine if limits to access should be made here or if the area should be designated Provincial Park. If research does indicate that the roads have encouraged heavy trail use to occur into the interior valley, measures should be taken to curtail the activity. Erosion from both the south and the north ends of the valley could fragment the park in an east west direction along the Castle Valley. Any future resource extraction should not be allowed within The Castle Wildland Provincial Park.

Passive observation of land use change was conducted while digitizing roads and trails, and identifying points of interest. Images from Google Earth allowed specific locations to be observed across time. Time frames for particular locations ranged in date based on location and cloud cover. Absolute dates of land use origination or termination cannot be acquired from static satellite images, but future estimates can be made. Observed land use change over time included forest recovery from logging activities, active or recent forest logging, informal camping at various times, gas well establishment, signs of ranching, amongst other unidentifiable human constructed features. Most common land use change was witnessed as the expansion of random camping within and adjacent to the Provincial Park (Figure 5.4).

Generally, the area of occupation of individual campsites expanded with inclusion of more camping structures at informal, established camp locations. Future studies are recommended to monitor the changes in area of these camp locations over time to determine camping occupation trends.

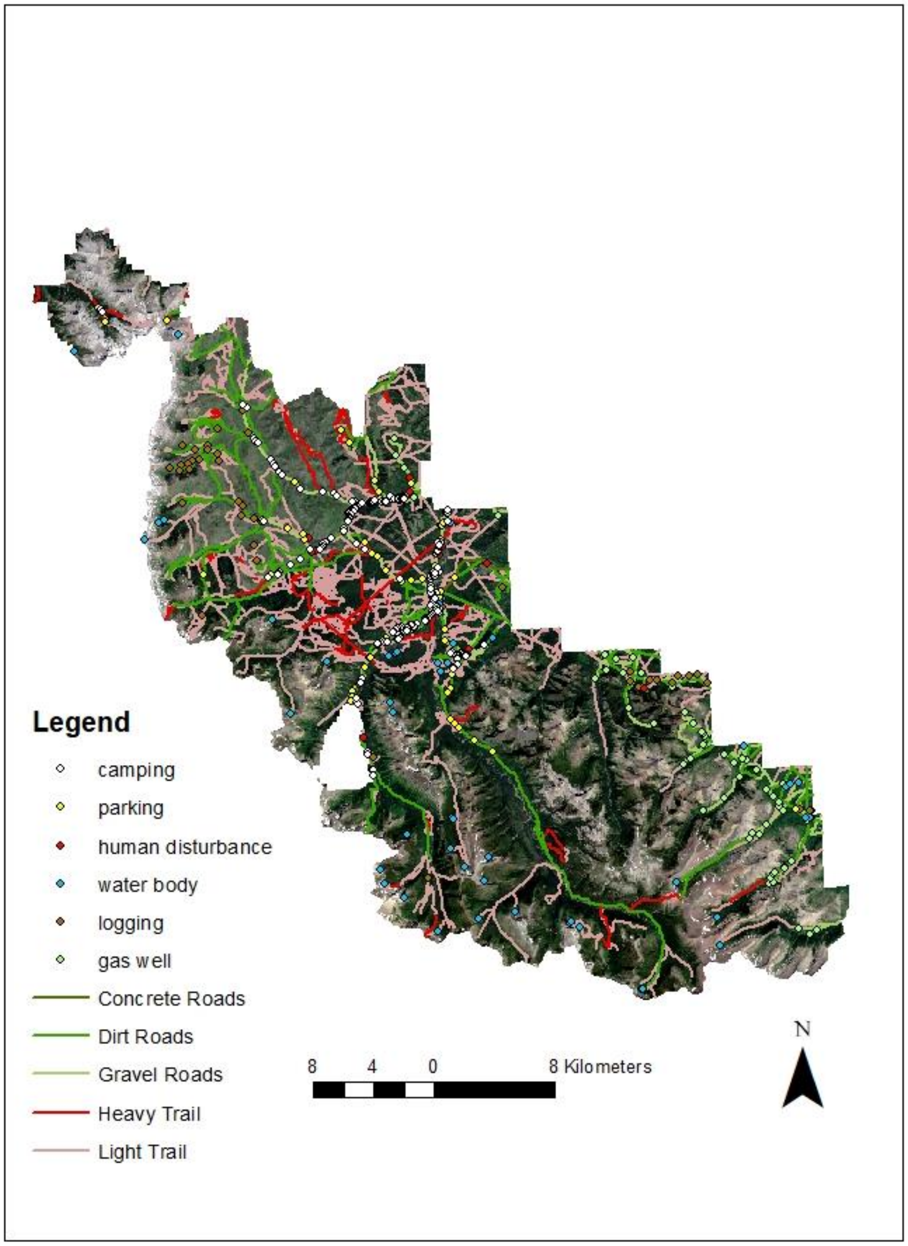


Figure 5.1 Points of interest with road and trail network in The Castle Parks. Camping = white, parking = yellow, human activity = red, water body = blue, logging = brown, gas well = light green, concrete roads = dark green, dirt road = light green, gravel roads = medium green, heavy trails = red, and light trails = pink. Roads and trails are often found close to points of interest. Strong visual correlations are evident between trail use and camping as well as water bodies.

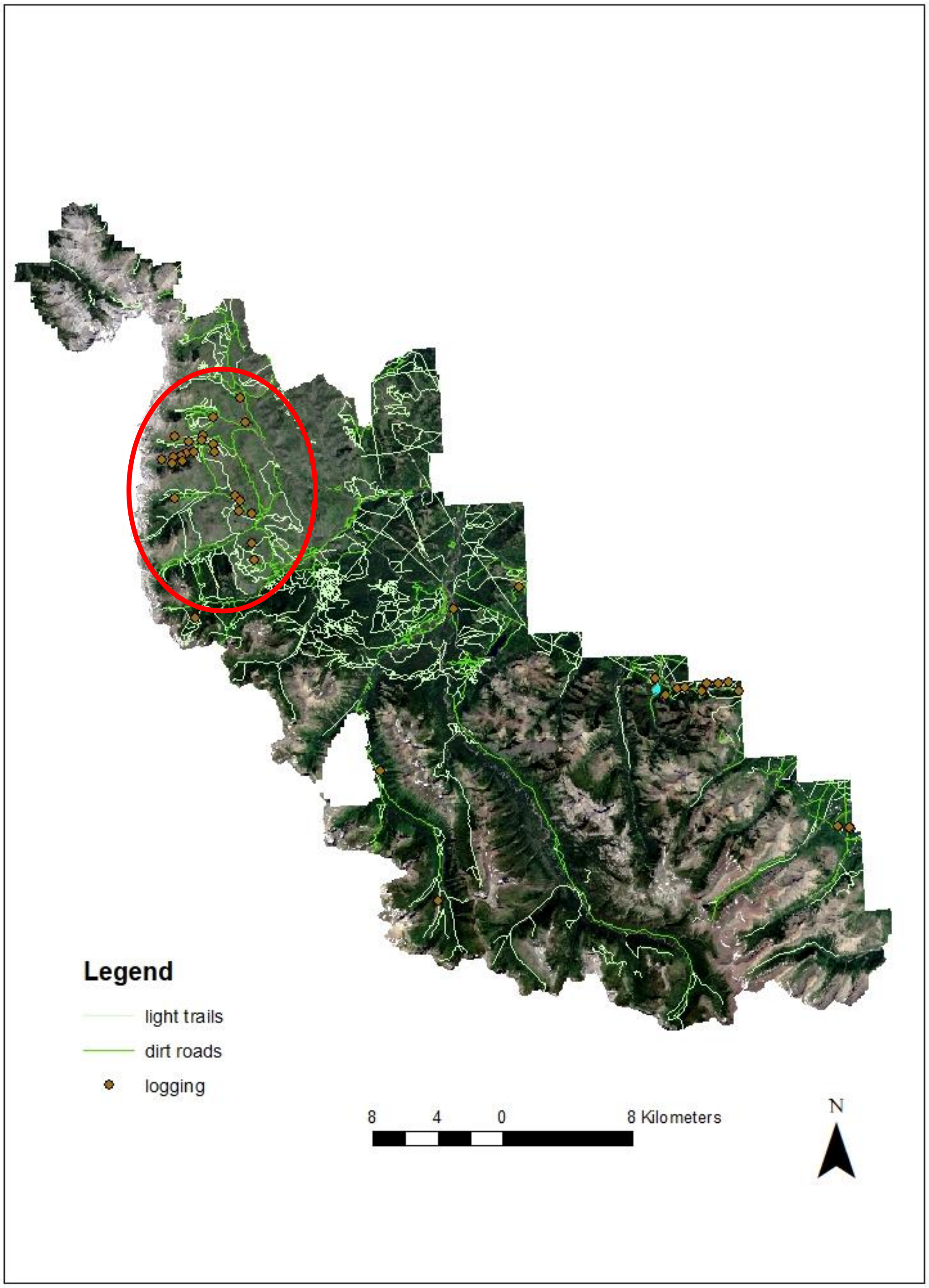
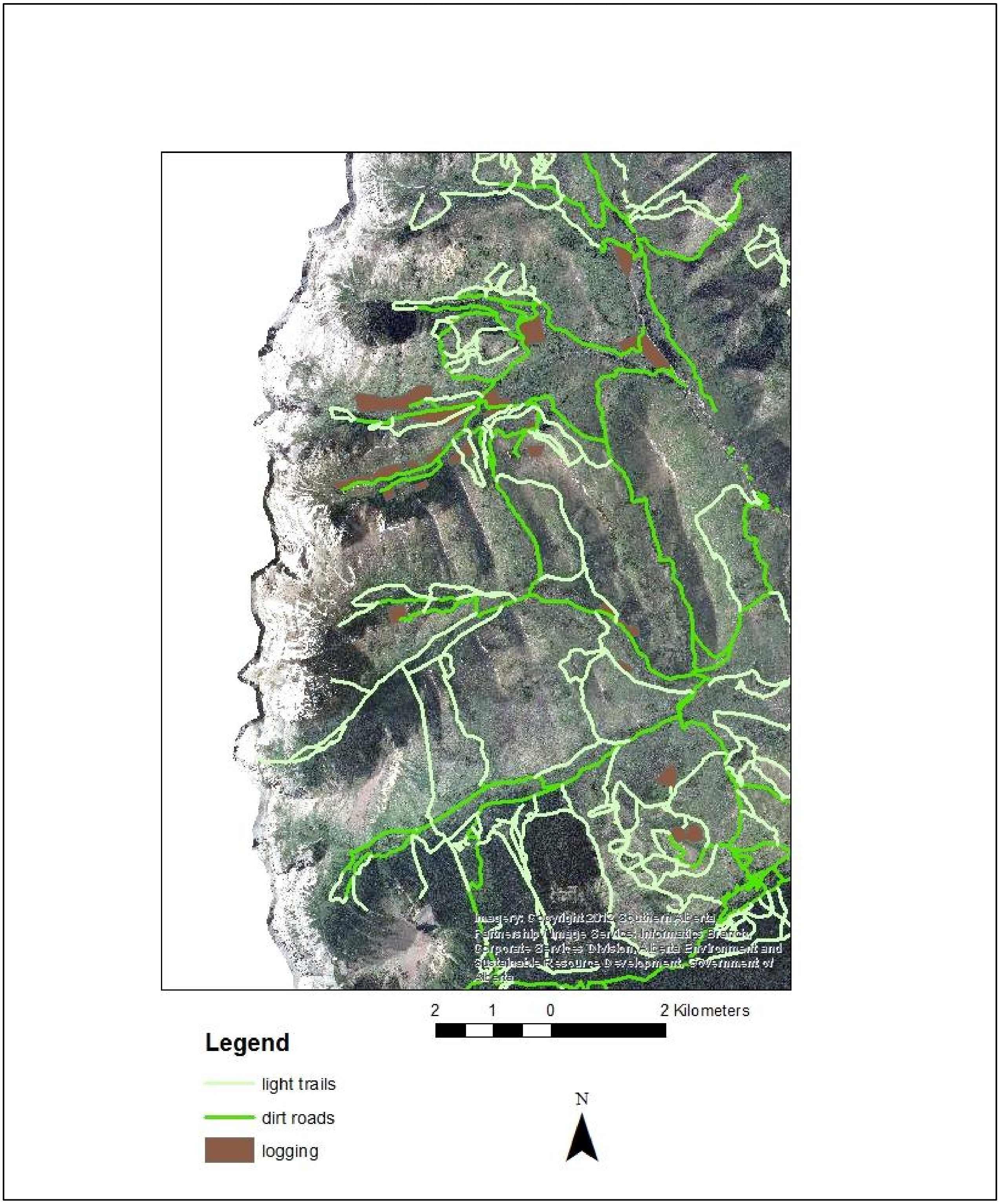


Figure 5.2a Primary location of logging within The Castle Parks, based on visual analysis of logging sites. Light trails = light green, dirt roads = green, logging = brown, and red= primary logging location. Figure 5.2b shows an enlarged image of the circled region.



Imagery: Copyright 2012 Southern Alberta Partnership / Image Services, Informatics Branch, Corporate Services Division, Alberta Environment and Sustainable Resource Development, Government of Alberta

Figure 5.2b Light trails and dirt roads near logging sites in The Castle Wildland Provincial Park. Light trails = light green, dirt roads = dark green, and logging sites = brown (digitized) in The Castle Wildland Provincial Park. Strong visual evidence indicates relationship between logging access roads and trail formation.

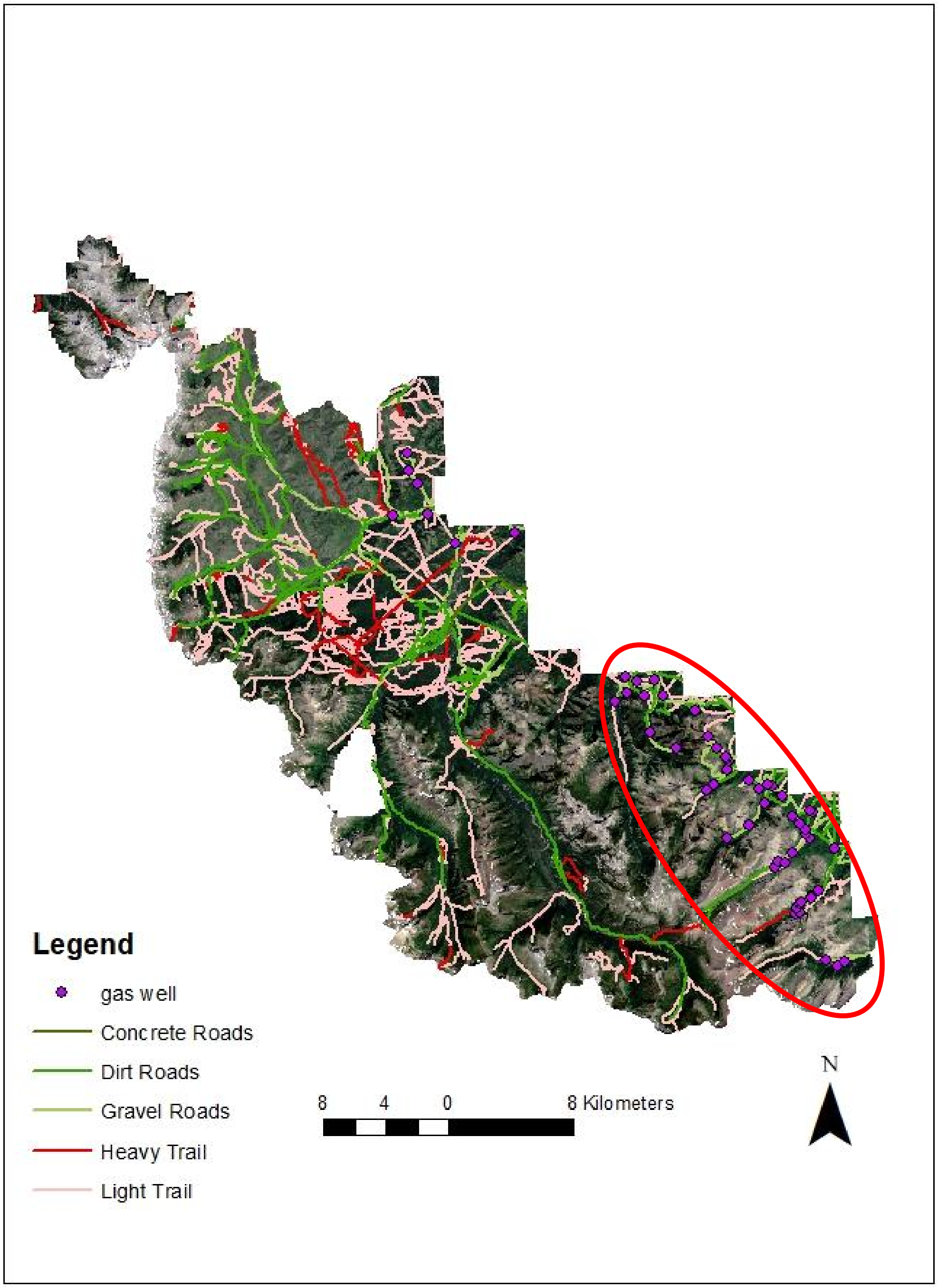


Figure 5.3a Location of heavy fragmentation near gas wells within The Castle Parks. Gas wells = purple, dirt roads = light green, gravel roads= green, heavy trails = red, light trails = pink, and red circled region= gas well region. Figure 5.3b shows a close up of circled region.

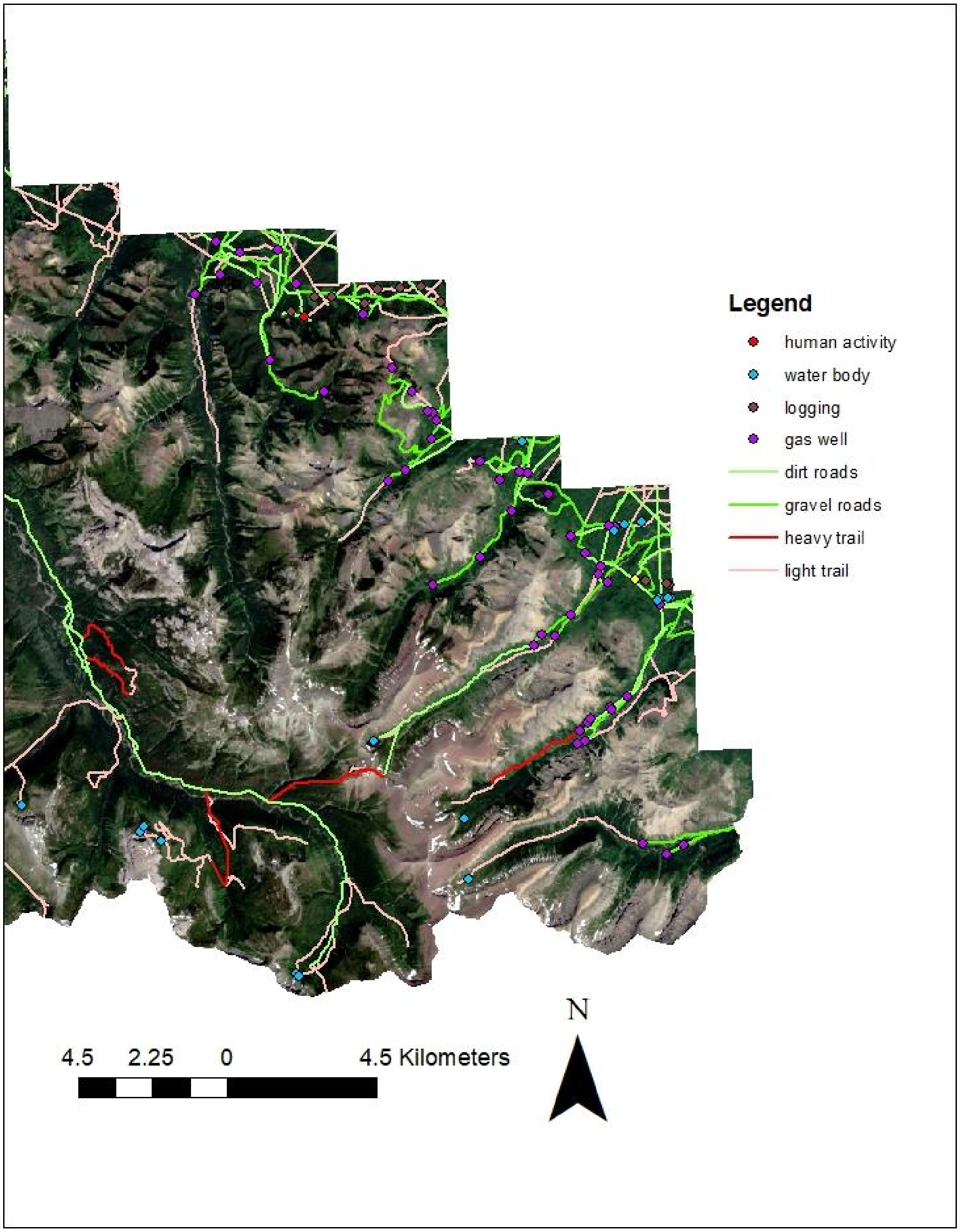


Figure 5.3b Heavy fragmentation near gas wells in The Castle Wildland Provincial Park. Human activity = red, water body = blue, login = brown, gas well = purple, dirt roads = light green, gravel roads =green, heavy trails = red and light trails = pink. The eastern portion of this image is unsuitable for wildlife due to heavy fragmentation. Strong visual evidence indicates relationship between gas access roads and trail formation.

The majority of non-regulated camping sites do fall within The Castle Provincial Park, which aims to offer front country experiences like camping (Alberta Government, 2017). However, eight possible non-regulated camping sites were identified by visual analysis, in The Castle Wildland Provincial Park, which will not allow camping in the future (Figure 5.4). These eight counted sites should be closed, in addition to posting nearby "no camping" signs and close monitoring by park officials. Campsites approaching the boarder of the Wildland Park should also be closed to inhibit future vehicle access into the Wildland Provincial Park.

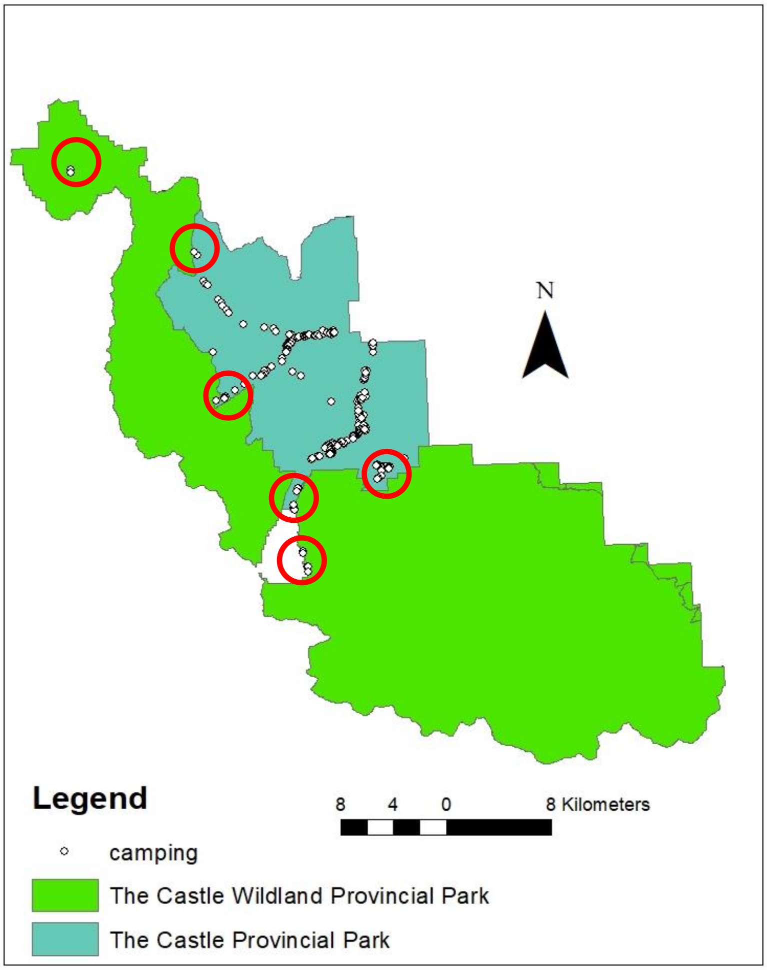


Figure 5.4 Camping sites within The Castle Parks. Camping sites = white, The Castle Wildland Provincial Park = light green, and The Castle Provincial Park = turquois. The red circles identify points outside The Castle Provincial Park and Points approaching the boarder.

The current points of interest should be used to identify heavily occupied areas. The campsites, parking spots and water bodies should be evaluated to determine human use. The sites with the most human use should be considered for a location to set up an educational station. At the station, maps should be available to show allowed access points and which activities are available in each park, such as hiking trails. There should be a clear explanation of what activities are allowed within the Provincial Park versus the Wildland Provincial Park. An additional brochure could educate visitors on the effect of fragmentation on the ecosystem, and the importance of maintaining a healthy ecosystem.

5.2.1Grizzly Bears

In years of low food sources, grizzly bears roam closer to humans in search of food (Mattson, Blanchard and Knight, 1992). This may cause bears to roam closer to camp sites. It is necessary to take precautions to avoid drawing bears into camp sites, and The Provincial Park. All camp sites should have bear boxes to store food and scented products, like shampoo, to limit grizzly bear encounters. Random access camping puts bears and people in danger during years when food is limited for bears.

5.2.2 Wolverine

Wolverines are very reclusive animals that require undisturbed habitat to survive and typically, avoid human activity (Leckie, 2002). To minimize human activity within The Castle Wildland Provincial Park, human activity points should either be closed or closely monitored. All unknown human disturbance points in the Wildland Provincial Park should be evaluated to see if it is necessary for these activities to stay within the Wildland Provincial Park. If it is not necessary, the activity should be closed, or moved to the Provincial Park. It is clear from the GIS analysis that water bodies draw visitors into the Wildland Provincial Park, as there are many trails leading to them. To allow undisturbed habitat for wolverines, ideally, the higher elevation lakes should be avoided in the summer, while the lower elevation lakes should be avoided in the winter. Signage should be posted to warn of sensitive habitat and discourage recreation based on this sensitivity. The resource sites including, gas wells and logging areas, should be limited to resource extraction and preclude other human activities. Future resource extraction should not be allowed within The Castle Wildland Provincial Park.

5.2.3 Cougars

Cougars require habitat with limited unknown human disturbance and avoid areas with buildings and wellheads (Alberta Government, 2012). As stated above, the fragmentation due to wellheads in the southeast end of The Castle Wildland Provincial Park is extensive. Similar to wolverine recommendations, human activity should be minimized and monitored in prime cougar habitat, including areas with unknown human disturbance, camping, parking and access to water bodies. However, logging sites may actually be seen as useful for cougars, as cutting forests creates edges for cougars to hunt (Alberta Government, 2012). Thus, areas of logging which have encouraged dense trails pose a particular area of potential conflict between humans and cougars.

5.2.4 Elk

No particular point of interest is considered a direct threat to the elk population; however elk avoid areas fragmented by roads (Rowland, Wisdom, Johnson and Kie, 2000). Resource extraction creates the most roads within The Castle Wildland Provincial Park. The road network is the densest in the lower slopes of the parks where elk are more likely to be found. To limit these roads, resource extraction should be closed if possible, and limited from future development.

5.3 Lengths of Transportation Network

A measured 1788.57 km of roads and trails cross The Castle Parks, 1366.81 km traverse the area which was not burned and 399.96 km dissect the Lost Creek Fire area. The greatest densities of network corridors are within the proposed Provincial Park, followed by the Lost Creek Fire area, and then the gas well extraction area to the south east, within the Wildland park (Figure 4.3 and 4.4). Network densities were distinguished between trail and road type within each land cover type. Densities ranged from the complete absence of paved roads in the burned area to a density of 1.79 km/km^2 of light trails within residual conifer stands, also in the burned area. Travel corridors were also measured across slopes to determine if slope angle inhibited transportation. The greatest lengths of road and trail networks were on the lowest slopes, between 0 and 20 degrees. Slopes greater than 50 degrees had no observable transportation networks.

Over 27 km of gravel roads allow access into the Lost Creek Fire area, bringing both hikers and OHV users. Total burned meadow regrowth has the overall highest linear kilometers (204.12 km) of transportation network, than any of the other vegetation areas. This could be due to proximity of human related activities and the ease of seeing roads/trails without a dense canopy. The density of the transportation networks, in these meadows for light trials measure 1.49 km/km^2, and 1.11 km/km^2 for dirt roads. The 96.78km of light trails in this vegetation type is particularly alarming, as healthy reestablishment is predicated on optimal conditions for early plant establishment. Overall, The Lost Creek Fire area also exhibits high dirt road densities in the mid-range conifer stands (0.897 km/km^2) and mixed shrubs (1.024 km/km^2). Light trail density is also high, ranging between 0.76 to 1.79 km/km^2 in all land cover classifications.

Within the non-fire area there are 352.56 km of travel corridors in the Medium Dense Mature Conifer woods; 25.39% of all the roads and trails in the non-fire areas of the park. Of all those roads and trials, 258.81km are light trails accounting for 18.64% of all corridors in the non-burn area. In the unburned area, meadows with tree encroachment have particularly dense dirt road (0.802 km/km^2) and gravel road (0.798 km/km^2) networks, which can account for why there are moderately high light volumes of trails as well. This could be due to lower slopes, or the ease of visually spotting trails/roads without a full canopy. Mixed woods indicate a density of 0.971 km/km^2 in the unburned area, and overall light trail density is high cross all land cover categories except medium density conifers. It should be noted that due to canopy density the trail volumes may not have been completely observable in medium density conifers stands, thus some trails may not have been mapped, resulting in potentially higher densities in all forested areas.

Soil or land compaction from trail use and development, may adversely affect the maturation of meadows or further development of tree encroachment or movement of encroaching trees into the meadow. Light trails are particularly dense across all land cover types except for mixed dense conifers. The burned meadow regrowth and shrub cover classes are particularly concerning, as these are the early stages of forest reestablishment and the trajectory of this landscape will dictate future mature vegetation types and community stand health (Harvey, Smith and Veblen, 2017). The sensitivity of landscapes revegetating, post forest fire, leads to the recommendation of limiting access to the burn area by closing access roads and posting signs to limit human activity to foot travel only.

With increased slope comes an increase in exposed geology. It is not surprising to find that the total percentage of roads/trails had the highest amount of occurrence on exposed geology, as exposed geology affords greater terrestrial visual documentation of corridors with satellite images, as the trails and roads are not camouflaged by vegetation. The high volume of corridors (447.03 km in total - 32.19% of all roads and trails; 236.34 km as light trails – 17.01% of all roads and trails and 111.21 km as dirt roads - 8% of all roads and trails) on exposed geology show a concern for sensitive ecosystems, that are highly susceptible to disturbance. The loss of these species here, such as moss and lichen, may substantially alter the trophic cascade not only in the alpine area, but across the park and extended area (Crisfield et. al., 2012). Research should be conducted to determine if OHV use is occurring in these areas. Additionally, informative and educational signs and flyers should be made available to restrict trail use where significant bedrock exposure exists.

Light trials and dirt roads are particularly prolific on slopes between 0-30 degrees. Slope angles between 0-10 had 117.63 km of gravel roads (6.61% of all roads and trails), 292.38 km dirt roads (16.42% of all roads and trails), light trails measured 520.38 km in length, or 29.23% of all roads and trails. Dirt road density on these slopes measured 1.08 km/km^2 while light trail density is 1.92 km/km^2. Slopes of 10-20 degrees had 114.75km of dirt roads (6.45% of all roads and trails), and 431.36 km of light trails or 24.23% of all roads and trails. The density of light trials at these slopes is 1.24 km/km^2. These observations associate strongly with high use areas and passive observation indicates that the greatest area of both these linear features are greatest around camping sites (Figure 5.1). Cluster analysis is required to confirm this and assess the relative distance from camping and other human features at which the density significantly diminishes. Cluster analysis, which groups data for analysis, would offer spatial information on the degree and location of trail related activities and aid in determining policies and mitigation enforcement where needed.

Dirt roads are not established by the Provincial government or private industry and are thus unplanned features developed ad hoc by recreation users to access areas of the mountain landscape. Light trails are also constructed ad hoc by recreation users and are the greatest volume of travel network type across both parks. Many, if not most, light trails appear to originate from heavy use trails or dirt roads. Like dirt roads, many heavy use trials are also constructed by recreationists. Consequently, the establishment of dirt roads and trails must be terminated to reduce continued fragmentation. This is particularly important within the burn area to allow vegetation to reestablish (Harvey et. al, 2017).

5.3.1 Effects of Fragmentation of Keystone and Umbrella Species

The primary causes of fragmentation within The Castle Parks are from human points of interest. Fragmentation from these regions decreases the area of habitat available for species, reduces connectivity, and causes species to expend more energy (Forman, 1995). Specifically within The Castle Parks, the largest fragmentation-related threats to conservation, to all study species, come from dirt roads, and light trails. To minimize trail use, signs may be posted to deny access to trails within prime habitat and season, based on species. Dirt roads no longer used by industry should be closed and allow for regrowth of vegetation. At minimum, no additional resource extraction should be allowed within the Wildland Park. If research extraction must continue, only current sites should be utilized. To minimize dirt road creation, roads no longer in use should be closed and allow for vegetation regrowth to occur.

Larger animals will cross varying road and trail widths, but at a lower rate than crossing their natural, uninterrupted habitat. Wider roads and trails are recognized as more difficult obstacles for animals, than narrow roads and trails, as road width is often a proxy for vehicle volume (Forman, 1995). The fact there is only one paved road is encouraging, located within the Provincial Park, which bisects north-south animal travel. The broad lower elevation valley that houses this road is likely an important east-west corridor to animal movement into and out of the Rockies. Each species reacts differently to road and trail fragmentation and should be considered independently with future research on the effects of this road within the valley. It is recommended that no additional paved roads be constructed within the Provincial or Wildland Parks.

A general recommendation is to limit OHV use within The Castle Parks, as OHVs bring users deep into the wilderness, creating additional trails and fragmentation. Not only does this negatively affect the large animals listed in this study, but it also negatively impacts the local vegetation. These vehicles produce trail compaction, making it difficult for vegetation to grow. OHV use also enhances erosion, which further inhibits vegetation growth over larger areas. Although beyond the scope of this research, OHV use also has damaging effects on air quality, streams, and water bodies (Ouren et al., 2007). Resource managers should consider limiting OHV use within The Castle Parks.

5.3.2 Grizzly Bears and Fragmentation

Grizzly bears prefer low density canopy areas for berry hunting, which include fire-successional communities and open landscapes. Within the Lost Creek Burn area, this includes the land covers: shrub mix, revegetated shrub, burned meadow regrowth, and conifer residual (Arc Wildlife Services, 2004). The data from this study show that concrete roads, gravel roads, and heavy trails are no particular threat to these cover types, as they are found at low densities. However, dirt roads and light trails do pose a threat (table 4-5). To improve access to berries for grizzly bears within these cover types, light trails and dirt roads should be minimized. To minimize trail use, signs may be posted to deny access to trails within conifer residual, shrub mix, burned meadow regrown, and revegetated shrub during berry season in the summer and fall. Forest fire recovery areas are particularly important bear habitat (Arc Wildlife Services, 2004). OHV use within the Lost Creek Fire area should be prohibited and signage along formal roads warning of bear occupation and revegetation sensitive landscape should be erected.

Within the non-fire region, grizzlies use the land covers of medium dense conifer mature, medium dense conifer, exposed geology, mixed woods, and meadow with tree encroachment (Arc Wildlife Services, 2004). The data from this study show that concrete roads and heavy trails are no particular threat to these cover types, due to their low density. Gravel roads, dirt roads, and light trails do pose a threat (table 4-6). The greatest threat from gravel roads are within the meadow with tree encroachment land cover classification. To minimize light trails signs should be posted to deny access to trails within medium dense conifer, mixed woods, and meadows with tree encroachment during spring through fall, and within exposed geology during spring.

5.3.3 Wolverine and Fragmentation

Wolverines are very reclusive animals that require undisturbed habitat to survive, and typically avoid human activity (Leckie, 2002). Wolverines prefer mature forests with a medium dense canopy (Arc Wildlife Services, 2004). Within the fire region of The Castle Parks, this description includes the land cover type of mature conifer and midage conifer. Data from this study show there are no threat to these cover types from concrete roads, gravel roads or heavy trails, due to low densities. Dirt roads threaten midage conifer with a density of 0.897 km/km^2. Light trails threaten mature conifer with a density of 0.76 km/km^2. To minimize light trail impact, signs should be posted to deny access to trails in the winter, when wolverines occupy lower elevations within the mature conifer stands (Carroll et al., 2001).

Within the non-fire region, wolverines occupy dense mature conifer, medium dense mature conifer, medium dense conifer, dense conifer, and exposed geology (Carroll et al., 2001). Data suggest that threats to these cover types are from light trails having a density of 0.602 km/km^2 within exposed geology, 0.751 km/km^2 within dense mature conifer, 1.66 km/km^2 within dense conifer, and 1.70 km/km^2 within medium dense mature conifer. To minimize light trail impact, signs should be posted to deny OHV access to dense mature conifer, dense conifer, and medium dense mature conifer. Signs should also be posted to deny access to trails in the summer when wolverines occupy higher elevations within exposed geology (Carroll et al., 1999).

5.3.4 Cougars and Fragmentation

Cougars prefer high forest cover to hunt and secure kitten sites (Alberta Government, 2012). Within the fire region cougars utilize mature conifer, midaged conifer, and conifer residual. The data show that concrete roads, gravel roads, and heavy trails are not a threat to these cover types, due to low densities. Dirt roads and light trails do pose a threat (Table 4.5). To minimize light trails signs should be posted to deny access to trails within conifer residual, midage conifer, and mature conifer.

Within the non-fire region cougars utilize dense mature conifer, medium dense mature conifer, medium dense conifer, dense conifer and mixed woods (Alberta Government, 2012). The data show that concrete roads, gravel roads, and heavy trails are not a threat to these cover types, due to low densities. Dirt roads and light trails do pose a threat (table 4-5). To minimize light trails, signs should be posted to deny access to trails within dense mature conifer, dense conifer, mixed woods, and dense mature conifer.

Cougars require habitat with limited human disturbance and will avoid areas with buildings and wellheads (Alberta Government, 2012). As previously stated above, the fragmentation caused by wellheads within The Castle Wildland Provincial Park is extensive on the east slopes of the park. The southern reaches of the park adjacent to these wellheads have some of the parks highest and most extensive relief, which is ideal for cougars (Alberta Government, 2012) as well as wolverines (Carroll et al., 2001). Similar to wolverine recommendations, to minimize human activity, points of interest should either be closed to OHV use or closely monitored, including unknown human disturbance, camping, parking, and access to water bodies. Logging sites may actually be useful land for cougars, as clearcutting forests creates edges for cougars to hunt (Alberta Government, 2012). These areas should be considered closed to OHV use, and signage should post warnings of the probability of cougar occupation.

5.3.5 Elk and Fragmentation

Elk avoid areas fragmented by roads (Rowland et al., 2000). Resource extraction creates the most formal roads within The Castle Wildland Provincial Park. To limit these roads, resource extraction should be closed if possible, and rejected from future development. In the summer, elk spend their time in meadows and open canopy areas foraging, while in the winter they are found within forested areas (Arc Wildlife Services, 2004). Within the fire region elk utilize mature conifer, midage conifer, shrub mix, revegetated shrub and conifer residual. The data show that concrete roads, gravel roads, and heavy trails are not a threat to these cover types, due to low densities. However, dirt roads and light trails do pose a threat (table 4-5). To minimize light trails, signs should be posted to deny access to trails during the spring and summer within burned meadow regrowth, shrub mix, and revegetated shrub. During the winter, signs should be posted to deny access to light trails within mature conifer, midage conifer, and conifer residual.

Within the non-fire region, elk utilize dense mature conifer, medium dense mature conifer, medium dense conifer, dense conifer, mixed woods, and meadow with tree encroachment. The data show that concrete roads and heavy trails pose no particular threat to these cover types, due to low densities. Gravel roads, dirt roads, and light trails do pose a threat (table 4-6). To minimize gravel roads, resource extraction roads should be closed and no future resource extraction should be permitted. To minimize light trails signs should be posted to deny access to trails within medium dense mature conifer, dense conifer, mixed woods and dense mature conifer during the winter, and deny access to trails within meadow with tree encroachment during the summer.

5.4 Landscape Slope Determined with Digital Elevation Model

Different species require various slope and elevation parameters to survive. While looking at the overall DEM model, a concern arises at the northern end of the parks. There is a small region with high elevations, creating a bottleneck effect (Figure 5.5). Not all animals prefer higher elevation sites. To allow a continuous wildlife corridor for all species, and movement throughout the park, additional land in Crowsnest Pass should be acquired to the north-east of The Castle Parks, with lower elevations. This land should first be analyzed to determine the level of fragmentation. If it could be acquired, it may need to be remediated to be suitable for wildlife. Acquiring this additional land may need extra funding. If it is not possible to purchase currently, it should be considered for a future expansion of the park system.

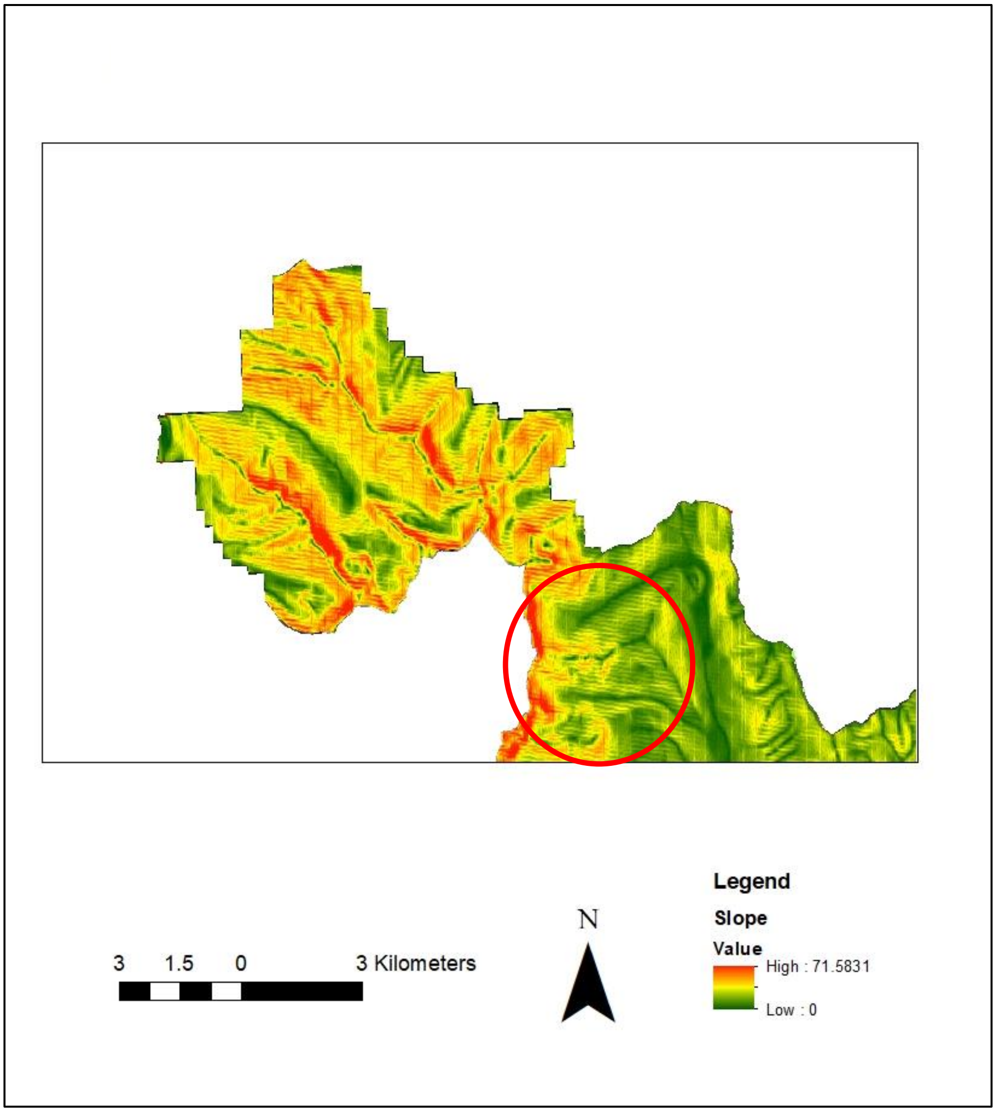


Figure 5.5 Ecological bottleneck at the Northern End of The Castle Parks. Red = high slope, yellow = medium slope, and green = low slope. Area circled in red is creating a bottleneck. The area north-east of the circled area should be added to the park to allow lower slope, access for wildlife.

For all study species data show that steeper slope sites are not at risk from fragmentation, whereas lower slope sites are at risk from dirt roads and light trails (Table 4.8 a, b and c). Park wide warning signs and fine deterrents, indicating sensitive areas, should be instituted based on species needs. Grizzly bears access steeper slope, higher elevation avalanche sites in the spring, and lower slope sites within the summer and fall (Arc Wildlife

Services, 2004). Trails should be closed adjacent to avalanche sites in the spring when bears are most in need of food resources, and are likely to be concentrating in and around avalanche slopes. Late summer and fall berry harvests increase the chance of bear-human encounters, humans should yield occupation to bears. Wolverines access steeper slope, higher elevations during the summer, and lower slopes during the winter (Carroll et al., 1999). It is clear from the map analysis that water bodies draw visitors into the Wildland Provincial Park, as there are many trails leading to them. To maximize wolverine habitat, trails leading to steeper slope lakes and treeline trails should be limited to hiking trail heads and should warn of sensitive wolverine habitat. If park rangers are able to enforce regulations, fines should be given for OHV use. All trails to be limited to hiking use should also be equipped with cameras to monitor possible violations. Cameras should be kept out of reach or site. Cougars prefer lower slope sites that offer adequate cover (Alberta Government, 2012). Finally, elk access steeper slope, higher elevations during the summer, and lower slopes during the winter.

Chapter 6 Conclusions

6.1 Conclusions and Recommendations for Future Study

Habitat fragmentation, within The Castle Parks, has been identified and analyzed to determine the threats to keystone and umbrella species and recommend ways to minimize fragmentation. Fragmentation poses a threat to all the species studied. Although all trails and roads fragment the landscape, the highest density fragmentation was created by dirt roads and light trails.

Mapping human points of interest showed a spatial relationship with all types of roads and trails. Resource extraction, in the form of logging and gas wells, create gravel roads, which generates the most fragmentation by allowing the development of local dirt roads, thus generating heavy and light trails. No further resource extraction should be allowed within The Castle Wildland Park, to eliminate this risk. In addition, educational stands should be constructed in areas of high human activity, to provide information on park maps, allowed low-impact activities, and the effect of fragmentation on the park ecosystem.

By calculating road and trail density for each land cover type, degree of fragmentation could be identified. Concrete roads and heavy trails did not yield a high density and, therefore do not pose an overall statistical threat. However, a study investigating the effects of traffic volume on species should be conducted in the Castle Parks. In addition, research is needed to determine the direct impact of specific road and trail features on individual species. This would include GIS tagging of individuals of various species to determine behavior and reaction to altered land features.

In both the fire and non-fire regions, light trails, followed by dirt roads and then gravel roads, showed the greatest habitat fragmentation. By calculating road and trail density for each DEM class, density and volume of fragmentation could be identified. The highest fragmentation occurred at the lowest slopes, particularly in slopes less than 20 degrees. This fragmentation was primarily caused by gravel roads and light trails. To minimize fragmentation gravel and dirt roads no longer in use should be closed and allow regrowth of vegetation, and light trails should be closed or minimized during certain seasons, based on animal use.

Key areas of fragmentation were identified throughout The Castle Parks region and suggested fundamental ways to minimize the fragmentation were outlined. This study can serve as a foundation for others to continue the investigation and improve habitat designs. Ground truthing in The Castle Parks will confirm land use and land cover conditions extrapolated from satellite image analysis. In addition, ground truthing can be used to verify current conditions of roads and trails. Discrepancies found on site can be corrected in the remote sensing models to improve accuracy and modeling. Furthermore, future research should assess species populations and fragmentation thresholds for each species, to greater understand the threat each species faces in this area.

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