When the flame goes out: an exploration of landscape change using repeat photography related to Indigenous burning in Kananaskis Country, Alberta

by
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B.Sc., University of Alberta, 2019

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Abstract

Fire exclusion has defined 20th century forestry practices in North America and produced many unintended consequences. In the Canadian Rocky Mountains, the removal of fire from the landscape caused significant landscape changes over the past century. Mountain forests are now more uniform in stand composition and structure, and understorey diversity is reduced. These changes mean that forests are now more susceptible to high-intensity, difficult-to-control wildfires. Re-introducing Indigenous led historical burning patterns modeled on traditional burning techniques can be a restoration technique for these highly altered ecosystems. Indigenous fire regimes that emphasized regular, low-intensity burning created forests that had less fuel build up and were not as susceptible to dangerous wildfires. In order to effectively re-introduce historical fire regimes onto the Canadian mountain landscapes, it is essential to understand the history of human management of landscapes with fire.

This project uses new methods of oblique image analysis that build on recent developments in oblique image analysis to examine the historical management of a portion of the traditional territory of the Stoney Nakoda Nation that overlaps present day Kananaskis Country in Alberta, Canada. While it is difficult to capture low-intensity Indigenous burns using traditional fire reconstruction methods, in-depth analysis of historical photos taken before the introduction of fire suppression laws may reveal new insights into historical fire regimes. Images were classified using machine learning software and compared to images classified by a human to verify the accuracy of the machine learning software. A case study of georeferencing images was also conducted, with the landcover estimates generated by georeferenced images compared to oblique estimates. Spatial signatures of Indigenous burning were identified and applied to repeat image sets to look for visual evidence of Indigenous burning on the landscape. The results from this study provide a useful starting point for further research into repeat photography and Indigenous burning.

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Dedication

I dedicate this thesis to my family:

Lara
Bruce
Kiera
Lynda
David
Rick
and Tianna

Thank you for believing in me since I was just a little know-it-all.

1.0 Introduction

The scope of this project has been developed with the close support and collaboration of William Snow, Acting Direction of Consultation of the Stoney Nakoda First Nation (SNN). When this project was initially developed in late 2019, the goal was to create a full-scale collaborative project between the Mountain Legacy Project and the Stoney Nakoda Nation to inform the creation of an Indigenous Burning Plan being developed by the SNN. The aim of the project was to explore what could be learned from the historical images that visually showed probable regions of traditional management through fire and how the landscape has changed in respect to these "signatures" of Indigenous burning. However, the COVID-19 pandemic prevented any in-person collaboration during 2020 and substantially limited the ability to connect with community members. Because of this, the scope of the project shifted focus to become an investigation of new techniques for classifying and georeferencing oblique images using Indigenous burning as a lens, opening the potential for supporting different insights into historical patterns of Indigenous use and creating a clear pathway for future researchers who will have more opportunity for collaboration. I am very grateful for the research connection with William Snow for his advice and resources on sites of potential interest and interpretation in this thesis in Kananaskis Country.

As in all research, it is helpful to understand the author's positionality. I am a White, Canadian-born researcher of settler descent. My interest in this research as a graduate student arose from my upbringing in the mountainous plateau region of northern British Columbia. I grey up hiking the mountains around my hometown and loved watching these landscapes change throughout the year. However, I was also aware of the perils facing these landscapes - throughout my childhood in the early 2000s I watched mountain pine beetle move throughout the forests. In my early teens my summers began to be dominated by heavy smoke and fire refugees. As a researcher, I am interested in how ecosystems work, how they have been historically managed, and what we can do to manage them in a way to increase their resiliency and biodiversity, especially in the face of climate change. This research, which focusses around using images as scientific data, is especially appealing because of the power and universality of images because I want my research to be accessible and understood by as many people as possible.

1.1 Background

On May 1, 2016, the Wood Buffalo Wildfire began southwest of Fort McMurray, Alberta, Canada. Over the next three months, the fire burned nearly 600,000 hectares of land and was nicknamed "The Beast" for its sheer size and unpredictability (Mamuji & Rozdilsky, 2018). On May 3rd, The Beast swept through the city of Fort McMurray, prompting the evacuation of 88,000 residents - the largest wildfire evacuation in Alberta's history (Simms, 2016). The destruction created by this fire made it Canada's most expensive natural disaster to date, costing approximately $6 billion (Mamuji & Rozdilsky, 2018). Wildfires pose a significant hazard in Western Canada, and the role they will play in Canada's natural hazard future is only going to grow (Mamuji & Rozdilsky, 2018). "Mega wildfires," or those that burn an aerial extent greater than 10,000 hectares (Stephens et al., 2014), are predicted to occur more frequently in the coming decades as climate change continues to drive temperatures higher and intensify droughts, both of which result in high quantities of dry fuels in forests (Mamuji & Rozdilsky, 2018; Coogan et al., 2019). Although climate change is often cited as the main culprit in the increase in wildfires over the past century, this is not the only complicating factor (Stephens, 2014).

In the late 1800s and early 1900s, colonial governments in Western Canada created fire suppression policies that pushed for the prevention and extinguishment of all wildfires (Keane et al., 2002). In the century since these policies began, there has been a dramatic shift in the makeup of the forests. In Jasper National Park, for example, researchers have found that total forest cover increased over 30% between 1915 and 1997, with substantial losses in shrubland, grassland, and juvenile forest (Rhemtulla et al., 2002). In the mountainous forests of the Southeastern Alberta Rockies, 28% of the landscape is now in a later succession stage than a century ago; there has been substantial increase in closed-canopy coniferous forests, broadleaf deciduous forest, and mixedwood forest, while grasslands and open canopy woodlands have disappeared (Stockdale et al., 2019). This densification of forests, which has been observed across the Rocky Mountains since the turn of the 19th century, is an increase in forest biomass that acts as fuel for future wildfires (Peet, 1992; Rhemtulla et al., 2002; Fortin et al., 2018l; Stockdale et al., 2019).

These changes have occurred throughout the Rocky Mountains, despite the fact that much of the Rockies are contained within Provincial and National Parks that are meant to leave them natural and “unimpaired for future generations” as per Parks Canada’s official mandate (Campbell, 2011). Despite the Canadian government’s expropriation of both Indigenous and non-Indigenous people from land to create unpeopled, so-called “natural” landscapes (Campbell 2011), studies continue to find that the landscapes in these parks have changed significantly since they were created in 1887 (Campbell, 2011; Fortin et al., 2019; Rhemtulla et al., 2002; Stockdale et al., 2019). There are several reasons to be concerned over the changes occurring in these “natural” forests.

Not only do these shifts represent a decline in plant and wildlife diversity, but they also constitute a substantial increase in dead and live biomass in the forest that can act as fuel for wildfires (Keane et al., 2002). Fire suppression, and the subsequent forest structure shift to later succession forests, has contributed to the increased frequency in massive, high-intensity mega wildfires (Stephens et al., 2014). These mega fires, such as the Fort McMurray wildfire of 2016, as well as the 2020 California wildfires and Australian bushfires have captured international attention for their devastating ecological, social, and health impacts (Keane et al., 2002; Mamuji & Rozdilsky 2018).

When fire suppression policies were created over a century ago, policymakers and scientists of the time assumed that the forests of the Rocky Mountains evolved with a high-severity fire regime (Amarosa et al., 2001). In a high-severity fire regime infrequent, large, and intense fires kill the majority of trees in the landscape and create homogenous, even-aged regenerating forest stands (Amarosa et al., 2011; Stockdale et al., 2016). More recent evidence suggests that the eastern Rocky Mountain Forests evolved with a mixed severity fire regime, with fires ranging in severity along a continuum from once in a century high-intensity fires that covered large landscapes to more frequent low-intensity fires that burned off surface fuel (Amorosa, 2011; Stockdale et al., 2016).

A key element of this mixed severity fire regime was the low-intensity fires set deliberately by the Indigenous people of the region on average 4-5 times per century in a given area. The Indigenous people of the Rockies used regular, low-intensity fires on the landscape to clear away underbrush to enable travel, attract game species, and encourage the growth of desirable plants, along with many other reasons (Barrett & Arno, 1982; Kay, 1995; Lewis & Ferguson 1988; Turner 1999). Such fires created a mosaic of habitats in various stages of succession in the that included mature forest stands, early seral stands, open woodlands, and shrub and grassland meadows (Lewis & Ferguson, 1988). This diverse patchwork on the landscape maintained a patchy lighter fuel load that inhibited the ignition of large, out-of-control fires that are becoming more common in contemporary times (Keane, 2002; Stephens et al., 2014).

In the face of global warming and each fire season seeing more frequent, intense, and large fires each year, many governments and forest managers are now looking for strategies to reduce the negative impacts of wildfires and to 'restore' these changed ecosystems to how they existed before fire suppression (Stephens et al., 2014). The scientific community has begun to look to the re-incorporation of Indigenous burning techniques that emphasize regular, low intensity fires into forest management plans to decrease the risk of mega wildfires (Stockdale et al., 2019b). However, Indigenous fires can be hard to detect using traditional fire regime reconstruction methods, such as tree scar analysis or charcoal analysis, which can make the re-integration of Indigenous burning into contemporary forest management plans difficult. In order to restore these altered ecosystems, the historical condition and change over the past century must be documented, along with the contribution of Indigenous burning to maintaining the historical ecosystem.

1.2 Mountain Legacy Project

My thesis research is associated with the Mountain Legacy Project (MLP), a 20-year research project that is focused on landscape change in the Canadian Rockies. This project is internationally distinctive for its access to collections of more than 120 000 high-resolution historical photos taken between 1880 - 1940 that cover the western mountain ranges in Canada (Trant et al., 2015). These images represent a vast reservoir of data that can be used to understand landscape ecology, ecological restoration, and social perspectives on landscape change. Over the past 20 years, the MLP research group has repeated over 9000 of these photographs.

Repeat photography, in its simplest form, is returning to the site where a photograph was taken in the past and taking it again and then comparing the two images to see what has changed. While simple at its core, when conducted systematically repeat photography can yield an abundance of information about landscape change, including information about fire regimes, land use, changes in anthropogenic features, and the location of historic use sites (Webb, 2010). Although the practice has existed since it was first used in the late 1880s to track the movement of glaciers in the Swiss alps, in recent times the practice has gained attention by research groups and the public alike for its ability to explain interactions in Earth systems with easy-to-understand visuals (Webb, 2010; Sanseverino et al., 2016).

Although one image pair can provide some valuable information about how an area has changed over the time between the two images, the use of large historical image sets and their systematic repeats can lead to the creating of long term, comprehensive image datasets that can display large changes over an area (Sanseverino et al., 2016). The Canadian Rocky Mountains are an excellent research site for repeat photography studies due to the large number of high-quality historical photos available through systematic mountain surveys conducted in the late 19th and early 20th century for the purpose of mapping Canada’s West. Such a large dataset can allow for the exploration of a multitude of scientific questions about natural and human caused changes on ecosystems and landscapes. When these vast image datasets are combined with software tools to help with visualization and quantification of changes between images, even more specific questions can be asked and addressed.

Since the beginning of the project in the late 1990s, the MLP has developed custom software tools to visualize, process, and quantify the landscape changes in the repeat image pairs (Sanseverino, 2016). The Image Analysis Toolkit (IAT) provides users the ability to compare, overlay, classify, scale, fade, draw, and annotate on image and image pairs (Sanseverino, 2016). It also offers comparative statistics on land cover categories and multiple ways to visualize change in image pairs (Sanseverino, 2016). To go along with IAT, a new machine learning (ML) tool for image classification has been developed. This ML offers researchers the ability to classify and analyze large numbers of images much quickly than has been previously possible.

The IAT on its own is a powerful tool in repeat photography science, and a new add on expands the possibilities of photo analysis. Newer developments with Image Analysis Toolkit can take oblique landscape photos and georeference them or assign real world locations to each pixel in the photograph. This allows for the quantification of the georeferenced area changed in repeat photograph pairs. This research aims to use a case study to test these new approaches to analysis of repeat photographs and its application to conservation, restoration, and traditional management. While other programs, such as WSL monoplotting (Bozzini et al., 2012), allow for georeferencing of images, that IAT suite of tools allows for large number of overlapping systematic images distinctive to the MLP collections to be classified, georeferenced, and analyzed by a single open-source software suite, which has the potential to create a more streamlined and efficient workflow for future researchers.

1.3 Study Objectives

The primary objectives of this study are:

1. To **test** ML-generated image classifications by comparing machine generated image classifications to human classification to assess the accuracy and identify strengths and weaknesses in ML image classification software to inform future development
2. To **explore** the relatively new process of georeferencing oblique photos and using their output as spatial data
3. To **test** the differences between standard oblique image classification and georeferenced orthogonal images classification to identify benefits and drawbacks of each method
4. To **identify** spatial signatures in historical images to explore the likely distribution of Indigenous fire management areas in Kananaskis Country, Alberta

1.4 Study Area

1.4.1 Location

The name for Kananaskis Country comes from the Cree "Kin-e-a-kis," which is the name of a warrior that survived an axe blow to the head. Places in the area now known as Kananaskis have been often given either English or Cree names, despite the fact that the Stoney Nakoda have lived in this area for much longer than each of these groups. The Stoney Nakoda, whose history will be discussed in the following section, have a long history in this area and an important cultural connection with the land that continues to this day. Where possible, the Stoney names for locations discussed below are used. The use of traditional place names can give information about how the Stoney people lived, what was important to them, and even what their sense of humor was like (Chiniki Research Council, 1987).

Kananaskis Country is the region on the eastern slopes of the Rocky Mountains approximately 85km west of Wîchispa Oyade (Calgary, Alberta). Kananaskis Country is a large provincially owned and managed mixed-use recreational protected area. It covers approximately 4000km^2 (Hallworth et al., 1997), shares its western boundary with Banff National Park, and extends eastward along the foothills of the Rockies (Hallworth et al., 1997). The region, which was established primarily for nature conservation and recreation, contains three provincial parks: Evan-Thomas Recreation Area, Spray Valley Provincial Park, and Elbow Sheep Wildland Provincial Park (Hallworth et al., 1997). It is a popular tourist destination for swimming, camping, hiking, and fishing. It was created to preserve a stunning and unique place in the Rockies that includes the rugged westward mountains and glaciers, the Îspa (Elbow), Kiska (Sheep), Châhâthkathka (Highwood), and Ozade Îmne (Kananaskis) Rivers and their tributaries, the countless lakes, and the transitional zone to the expanse of foothills plants and scenery.

Broadly, Alberta was covered in ice during the last glacial maximum, which began retreating approximately 19 000 years ago (Clark et al., 2009). The last glaciation of Kananaskis was the Canmore Advance 9 300 years ago (Jackson et al., 1982) – it was after this point that treed vegetation was able to take over the previous sparse shrubs and forbs (Reasoner &

Huber, 1999). The bedrock in this area is primarily carbonate, shale, and some sandstone (McMechan & Macey, 2014).

The climate of Kananaskis Country is snowy and humid, with cool summers (Kottek et al., 2006). The climate in the region is transitional between the continental climate of the prairies on the East and the wetter, milder climate that is on the West side of the continental divide. Therefore, the north end of the valley has a prairie-like climate of cold winters and warm summers (Hallworth et al., 1997). The south end of the valley has a more cordilleran-like climate with cold winters, cool summers, and variable precipitation. The average temperature in January is -11°C, white the average temperature in July is 13°C (Hallworth et al., 1997). Average precipitation across the region is 405mm, 30% of which falls in June (Jakob, 2014). The relative humidity of the region dips as low as below 30% in the summer (Hallworth et al., 1997).

Existing settlements in the area include Chuwapchîpchîyan Kude Bi (Canmore), Exshaw, Dead Man's Flat, Kananaskis Village, Cochrane, Sna mimâ Waptan (Bragg Creek), Turner Valley, Morley, and Longview. The largest of these communities, Cochrane, has a population of 35,000 and Chuwapchîpchîyan Kude Bi (Canmore), the second largest community, has a population of approximately 14,000, while the rest of the communities in the region have a population of 1,000 or less (Canadian Census, 2016). In addition to its permanent residents, Kananaskis Country attracts millions of visitors every year to access its recreation facilities that include camping, golfing, skiing, horse trails, climbing, hunting, and fishing (Government of Alberta n.d.).

My study area, which is located within Kananaskis Country, focuses on the Châse Tîda (Baldy Pass) area of Kananaskis along highway 40 and around the townsite of Chuwapchîpchîyan Kude Bi (Canmore, Alberta) along highway 1. This area is part of the Evan-Thomas Recreation Area, Spray Valley Provincial Park, and Elbow Sheep Wildland Provincial Park, all of which are components of Kananaskis Country. The elevation of photograph locations ranges from a low of 1334m to a high of 2689m above sea level. The distance between the northern and southernmost photographs is 27.68m, and the distance between the eastern and westernmost photograph is 28.78m. The study area is approximately 850km^2, and a map of all

13 photograph locations can be seen in figure 1.3.1 and the natural subregions present in this area are alpine, subalpine, and montane.

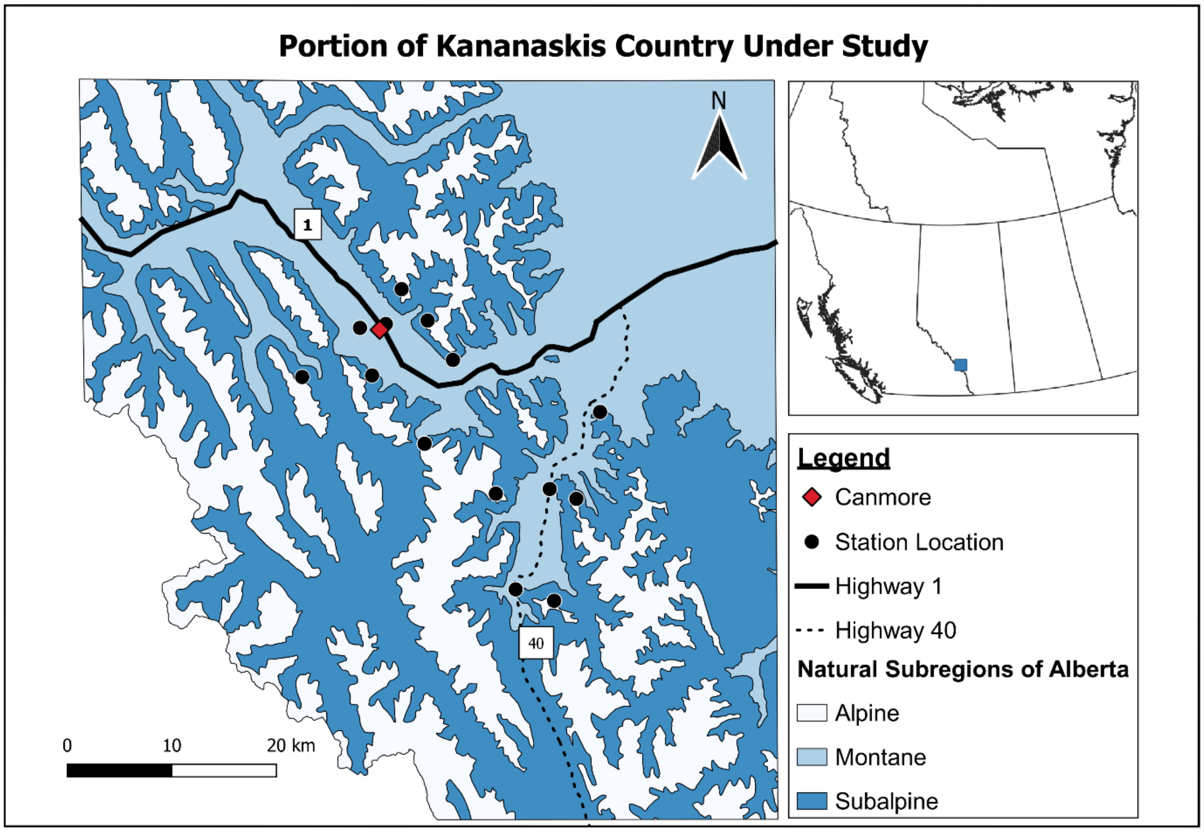


Figure 1.4.1: *Portion of Kananaskis Country Under Study. Photographic survey stations are marked on the map and natural regions are indicated by colour. Highways 1 and 40 and the town of Chuwapchîpchîyan Kude Bi (Canmore) are used as identifiers. Map created in QGIS using Government of Alberta open-source map data.*

1.4.2 The Ĩyãȟé Nakón Mąkóce (Stoney Nakoda)

The land in Kananaskis and its people are intertwined, and this history is what ultimately drives changes in the management practices that are researched in this thesis. The Indigenous people of the Kananaskis region are the Stoney people, known in their Nakoda language as Iyarhe Nakoda (Native Land Digital Team, 2021). The Stoney people have been called the original “people of the mountains” and as well as a variety of other names, including the Stoney Nakoda, the Mountain Stoneys (Sioux), the Rocky Mountain Stoney, the Warriors of the Rocks, Cutthroat Indians, and wapamanthe (Native Land Digital Team, 2021). The Stoneys were historically known as Assiniboine by their neighbours, which literally means people who cook with stones (Snow, 2005). I am grateful for the extensive recounting of oral history of the

Stoney Nakoda peoples in John Snow's 2005 book, *These Mountains Are Our Sacred Places*. Except where otherwise noted, this section is largely derived from Snow's book.

People have travelled and lived in the Canadian Rockies for over 10,000 years. In 1969, when archaeologists were sent to conduct surveys in Banff for the construction of a highway, they found over 100 sites ranging from the valley floor to alpine hunting camps. These sites included butchering camps, flint knapping sites, and diagnostic points. The archaeologists concluded their report by stating that both Plains and Plateau people have resided in this region since at least 11,500 years ago.

All Stoney groups throughout the Alberta and Montana Rockies are related through family and history (Andersen, 1970). Since 1841 there have been three main Stoney bands, each with their own leader (Andersen, 1970). There was the northern band, known as the Wesley band, who kept largely to themselves in the easterly ranges (Andersen, 1970). The southern band, the Bearspaws, hunted in lands between the Îjathibe Wapta/Bow River and the Montana border. The central band, known as the Chiniki, hunted largely between the Saskatchewan and Îjathibe Wapta/Bow River and likely entered the Alberta foothills some time ago from Montana. The Chiniki are the group that currently live in Morley, which is about 40km from the study area of this project. The study area falls within the Chiniki Stoney's traditional territory.

The first people to live in the Rocky Mountains were not confined to just one area - the Rockies are criss-crossed with well developed trails and trade routes (Andersen, 1970). Neighbouring bands were typically respectful of each other's hunting territory. The people who lived throughout the Rockies lived a "nomadic way of life, hunting, fishing, and gathering from the abundance of [the] good land." Buffalo were abundant on the prairies, and into the Rockies game animals included moose, elk, deer, wild sheep, and goats. The Stoney Nakoda spend the majority of their time in the Rockies and the surrounding foothills; they travelled as far north as Jasper National Park and as far south as Montana. The mountains are a sacred place to the Stoney people and involved in several important rites-of-passages and rituals.

Although European colonizers arrived much earlier, significant changes to Stoney life began in the mid-nineteenth century. At this time the changes were small and mostly trade based, and although trapping for trading purposes became more popular, the Stoneys never saw trade become the backbone of their economy as they still mostly relied on hunting and gathering for subsistence. Gradually through trade, European firearms replaced bows and arrows for hunting, and the horse replaced the dog for transportation. Steel and woven cloth also became more common. However, traders and missionaries when they did visit were still no more than curiosities to the Stoney people.

In the 1870s, the influence exerted by colonizers on the Stoney people grew. In 1872, the Canadian Government planned the construction of a railroad to help white colonizers start cattle ranches, agricultural businesses, and other enterprises in the largely unsettled West. Reverend George McDougall, a Christian missionary, arrived and built a church in Morley in 1875. This attracted more colonizers to the area who arrived with the mission to “educate, Christianize, and civilize” the Stoneys. In the same year, the North West Mounted Police arrived in Morley to bring “law and order” to the region and mediate the contact between the local Indigenous groups and colonizers.

On September 22, 1877, Treaty Seven was signed by five First Nations: Stoney Nakoda, Siksika (Blackfoot), Kainai (Blood), Piikani (Peigan), and Tsuut’ina (Sarcee). Like the treaties before it, the most prominent goal of Treaty Seven was to eliminate all Indigenous groups’ claim to their traditional land without their knowledge (Little, 2017). The effect of Treaty 7 was to relocate signatory Nations to reserve lands, and then to develop traditional territories for settler agriculture, mining, and development. The Stoney were allocated under the treaty a single reserve located in present-day Morley, Alberta. The buffalo, a key animal for the Stoneys, saw a rapid decline in population from 1885 to 1899 as a consequence of settler hunting. In addition, it became more and more difficult to cross the Montana border, and even travel within traditional territories became difficult because of intensifying settlement.

The eroding of the traditional life of the Stoney Nakoda, along with the rest of Canada’s Indigenous peoples did not end with the Treaties. From the 1870s until the 1990s, the Canadian government ran residential schools across the country that aimed to assimilate Indigenous children into Canadian society by eradicating the language, traditions, customs, and spiritual beliefs of Indigenous children (Kirmayer et al., 2003). In Morley, the first residential school was built by the earliest missionaries in the area in the 1880s; a second, newer school was built in 1925. Children were removed from their homes at age eight and forced to attend these schools (Snow, 2005; Wilk et al., 2017) where they were made to learn and speak English and their culture was both explicitly and implicitly condemned (Snow, 2005; Union of Ontario Indians, 2013). In Morley, the teachers at the residential school were uncertified and hired for their closeness to the church and ability to "Christianize" the Stoney children. "Education" through these residential schools was seen by the Canadian government as the key way to integrate Indigenous children into Western society and remove all traces of their traditions and culture.

It is estimated that over 150 000 children across Canada attended these schools; in addition to the complete eradication of their culture, many children also suffered physical, sexual, and spiritual abuse while attending theses schools (Corrado & Cohen, 2003). The effects of these schools continue to this day, manifesting in ways that negatively affect Indigenous peoples' physical, mental, emotional, and spiritual wellness (Wilk et al., 2017). These attempts at forced assimilation were unsuccessful due to the resistance and resilience of many Indigenous communities; however, they did have profound effects on both the individual's wellness and the "structure and integrity of families, communities, bands, and nations" (Kirmayer et al., 2011, Kirmayer et al., 2003).

In the 1960s, the federal Department of Indian Affairs introduced a program for local reserve self governance (Snow, 2005). In January 1969 John Snow was elected Chief of the Wesley Band, along with Tom Twoyoungmen as Chief of the Bearspaw Band and Frank Powderface as Chief of the Chiniquay Band. Twelve councillors were also elected to form the first Tribal Council. Under self government, Indigenous culture could begin again after a century of suppression. Since the election of the first Tribal Council in 1969, the Stoney Community has slowly worked toward revitalizing and rebuilding culture and traditions.

1.4.3 Vegetation

The study area is in the Montane Cordillera ecozone and can be further classified as part of the alpine, subalpine, and montane natural subregions (Natural Regions Committee, 2006). The montane natural subregion occurs at the intersection of the foothills and the Rocky Mountains on lower slopes and valley bottoms (Natural Regions Committee, 2006). The average elevation of the montane subregion is 1400m (Natural Regions Committee, 2006). Eastern and northern aspects are dominated by lodgepole pine (*Pinus contorta* Douglas.), Douglas-fir (*Pseudotsuga menziesii* Mirbel.), and trembling aspen (*Populus tremuloides* Michx.) stands (Johnson & Fryer, 1987). Grasslands comprised of mountain rough fescue (*Festuca altaica* Trin.), bluebunch fescue (*Pseudoroegneria spicata* Pursh.), and parry oatgrass (*Danthonia parryi* Scribn.) are common on western and southern aspects (Johnson & Fryer, 1987; Natural Regions Committee, 2006).

The subalpine natural subregion vegetation is highly variable depending on the elevation, latitude, wind exposure, and topography (Johnson & Fryer, 1987; Natural Regions Committee, 2006). The elevation of the subalpine zone ranges from 1300m – 2300m (Natural Regions Committee, 2006). At lower elevations, forests are made up of Engelmann spruce (*Picea Engelmannii* Parry x Engelm), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and white spruce (*Picea glauca* (Moench) Voss); as elevation increases, forests become less dense and include subalpine larch (*Larix lyallii* Parl.) and whitebark pine (*Pinus albicaulis* Engelm.) (Johnson & Fryer, 1987, Natural Regions Committee, 2006).

This region comprises steep inclines, exposed bedrock, with extremely short and cold summers and winters dominated by snowfall and intense winds. It is one of the only natural subregions in Alberta where fire has not played a strong role in the development of the plant community (Natural Regions Committee, 2006). There are no trees present in the alpine natural subregion except for a few scattered krummholz in sheltered location (Natural Regions Committee, 2006). The vegetation present is mainly when there is enough shelter and moisture include dwarf heath shrubs, grasses, and forbs (Natural Regions Committee, 2006).

1.4.4 Fire Regime

A fire regime is defined as a set of fire characteristics for a given area that include cause, frequency, intensity, and severity (Rogeau, 2004). For over a century, scientists and forest managers have assumed that the forests of the Rocky Mountains have been shaped by a high-severity fire regime; this assumption has had a strong influence on research, forest management, and policy creation (Amorosa et al., 2011). A high severity fire regime is characterized by large, infrequent, and intense fires that sweep across the landscape, killing over 75% of trees with few unburned islands (Rogeau et al., 2016).

However, recent research in the southeastern foothills and Rocky Mountains of Alberta has begun to challenge this assumption as new evidence shows that these forests actually evolved with a mixed severity fire regime (Amorosa et al., 2011; Chavardes & Daniels 2016). In a mixed severity fire regime, fires range in severity along a continuum from low intensity surface fires that have little to no effect on mature trees to massive, high intensity stand replacing fires (Rogeau, 2004). This variation in fire patterns results in forests that are different age and successional stage, often meaning that the diversity of tree species is higher (Amorosa et al., 2011). Mixed severity fire regimes can be difficult to identify since the evidence left behind by low and high severity fires is different and requires different techniques to interpret. Evidence of earlier events deplete over time as trees decompose or are burned off by subsequent fires (Chavardes & Daniels, 2016; Kent, 2014). This means that mixed severity fire regimes are often under-identified and require distinctive methods to identify on the landscape (Amorosa et al., 2011).

Understanding the forests of the Rocky Mountains as being shaped by a mixed severity fire regime is significant because this helps develop a stronger understanding of forest composition, structure, and ecosystem dynamics (Amorosa et al., 2011). Where high severity fires kill most of the trees on a landscape, leaving behind an open landscape, low to moderate fires kill fewer than 75% of trees on a landscape (Rogeau, 2004). This means that the trees that die leave canopy openings surrounded by surviving trees, which increases structural complexity for new trees to establish (Amorosa et al., 2011). Different trees are adapted to different fire regimes: for example, lodgepole pine establishes rapidly following high severity fire in the sunny, unshaded landscapes that are left behind (Tande, 1979). Conversely, Douglas-fir is an indicator of frequent, low severity fires as they have thick bark that enables them to survive low and moderate intensity fires. In an ecosystem shaped by a mixed severity fire regime, both species of trees will exist on different parts of the landscape, creating a more diverse ecosystem than if the fire regime was strictly high- or low- intensity.

The fire history of Kananaskis Country largely takes place within a noticeably short summer (Rogeau et al., 2016). There are essentially three snow-free months that make up the majority of the fire season – June, July, and August (Rogeau et al., 2016). In the peak of summer, from June to July, approximately 81% of historical fires in Kananaskis were caused by lightning strikes, whereas outside of the summer months (April-May, August-September) it is estimated that up to 70% of fires were historically started by people pre-colonization (Rogeau et al, 2016). The fire history of Kananaskis Country was largely unstudied until the late 1970s, when a paved road was constructed that increased access to the area (Hawkes, 1980). Aside from Indigenous people, whose role the fire regime will be discussed further in this section, Kananaskis Country had quite limited development and use by people until the early 1980s (Hawkes, 1980).

Overall, throughout the Rockies, various studies have found that the fire return intervals in the forests have lengthened substantially in the past century (Rogeau et al., 2014). Kananaskis is not unique in this respect and research conducted throughout the region has found a similar shortening of fire intervals since the 1940s (Rogeau et al., 2014). When studying the fire regime of Kananaskis, the subalpine and alpine are grouped together and analyzed separately from the montane region. The montane region, at elevations between 1200m – ~1700m, is dominated by fire-sensitive lodgepole pine with scattered pockets of Douglas fir and trembling aspen (Downing & Pettapiece, 2006). The median fire return interval (MdFRI) for this area is approximately 30.5 years (Rogeau et al., 2016), which represents a 175% increase in time between fires since the mid 20th century (Rogeau et al., 2016). The subalpine region, at elevations between ~2000m – 3300m, has a MdFRI of approximately 75 years (Rogeau et al., 2016). This represents an approximate 85% increase from the MdFRI that existed in the early

20th century; however, while this increase in MdFRI is important to note, this change was determined to be within the historic range of variability (Rogeau et al., 2016).

The lengthening of fire return intervals is not exclusive to Kananaskis Country, or even the Rocky Mountains; this trend has been noticed throughout North America (Ryan, Knapp, & Varner, 2013; Prichard, Stevens-Rumann, & Hessburg, 2017). In the boreal forests of northern Quebec, the fire cycles have doubled from an average cycle of 100 years pre-1850 to nearly 200 years at the turn of the century (Bergeron et al., 2000). In the Canadian Pacific Northwest, fire-dependent Garry Oak ecosystems are now at risk due to colonization and subsequent fire suppression (Pellatt, McCoy, & Mathewes, 2017). In the semi-arid temperate forests of the United States, the dramatic reduction in wildfires beginning in the 20th century has been dubbed a “fire deficit” (Parks et al., 2015). Even outside of North America, land managers are looking to reintroduce fire to heal their landscapes - in Australia, for example, when long fire-free intervals in the 20th century saw expansion of rainforest into savannahs, active prescribed burning was implemented in the 1960s to combat this and mitigate wildfire hazards (Boer et al., 2009). The problem with fire that comes from fire suppression and subsequent lengthening of fire intervals is not exclusive to Kananaskis - this is a problem that many land managers are facing.

The lengthening of fire intervals over the past century is likely due to fire suppression (Rogeau et al., 2016; Chavardes & Daniels, 2016). Although the historical fire regime of Kananaskis had likely been slightly altered in the late 1800s by the introduction of grazing animals (Hawkes, 1980; Keane et al., 2002). By the 1940s, the combination of the removal of Indigenous people from the landscape, fire suppression policies, and effective fire awareness campaigns resulted in the substantial alteration of the fire regimes that we see today (Rogeau et al., 2016). In 1948, the Eastern Rockies Forest Conservation Board was formally established to further increase protection and management of the forests of the Rocky Mountains – this date marks the beginning of the strongest, most effective fire exclusion period (Rogeau, 2004). The time since the creation of this board represents the contemporary fire regime era in the Eastern Rocky Mountains, with a fire cycle (number of years required to burn the area of interest) of 5000 years – and each year without significant burned area continues to lengthen the fire cycle (Rogeau et al., 2014).

A proposed alternate explanation for the decreased fire frequency observed in Kananaskis Country post 1940s is climate change (Chavardes & Daniels, 2016). However, since the 1960s summer climate conditions have become quite variable, with many hot, dry summers that are generally conducive to fires; there is no evidence that the climate in the 20th and 21st century has been unsuitable for fires (Chavardes & Daniels, 2016; Luckman, 1998). Anthropogenic climate change has been extending the fire season in the Rocky Mountains and this trend is predicted to continue as summers become hotter and drier (Riley & Loehman, 2016). Additionally, there has been no substantial changes in the amount of lightning strikes in the region and it has been determined that lightning fires are relatively rare; Kananaskis is in a lightning shadow (Rogeau, 2004; Kay, 2007). Therefore, as the conditions have been favourable for fire since the 1940s, but the occurrence of fires has decreased substantially, it appears that fire suppression has been instrumental in the alteration of the fire regime of Kananaskis Country.

The removal of Indigenous people from Kananaskis Country is likely the single most important factor in fire suppression legislation that has resulted in dramatic shifts in the fire regime of the region. In the Montane subregion of Kananaskis, 90% of all fires are anthropogenic in origin, and in the subalpine 75% of fires are human caused (Rogeau, 2004) – and this is despite intense fire suppression. As lightning fires in Kananaskis are rare (Kay, 2007) and fire return intervals were much shorter prior to fire suppression laws, it can be inferred that Indigenous people in this area likely played a significant role in contributing to the fire regime prior to the arrival of European settlers. Across the Western forests of Canada and the United States, it has been found that Indigenous people were responsible for setting the low intensity fires that helped to make up the mixed severity fire regimes that dominated these regions (Rogeau et al., 2016). This is further supported through fire scar evidence which shows that many of these historic low-intensity fires occurred outside of the normal fire season in early spring when lightning activity is extremely low (Rogeau, 2004). The importance of Indigenous caused fires to the fire regime of Kananaskis Country, and the importance of understanding Indigenous people as key participants in a healthy ecosystem, will be discussed next.

2.0 Literature Review

2.1 People as Active Participants in the Landscape

Since the 1950s, the influence that people have had on the Earth and its natural systems has increased so significantly that this period is known as “The Great Acceleration;” this time period is marked by an explosion in human population and human impacts on Earth’s natural processes (Lewis & Maslin, 2015). The Great Acceleration is a small component of the Anthropocene Epoch, the proposed new Epoch wherein human activity is the dominant cause of environmental change on Earth (Lewis & Maslin, 2015). Although humans have been shaping the Earth’s natural systems for tens of thousands of years (Lewis & Maslin, 2015, Biliege Bird 2019), the influence of our own activity since the beginning of the Great Acceleration is such that the impact of human development on worldwide ecosystems has reached unprecedented levels (Ellis, 2015). This framing of the Great Acceleration and the Anthropocene, while prominent in science and pop culture, suggests that previous to the Industrial Revolution, humans did not impact the environment in significant ways and the earth was “more natural” because of this. This is simply not true and is a manifestation of what our modern, western culture considers “natural.”

While it is true that humans have always impacted the environment, the rate and scale at which these changes are happening is greater than ever before. These rapid physical changes in the Earth are compounded by our rapidly changing understanding of the natural world (Levinovitz, 2020). People are selective with memories of the past - what grandparents, or their grandparents, considered to be natural is quite different than what is today called “natural” (Levinovitz, 2020). The colonial concept of natural landscapes or “wilderness” are not intrinsic truths about the world - they are concepts that have been created by people. The terms “wilderness” and “natural” as we understand them today arose in the last 300 years. When Europeans arrived in North America, they believed wilderness was a harsh, unforgiving, and ungodly landscape; however, over time, as cities and civilizations grew larger, denser, and more cramped, combined with the Romanticism movement that grew in both Europe and America in the early 19th century, people became quite interested in the idea of “Wilderness” (Cronon, 1992; Murray et al., 2011). Wilderness, which was defined as areas that were completely devoid of human influence, became a symbol for spirituality, purity, and God (Cronon, 1992; Murray et al., 2011). In this colonial definition of wilderness, which continues to persist today, people are considered separate from nature and therefore unnatural. The evidence of this western colonial view of wilderness is apparent in the American Wilderness Act of 1964, which defines wilderness as “…an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain” (Wilderness Act, 1964).

From the beginning of European colonization on the continent until the twentieth century, more Indigenous people in North America died every year than were born. This rapid depopulation, which began in the sixteenth century when European colonizers landed in North America along with smallpox, measles, bubonic plague, diphtheria, typhus, cholera, and scarlet fever, diseases to which the Indigenous people of North America had no immunity, extended from 1520 to 1918 (Dobyns, 1983). The North America Indigenous population plummeted from a potential high of millions down to fewer than 500,000 survivors, which fueled European colonizer’s notions that the “New World” was an unpopulated, virgin wilderness that was ripe for European exploitation (Dobyns, 1983). This misconception about the population of North America and the impact the people living there had on the natural environment has been termed the “Pristine Myth” by the geographer William Denevan (1992). The population of Indigenous people living in North America was large and the impact that the people had on the local environment was substantial, from the alteration of forest composition and the creation of grasslands to disruptions in food chains and wildlife interactions (Denevan, 1992). However, through European eyes, everything they saw in the vast wilderness of North America was the result only of “nature,” and not of people.

The conception of Wilderness and natural spaces as spaces which are separate from people is just one perspective, yet it has come to dominate the Western canon; it is so dominant a perspective today that it seems to be simply a fact of life - where there are people, there is civilization, and where there are not people, there is true wilderness. But far, far before the European colonizers arrived in North America and “discovered” the vast untouched and pristine wilderness before them, other humans already lived here. Europeans did not understand the importance of the Indigenous people on the landscapes of North America and described them as just a small number of people living in harmony with nature. The 18 million people who lived in North America on the eve of 1492 when Columbus arrived (Dobyns, 1983) were not just visitors, but active members of the ecological community (Cronon, 1992; Levinovitz, 2020).

There are many key ecosystem functions that Indigenous peoples have historically represented, and these were vital to intricate cultural relationships with lands and waters (Biliege Bird & Nimmo, 2019). Some examples of these include: soil turnover through digging starchy tubers and burrowed prey, which increases vegetation patch biodiversity; hunting prey animals, which acts as a top-down predation control that benefits primary producers and consumers; seed dispersal through long-distance transport of both edible and inedible seed, which increases landscape heterogeneity and gene mixing; and burning to increase the growth of desirable plants, which increases landscape diversity (Biliege Bird & Nimmo, 2019). In the face of the Great Acceleration and societal conceptions about humans invading Wilderness, it is key to reframe the discussion surrounding natural spaces away from a colonial view of nature, which asks “How can we remove humans from Wilderness?” to a more holistic view of nature which asks, “How can we, as humans, have positive roles in Wilderness?”

In the context of the Great Acceleration, the United Nations has called 2021 - 2030 the “Decade on Ecosystem Restoration” (https://www.decadeonrestoration.org/about-un-decade). While “ecosystem restoration” simply refers to the reversing the degradation of ecosystems to regain their ecological functionality and productivity, the field of ecological restoration includes not only the actual practices of restoration, but also cultural elements, politics, technologies, and economic factors that are important to each specific restoration project (Higgs, 2005). Under the umbrella of ecological restoration are other, more specific restoration practices. For example, rewilding refers to a form of restoration that focusses on restoring ecological processes to be self-sustaining and re-creating large, connected areas of landscape for reintroduction of lost animal species (Perino et al., 2019). Land reclamation is the converting of land disturbed by human activities, such as mining, forestry, or oil extraction, to its historical state, or to another productive state (Government of Alberta, 2018). These terms, as well as ecological enhancement, ecological recovery, and ecological mitigation, are all related terms that are sometimes used interchangeably along with restoration, rewilding, and reclamation (Uprety et al., 2012); however, ecological restoration should be considered the umbrella term that encompasses all other practices (SER, 2004)

The western definition of Wilderness, which excludes people, has caused people to be left out of many discussions surrounding ecological restoration as this field has gained popularity over the past two decades. This absence, which seems intuitive to the colonial ideal of “natural,” ignores the stark reality that people have been vital to many ecosystems across the globe for thousands of years (Biliege Bird & Nimmo, 2019). For example, the definition of rewilding goes so far as to state that it’s aim is to “restore self-sustaining and complex ecosystems, with interlinked ecological processes that promote and support one another while **minimizing or gradually reducing human intervention.** (Perino et al., 2019; emphasis added)” The Society for Ecological Restoration (SER, 2004) has long been advocating for the inclusion of including Indigenous people and knowledge in ecological restoration, and practitioners and institutions that restore ecosystems have been increasing their inclusion of Indigenous people and knowledge (Evans & Davis, 2018); in 2004, the International Primer on Ecological Restoration included the restoration of traditional landscape management practices as a sustainable goal of restoration projects (SER, 2004).

Despite the inclusion of traditional management practices in the goals of ecological restoration, there is still some ambiguity about the role that humans play in natural or restored ecosystems. The International Principles and Standards for the Practice of Ecological Restoration (2019) defines cultural landscapes as those that “have developed under the joined influence of natural processes and human-imposed organization.” Considering what is now known about the pervasive impact of humans on the landscape throughout human history, it seems that many, many ecosystems could be considered cultural ecosystems (Evans & Davis, 2018; Biliege & Nimmo, 2019). The Standards also do not specify under what circumstances human-caused impacts are considered to be within the natural range of variation for a region, and when they are not (Evans & Davis, 2018). While literature demonstrates that pre-industrial humans had significant impacts in their environments (Lightfood & Cuthrell, 2015; Biliege Bird & Nimmo, 2019), the Standards paints their landscapes as similar to unmodified states (SER, 2019; Evans & Davis, 2018). Even the modern restoration practice which does emphasize the importance of including Indigenous people, knowledge, and management in the restoration of ecological restoration, still under-emphasizes the roles that humans have played and continue to play in ecosystems.

2.2 Indigenous Fire Management in the Rocky Mountains

My research focuses around one discipline where the western discrepancy between the natural, human-free world and the unnatural, human-filled world has had larger-than-anticipated consequences: fire science. European colonizers, who arrived in the Canadian Rockies in the early 19th century, did not understand the contribution of Indigenous land management – in this case, fires - in creating the landscapes they saw. The colonizers believed they were arriving in a pristine, untouched, and virgin wilderness, whose plentiful streams and vast forests were a product of "nature" and were entirely free from human influence (Denevan, 1992; Cronon, 1996). They outright dismissed the Indigenous inhabitants of the land, calling them "transparent on the landscape, living as natural elements in the ecosphere. (Shelter, 1991)" At the turn of the 20th century, white Europeans began to develop an interest in protecting Wilderness - and, by their definition of Wilderness, this meant excluding humans from the landscape, including Indigenous people who had been living on and with this land for millennia. Banff National Park, which is only 15km from the study area of this research, was established in 1885. The Indigenous people of this region, who had been there for over 10,000 years (Snow, 2005), were removed from the landscape in the name of "preserving" the naturalness of the park.

Along with their beliefs about Wilderness, European colonizers also brought with them a belief that fire was destructive and unnatural (Barrett & Arno, 1982). In the early 20th century and continuing to present time, governments have written laws explicitly forbidding deliberate large-scale burning of any kind on the landscape and calling for the immediate extinguishment of accidental fires in the interest of protecting the Wilderness from the "unnatural" disturbance of fire (Arno et al., 2000). After a century of successful fire exclusion policies that ignored the historical mixed-severity fire regime of the study area that contributed substantially to the landscapes that the European colonizers thought of a “natural,” Canada’s mountain forests have transformed from a mosaic of diverse tree stands to homogenous, high-density, single aged stands (Hessburg et al., 2019). This landscape, despite being substantially changed over the past century, is considered ‘natural’ to the millions of tourists who visit Canada’s Rocky Mountains each year - creating a complex discussion surrounding what constitutes a natural landscape and what role should people play in it.

The Stoney Nakoda, like most Indigenous groups in North America, have a deep oral tradition and history (Snow, 2005). The reliance on the oral transmissions of stories, histories, and other knowledge to maintain a historical record is something that has often been at odds with Western society, which prioritizes written records (Hanson, 2018). Despite notions of oral histories being “not as good” as written histories by Western scholars, oral traditions and histories are able to record and document history in complex and sophisticated ways and form the foundation of Indigenous societies (Hulan & Eigenbrod, 2015). An important element in Indigenous oral histories is the landscape in which they are told; histories are often connected to the landscapes and the lived experiences within those landscapes (Basso, 1996).

Oral histories connected to landscape can exist in the traditional place name of an area. During the colonization of Canada, lakes, rivers, valleys, and other areas of land were renamed into English or French names, erasing the Indigenous people that stewarded and knew this land (Wojtuszewska, 2019). Indigenous place names are deliberate, significant names that provide a rich understanding of the land and the people who live there (O’Connor, 2016). Recognizing the original Indigenous place names is a meaningful process that allows both Indigenous and non-Indigenous people to honour this previously hidden past, bring traditional knowledge back to an area, and move forward with reconciliation and post-colonialism (Wojtuszewska, 2019). For example, Kananaskis Valley is called Châse Tîda in Stoney, which translates to “Burnt Timber Flats” in English. It earned that name due to a large fire that was deliberately set by a member of the Stoney Nakoda (Chiniki Research Team, 1987) - this place name evokes a story related to members of the community and reminds future generations what has taken place there and why it is significant.

Other forms of historical evidence include traditional stories of local Indigenous communities and records by early colonizers and missionaries in the late 18th/early 19th century (Barrett & Arno, 1982; Coues, 1897). The ethnohistory of 'Indian' fires as told by oral histories and traditions was documented in 1982 by Barrett and Arno through interviews with knowledgeable descendants of early-day Indigenous people throughout the Rocky Mountains and European colonizers. Many early colonizers documented regular fires started by Indigenous people in valley bottoms such as Kananaskis Valley "when the seasons were about to change" - Captain Meriwether Lewis would submerge his expedition's canoes under water during late fall to protect them from the "fire which is frequently kindled in these plains by natives" (Barrett & Arno, 1982). A review of forty-four historical accounts of fires recorded by European colonizers in the Inland West suggested that at least 41% of the fires were definitely of anthropogenic origin (Gruell, 1985). Interviews conducted with Indigenous elders by Lewis and Ferguson in 1977 found similar accounts of the use of fire for a variety of reasons; the Indigenous people did not fear fire the same way European colonizers did as they understood its benefits. One elder noted to Lewis & Ferguson (1977): "We didn't watch over the fires. Every time in the spring [that] we came to a prairie in the bush, we would make a fire there."

While historical evidence of Indigenous burning can be fairly straightforward, physical evidence of Indigenous burning can be tricky to work with for two reasons. The first is that Indigenous fires were typically low intensity fires that burned only surface fuels, and these types of fires do not leave appreciable evidence on the landscape (unlikely to be hot enough to leave fire scars on established trees) (Kay, 2007). The second issue is that it can be difficult to separate fires that are started by lightning from those that were started by people with any certainty, as the physical evidence that is left behind by fires does not indicate the source of ignition.

However, despite these limitations, physical evidence can still be used to infer the patterns of Indigenous burning. Although surface fires do not always leave fire scars on mature trees, they can leave scars on smaller, younger trees with softer bark. When they do leave scars, the seasonality of these fires can be identified through the position of fire scars - many scars show up in the dormant or early wood portion of the tree cambium, which is evidence that burning occurred outside summer, the typical period of tree growth (Rogeau, 2016). If fires occurred in fall, winter, or spring, there is a strong possibility that they were human caused, as lightning activity is very low in the Rocky Mountains outside of July and August (Rogeau, 2016; Kay, 2007). It was also documented by Barrett and Arno (1982) that most anthropogenic fires started by Indigenous people took place in fall or early spring; starting fires in summer is much more dangerous. In addition to many fires appearing to take place outside of active lightning fire season, the study area in question exists in a well-documented lightning shadow (Kay, 2007; Rogeau, 2016; Wierzchowski, 2002) where lightning strikes are not well correlated with fire ignitions (Rogeau, 2016).

As previously discussed, the fire return intervals of this region have lengthened considerably since European colonization, especially in the lower montane region. Pre-1940s, the fire return interval of this region was approximately 30 years; post-1940s, the average fire return interval more than trebled to 95 years (Rogeau, 2016). Based on the lengthening of fire return intervals since colonization, coupled with the minimal influence of lightning strikes in the area and the fact that many fires were found to take place outside of summer, we can assume that Indigenous people played a large role in contributing to the fire regime, and by extension the overall forest structure, prior to the arrival of European colonizers (Rogeau, 2016).

2.3 Consequences of Fire Suppression

It is well documented that most forests in the Rocky Mountains evolved with fire (Agee, 1996). Fire, in healthy ecosystems, performs a wide variety of functions, including nutrient cycling, maintenance of biodiversity, reduction in overall biomass, control of insect and disease populations, regulation of interactions between vegetation and animals, and maintenance of biochemical and biogeochemical processes (Agee, 1996). Many early environmentalists, such as John Muir, Aldo Leopold, and Gifford Pinchot recognized the importance of fire in maintaining ecosystem health and preventing fuel buildup (Keane, 2002). However, despite these early observations, fire suppression emerged as the most desirable policy for public lands, both in the interest of forestry and to appeal to European fears of fire (Keane, 2002; Barrett & Arno, 1982).

The exclusion of fire from the landscape has caused a series of cascading effects in the Rocky Mountain forests. While these effects may seem beneficial in the short run - the preservation of timber and watersheds, for example, are key reasons why fire suppression was supported as a policy in the first place - in the long run, the negative consequences outweigh the positives (Keane, 2002). These effects are profound because fire suppression has been an effective policy. For example, prior to 1900, it was estimated that in the US burned approximately 1.4 million hectares annually; since the introduction of this policy, modern fires burn less than one quarter of the land that burned historically (Keane, 2002; Gruell, 1985).

The consequences of this fire suppression campaign are numerous. At the stand level, forests have shifted from early seral species to late seral, shade tolerant species (Veblen & Lorenz, 1991). It is this single change in vegetation composition and structure that has cascaded into dozens of other changes in the ecosystem (Keane, 2002). This shift represents a decrease in forage quality, as many late seral species are tough and woody as opposed to palatable early seral forbs and shrubs (Keane, 2002). Stand level shifts toward late successional species also favour species that are less fire tolerant and vigorous, and landscapes that have lower biodiversity overall. Ecosystems in a landscape shift to greater homogeneity of vegetation structure and pattern instead of a mosaic landscape with stands in different stages of succession (Keane, 2002).

Suppressing fire makes landscapes less biodiverse overall. Landscapes with the highest biodiversity are those that have fires with high variability in timing, pattern, intensity, and frequency (Brown et al., 1994; Swanson et al., 1990). In Banff National Park, which is proximate to my study area, a model of future vegetation over the next century with continued fire suppression found a loss of biodiversity caused by a complete loss of 19 out of 26 vegetation types present in the park (Achuff et al., 1996). The reason that diversity decreases with advancing successional stage is simply because there are a higher number of species that are adapted to colonize highly disturbed, postfire settings from dispersed seeds or dormant propagules (Keane et al., 2002). These species are out-competed by a smaller number of species that are able to survive in highly shaded environments as trees re-establish themselves post-fire.

One important function of low-intensity surface fires is to burn up the dead and live biomass ("fuel") that is present on the ground such as twigs, leaves, logs, grasses, branches, and shrubs (Rogeau et al., 2016). Without regular fires, as succession advances, there is simply more live and dead biomass present on the forest floor, which acts as fuels for wildfire (Peet, 1992). This accumulation of fuels leads to the creation of "ladder fuels," which are fuels that connect the surface level fuel (typically smaller leaves, twigs, and grasses) to the tree crowns (Mason et al., 2006). Once fires reach the tree crowns is when they tend to shift from small, controllable fires to large, out of control wildfires that spread quickly and burn hot (Mason et al., 2006). Without regular fires to burn off this ladder fuel, it accumulates and quickly turns most fires into out of control, high intensity mega wildfires (Stephens et al., 2014).

While these are some of the most important changes in forests caused by fire suppression policies, the effects do not stop there. Without fires turning over nutrients in a forest, the availability of nitrogen, phosphorous, and sulfur in soil decreases; it takes longer for soil decomposers to release these nutrients from dead biomass than a fire would (Keane et al., 2002). With no fires to remove the old, weak trees from the landscape, bugs and diseases are able to find hosts and spread rapidly, leading to increased outbreaks (Keane et al., 2002). Finally, the reduced biodiversity in plants offers less variety and quantity of forage and reduced habitat types available for wildlife, leading to decreased wildlife diversity (Keane et al., 2002).

Perhaps the most noticeable change in the forest is that which can be seen with the naked eye. Through repeat photography projects, the Mountain Legacy Project (MLP) has documented changes in forest structure in the Rocky Mountains over the past century that are easily observable in photographs. In Jasper National Park, research have found that total forest cover increased over 30% from 1915 and 1997 with substantial losses in shrubland, grassland, and juvenile forest (Rhemtulla et al., 2002). In the mountainous forests of Southern Alberta, 28% of the landscape is now in a later successional stage than a century ago; this can be observed by the substantial increase in closed canopy coniferous forests, broadleaf forests, and mixedwood forests, which grasslands and open canopy woodlands are rapidly disappearing (Stockdale et al., 2019).

2.4 Repeat Photography to Understand Landscape Change

There are several tools available to researchers through the Mountain Legacy Project's Image Analysis Toolkit to allow for repeat image analysis. One key tool is an image alignment tool, which matches features between image pairs and then alters them through scaling, translation, shear, and rotation to make them as identical as possible for analysis (Sanseverino et al., 2016). This allows for the comparison of photos by matching up features in the photo pairs and ensuring the images are the exact same size and show the exact same view, which is essential for relative comparison of change. Figure 2.4.1-2 shows an example of an image pair that is not aligned and a pair that is aligned.

Figure 2.4.1*: An unaligned image pair. Although these images were taken from the same location, differing cameras have produced different fields of view. In this photo, this is most clearly noticed by the difference in amount of visible foreground in the modern vs. historic image.*

Figure 2.4.2: *This is the same image pair as above, but these images have been aligned using the MLP's Image Analysis Toolkit. This has aligned key points in the image, such as the mountain peak, and made the amount of foreground visible in the image consistent between both the modern and the historic.*

Another key tool for image analysis is the ability to create landcover categories (such as snow, coniferous forest cover, rock, etc.) and overlay them onto the image. This creates "image masks," which turn the images into coloured polygons that represent the various landcover categories that make up the image. Figure 2.4.3 shows an example of a photo mask. It allows for easy comparison between images, as the pixel counts generated per category can be directly compared in the historical and modern image (e.g., 500 pixels of conifer in the historical image versus, say, 5,000 in the modern), which allows for more precise comparison (Sanseverino et al., 2016). While a multitude of other tools exist within the Image Analysis Toolkit, the ability to align and categorize photos are the two tools that are most important to the repeat photography analysis in this study.

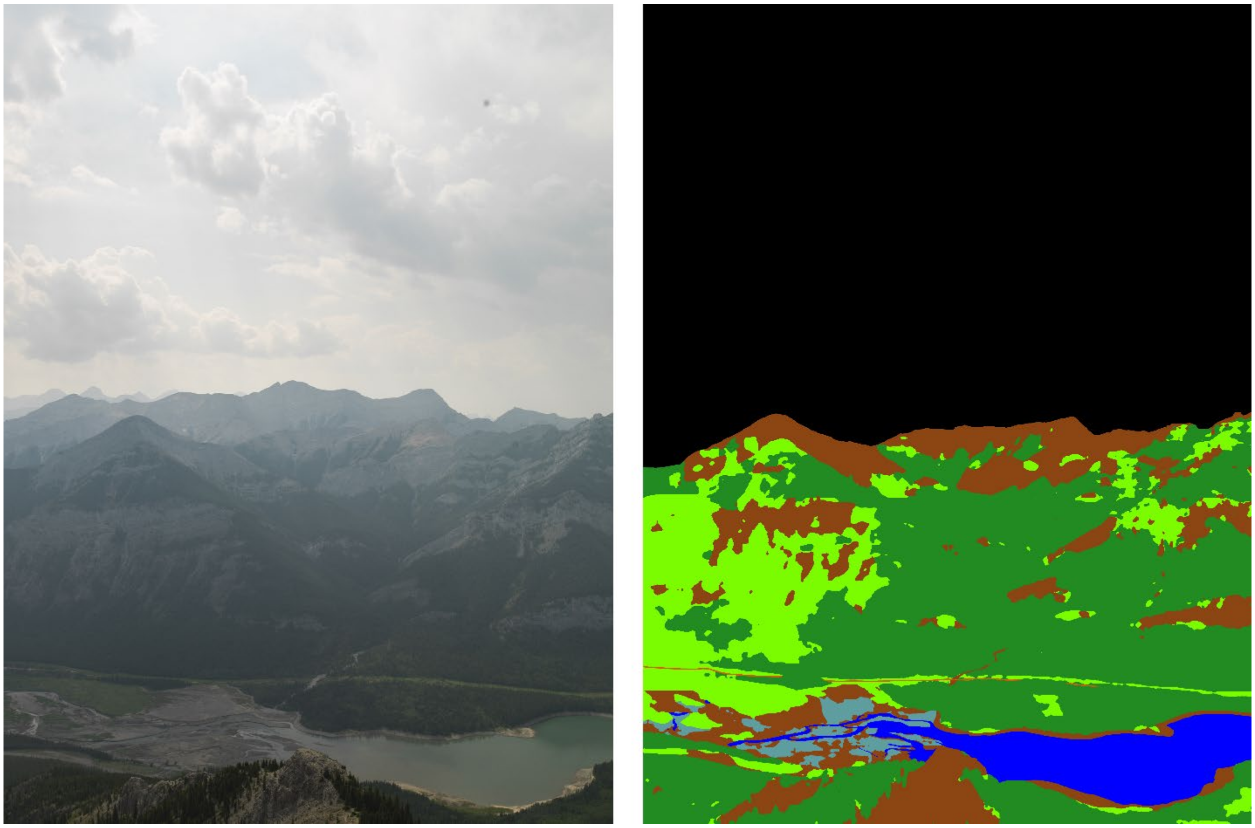
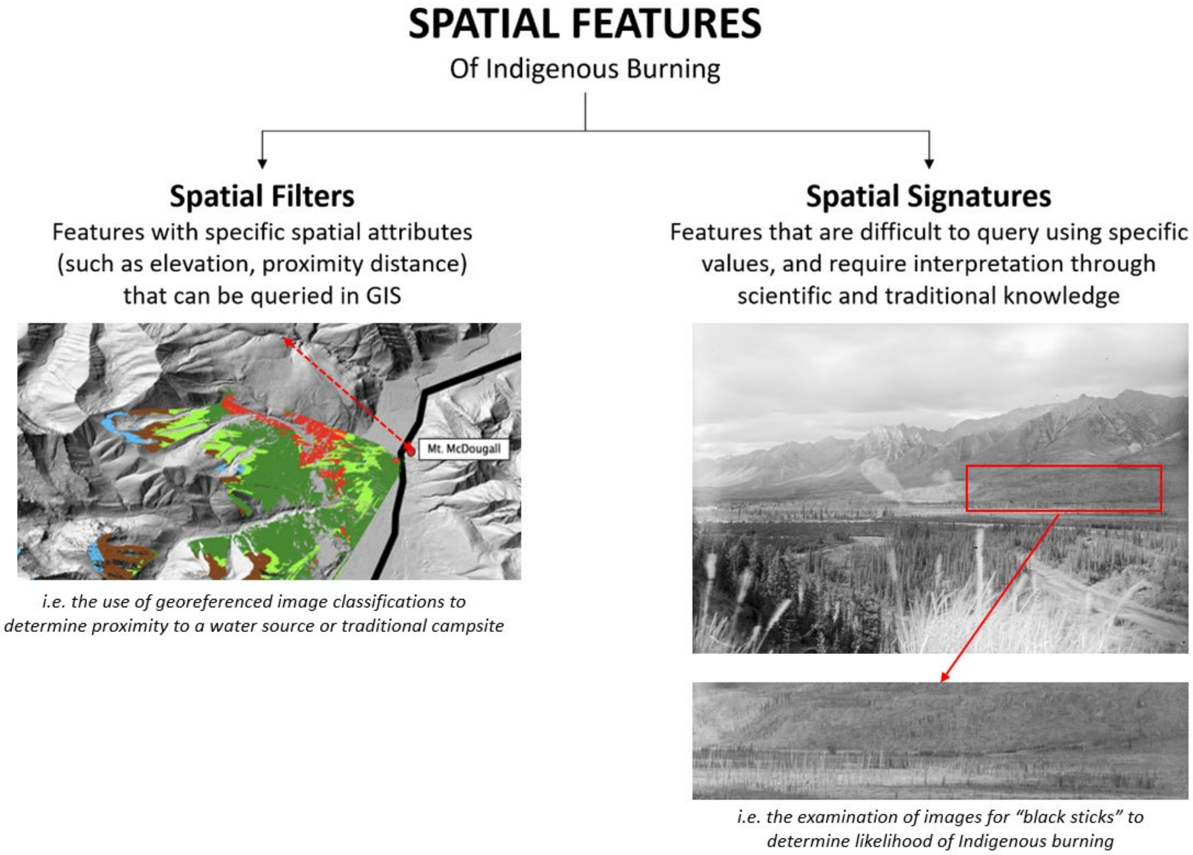


Figure 2.4.3*: A modern image and its corresponding photo mask. In the mask, each colour corresponds to one landcover type. In this example, dark green represents coniferous forest, light green is shrub, dark blue is water, light blue is wetland, and brown is rock. These categories allow images to be easily viewed and analyzed by their percentage of landcover type.*

2.5 Spatial Features of Indigenous Burning

The signatures of Indigenous burning discussed in section 2.2, while useful for quantifying fire characteristics, are not readily identified in historical or repeat photographs. Therefore, for this study, I identified and documented several spatial features that can be used to investigate Indigenous burning using repeat photograph sets. Spatial features of Indigenous burning can be split into two broad categories. The first is spatial signatures, which are features that are difficult to query using specific values and require interpretation through scientific and traditional knowledge. These signatures are visible on photographs to the trained eye and will be discussed further in this section and are summarized in table 2.5.1. The second category is spatial filters, which are features with specific spatial attributes, such as elevation, that can be queried in GIS programs. Spatial filters will be discussed further in section 5.3. Figure 2.5.1 summarizes this distinction.



SPATIAL FEATURES

Of Indigenous Burning

Spatial Filters

Features with specific spatial attributes (such as elevation, proximity distance) that can be queried in GIS

i.e. the use of georeferenced image classifications to determine proximity to a water source or traditional campsite

Spatial Signatures

Features that are difficult to query using specific values, and require interpretation through scientific and traditional knowledge

i.e. the examination of images for "black sticks" to determine likelihood of Indigenous burning

Figure 2.5.1. *Summary of categories of spatial features of Indigenous burning.*

Table 2.5.1: Summary of the spatial signatures of Indigenous burning used in this study.

Spatial Signature	Identification on Photo
Proximity to traditional habitation sites	Photo stations and their viewshed are compared to known traditional camping, travelling, or hunting sites - those whose viewsheds overlook traditional habitation sites are considered to have been likely managed by Indigenous burning.
Black sticks	The presence of blackened tree trunks in a clearing indicates that a fire recently passed through this area. While this is likely the reason this area is a clearing, if black trunks are present, it was probably not an area managed by Indigenous burning.
Vegetation shift: early seral to late seral	This is identified through the creation of photo masks on historical and modern images and looking for areas where the vegetation is in a later successional stage than it was historically. This can be an indicator of an area that was likely managed by Indigenous burning.

Spatial signatures of Indigenous burning show where Indigenous management through burning may have taken place on the landscape, usually in visual imagery of historical landscapes. This research aims to dive deeper into Indigenous burning in the Rocky Mountains by identifying and describing these ‘spatial signatures’ of Indigenous burning through examination of the literature on Indigenous burning. The challenges of COVID-19 prevented my original intent to collaborate more widely with Stoney Nakoda knowledge keepers to understand the ways in which fire in particular was used in the past. I was fortunate in the end to receive guidance from one member of the Nation, and also a long-time fire specialist in Alberta.

The first spatial signature used in this study was the proximity to traditional hunting, travelling, and camping grounds. Indigenous people were likely to burn campsites and travelling routes to keep them clear so they were easier to live and travel on, and traditional hunting grounds to promote the growth of favourable plants that would attract game. Information and documents describing the location of these traditional sites was provided for this research, which allowed me to determine which photos had viewsheds that overlooked traditional habitation sites, and therefore which were more likely to have been impacted by traditional management.

From the literature, Indigenous burning was most likely to take place in early seral vegetation, as burning early seral vegetation maintained open forests and grasslands and ensured easy paths for travel (Lewis & Ferguson, 1988; Lewis, 1983; Kay, 1995; Parminter, 1995; Turner, 1999). These burns in early seral vegetation improved hunting prospects by promoting the growth of desirable grasses and shrubs, instead of allowing later seral vegetation to move in, which is often woodier and less desirable for game species (Parminter, 1995; Turner, 1999). The maintenance of these early seral vegetation patches could be used as a form of corralling or impounding animals - for example, in a low elevation location surrounded by high mountains such as Dead Man’s Flats, the Stoney people would burn the grass there yearly to promote the growth of fresh, soft grass that attracted bison. Since the area around Dead Man’s Flats is enclosed by high mountains, they could then set up camp at the entrance of the area to keep the bison entrapped. When the community needed meat, they would simply kill one bison off of the herd trapped in the Flats (pers. Comm. Arthur, Snow 2021). This is just one example of burning of vegetation being used to improve hunting prospects, but early seral vegetation was burned for other reasons, including the promotion of desirable plant species used for food, medicine, and ceremony. The Stoney people only use poplar wood - an earlier seral species than coniferous trees - for their ceremonies, meaning maintaining poplar patches by burning off encroaching conifer trees was also practiced (pers. Comm. Snow, 2021). For these reasons, the presence of early seral vegetation that later shifts to late seral vegetation is considered one of the key spatial signatures of Indigenous burning.

The final spatial signature used in this study was examination of photos for the presence of “black sticks” (charred old tree growth) indicating that an early seral clearing exists due to a recent large fire, rather than regular Indigenous burning. As Indigenous burning usually took place on a short timer interval (5-20 years), there was not time for trees to grow to sizes that would leave thick, blackened trunks behind. Therefore, clearings that do not show evidence of black sticks were more likely to be maintained by regular burning, and clearings that show blackened sticks and logs were likely not regularly burned. These three spatial signatures, which are either visible on photos or easily determined through the knowledge of photo location and traditional habitation site location, were used to analyze images in this study to determine if they show areas that were likely or had the potential to be managed by Indigenous burning

2.6 Oblique Imagery

Oblique images, which are photos taken at a parallel viewing angle to the ground at a typical “human-eye” view are primarily used in repeat photography studies. However, these are not the standard for most image-based remote sensing studies. The majority of imagery that is used for landscape change studies is aerial, taken perpendicular to the ground from directly above, or at a “bird’s-eye” view. These images, also called orthogonal images, were taken first from planes in the early 20th century and later by satellites. These images are often favoured for their uniform area represented by pixel size, which allows for easy comparison between modern and historic images. Figures 2.5.1-2 show an example of the same site viewed from an orthogonal vs. oblique view. Despite the ready availability of aerial imagery and the ease of use for analysis, systematic aerial imagery did not begin in Canada until the 1940s, and complete coverage of Canada was not available until 1957 (Sanseverino et al., 2016). Therefore, for a study such as this one, aerial photography does not provide sufficient temporal depth as the introduction of fire suppression laws occurred prior to the 1940s. In order to study the implications of such changes in land use it is necessary to use photographs taken earlier. As oblique photos can go back as far as the 1880s in mountains of western Canada, they provide the perfect temporal depth for analysis.

Figure 2.6.1: *Barrier Lake viewed from on* ***oblique angle****. This photo was taken from the peak of Mt. Baldy and looks north.*

Figure 2.6.2: *Remotely sensed satellite* ***orthogonal imagery*** *of Barrier Lake from Google Earth.*

Oblique images have several advantages and disadvantages over orthogonal imagery. Orthogonal imagery is often considered superior because it can be easily converted to GIS analysis, which the important for many landscape-level studies. This ease of conversion arises from the assumption that each pixel in an orthogonal image represents a constant area, as the image is taken at a perpendicular angle to the ground (Fortin et al., 2018). Orthogonal imagery in the form of satellite imagery has been widely available since the 1970s, with the quality and abundance of these images increasing every year (Belward and Skøien, 2015). However, there are some disadvantages to using orthogonal imagery that are addressed by oblique images.

To begin, in mountainous landscapes, the sharp angles of steep slopes and cliffs can cause issues with the uniformity of the pixel size in orthogonal imagery, making it difficult to make comparisons between images or causing details to be missing (Fortin et al., 2018). In cases such as these, oblique imagery can provide a better view of mountain sides that have steep angles of incidence (Sanseverino et al., 2016). Oblique images, especially ones taken in the early 20th century, can provide a much higher resolution than early days aerial imagery (Chandler et al., 2002). Finally, oblique images are ubiquitous in our modern life - images surround us in Google Earth Street View, on social media, and personal photo collections. These photos, taken by scientists and average citizens alike, are an enormous untapped data source, and especially coupled with appropriate photo analysis software, they have potential to be useful for applications such as urban planning, tree cataloging, and land cover change analysis (Fortin et al., 2018). Oblique photos offer a special appeal to both scientists and the public alike because they are easy to interpret as they reflect our everyday experience of the environment (Bozzini et al., 2012).

However, using oblique images does come with a unique set of challenges. The most prominent challenge in using oblique images as a data source is the continuously variable area represented by a pixel in an image, and the occlusion of some landscape features (e.g., features obscured by a ridge or hill). Figure 2.5.3 provides a demonstration of this phenomenon. Imagine the two squares on the image are one pixel. The red square, on the foreground, likely represents a real-life area of about one metre square. The green square in the back of the image on the mountains, however, likely represents an area that is hundreds of square kilometres. The inconsistency of area represented by each pixel in an oblique image creates a challenge when working with these photos, because this makes it difficult to quantify changes. For example, if we note that 1 pixel has changed from being a grassland to a coniferous forest in a repeat photo set, it is difficult to say how much actual area on the ground has changed due to the inconsistent area represented by each pixel. When comparing entire images, the only comparison that can be made is a relative one, where the relative percent change in landcover type in one image is compared to the other, but this provides no insight on what the actual area that has changed between two areas is.

Until recently, most studies published using repeat photography have relied on either a simple side-by-side comparison with notes about broad changes observed in the photos, or pixel by pixel identification of landcover types with only relative changes noted. Although the data gathered from these studies can provide insight into useful trends, such as the trends noted by Rhemtulla et al. (2002) and Fortin et al. (2018) about the increase in conifer cover in the Rocky Mountains over the last century, they cannot say how much or exactly where this increase is occurring on the landscape. Recent work by Stockdale et al. (2019) has begun to quantify change on the landscape using WSL monoplotting, and these new methods are beginning to change the way the repeat photography can be used to investigate landscape change. The addition of the georeferencing tool in the IAT toolkit will be another option for researchers looking to quantify change in their repeat photograph sets.

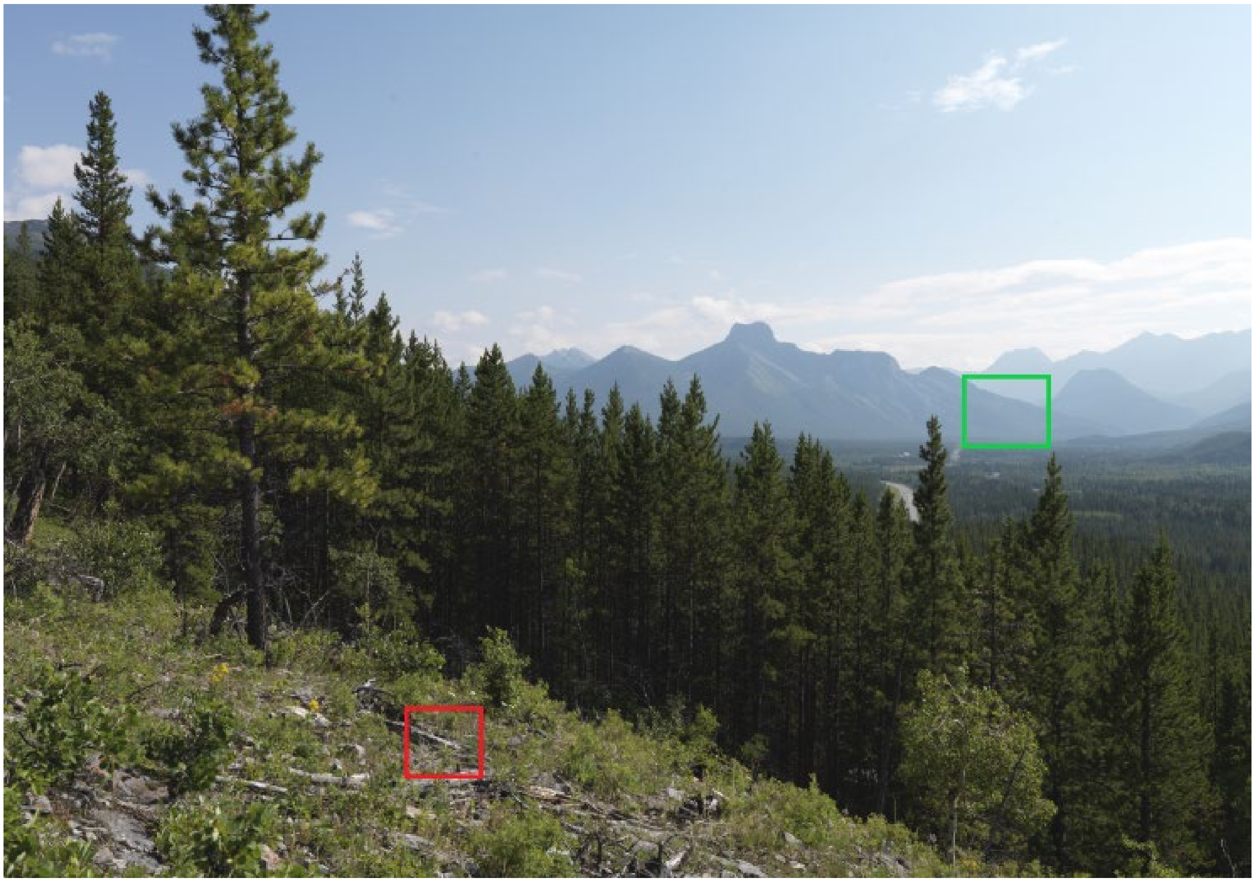


Figure 2.6.3*: This image depicts one of the most difficult challenges of working with oblique images. In this example, if you assume each square is one pixel, the red pixel represents a “real world” area of perhaps 1m^2. The green pixel in the background, however, likely represents an area that is several km^2. This variation in pixel sizing makes it difficult to produce quantifiable results when using oblique images.*

In recent years, technological developments have led to the ability to georeference oblique photos, which allows for much more accuracy in calculating area of change within and between image pairs (Bozzini et al., 2012; Sanseverino et al., 2016). Georeferencing means that the pixels in an oblique photo can be related to a ground system of geographic coordinates - in essence, each pixel in an image’s exact real-world coordinate is known. This means that instead of simply comparing relative pixel changes in categories between images, it is now possible to determine actual area changed between photosets. The WSL monoplotting tool developed by Bozzini et al. (2012) is able to georeference images using a DEM, digital photograph, and control points; this software has been utilized by fellow researchers to quantify viewshed area in repeat photo studies (Stockdale et al., 2019). The software functions in a similar way to the georeferencing tool contained within IAT - it relates each pixel in the image to its real-life latitude, longitude, and elevation. The accuracy of this tool was tested by Stockdale et al. (2015), who found that the WSL monoplotting tool was quite accurate when paired with high quality images and DEM data.

As the use of the IAT's georeferencing tool is still in its infancy, this research project will utilize a 'case study' of this software, where a subset of images will be georeferenced, and the results will be compared to the results of the non-georeferenced images to gain insight onto the potential benefits, drawbacks, and biases in oblique and orthogonal image analysis in this way. Future research into the accuracy of the IAT georeferencing tool, including comparing its results to the WSL monoplotting tool, will be invaluable for future researchers. Currently, the benefits offered by the IAT's georeferencing tool include the creation of virtual photographs, which allow for easy visualization of the landscape and can aid in the selection of control points and the ability to work completely in one program for image analysis, from classification to georeferencing to quantification of landcover.

2.7 Machine Learning Techniques to Create Photo Masks

Another issue in repeat photograph analysis is the time input that is required to categorize photos. Creating the categories and overlaying them on the image is typically done by hand, and a single image can take up to ten hours to categorize, depending on the analyst's experience and the level of detail required for the image. This means for a dataset of just eighty photos, with forty historical photos and forty repeats, can take over 800 hours of work just to classify and categorize the images. This makes image categorization one of the biggest constraints on the size of the datasets that can be worked with for landscape studies, especially when the size of some datasets, such as the Mountain Legacy Project's 8000 repeat photo pairs, is considered.

To address this problem, automatic segmentation of images is beginning to feature in image analysis. For the present study, machine learning (ML) software created specifically for the classification of Mountain Legacy Project photos was developed (Rose, 2020). As this technique is still in infancy with respect to MLP research, images processed with it required manual correction, but average time per photo was cut down from 10 hours to 1 hour. The images created and corrected using the ML in this study will be used as training material to further improve the precision and quality of the ML going forward.

The demand for fully automated pixel scale classification and segmentation of images has grown over the past half century as remote sensing has grown as an ecological discipline (Rose, 2020). Artificial intelligence software enables ecologists to identify and segment objects in orthographic imagery (aerial and satellite imagery) rapidly and with a high degree of accuracy (Brodrick et al., 2019). While most automated image classification techniques are centered around orthographic imagery, these techniques are beginning to be applied to oblique imagery.

Recent work in artificial intelligence has advanced automatic image segmentation and has been adapted for the computer vision task of scene identification, where the computer is able to identify the different “scenes” in an image and classify them as objects such as barren rock, water, vegetation, or sky (Rose, 2020). By feeding these AIs “training models,” or images along with their photo masks that have been manually segmented by a human, the ML is able to create its own photo masks of new photos in a matter of seconds. Rose (2020), the developer of this ML that was trained specifically on MLP photosets, found that the ML generated photo masks were slightly more accurate (+3% for historic images; +1% for modern images) than human generated masks, and there were much larger gains in under-represented classes, such as wetland or broadleaf forest (Rose, 2020). This study features seventy eight photos that were processed using this software to take advantage of its increased accuracy and time saving. The use of artificial intelligence to classify oblique landcover images is novel territory.

3.0 Methods

3.1 Digitization, Selection, and Pre-Processing of Images

Most of the images used by the Mountain Legacy Project are held at Library and Archives Canada's (LAC) Gatineau Preservation Facility. These high-resolution photos are preserved on glass plate negatives, which need to be scanned to a digital format to allow them to be used for research. The glass plates are digitized using a high-resolution scanner to capture as much image data as possible from the glass plates. Typical scan rates are 2,000 lines/inch (lpi), which results in image files of several hundred megabytes in size. The collection at LAC is well over 70,000 images, and the MLP is digitizing more images when time and funds allow.

Once the historic images are digitized, they can be repeated by MLP field teams. The MLP travels to the original sites of as many photographs as possible each summer to repeat the historic images. Since 1990s, the MLP has repeated over 8,000 historic photos. This is painstaking work that requires extensive planning to find the exact location of the historic photos, hiking to the peaks where these photos were taken, finding the exact photo locations once on the mountaintop and then a slow process of lining up the camera and ensuring what is seen in the viewfinder matches the historic image. Due to time constraints, the modern photos used for this study were all ones that were already present in the MLP collection. Overall, I selected 39 image pairs from the MLP's collection for my research.

The positions on mountaintops, ridges, and valley bottoms where historical surveyors took their photos are known as *stations.* An example of a station would have a name, usually of the peak it is on, such as Mount Baldy - this means all photos in this station were taken on the peak of Mount Baldy. Within each station there may be several locations where the camera was positioned to take the best photos. At a given station, for example, there could be two photo locations (Location A & Location B) used to avoid a large outcrop that may have been blocking some photos at Location A. Within each location there can be a variety of images. Often, stations were photographed in a panoramic style aiming for 360° coverage from the peak - this could include up to sixteen images. In this study, the original photographs and their repeats are grouped together by *azimuth*, which refers to the direction that the observer was pointing when they took the photograph measured in degrees; for example, an azimuth of 90° would be pointing exactly east.

This study was restricted to photos within the Baldy Pass area of Kananaskis Country. The stations were drawn from surveys including Donaldson Bogart Dowling (1905), James Joseph McArthur (1889-1890), and David A. Nichols (1916). The repeats were taken between 2009 - 2014, giving a temporal range of about 108 years. There is a total of 39 pairs for a total of 78 images. There were six criteria used when selecting images within the study area:

1. There must be both a historic and repeat image available that have the ability to be successfully aligned. Not all stations have been repeated - these were removed because there is no comparison to be made without the repeat image.
2. High resolution scans must be available of the historical images. If scans are not high quality, they are unable to be used because the images are too small to be aligned to their modern repeats and too low quality to reliably make out features in the images.
3. Both images must be unobstructed by foreground or other objects. Images with small foregrounds were chosen for maximum view of the landscape - when foreground makes up a significant portion of the photo, this skews the net pixel count of the image. Additionally, a number of modern repeats were unusable because of tree overgrowth that obstructed a significant portion of the photos. Pairs that had either of these problems were not considered.
4. Unique azimuth and coverage were necessary. As I am drawing from several surveys, some of the photos have overlapping coverage of their images. The azimuth of an image refers to the direction that it is looking, measured on a 0-360° angle, where north is 0/360°. As two photos with the same azimuth would show the exact same coverage, photos that had the exact same or similar azimuths were eliminated to reduce redundancy. Where two photos did have azimuths that were considered too close, the images with more coverage were chosen.

5. Images needed to be high quality. While all modern images are taken with high resolution cameras, there can be issues with historic photos. These include blurriness, burn marks, scratching, or other imperfections that make the image difficult to see. Images with excessive quality issues were removed from consideration.
6. All images selected had to contain vegetation to be considered. Several stations had images that were simply rocky peaks and little else.

The application of the selection criteria resulted in a final 78 images from 15 stations being selected. These stations, their surveyors, and the number of images used for this research are summarized in Table 1.

Table 3.1.1. Summary of surveyors, year of survey, stations, and image pairs used in this study

Surveyor	Year of Survey	Stations	Image Pairs
Donaldson Bogart Dowling	1905	4	10
James Joseph McArthur	1888-1889	7	13
David A. Nichols	1916	3	16

Once the images were selected, the modern and historic images were aligned with each other in a process known as "mastering" using the Image Analysis Toolkit. When mastering an image, four common points (known as "control points") on both images are selected. These common points are typically topographical features such as mountain peaks or other geological features that would remain unchanged in the time between both photos. Once these four control points are selected, the mastering tool attempts to crop and align the two photos to create two identical photos using scale, translation, and rotation of the images. The alignment runs best when the four control points are spread evenly across the image, and the alignment can be checked manually with a slider tool to view the images.

3.2 Segmentation of Images Using Machine Learning Software

The machine learning tool (ML) is a tool that creates photo masks for images based on landcover categories. The Alberta Vegetation Inventory Interpretation Standards, including the Alberta Vegetation Inventory (AVI) classifications were used to develop the artificial intelligence that segmented the images in this project (Rose, 2020). The AVI system is based on air photos that are delineated with polygons as the smallest unit areas – however, for repeat photograph studies, the scale used by AVI is too fine to be consistently identified on an oblique photo. For this reason, the categories have been grouped and modified from AVI classification. This was based on previous images that were manually segmented by MLP researchers (Taggart-Hodge 2016; Fortin et al., 2018) that were used as the training images for this ML. The categories identified and their explanation can be seen in Table 2 (Rose, 2020).

Table 3.2.1. The categories used by the ML to create photo masks.

Colour	Category	Definition
⬛	Not categorized	Sky, obscured by objects in the foreground, or otherwise unidentifiable.
🟨	Broadleaf – Mixedwood Forest	26 – 75% broadleaf trees, with the rest largely comprised of coniferous trees and/or shrubs
🟩	Coniferous forest	Greater than 75% coniferous trees
🟩	Herbaceous – Shrub	Less than 6% tree cover, with the rest being shrub/herbaceous coverage
🟥	Regenerating Area	Fire boundaries clearly identified, or a clear sign of recent timber harvesting
🟫	Barren Rock	Soil, sand, gravel, or rock
🟦	Wetland	“Wet” or an aquatic moisture regime, but not open water.
🟦	Water	6% or greater flowing or standing water
🟦	Snow/Ice	Permanent snow and ice

The ML created for the MLP and used in this study, which is called the PyLC Landscape Classifier (PyLC), can be downloaded from https://github.com/scrose/PyLC. PyLC contains nine pretrained models which must be also downloaded from the GitHub, five of which are trained on high resolution greyscale historical photos and four of which are trained on full colour modern photos. Due to differences between greyscale and colour images, two non-interchangeable categories of models are needed. All nine models have been trained and optimized using different parameters, and thus may generate slightly different results.

PyLC utilizes deep convolutional neural networks (DCNNs) that have been specifically trained on high resolution greyscale and colour photography from the Mountain Legacy Project collection. It also uses threshold-based data augmentation to improve detection of rare classifications, such as wetland or broadleaf forest, to prevent them from being over dominated by more common classes such as conifer. Finally, PyLC applies optional Conditional Random Fields filter to improve segmentation accuracy over a human classifier. All nine DCNN models available with PyLC are implemented in [PyTorch] (https://pytorch.org/), which is an open source Python library, and [OpenCV] (https://opencv.org), which is a library of programming functions developed for computer vision. The PyLC tool has three modes: data preprocessing, model training, and model testing. In model testing, photo masks are created, so this was the mode that was used for this research. All data preprocessing and model training was completed by Spencer Rose in the creation of this ML.

When PyLC is creating photo masks for images, it first must segment the image into smaller tiles that are more manageable for the conditional random fields filter to work on. This is known as the "scale" of the model that is run. The scale ranges from 0.1 – 1 and determines how many tiles the image is broken into. A lower scale breaks the image into fewer tiles and therefore has lower detail in the mask that is created. A higher scale breaks the image into more tiles, producing more detail, but also more noise into the image. For my images, I chose to work at a scale of 0.4, which was a good balance of detail without too much noise. Figure 3.2.1 shows the tiling process of PyLC, and figure 3.2.2 demonstrates the difference between a low scale and high scale mask.

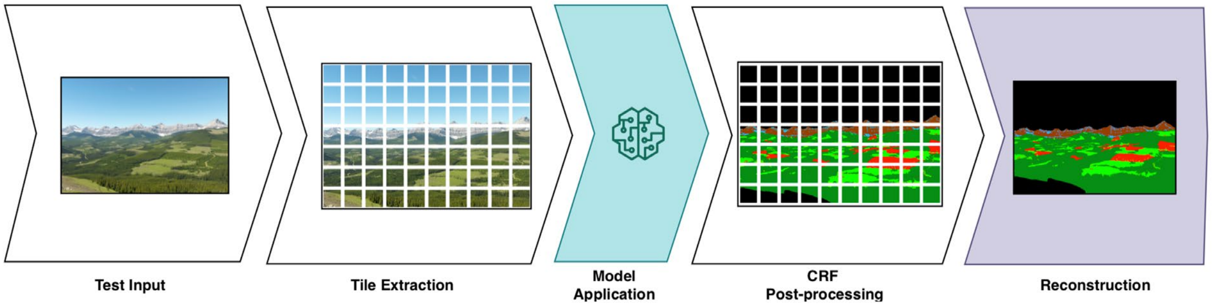
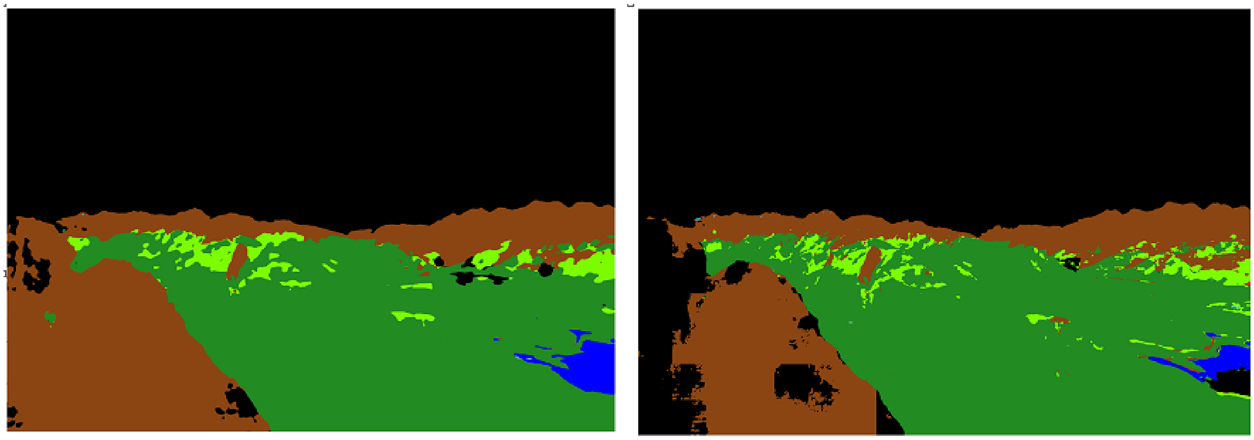


Figure 3.2.1. *Image segmentation into tiles before processing. The image is reconstructed before the final output is generated (Rose 2020).*



Resolution 0.3 – 15 tiles

Resolution 0.9 – 187 tiles

Figure 3.2.2. *Demonstration of the difference between a low scale image and a high scale image. Although the higher scale image shows more detail, it is also more prone to error from the noise it generates, as can be seen in the water on the right side of the image. The lower scale model picks this up correctly as water, but the higher scale model classifies this lake as rock, water, shrubland, and uncategorized.*

After running all nine models on a few sample images, I decided to use model 2-3-ch1 for my historic images and model 2-3-ch3 for my modern images because this model generated the most accurate masks for my photoset. I chose just one model to run for all of my photos to maintain consistency amongst all photo masks that were generated. The code that was generated and used to run PyLC for this analysis can be found in Appendix 1.

Once everything is set up, the running of the model took approximately 2-3 minutes to generate an image mask, or about 4 hours to generate masks for all 78 images used in this research. As the first MLP researcher to use PyLC to generate masks in an applied setting, there was significant time required to learn about, download, troubleshoot, and run PyLC to establish the code required to run it. Future researchers should have significant time saved by simply following the procedure in Appendix 1 and be able to run many more photos for their own research.

The masks generated by PyLC are fast and relatively accurate but do have some issues. One prominent issue is found with the classification of water, especially when the water is reflective. Water is often classified as “not categorized” or is classified based on the reflection of the surrounding landscape in the water. As several of my photos had significant water in them, this presented a challenge. An example of this error can be seen in Figure 3.2.3. Another issue with the PyLC classification is the lack of category for human infrastructure. In Kananaskis Country, significant development has taken place over the past century. PyLC typically incorrectly classifies human infrastructure as rock or water. An example of this can be seen in Figure 3.2.4.

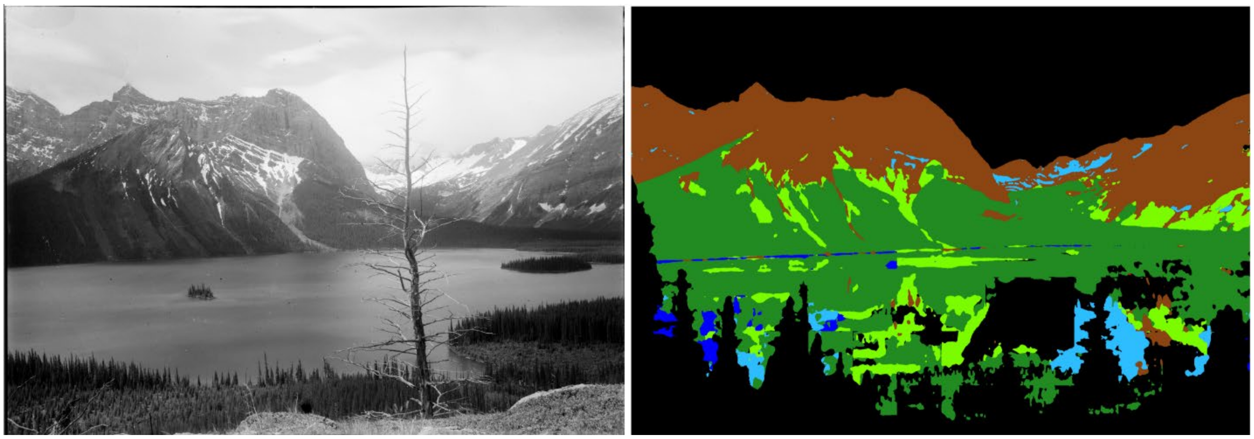


Figure 3.2.3: *In this example, PyLC has done a good job of segmented and classifying the background mountains of this image - however, the water is clearly mis-categorized. Using a mask like this with no alteration would introduce significant error into this study.*

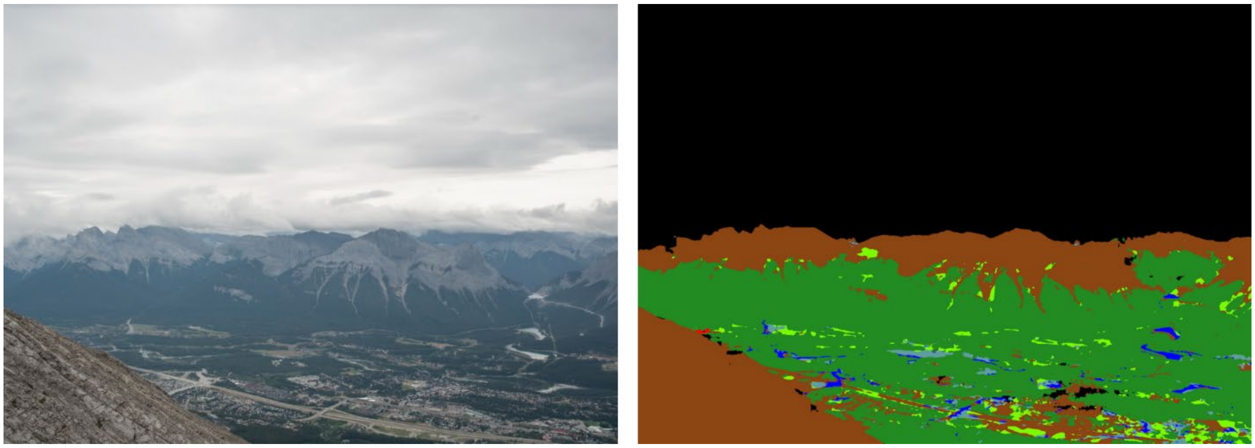


Figure 3.2.4: *In this example, PyLC again has no trouble classifying the mountain peaks in the horizon. As this image overlooks the town of Chuwapchîpchîyan Kude Bi (Canmore), however, the classification in the valley has incorrectly picked up houses, roads, and other human infrastructure as rock, water, wetland, and shrubbery.*

In light of these errors, I manually corrected my masks using Adobe Photoshop (PS). Although this increased the time required for completion of the masks, the increase in accuracy was worth the extra time invested. In the process of tiling and re-stitching the masks together, PyLC alters the size of the mask so that the finished product is not the same size as the photo that the mask is based on. To begin the process of fixing the masks, the mask must first be resized to fit the exact dimensions of the photo it is based on. This can be achieved by using the "Photo Resize" function in Photoshop and ensuring that the "nearest neighbour" option is selected to keep the colours in the mask from bleeding into each other.

Once the mask was the same size as the image, I imported it into the same PS project as the mask and created a layer with the photo. After locking the photo layer to ensure there are no changes made to the photo, I turned down the opacity of the mask so the photo is visible behind the mask. An example of how this looks can be seen in figure 3.2.5. Next, I used the grid function to overlay a grid onto the photo. Finally, working square by square, I zoomed into the photo closely and corrected errors in the mask based on my own visual inspection of the photo behind the mask and the classification PyLC gave the area. I corrected the mask using the lasso, bucket, and pen tools in PS.

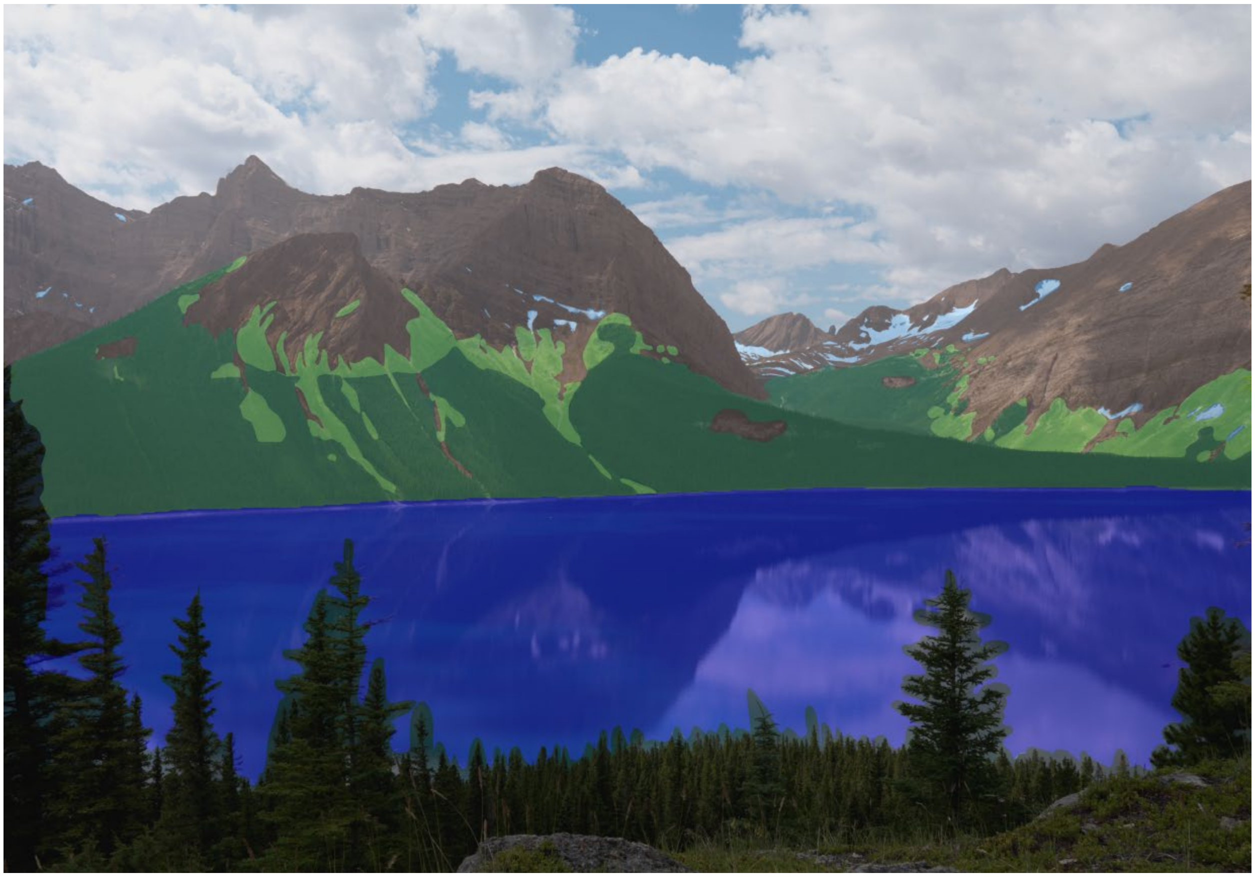


Figure 3.2.5*: An example of a photo with a semi-transparent mask overlaid on top in Photoshop. Working at this opacity, I was able to manually correct errors in the mask that were visible in the photo behind.*

I aimed to correct the PyLC generated masks as little as possible to maintain consistency. Masks were only altered when I was completely certain there was an error - such as the classification of water as conifer, or the classification of blue sky in ice. Otherwise, in situations such as ones where it was unclear exactly where the forest transitioned to shrubland, I deferred to the classifications made by PyLC to reduce human error or inconsistencies in my own classifications.

Depending on the amount of error in an ML mask, the time it took to correct each mask took anywhere from 5 to 90 minutes. Once the masks were completed, the photo layer was deleted, opacity was turned all the way back up, and the masks were saved as a high quality .png file to preserve the integrity of the categories. The use of these masks as training material for later versions of PyLC will hopefully reduce the need for future researchers to manually correct masks and will lend to the correction of the misclassification of water and other errors noted above. The ultimate goal for PyLC is to be able to correctly classify MLP images with no correction needed.

Once the masks were manually corrected, the handmade and PyLC made masks were separately run through IAT and their landcover types documented by pixel. This data was analyzed in R to compare PyLC generated masks to the human corrected masks and discover the strongest and weakest classification categories of PyLC for future versions. This is discussed in further detail in section 3.4.

3.3 Georeferencing of photo masks for landcover quantification

For the case study of georeferencing, 9 masks from the Dowling stations Limestone Ridge (Azimuth 168, 282, and 332), Mount McDougall (Azimuth 158, 211, and 272), and Wedge Mount East (Azimuth 118, 176, 236, and 290) were georeferenced using the Image Analysis Toolkit's georeferencing tool. All photos georeferenced were modern photos because the high quality of the modern images makes them easier to work with, which was optimal as this is a preliminary case study of georeferencing images with this tool.

Once the masks were corrected in PS, they were ready for georeferencing. The inputs required to georeference an image in IAT include an image, a photo mask, a digital elevation model (DEM) that covers the entire viewshed of the image, and a hillshade map of the same extent. A DEM is a map where each pixel is classified with a number that represents elevation at a specific latitude and longitude. DEM resolution varies - for this study, a 2m DEM was used, which means that each pixel of the DEM represents a real-world area of $4m^2$, or 2m*2m. This DEM was originally a 1m LiDar DEM that is Open Government License obtained from the Alberta Environment and Parks Provincial Geospatial Centre. This DEM was resampled in QGIS to a 2m resolution using cubic convolution to reduce file size to one that could be easily used in the Image Analysis toolkit. Cubic convolution was used as the resampling method to generate smooth slopes that would be optimal for image generation. Acquision of a high quality, large DEM was a large obstacle in this project, and the ultimate study area that ended up being studied was determined by where DEM data was available.

A hillshade map is a relief map based on the DEM that uses shades to indicate slopes and heights. An example of a DEM and a hillshade can be seen in figure 3.4.1. The hillshade used for this project was generated by the hillshade tool in QGIS based on the 2m DEM. In addition to this data, the exact camera location including latitude, longitude, elevation, orientation, and field of view is required. Most camera information was recorded by the MLP field crews when repeat photos were taken and can be accessed alongside the photos online.

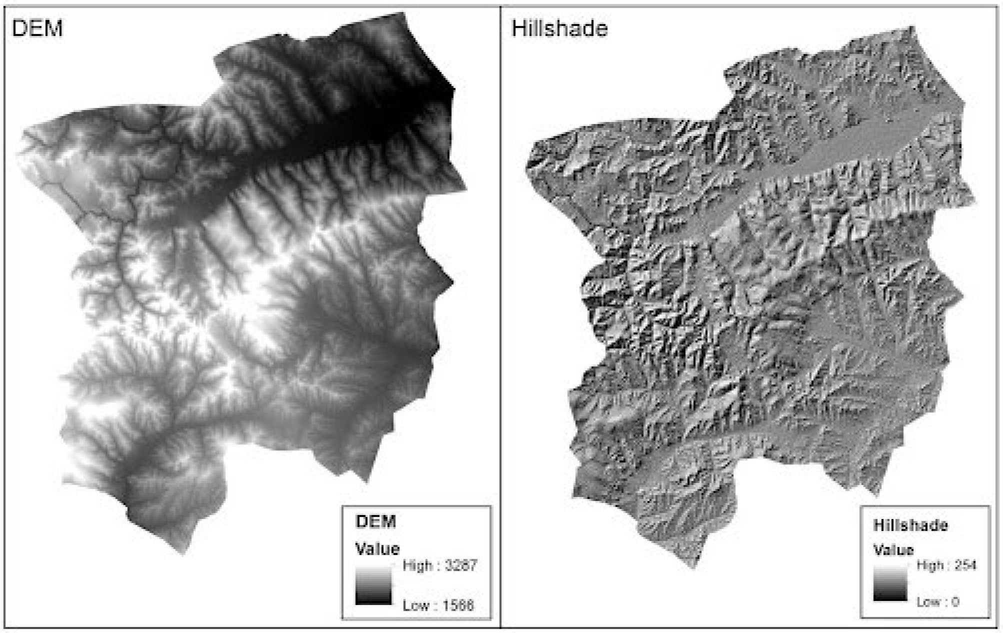


Figure 3.3.1 *- An example of a DEM and the corresponding hillshade. (Credit: Colorado State University, 2009. http://ibis.colostate.edu/webcontent/NR505/2012_Projects/Team9/GISConcepts.html)*

The first step of georeferencing a photo mask is the creation of a virtual photograph (VP). A VP is a visualization of what can be seen in the landscape from the specified camera location and orientation. This is calculated by the georeferencing software (in this case, IAT) by drawing an imaginary line from every pixel in the DEM to the camera location to see if and where that point falls in the photo frame. Figure 3.4.2 shows an example of an example image and a virtual image of the same location side by side. The generation of a virtual image creates one that is identical in form to the original optical image, but every pixel has a latitude and longitude coordinate associated with it that is pulled from the DEM. This association of each pixel with a real-world location means that the VP is georeferenced.

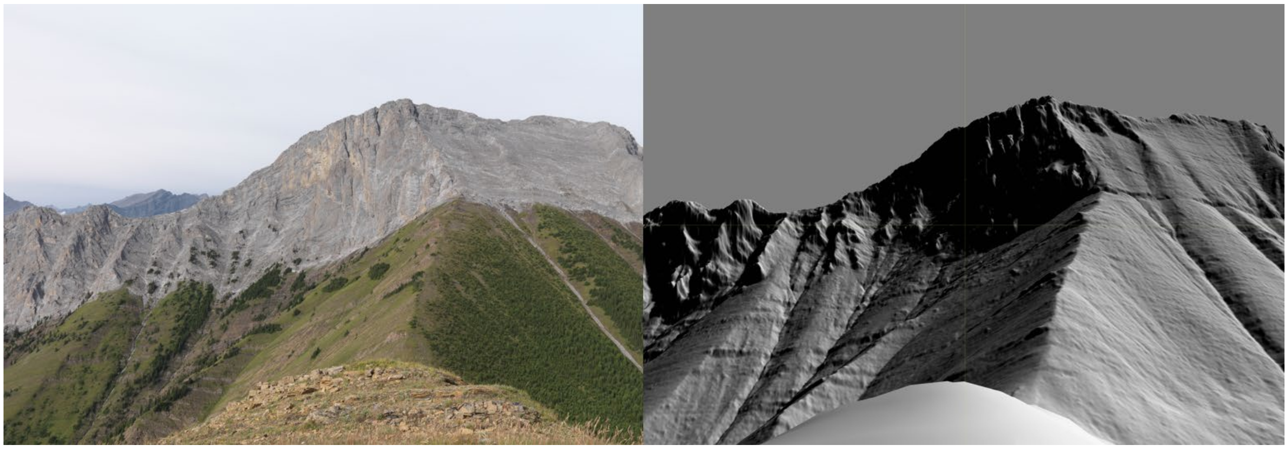


Figure 3.3.2. *A virtual photo of the Dowling station Wedge Mt. East (Azimuth 236). This virtual image was generated in IAT using a DEM, hillshade model, and precise camera location data.*

Once a VP that is identical to the real-life image is generated, the next step is to drape digitally the image mask over the virtual image. This is done by using the align feature in IAT. First, the virtual photo is aligned to the real-life photo by picking out salient features in both photos as control points, which essentially georeferences the real photo. Then, using the alignment points generated by this step, the photo mask is aligned to the virtual photo. At this point, the mask is now georeferenced - every pixel in the photo mask has a corresponding latitude and longitude location.

The final step in the process is the creation of a viewshed. To create a viewshed, IAT maps out where each oblique photo pixel belongs on the DEM based on its latitude and longitude information. This creates a viewshed, showing the parts of the landscape that are present in the photograph and their corresponding landcover type that was mapped in the image mask. The viewshed typically appears patchy, because some features in the image are obscured by certain landscape features (e.g., ridge, hills, mountains). Therefore, when the viewshed is projected onto the DEM, these obscured pixels behind mountains and other features will not be coloured. Figure 3.4.3 shows a photo mask that has been turned into a viewshed and overlaid on a hillshade map of the area. The viewshed is georeferenced and tied to the DEM, which entails the size of each pixel is now consistent and matches that of the DEM. In this study, as the DEM used was 2m*2m, each pixel in the viewshed represents an area of $4m^2$. When the viewshed subsequently is put into IAT and the count feature is run, the count of pixels for each class can be multiplied by the area of each pixel to generate total area represented by each landcover class.

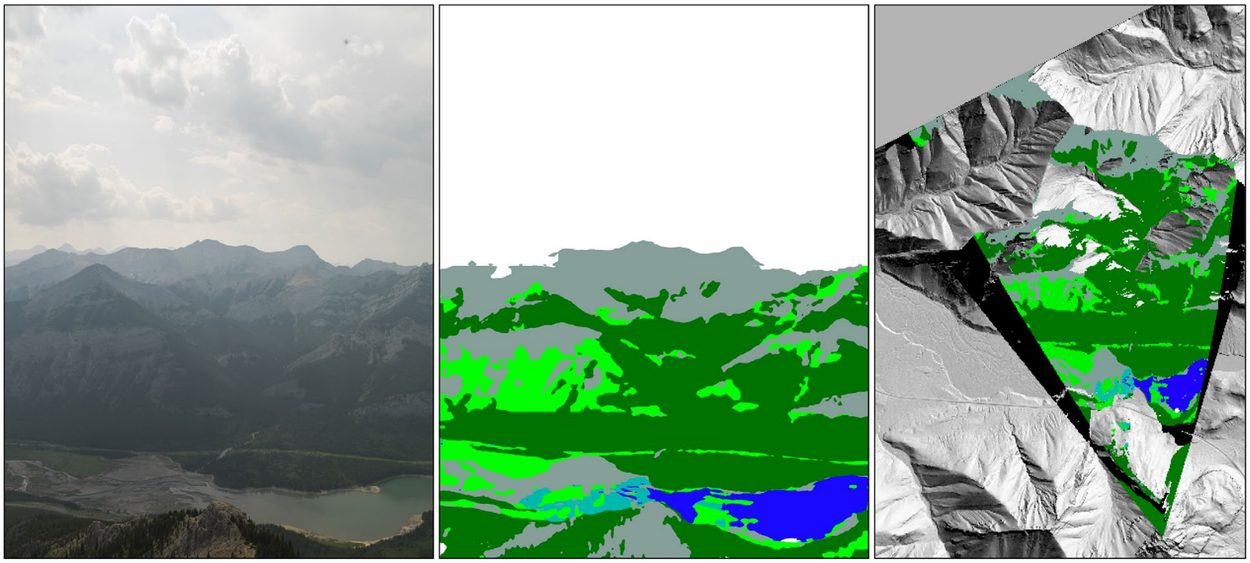
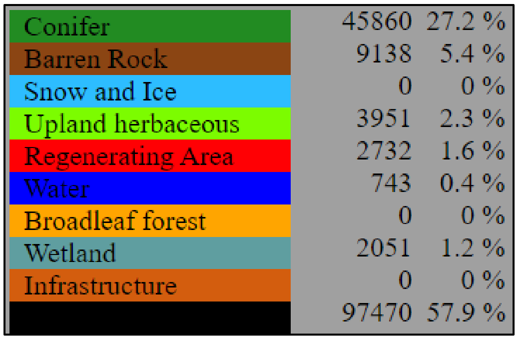


Figure 3.3.3*. This example shows the station Mt. Baldy's photo mask projected as a viewshed over the landscape. The gaps present indicate where peaks have obscured seeing what is behind them in the oblique photo.*

Once these viewsheds were generated, they were uploaded to QGIS as raster data and overlaid onto OpenStreetMap satellite imagery (https://www.openstreetmap.org/) to create an aggregated map of landcover type in Kananaskis County. Overlaying georeferenced viewsheds onto satellite image can be a method to explore the accuracy of the georeferencing as well as create much more robust maps of landcover change that are easy for the viewer to interpret. The final map of landcover viewsheds can be seen in figure 4.3.1. Analysis of the results of this case study are outlined in section 4.3.

3.4 Choice and Application of Analysis

The masks and viewsheds that were created and editing in section 3.2 and 3.3 were analyzed using the Image Analysis Toolkit's "count" feature. This tool enables the user to input landcover categories, their corresponding colour ID, and an image mask. Once this information has been uploaded, the IAT count feature generates a report of how many pixels of each category are present in the photo mask. If oblique images are being compared, these values give the proportional change in landcover type. If orthogonal viewsheds are being analyzed, these pixel counts can be multiplied by the known area of each pixel to generate landcover area. An example of a pixel count output generated by IAT can be seen in figure 3.6.1.



Conifer	45860	27.2 %
Barren Rock	9138	5.4 %
Snow and Ice	0	0 %
Upland herbaceous	3951	2.3 %
Regenerating Area	2732	1.6 %
Water	743	0.4 %
Broadleaf forest	0	0 %
Wetland	2051	1.2 %
Infrastructure	0	0 %
⬛	97470	57.9 %

Figure 3.4.1 *An example of an output generated by IAT's count function. This image has 45 860 conifer pixels, which corresponds to 27% of the total image. The black band at the bottom represents the "not categorized" pixels.*

Data regarding pixel count of each landcover type for every image mask was input to Microsoft Excel for analysis. Percent change in landcover categories for oblique images was calculated for each landcover category using the formula [[(New Value - Old Value)/(Old Value)]*100]. Data on landcover for all historical and all modern photos was aggregated and averaged for generation of graphs showing overall change across the landscape. The raw data was then imported into RStudio (RStudio Team, 2020) to analyze accuracy, efficiency, and shortcomings of both ML generated photo masks when compared to human-generated photo masks and georeferenced landcover estimates compared to oblique landcover estimates.

First, in order to visualize landscape change, the mean of each landcover type in modern and historical images was plotted in RStudio. This allowed for a quick and easy understanding of which landcover types in the study area have changed over the past century, and in what direction. These data were summarized as the average coverage of each landcover type across all photos and recorded in table 4.2.1.

To quantify error in the ML-generated masks, I used a linear regression model in RStudio (RStudio Team, 2020) to assess how well the ML generated masks were explained by human drawn masks. For this analysis, I assumed that the human-generated masks were more accurate than those drawn by the ML. R^2 values were used to assess the strength of the relationship between the ML-estimated landcover types and human-generated masks, with a stronger relationship indicating that ML-generated masks were more accurate as this meant they aligned more strongly with human-generated masks. I separated each landcover type and analyzed them one at time. I did this because, as discussed previously, visual observation showed the ML masks struggling with certain land types such as open water. Therefore, I wanted to examine each landcover type one at a time to see which landcover types were the strongest and weakest for the ML to estimate. These relationships were also graphed using ggplot2 for visualization (Wickham, 2016).

In order to assess the differences between landcover estimations generated by georeferenced masks and oblique masks, linear regression models for each landcover type were generated in RStudio. R^2 values from this analysis was used to assess the strength of the relationship between these two classes. With this analysis, I was not aiming to prove that georeferenced or oblique landcover estimates were better; rather, I was aiming to see if the landcover estimates by each method are relatively similar. For this step, each landcover type was analyzed separately. This is because it is known that oblique images bias certain landcover types over others. Due to the nature of oblique images, landcover types that tend to be nearer to the camera (such as conifer, upland herbaceous) tend to make up a larger percent of the landcover classification simply because they appear larger due to being close to the camera. Conversely, landcover types that tend to be far away (such as snow/ice on mountain peaks) will tend to be under-reported due to being so far away from the camera that it appears smaller and less significant. Separating the landcover types for this analysis allowed me to see if the oblique and georeferenced images have similar estimations for all landcover types, or if there are some landcover types where they diverge significantly. These relationships were graphed using ggplot2 for visualization (Wickham, 2016). All graphs generated are in section 4.0 of this thesis.

3.5 Identification of Spatial Signatures of Indigenous Burning

In examining images for spatial signatures of potential Indigenous burning, images were first organized by percent change to later seral vegetation, quantified by the percentage landscape cover increase in later seral stage vegetation (such as herbaceous to conifer, or regenerating to herbaceous). This value was determined by comparing the modern image masks to the historic image masks in the Image Analysis Toolkit and generating a third image mask, known as a “change mask.” This mask shows where landcover has changed to later seral vegetation between the two masks, and what the previous landcover type was. An example of a mask of change and further explanation can be seen in figure 3.8.1. The change masks were overlaid onto historical and modern images to highlight areas of change in these images. An example of a change mask which has been recoloured overlaid on a historical image can be seen in figure 3.8.2. This was the starting point for delving further into the evidence of Indigenous burning that is present in the images.

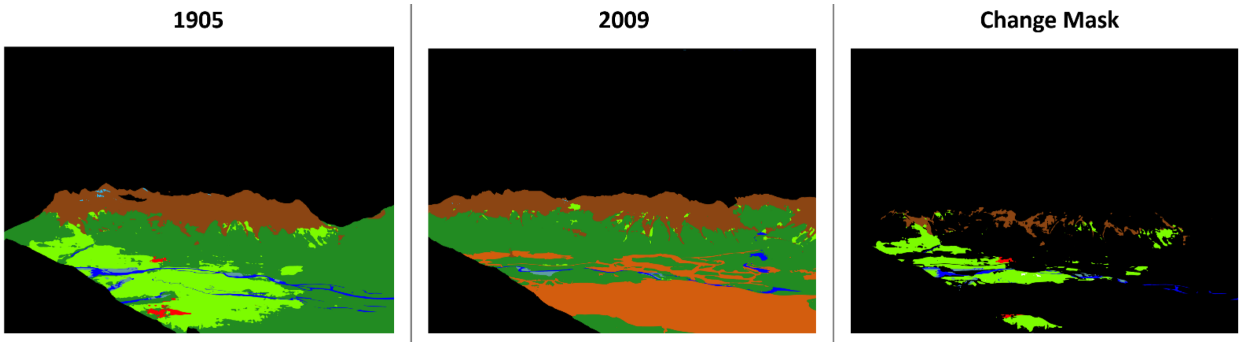


Figure 3.5.1. *1905 and 2009 masks for an image pair, and the third change mask created from the comparison of these images in IAT. The change mask represents the area in the 2009 mask that has shifted to later seral stage vegetation. The colours in the change mask show what these areas of change were in the 1905 mask. For example, the light green area in the change mask represents area that has shifted from upland herbaceous to conifer between 1905 and 2009.*

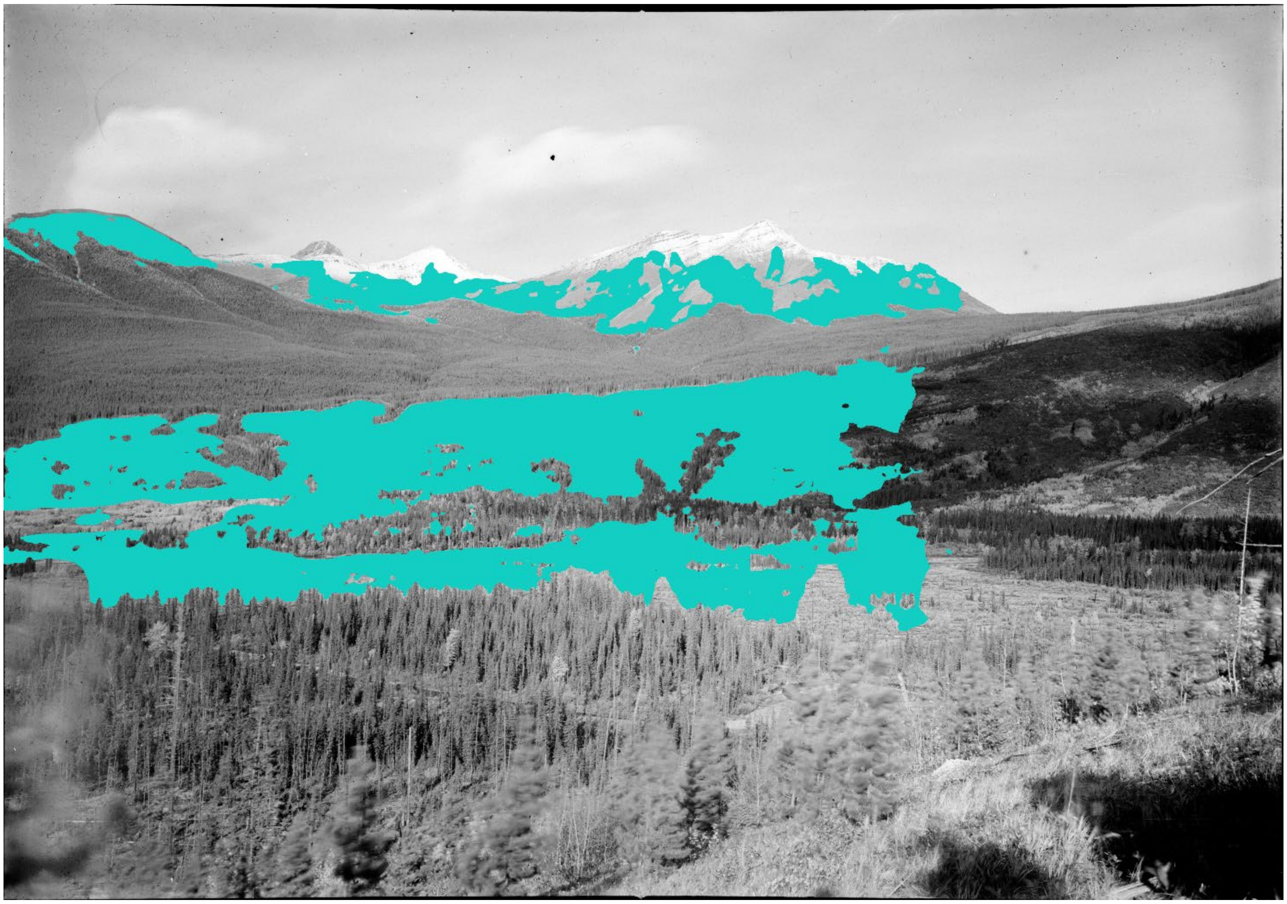


Figure 3.5.2 *Historic (1908) Mt. McDougall Az272 image, with areas of landscape change to late seral vegetation coloured in. When compared to an unaltered image, it is easy to make note of which areas have changed.*

Once areas of change were highlighted on the photo, the images were shared with Rick Arthur and Bill Snow, two long-time associates of the Mountain Legacy Project, for further advice on how researchers can discern which of these areas of change are likely related to the removal of Indigenous burning from the landscape. This methodology was also based around Lewis and Ferguson's 1988 paper which described open clearings called "fire yards" and "fire corridors" as evidence of a landscape that was regularly burned by its human inhabitants. A three-step process was developed to determine if change on the landscape was likely related to the removal of Indigenous burning from the landscape:

1. When open areas (such as aforementioned fire yards and corridors) occur in historic photos, do they persist in the modern images? If an area was open in 1905 and remains open in 2015, for example, it is likely that the reason that it is open is not related to fire

keeping the area clear, but some other factor restricting tree growth, such as soil or water conditions.

    a. The change masks were developed to quickly visualize this on the landscape. See Figure 3.8.3 for an example of how these masks allow researchers to quickly tell which open areas on the landscape have remained open, and which have shifted to a later seral stage of vegetation. While the shift from herbaceous to conifer coverage can be clearly seen in most cases, a more subtle shift from herbaceous to mixedwood might be more difficult to see a first glance. The change masks help cut out the guesswork involved by using the already-generated landcover masks.

2. When clearings occur in historical images that are later filled in by later seral vegetation, is there evidence of large fire in the historical image? The presence of blackened tree trunks in a clearing indicates that a fire recently passed through this area. While this is likely the reason this area is a clearing, if black trunks are present, it was probably not an area managed by Indigenous burning. Indigenous burning typically occurred on a short time interval of 5-20 years, which would not be enough time for large trees to establish themselves; therefore, clearings that were regularly maintained through Indigenous burning would not this show evidence of fire.
3. Was the clearing located near known traditional camping, hunting, or travelling routes of the local Indigenous population? While this information can be sensitive and is highly specific to location, this information can be invaluable to determining if a clearing was more likely to have been maintained by Indigenous burning. For this project, I was provided with hand-drawn maps of traditional campsites and travelling paths of the Stoney Nakoda, which were digitized in QGIS, which also had a shapefile of all image locations. I then marked in a spreadsheet which images overlooked areas that were traditionally used or inhabited by the Stoney Nakoda to aid in my analysis.

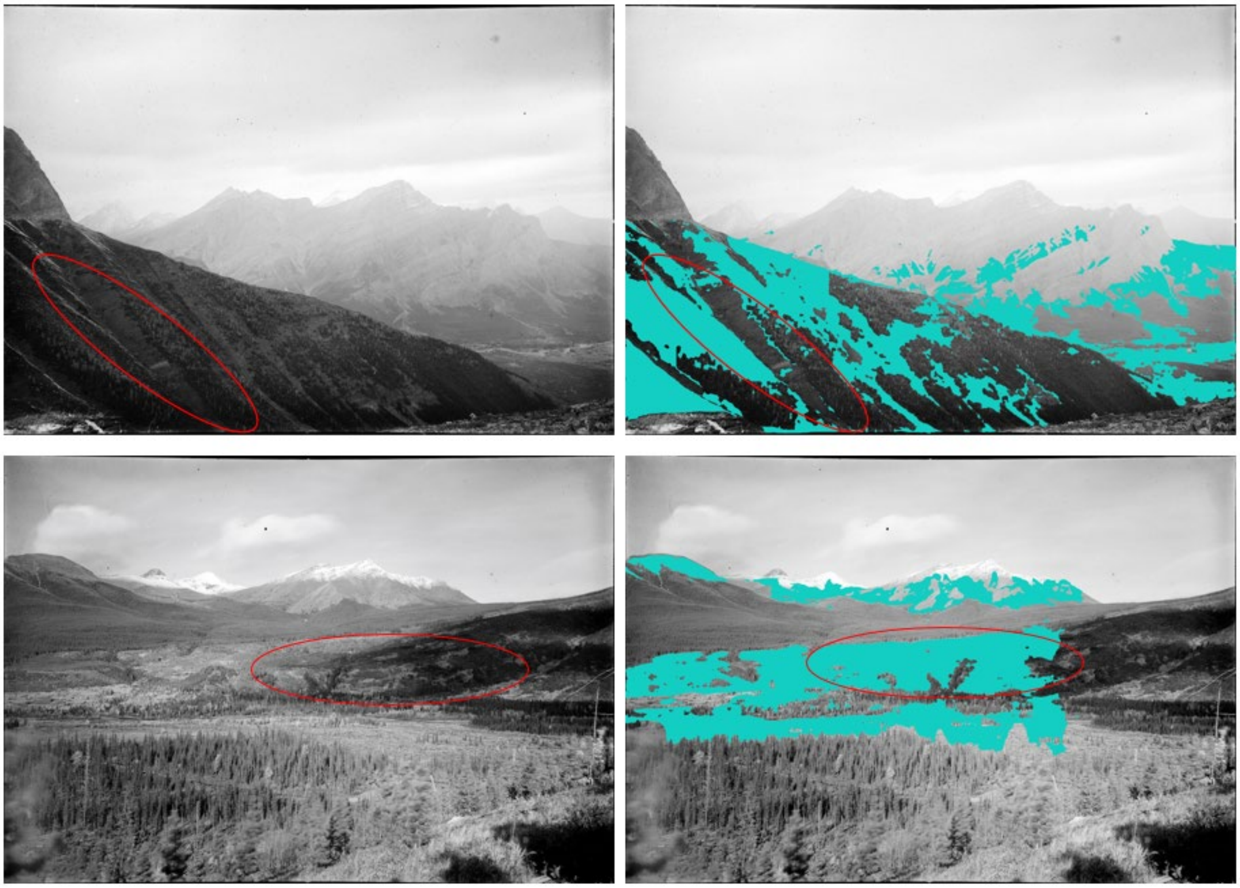


Figure 3.5.3. *Two clearings on historic images, and their associated change mask. For example, In the top two images, it is evident that the clearing circled remains clear as it is not filled in on the change mask. This is an example of an area that is likely clear due to external controlling factors. On the bottom two images, the clearing that is circled is almost completed filled in by later seral vegetation.*

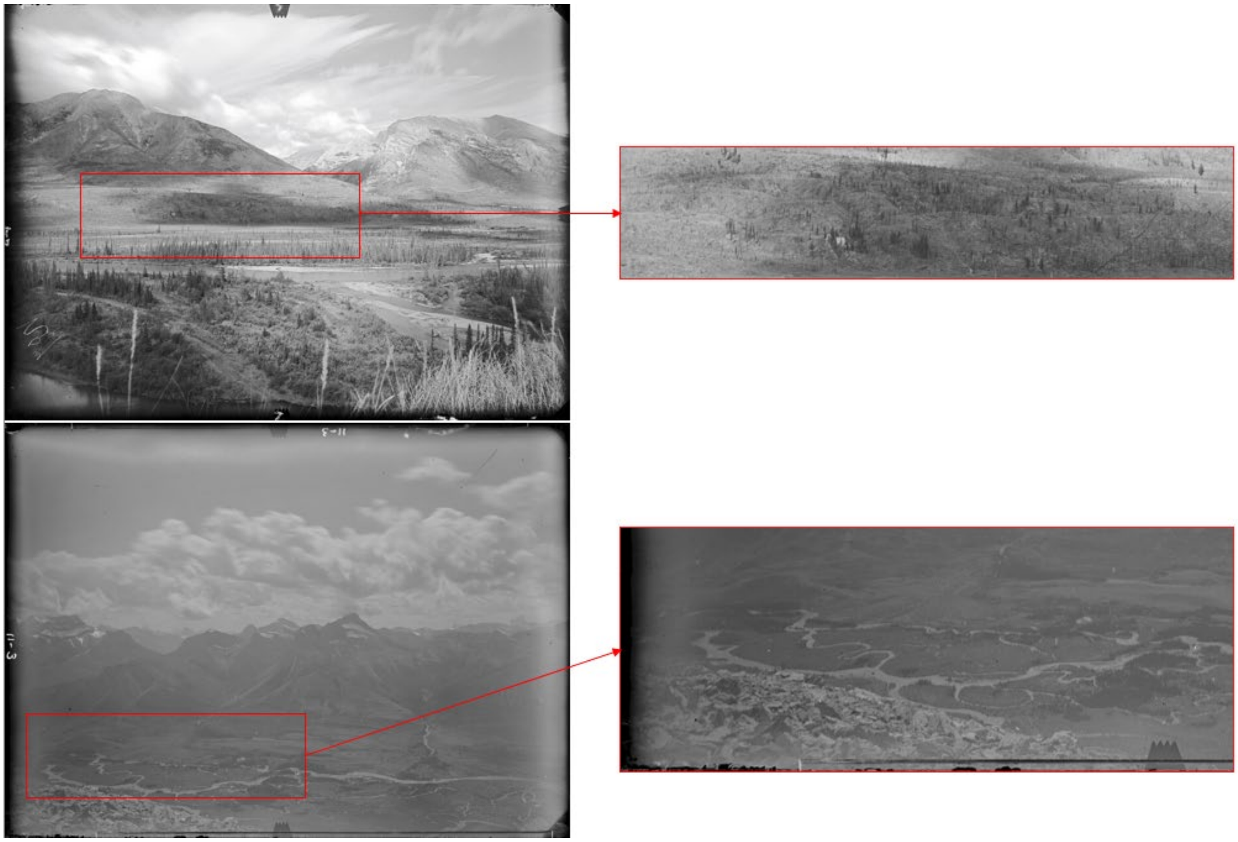


Figure 3.5.4. *Both magnified cutouts shown here represent areas that are clearings in historical imagery but are filled in by later seral vegetation in modern imagery. The top image and cutout show an example of a clearing where blackened sticks present, indicating that fire was likely not regular here. In the bottom image, the clearing shown has no evidence of blackened sticks, which may indicate it was burned more regularly.*

The methodology laid out here for describing Indigenous burning is meant to bring attention to the contribution of Indigenous burning to the makeup of historical and modern landscapes, not to definitively prove exactly how much Indigenous burning shaped the landscapes in this region. The results of this method should be thought of as highlighting areas that were most *likely* to be managed by Indigenous burning. It can be difficult to definitively prove that Indigenous burning took place any given area (as described in section 2.2), so this method is meant to bring attention to how large the area is that was *likely* to have been managed using Indigenous burning. This can be useful for both public awareness of the benefits and contributions of fire to a healthy ecosystem, and for land managers looking to incorporate prescribed burns into their landscape management plans. Previously there has been an underreported accounts of Indigenous burning in Kananaskis Valley and this method shows us how we might use these photos to see and quantify this traditional landscape management.

4.0 Results

4.1 Introduction

In this chapter, I provide an overview of the results of the landcover changes stemming from the analysis of the 78 images located in the study area. To begin, the extent (in %) of landcover classes in both the historical and modern images is described in section 4.2, which describes the landcover classifications most prevalent in the image pairs as well as changes in the landscape over the 120 intervening years that form the contemporary landscape. In section 4.3, I describe the case study of landcover change documented by oblique and georectified analysis and describe the differences captured by each method. Finally, section 4.4 will briefly describe the results of these analyses and how they relate to Indigenous burning as documented in literature.

One of the distinguishing features of this study is the use of georeferencing to examine the difference in landcover classification in oblique versus orthogonal images. Most studies previous to this have only been able to document change in oblique photos using a relative comparison, such as percentage of pixels in the photo. When georeferencing is used, an actual area of each landcover classification can be determined, which can eliminate biases in oblique images and provide a more accurate representation of the landscape. As this is an early study to use this approach, only a case study using a subset of images was possible; this can provide a springboard for future study into georeferencing oblique photos and expanding the field of repeat photography. The ability to know the location and actual area of landscape change through georeferencing will not only aid future studies in examining historical Indigenous burning, but many other research questions that require more specific data on landscape change than just relative change.

4.2 Extent of landcover classes

At the turn of the 20th century, the prevalent landcover classes in the study area were barren rock (43% coverage), coniferous forest (31% coverage), and upland herbaceous (18%). By the early 21st century, the dominant land classes were coniferous forest (53%), barren rock (34%), and upland herbaceous (7%). While the top three categories have remained the same over the century, the landscape composition has shifted. These results are summarized in table 4.2.1 and figure 4.2.1.

Table 4.2.1 Average coverage of each landcover type in both historic and modern photos. Each number represents the percentage (%) of the landcover type in oblique, non-georeferenced photos.

	Conifer	Barren Rock	Snow/Ice	Upland Herb	Regen	Water	Broadleaf	Wetland	Infrastructure
Historic	31%	43%	0%	18%	6%	1%	0%	1%	0%
Modern	53%	34%	0%	7%	0%	2%	0%	0%	4%

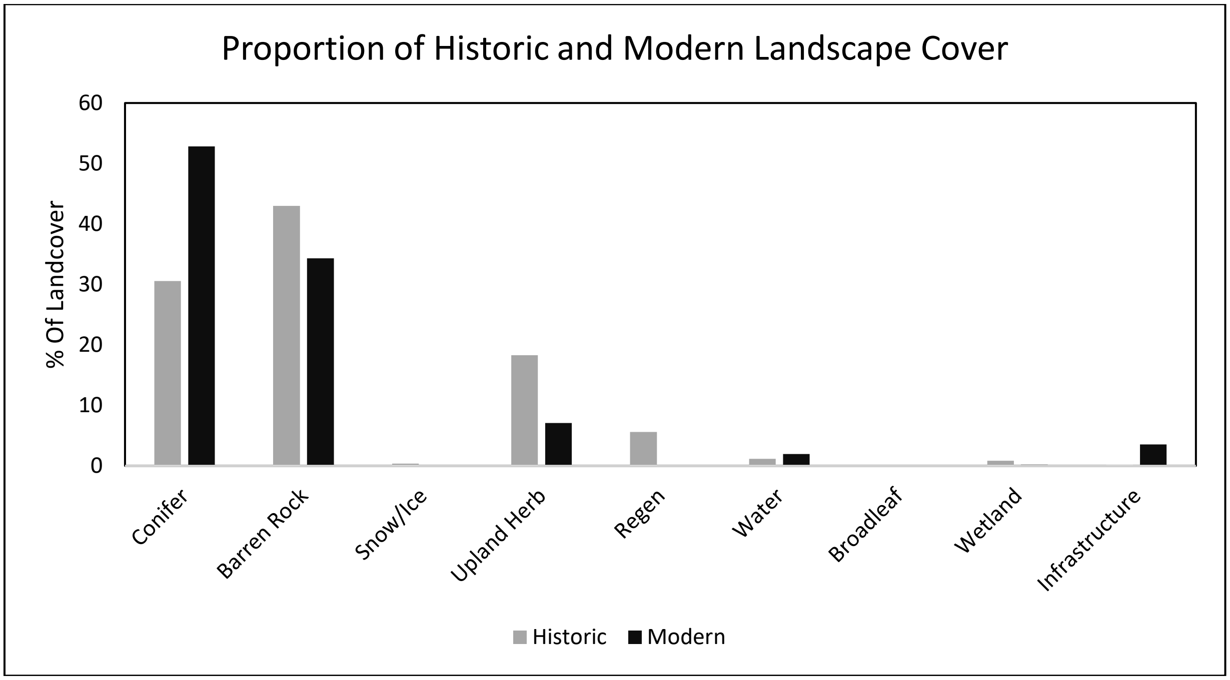


Figure 4.2.1 *Overall extent (in percentage) of each landcover category in the orthogonal images and their corresponding masks. Grey represents coverage in historical images compared to modern coverage in black.*

The change to conifer is the most significant change seen on the landscape. Further analysis was conducted using the Image Analysis Toolkit to examine exactly which categories were changing into conifer between the historic and modern photos. Figure 4.2.2 shows a graphical representation of which landcover types in the historical images changed to conifer in the modern images. The data for this graph are summarized in Table 4.2.2. Overall, about half of all conifer forests in modern images was also coniferous forest in historical images, but significant changes in historic land cover types were detected: 26% of what is conifer in modern images was upland herbaceous in historical images; 14% of modern coniferous forests were barren rock in historical images; and, 11% of modern coniferous forests were wetland, water, or regenerating area in the historical images.

Table 4.2.2. Summary of change to conifer observed in the modern images. The percentages represent what proportion of the conifer in the modern images was which landcover category in the historical images. For example, this means that 26% of what is conifer in modern images was upland herbaceous in historical images.

	Conifer	Upland Herb	Barren Rock	Regen	Wetland	Water	Broadleaf	Snow/Ice	Infrastructure
Modern	49%	26%	14%	8%	2%	1%	0%	0%	0%

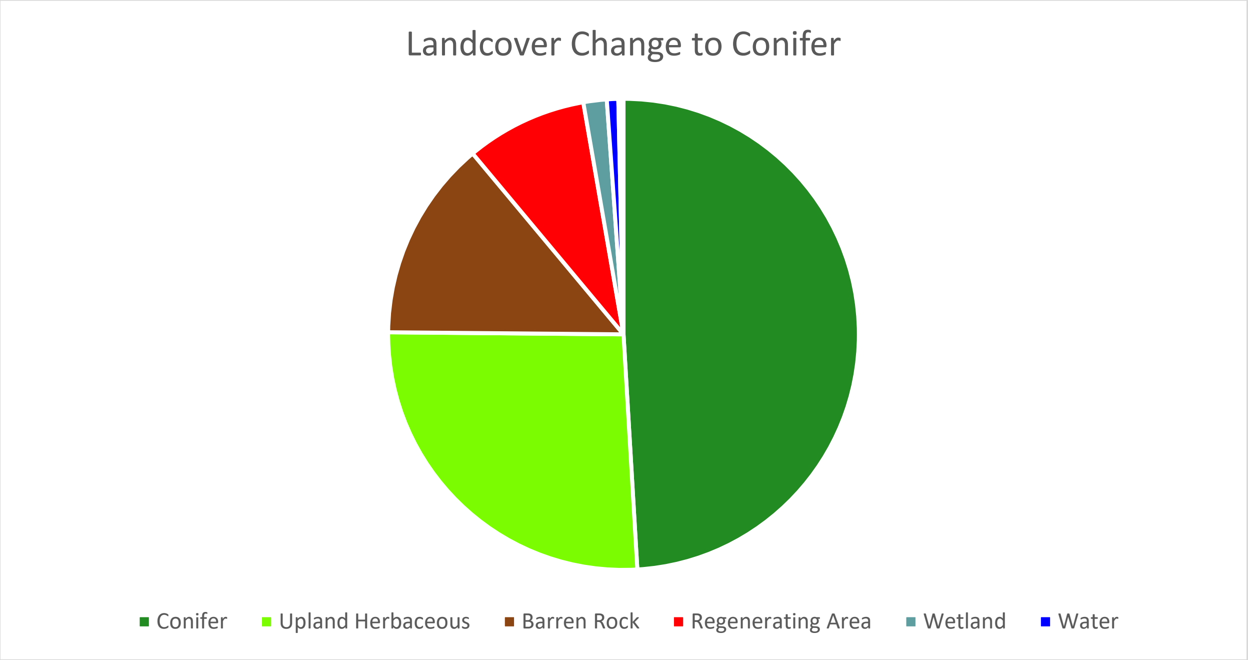


Figure 4.2.2 *Landcover types make up the coniferous coverage seen in modern images. As conifer increased dramatically between historical and modern images, much of what was regenerating, upland herbaceous, wetland, snow, and water was converted to coniferous forest over the century between images.*

4.2.1 Error in PyLC-Generated Masks

A table containing the results generated from the error experiment run on the PyLC-generated vs. human corrected masks can be seen in table 4.2.1. The PyLC-generated and human corrected masks were largely similar and deviated at most 2% from each other. PyLC seems to be the most accurate at predicting barren rock, snow/ice, regenerating area, water, and wetland, as these percentages were all the same between the PyLC-generated masks and the human corrected masks. There were slight deviations found in conifer, barren rock, upland herbaceous, infrastructure, and non-categorized landcover. The results from this table are summarized in figure 4.2.1.

A regression analysis was performed, comparing each landcover proportion estimation in the human generated masks to the landcover proportion estimates generated by PyLC masks. This can be seen in figure 4.2.2. The r^2 value is 0.9352 with 160 degrees of freedom and a p value < 2.2×10^{-16}. Table 4.2.2. shoes the r^2 values of individual regressions performed on each landcover type comparing human and ML generated masks in descending order.

Table 4.2.1.1 Landcover proportions estimated by ML generated masks and human-corrected masks. Values are rounded to the nearest %.

	Conifer	Barren Rock	Snow/ Ice	Upland Herbaceous	Regenerating Area	Water	Wetland	Infrastructure	N/C
AI	24%	17%	0%	8%	1%	1%	0%	0%	49%
Human Corrected	25%	17%	0%	7%	1%	1%	0%	1%	47%

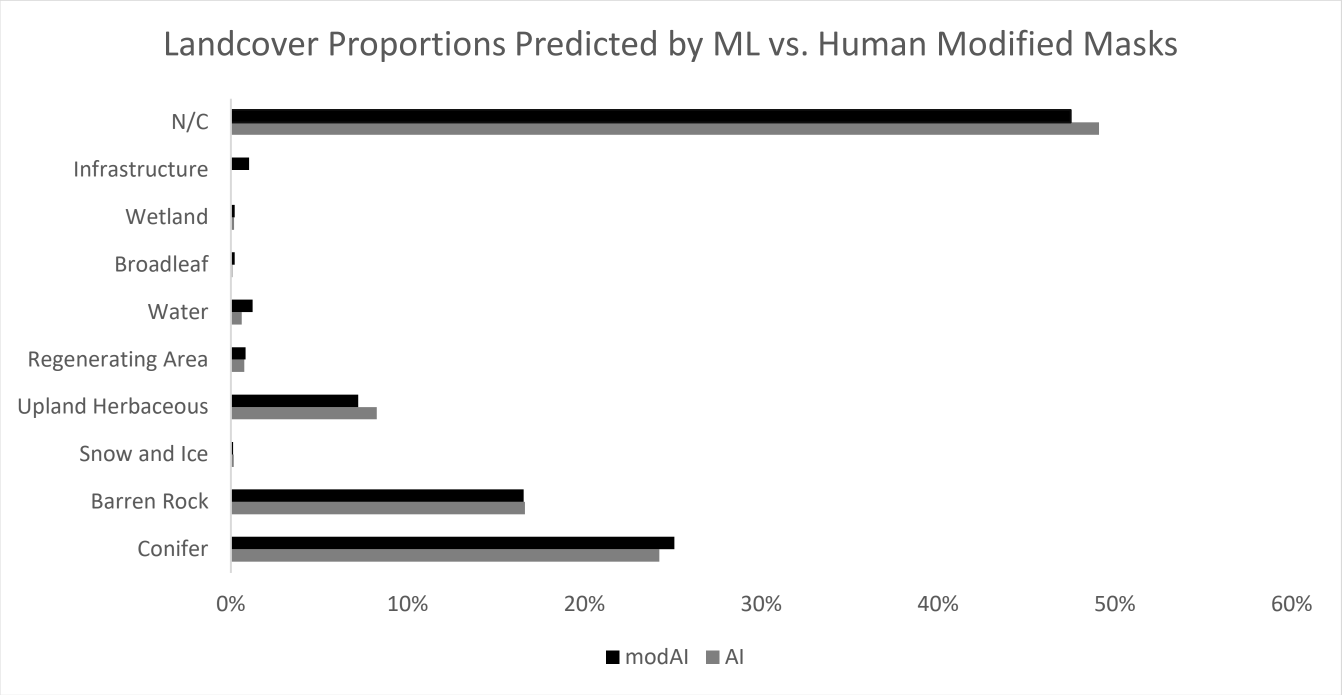


***Figure 4.2.1.1** Landcover proportions estimated by both ML and modified ML (modML) masks.*

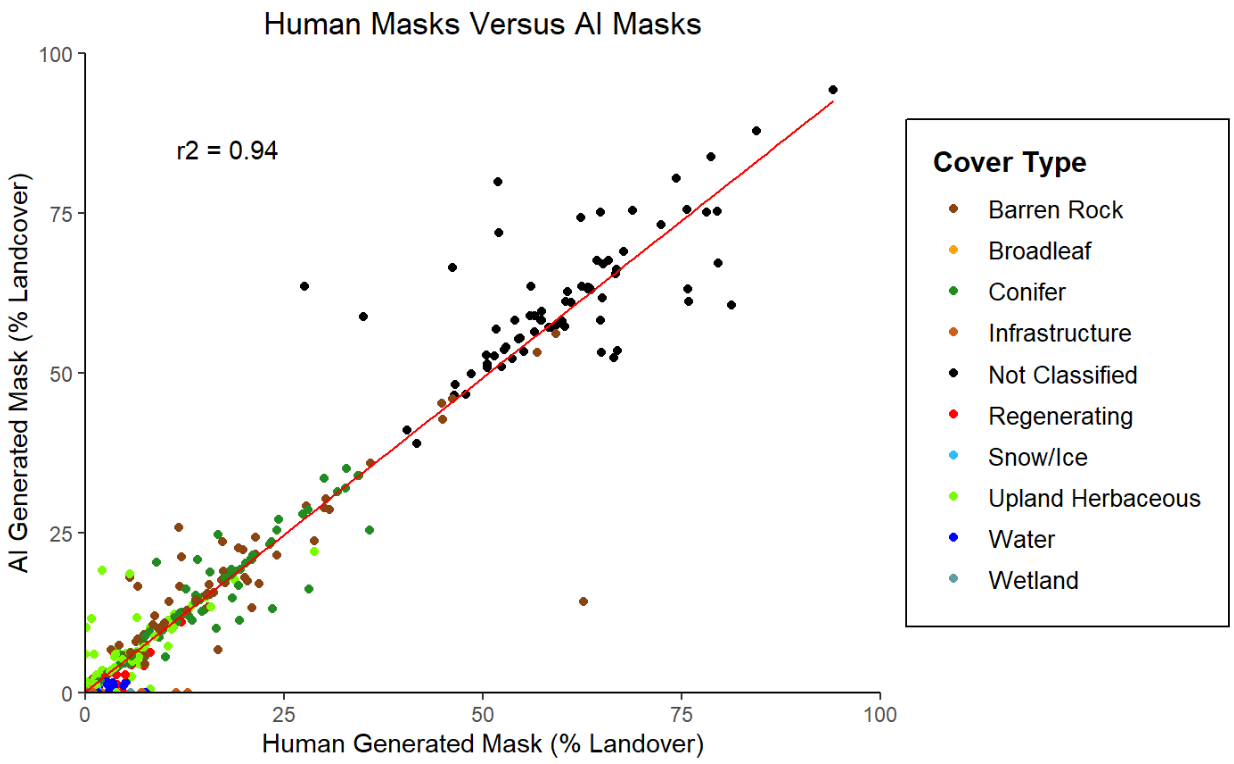


Figure 4.2.1.2. *Landcover categories and their estimated landcover in human generated vs. ML generated landcover masks. The r^2 value is 0.9352 with 708 degrees of freedom and a p value < 2.2×10^{-16}.*

Table 4.2.1.2. All r^2 for the individual landcover types in human generated masks versus ML generated masks listed in descending order.

Landcover Category	**R^2**
Conifer	0.861
Broadleaf	0.848
Regenerating	0.848
Barren Rock	0.742
Upland Herbaceous	0.587
Uncategorized	0.445
Water	0.419
Snow/ice	0.418
Wetland	0.065

4.3 Change documented in oblique images versus georeferenced images

This section covers a case study of 18 photos analyzed with the IAT georeferencing tool. A table summarizing the images can be seen in Table 4.3.1. These nine image pairs were selected for their close proximity, high and consistent quality of the historic images, and availability of a high-quality DEM for the georeferencing process. One station, Mt. McDougall Azimuth 158, was left out from the Dowling survey due to the lack of high-quality DEM available in that image's viewshed. Figure 4.3.1 shows the nine image masks projected onto the landscape for easy visualization of the landcover categories and the change that has taken place between the 1905 historic images and their corresponding repeat images taken in 2009.

Table 4.3.1. A summary of the three stations photographed by Dowling used for this case study. The azimuths that the photo pairs were taken at are recorded and used to differentiate pairs.

Surveyor	Station	Azimuth
Dowling	Limestone Ridge	168
Dowling	Limestone Ridge	282
Dowling	Limestone Ridge	322
Dowling	Mt. McDougall	211
Dowling	Mt. McDougall	272
Dowling	Wedge Mt. East	118
Dowling	Wedge Mt. East	176
Dowling	Wedge Mt. East	236
Dowling	Wedge Mt. East	290

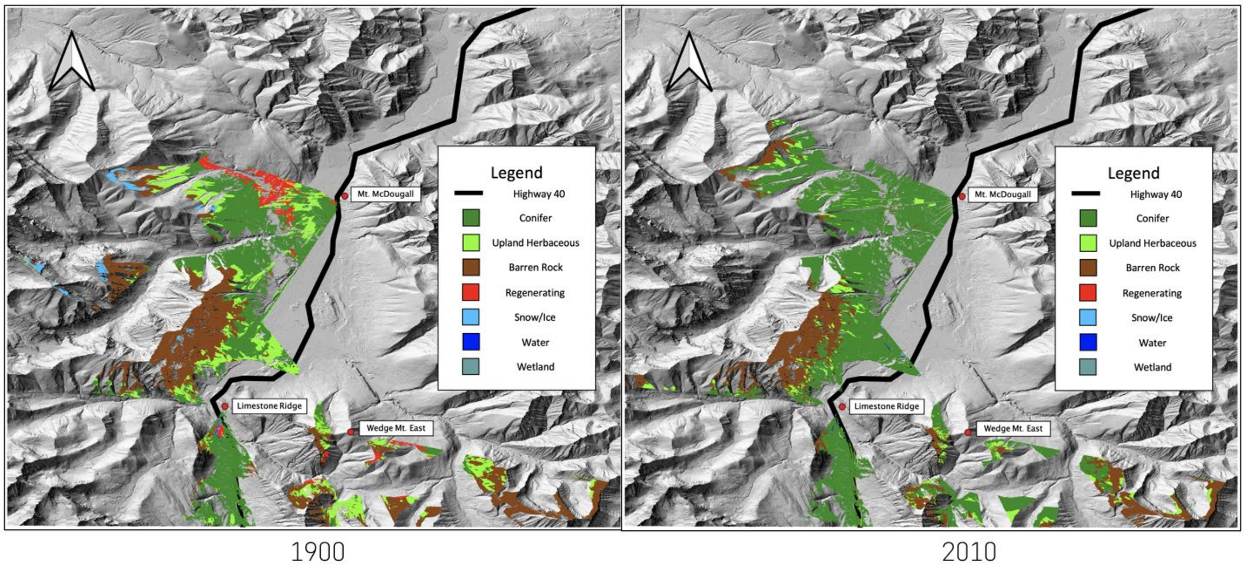


Figure 4.3.1 *Georeferenced masks for 9 images in the Dowling 1905 survey. The left map shows the historical masks projected onto the hillshade map of the study area with the three stations in the Dowling study labelled. The right map shows the modern masks projected on the same hillshade map.*

The digital elevation model and hillshade used to georeference these masks was a 2m*2m resolution, meaning each pixel had a 4m^2 area. Therefore, to calculate the area coverage of each landcover category in the georeferenced masks, the pixel area (4m^2) is multiplied by the number of pixels for each landcover type. Table 4.3.2 shows the area of each landcover type for all 9 image pairs in this case study.

Figure 4.3.2 shows the difference in landcover estimates between these 18 images when left oblique and when georeferenced, the values of which are summarized in table 4.4.3. The values generated for the georeferenced masks are calculated by total area estimated by the georeferenced masks. Note that these figures are only comparing the nine Dowling photo pairs that were georeferenced against their oblique counterparts.

Table 4.3.2 This table shows the average coverage of each landcover type in oblique and georeferenced photos. Each number represents the percentage (%) of the landcover type estimated to make up the landscape

	Conifer	Barren Rock	Snow/Ice	Upland Herb	Regen	Water	Broadleaf	Wetland	Infrastructure
Oblique	51%	31%	0%	14%	3%	0%	0%	0%	0%
Georeferenced	54%	33%	1%	15%	2%	0%	0%	0%	0%
Difference	+3%	+2%	+1%	-1%	-1%	0%	0%	0%	0%

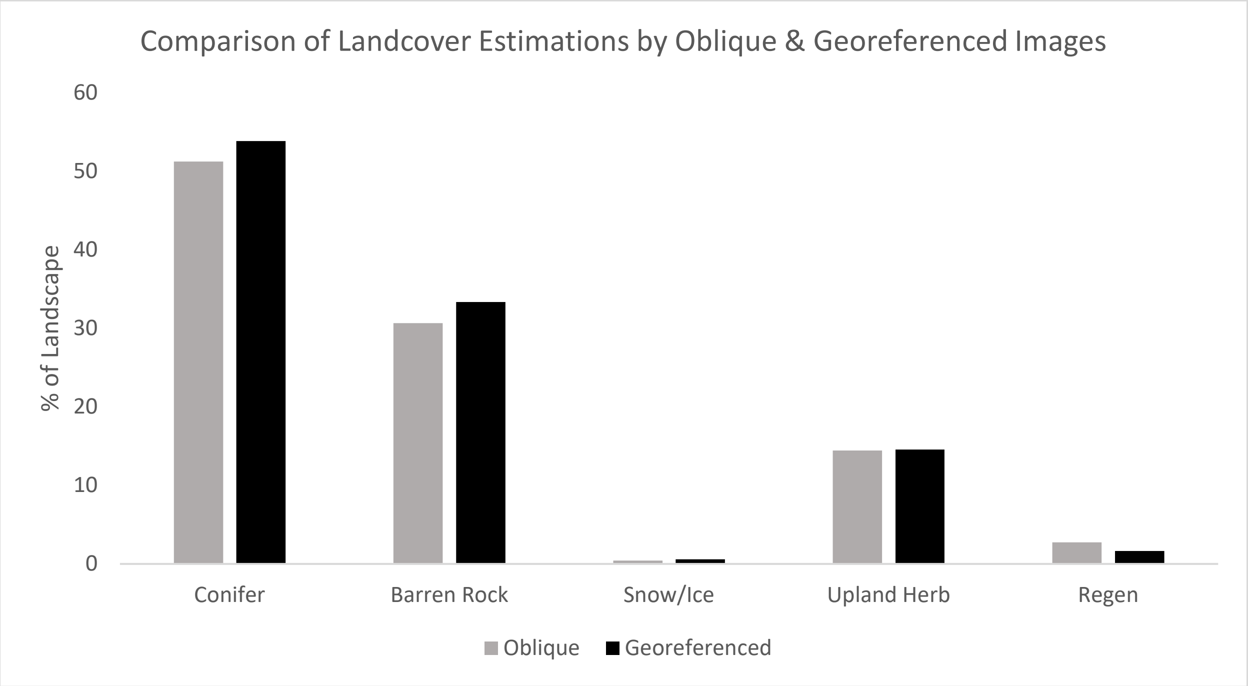


Figure 4.3.2 *Estimated percentages of the landcover between the oblique and georeferenced images.*

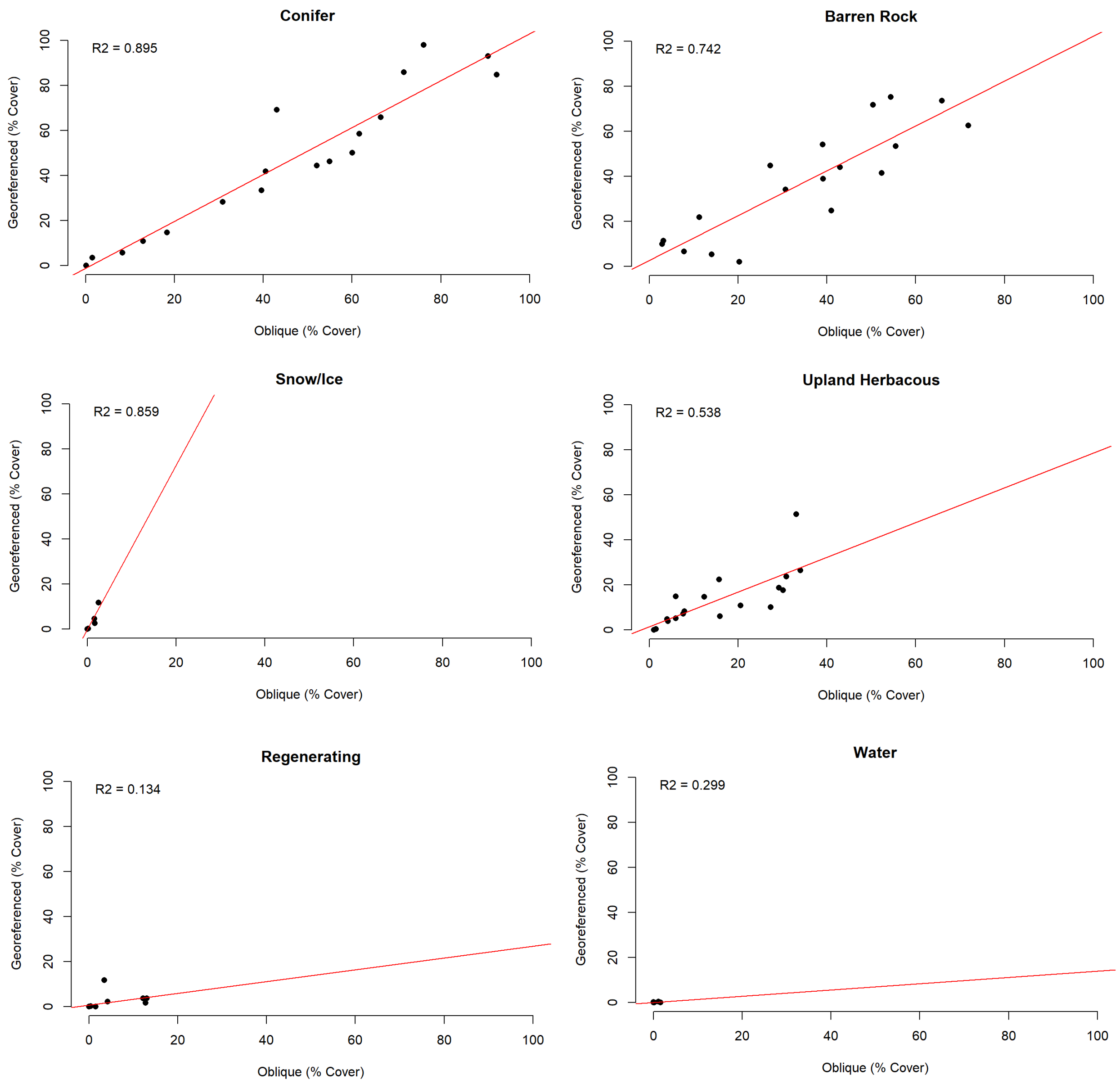


Figure 4.3.3. *Percent cover of the 6 most abundant landcover types in both the oblique classification and georeferenced classification for the case study. R-squared values are displayed on each graph.*

Finally, figure 4.3.4 shows the estimation in change of landcover types between the modern and historic images, as predicted by oblique and georeferenced photos. As found above, there was not significant differences predicted by each method. This will be discussed further in section 5.2.

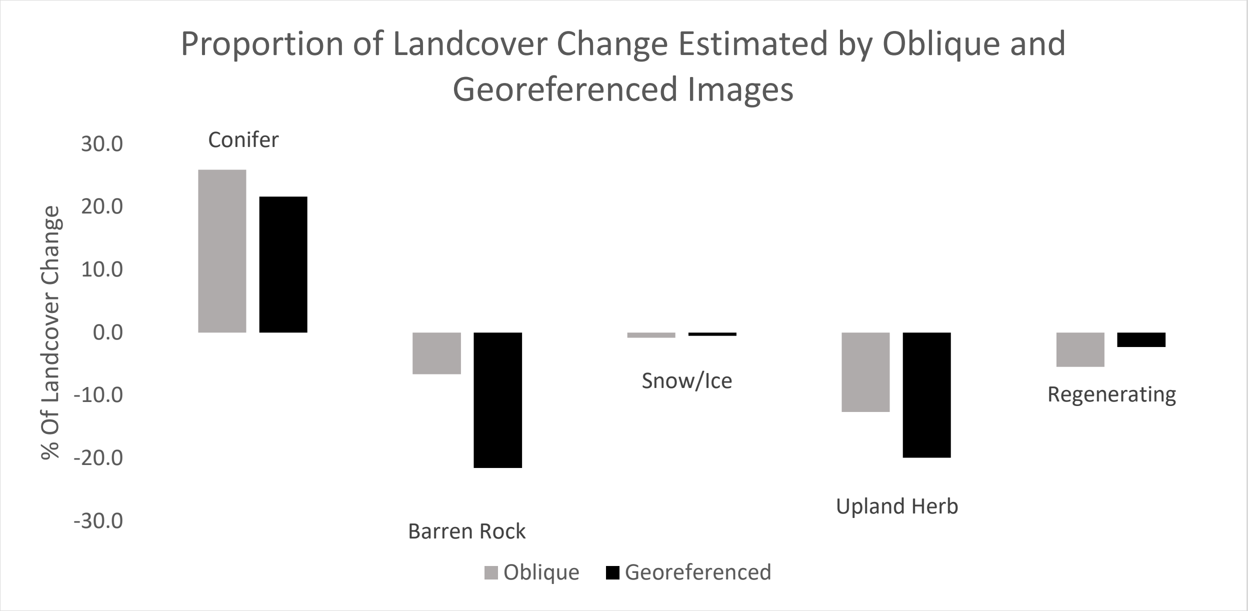


Figure 4.3.4 *Estimation in landcover change with oblique and georeferenced images between historic and modern photos.*

A regression was performed on the oblique landcover estimates vs. the georeferenced landcover estimates using RStudio.

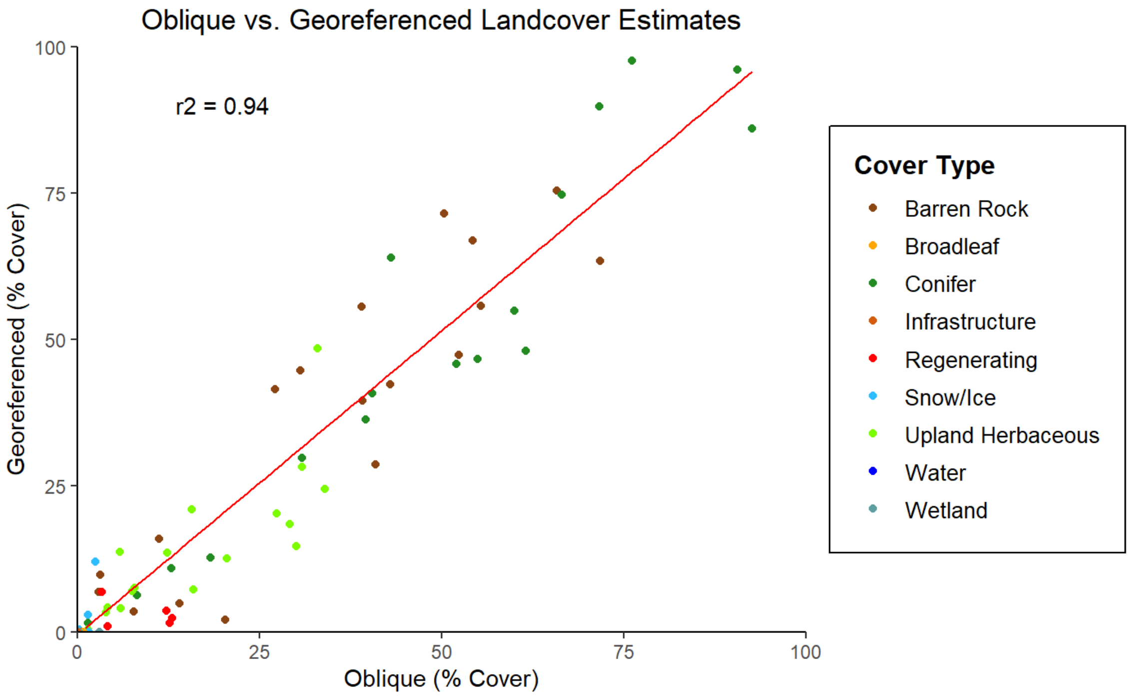


Figure 4.3.5. *Landcover categories and their estimated landcover in an oblique vs. georeferenced image. The* r^2 *value is 0.9445 with 160 degrees of freedom and a p value <* 2.2×10^{-16}.

4.4 Spatial signatures of Indigenous burning

Overall, of all thirty-nine images that were examined using the three-step method described in section 3.5, fifteen of the images showed areas that were likely to have been managed by Indigenous burning, eight images were inconclusive due to limited viewshed, and sixteen images were unlikely to show areas traditionally managed by Indigenous burning. Each image, its classification, and justification for its classification can be found in Appendix 2. All images were analyzed using the three spatial signatures of Indigenous burning that were introduced in section 2.5. Once images were organized according to which overlooked traditional habitation sites and which didn't, the presence of black sticks on the landscape became the most important factor when deciding if an image showed an area regularly maintained by Indigenous burning. This is because most images did have a shift to later seral vegetation - this has been a change noted in Kananaskis and broadly across the Rocky Mountains. As was expected based on literature review, most images that had evidence of Indigenous burning took place at lower elevation sites, near riparian/wetland areas, and very close to well-known traditional travelling routes, campsites, and hunting grounds. These areas were the most likely to be clear and free of blackened sticks, but to have filled in with thick conifer coverage in the last century.

The methods used in this study can be combined with other methods, some of which I will discuss in in section 5.3 of this thesis, in order to gain further insight into these landscapes, how they were historically managed, and what has led to the significant landscape changes I have described in this research. Section 5.3 will also discuss some of the most notable images that did and did not show evidence of Indigenous burning as determined by the three step criteria. While the information generated by these methods cannot yield any 'concrete' numbers regarding the amount of the landscape that was burned, they provide a starting point for future researchers to investigate these questions more thoroughly.

4.5 Summary

Overall, the landscape of Kananaskis Country has transitioned toward a more conifer-dominated landscape at the landscape level. The analysis of the results generated by oblique and georeferenced images shows meaningful implications for further image analysis work, and all of these results have implications in the analysis of Indigenous burning patterns in the Rocky Mountains

As of the mid 2010s, Kananaskis Country is dominated by conifer coverage (53%) and barren rock (34%). Less than 10% of the landscape is made up of snow, regenerating area, water, broadleaf forest, and wetland. Since the early 1900s, the landscape of Kananaskis has grown more homogenous and become more dominated by conifers by 20%. This has come at the cost of less barren rock, upland herbaceous, regenerating area, and wetlands in the landscape. The differences in landscape coverage estimated by oblique and georeferenced images are overall less than 2% different. This may indicate that estimates of landscape coverage generated from oblique photos are sufficient for most analyses. The location of these changes in the landscape may indicate that the removal of Indigenous burning from the landscape has played a large role in the changes that have taken place. In the next chapter, I will interpret these results against the backdrop of Indigenous burning as well as direct and indirect ecological changes.

5.0 Discussion

5.1 Introduction

This thesis had four main objectives:

1. To **test** ML-generated image classifications by comparing machine generated image classifications to human classification to assess the accuracy and identify strengths and weaknesses in ML image classification software to inform future development
2. To **explore** the relatively new process of georeferencing oblique photos and using their output as spatial data
3. To **test** the differences between standard oblique image classification and georeferenced orthogonal images classification to identify benefits and drawbacks of each method
4. To utilize historic images to **identify** spatial signatures to explore the likely distribution of Indigenous fire management areas in Kananaskis Country, Alberta

There were two novel methods used in this thesis for examining land cover changes using repeat image pairs. The first was the use of machine learning to classify images. The second was the use of georeferencing oblique images and their corresponding image masks to create rudimentary maps of landscape cover in the past and present. While both of these methods are in their infancy in these applications, this thesis is a starting point for examining the strengths, weaknesses, and areas for further research surrounding these approaches. There is much promise in the field of repeat photography analysis and how innovative software can generate new data from historical and repeat photographs.

The investigation of the spatial signatures of Indigenous burning has found that large sections of the landscape may have been traditionally managed by burning, and research into this should continue, especially at lower elevations in the foothills of the Rocky Mountains. This finding is likely related to the substantial shift in the landscape over the past century, a trend that has been noted by other researchers. Conifer coverage has increased substantially at the expense of earlier seral vegetation types. This trend has important implications for the health of the ecosystem that will be discussed further in this section. The sample comparing georeferenced masks to orthogonal masks found that there were not substantial differences in the estimates of landcover between mask types. This may mean for studies where precise location of the change is not important, the arduous task of georeferencing may be unnecessary, however as the technology improves the process can hopefully be streamlined and made more accessible to all researchers.

This chapter addresses the results and how they relate to the research goals of this thesis, which is to explore the implications of the landcover changes discovered by these novel methods of photo analysis. Section 5.2 discusses the landcover changes found by the georeferenced and orthogonal photo masks and how these changes relate to other literature in Kananaskis Country. Section 5.3 relates this changes to those found in the Indigenous burning section, and how we can continue to emphasize the importance of human management in our landscapes. Section 5.4 examines the application of artificial intelligence and georeferencing software to repeat photography studies. Finally, section 5.5 discusses the limitations of this study, with suggestions for improvements for future studies.

5.2 Interpretation of landcover changes

Over the past century, there has been a transition of the landscape in Kananaskis Country's Baldy Pass. As of the mid 2010s, over half of the landscape in this area is dense conifer forest. This is a substantial increase that has occurred in the last hundred years, as conifer coverage in the early 1900s was estimated to be only 31% of the landscape. This shift to increased conifer coverage is possible due to encroachment of upland herbaceous, rocky, regenerating, and wetland landcover by coniferous trees.

As of the mid 2010s, coniferous forest and barren rock make up 87% of the landscape in Kananaskis. Combined with the increase in human infrastructure, which now makes up 4% of the landscape, that leaves only 9% of the landscape as snow, regenerating area, water, broadleaf forest, upland herbaceous, and wetland. This transition of the landscape has consequences on the fire regime of the area, wildlife abundance and diversity, and overall health of the ecosystem.

There have been many studies using a variety of different research methods that have noted vegetation shifts similar to what was observed in this study. Pollen palynology conducted in 1975 (Strong) noted the shift in vegetation in Alberta from early seral graminoids to later stage prairie species and hypothesized fire control, elimination of bison grazing, and agriculture as some causes for this shift. Hessburg et al. (2003) found in their environmental narrative of Northwest forests that the shift to later stage, fire-intolerant coniferous species has been observed throughout the inland Northwest. Gruell (1985), Rhemtulla et al. (2002), Fortin et al. (2018), and Stockdale et al. (2019) all utilized repeat photography to study landscape change in the Rocky Mountains and found substantial increase in coniferous coverage.

The changes observed in this research (and other studies) are likely due to a combination of factors. Forest expansion and treeline creep has been observed and linked to global climate warming (Brown 2013). Global warming is related to changes in precipitation patterns and growing season length (Fortin, 2018; Falk, 2014), along with the warming of ambient air temperatures at high mountain elevations, all of which contribute to forest recruitment, densification, and expansion. Along with global warming, the reductions in population of elk, bison, and other ungulate species on the landscape since European colonization also contribute to the expansion of forests - ungulates naturally function to reduce forest recruitment through grazing and trampling of young woody plants, so the removal of their presence on the landscape favours forest growth (Stockdale, 2019; Painter et al., 2018).

The most significant mechanism behind conifer encroachment is the increase in time since disturbance (Stockdale et al., 2019). The mean time since disturbance in Western Canadian forests has lengthened considerably since European colonization (Stockdale et al., 2019). The most significant disturbance in these forests is fire - and the forests of North America evolved with and are adapted to fire as a regular disturbance (Rogeau et al., 2016). Many studies have described the effects of fire exclusion on the forests of Western North America since the early 1900s, all of which agree that the removal of fire as a disturbance on the landscape have led to substantial conifer encroachment (Hawkes, 1980; Arno, 1980; Baker, 1993; Keane et al., 2002; Hessburg & Agee, 2003; Rogeau et al., 2016). The annual area burned in the Rocky Mountains has declined dramatically since pre-1900 (Rogeau et al., 2016). This alteration of fire regimes not only leads to an increase in conifer encroachment, but also to forest densification as both live and dead fuels are not burned off by regular low intensity fires (Stockdale et al., 2019). In some of these where forests fires used to return every 5-20 years there has not been fire in over a century - this means that about 10 low severity fires have been missed due to fire suppression, meaning that there is 10 times the amount of dead and live debris in these forests now (Hessburg & Agee, 2003).

The consequences of conifer encroachment are numerous. There is research that suggests that these conifer dense, homogenous forests are more susceptible to wildfire loss (Hessburg et al., 2000; Fule et al., 2004; Prichard et al., 2017) due to the accumulation of dead and live fuels in the forest, building what are known as "fuel ladders" (Hessburg & Agee, 2003). These fuel ladders connect surface fuel to tree crowns and facilitate the growth of fires into intense, large crown "mega wildfires" that spread rapidly and are difficult to control (Stephens et al., 2014). With global warming continuing to increase temperatures in the Rockies, these risks of mega wildfires only increase every year. By suppressing fires for a century and allowing fuels to accumulate, the fire regime of these forests has been effectively shifted from one of frequent, low intensity fires where forests were adapted to fire to a fire regime characterized by infrequent but large, intense wildfires that burn off large swaths of the forest at once (Barret, 1996; Hessburg & Agee, 2003).

Not only are these conifer dense forests at risk to wildfire loss, but they are also susceptible to insect disturbance. The mountain pine beetle represents one of the greatest insect threats to mature pine stands in Western Canada (Raffa, 1988; Dordel, Feller, & Simard, 2008). Stands of trees that are older than eighty years are considered highly susceptible to beetle infestation (Shore & Safranyik, 1992) unlike young, diverse, and vigorous stands, which are better able to fight off the insects. The stands that make up the Rocky Mountains have long passed this 80-year threshold, and their over maturity and homogeneity makes them perfect for sustaining an insect outbreak.

Finally, the conifer encroachment of the forests of the Rocky Mountains represents a loss of overall diversity. In Banff National Park, just 20km away from this study area, it was predicted that if the current new fire regime continues, the park will see a loss of a third of all vegetation types (Achuff et al., 1996). The reduction in available, diverse habitat for many species could lead to modified species' ranges, altered interspecific interactions, and new community species assemblages (Fortin et al., 2018). Given that the protection of Canada's National Parks in the Rocky Mountains is important for the conservation of many species, further understanding is needed about these landcover changes and their resulting impacts on biodiversity (Fortin et al., 2018).

5.3 Indigenous burning and landcover change

Overall, sixteen images in this study were determined to have been likely to be managed by Indigenous burning. While this is less than half of all the images used, these images were not chosen with capturing Indigenous burning in mind - in future studies, researchers looking to examine Indigenous burning may elect to choose images that are along well-known travelling routes, campsites, and hunting grounds, as these images were the ones in this study that were mostly likely to show evidence of Indigenous burning on the landscape. In this section I present two images as examples that showed strong evidence of Indigenous burning: Grotto Mt (Az 201) and Mt. McDougall (Az 272); and two images where it was determined that Indigenous burning was unlikely to play a strong role on the landscape: Georgetown (Az 0) and Stn 6 Mt. Allen (Az 10).

The Grotto Mountain station was originally captured by McArthur in 1889. The photoset that looks along the 201st azimuth faces southwest over what is today the Bow Flats Natural Area, just five kilometres south of Chuwapchîpchîyan Kude Bi (Canmore). This area was both a traditional campsite and hunting area of the Stoney Nakoda (Chiniki Research Team, 1987). The historical image and the modern repeat for this station can be seen in figure 5.3.1. The valley area of this image, which was the area used traditionally for camping and hunting, is open wetland and herbaceous shrubbery in the 1889 image, which by 2014 has filled in to thick conifer coverage. There is no evidence of black sticks in this area, which indicates that it was not a recent, large fire that swept through this area that is responsible for the clearing. Due to its proximity to traditional habitation and hunting sites, the lack of evidence of large fire in the historic, and the infilling to thick conifer coverage in the 2014 image, this photoset is a strong example of an area that was likely maintained and managed by regular Indigenous burning.

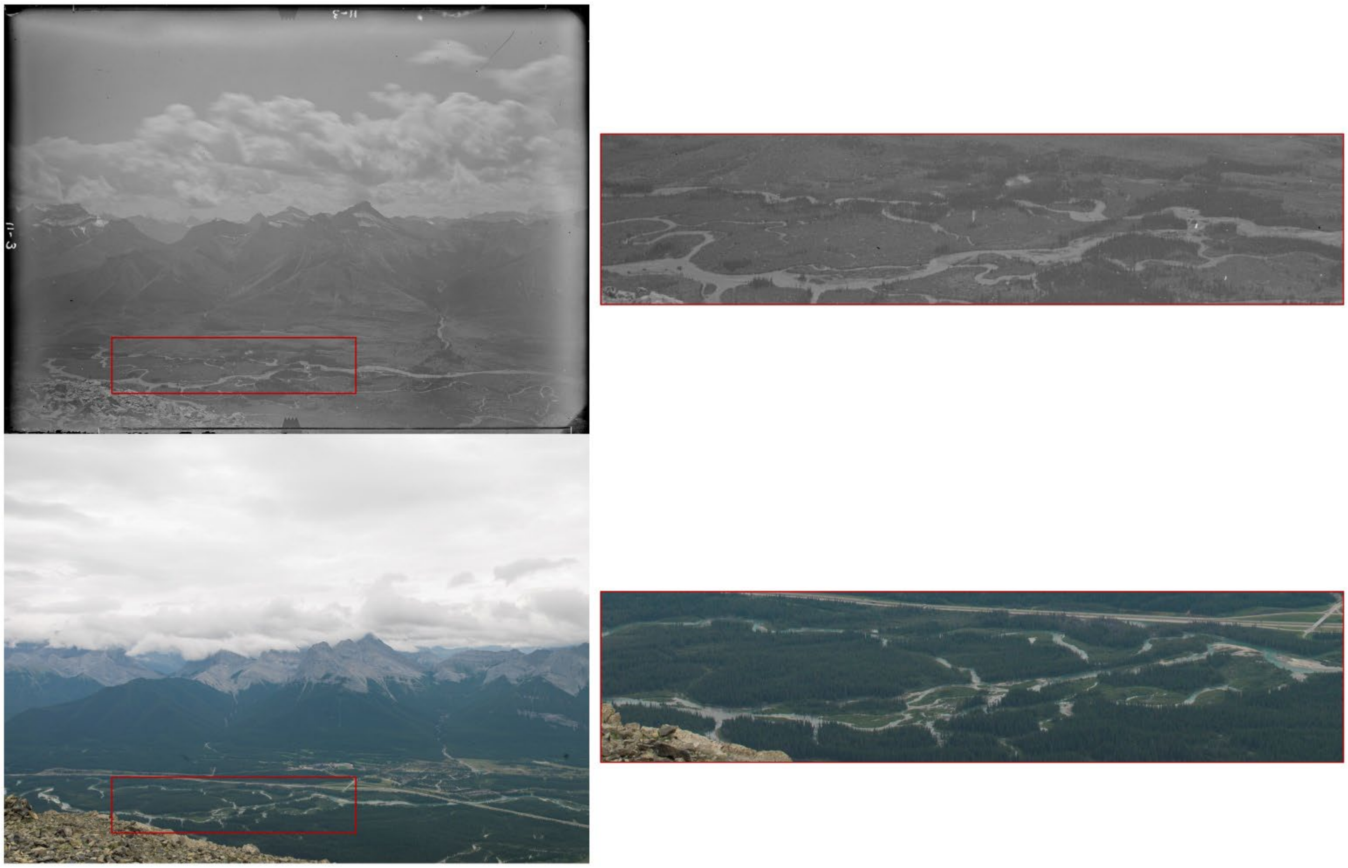


Figure 5.3.1. *Historic and modern images of Grotto Mt. Azimuth 201. A section of the image has been outlined and enlarged for viewing purposes. This area was clear in 1889, likely maintained by Indigenous burning, and has since filled in with thick conifer coverage in 2014.*

Mount McDougall North is a 1905 station originally captured by Dowling that was repeated by the Mountain Legacy Project team in 2009. This image set directly overlooks the Ozade Châgu traditional travelling route of the Stoney Nakoda and today overlooks the Kananaskis Valley and townsite, which was also a traditional campsite of the Stoney Nakoda. The historic image shows a clear valley bottom and lower slopes of the mountain, and upon close inspection there is no indication of black sticks from a large fire to maintain this open area. In the modern repeat, the infill of conifer into this area is striking. For this reason, this photoset shows an area that was highly likely to have been managed by Indigenous burning. Figure 5.3.2 shows this photoset with an enlarged area to demonstrate the above observations.

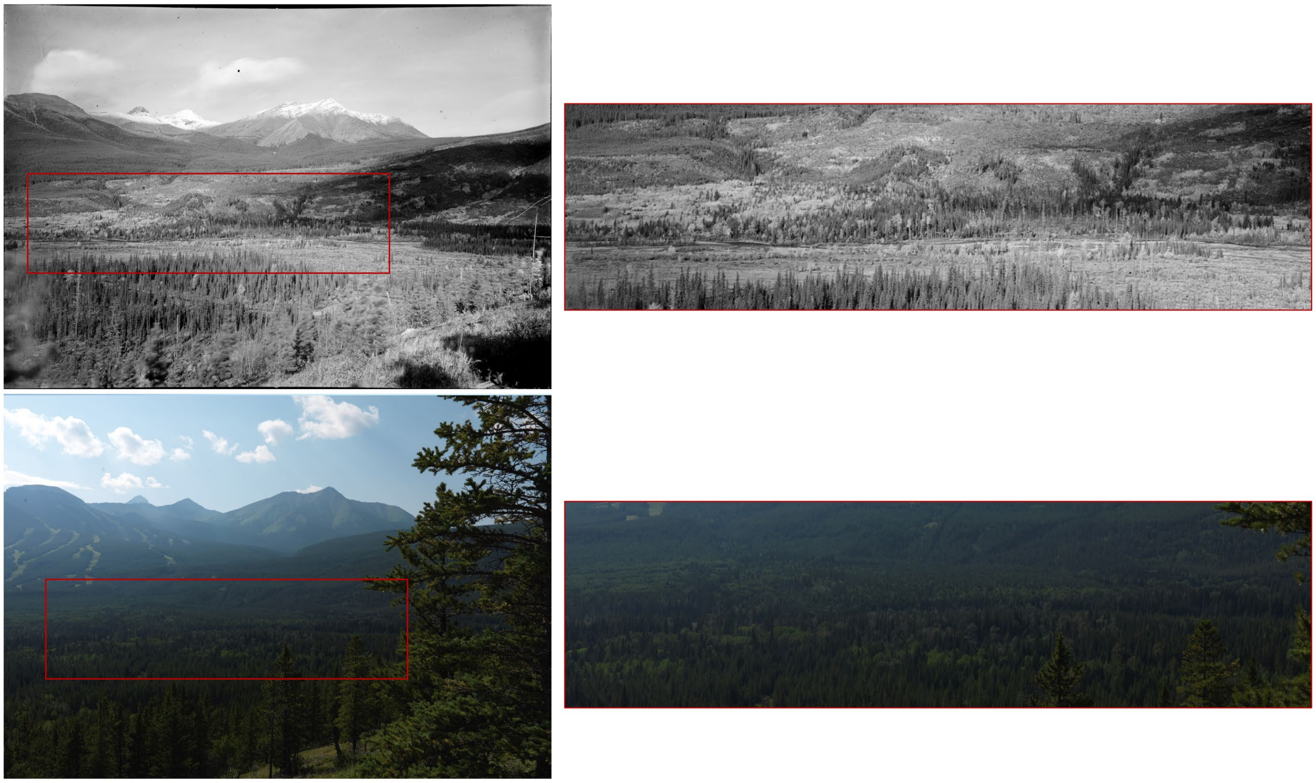


Figure 5.3.2*. The historic and modern images of Mt McDougall north, azimuth 272. A section of the image has been outlined and enlarged for viewing purposes. This area was clear in 1905, likely maintained by Indigenous burning, and has since filled in with thick conifer coverage in 2009.*

Georgetown is an 1889 station originally captured by McArthur which was repeated by the Mountain Legacy team in 2009. The 38th azimuth photoset looks northeast, away from any traditional campsite, travelling route, or hunting ground of the Stoney Nakoda. The historic image shows a large swath of burned trees and logs on a mountain side, indicating that the clearing in this area likely exists due to a recent large fire, and not because it was regularly burned by Indigenous people. This, coupled with the fact that the area has filled in with conifer trees in the modern repeat and the lack of historical settlement in the area, means that this photoset was determined to capture an area that was unlikely to have been regularly burned by Indigenous people. Image 5.3.3. shows this burn evidence in the historic image.

Figure 5.3.3*. Historic images of Georgetown, azimuth 38. A section of the image has been outlined and enlarged for viewing purposes. This area, which is dominated by open shrubby and herbaceous landcover in this 1889 image, upon closer inspection shows dead, blackened logs and sticks that indicate that this area is likely clear due to a recent large-scale fire, and not due to Indigenous burning or management.*

Finally, Stn. 6 (Mt. Allen) in a 1916 station, originally captured by Nichols, that was repeated in 2014 by the Mountain Legacy Project team. This image, which is not located near any traditional travelling, camping, or hunting site, looks directly north at relatively thick, homogenous conifer forest in both the historical and repeat image. Due to the lack of substantial change in the composition of the forest in between the two images, it's likely that the conifer encroachment that is seen up the mountainside in this image set is due to climate change and is unrelated to Indigenous burning. This image pair can be seen in figure 5.3.4.

Figure 5.3.4. *1916 and 2014 image of Stn. 6 Mt Allen, azimuth 10. This image shows that while conifer coverage has increased in the area, it has largely encroached up the mountainside, rather than filling in any open areas that previous existed.*

These results emphasize the need for future research with local Indigenous communities regarding Indigenous land management methods. Indigenous people manage over a quarter of the world's land surface, despite making up <5% of the global population (Garnett et al., 2018). Indigenous management often supports biodiversity conservation by working with natural processes that create cultural landscapes with high habitat and genetic diversity (Garnett et al., 2018). However, despite this, Indigenous people have identified numerous problems with the scientific attempts to include traditional ecological knowledge in research (Wheeler et al., 2020). Some of these issues include that Indigenous knowledge is treated as less valuable than empirical scientific knowledge, is often forced into frameworks that do not match Indigenous people's understanding of the world, and funding for studies centered around Indigenous knowledge is insufficient (Wheeler et al., 2020). Indigenous knowledge has often been left out of western scientific studies due to ignorance, prejudice, and the fragmentary evidence that Indigenous burning leaves on the landscape (Kimmerer et al., 2001). In the field of fire study, Indigenous burning is often mentioned as an anecdote at the end of a study instead of being included as a significant contributor to the historic fire regime and landscape makeup.

Indigenous burning is estimated to have begun in Alberta over 8500 years ago, leading to ecosystems that were complex, diverse, and accustomed to frequent fire (Christianson et al., 2015; Barret & Arno, 1982). Some have argued that Indigenous burning did not play a large role in the fire regime of the Rocky Mountains before the 1900s - however, there is simply no evidence that there is enough lightning in the region to sustain the mixed severity fire regime that existed, which leaves humans as the only major fire source (Kay, 2007; Kimmerer et al., 2001). Many of the fires set by Indigenous people were systematic in nature; fires were set along routes of travel, or in patches where key resources were. This "fire foraging" created a mosaic of patches of different aged stands throughout the landscape where different strips and sections burned as fuel became available (Pyne et al., 2000; Lewis & Ferguson, 1984). Indigenous burning was so prevalent on the landscape in the Rockies that its absence in just the past century has seen substantial shifts in forest composition (Kimmerer et al., 2001). As Historian Dennis Martinez said: "There was no pristine wilderness here. Prairie and forest were… the creation of the Indigenous people" (1998), and it is important to keep this at the forefront of all fire science that is conducted in these landscapes.

People have been integral parts of these ecosystems for thousands of years; all forests have developed under human influence of some kind (Kimmerer et al., 2001). As land management moves forward to address biodiversity and climate change concerns, it is important that the influence of past humans on the landscape is considered as an important part of the forest structure (Kimmerer et al., 2001). Multi-stakeholder collaborations are extremely important in local landscape management, and all management plans in the Rockies need to include the local Indigenous communities that live there to support better landscape management and planning for healthier landscapes that are resilient to climate change (William et al., 2020). The suppression of traditional knowledge about caring for the land has contributed to the declines in forest health. Therefore, the resumption of human responsibility and management with fire can be part of the solution (Kimmerer et a., 2001).

The work that I have done on these images is simply observing the images for spatial signatures that can be identified and combined with knowledge about image location and traditional use of the area in order to assess a likelihood that the area was traditionally managed by Indigenous burning. In future studies, this work could be taken further through the use of georeferencing software and more signatures of Indigenous burning that are not readily visible on a photograph but are spatial attributes that can be queried using GIS software. Two spatial filters of Indigenous burning that could be queried in GIS are elevation and proximity to water.

Elevation is considered a key spatial filter, as most burning took place at lower elevations, where people were most likely to live, travel, and hunt (Arthur, 2015; Parminter, 1995; Turner, 1999). These lower elevations in the montane and down into the foothill regions often had topography that was desirable for corralling, pounding, and hunting bison and other animals (Snow, 2021). Jumping Pound, a site 35km east of the study area for this research, was known for its use as a buffalo jump by the Blackfoot First Nations - and these sorts of jumps and pounds were used into the montane region of Kananaskis, like in Dead Man's Flats as described above. For these reasons, lower elevation is considered to be the second spatial filter signature of Indigenous burning.

Proximity to water is another spatial filter of Indigenous burning as the regular burning of riparian vegetation attracted game animals for hunting (Lewis & Ferguson, 1988; Day, 1953; Parminter, 1995). One Indigenous woman, when interviewed (Lewis & Ferguson, 1988) described the importance of burning riparian areas albeit in boreal forest landscape: “They used to burn places where they think it was very useful… sloughs, where there’s muskrats, that’s where they used to burn.” Since riparian zones and their associated vegetation are important to a wide variety of animals, it was important to burn away old and dead vegetation to promote new growth that would attract animals (Lewis & Ferugson, 1988; pers. Comm. Snow, 2021). This is why proximity to water was chosen as the final spatial signature of Indigenous burning for this analysis. These spatial signatures are summarized in table 5.4.1.

Table 5.4.1. Summary of spatial filters of Indigenous burning, their subcategories, and the explanation for each factor that was used when delineating areas of Indigenous burning on the images.

Spatial Filter	Sub-Category	Explanation	Source
Elevation	Montane	<1500m	Arthur, 2015; Parminter, 1995; Turner, 1999; Hallworth & Chinnappa, 1997; pers. Comm. Snow, 2021
	Subalpine; Alpine	>1500m	
Proximity to Water	<15m	Wetland, riparian	Lewis & Ferguson, 1988; Day, 1953; Parminter, 1995; Snow, 2021

The georeferencing of viewsheds in a project would also improve the accuracy of determining exactly which elements of a photo overlapped with traditional travelling routes or campsites - however, these boundaries are not precise, so they should not be treated as hard stops where effects on the landscape don’t extend beyond them. The combination of the spatial signatures used in this study, as well as the spatial filters in GIS, can help to build thorough maps on the landscape showing where Indigenous burning was the most likely to have been used to manage the landscape. Image 5.3.5 shows the georectified viewsheds of the case study in this research, but with only areas that have shifted to later seral vegetation highlighted in blue. This map could be further refined and expanded upon using the aforementioned techniques, and for now should be considered only a sample of what could be possible.

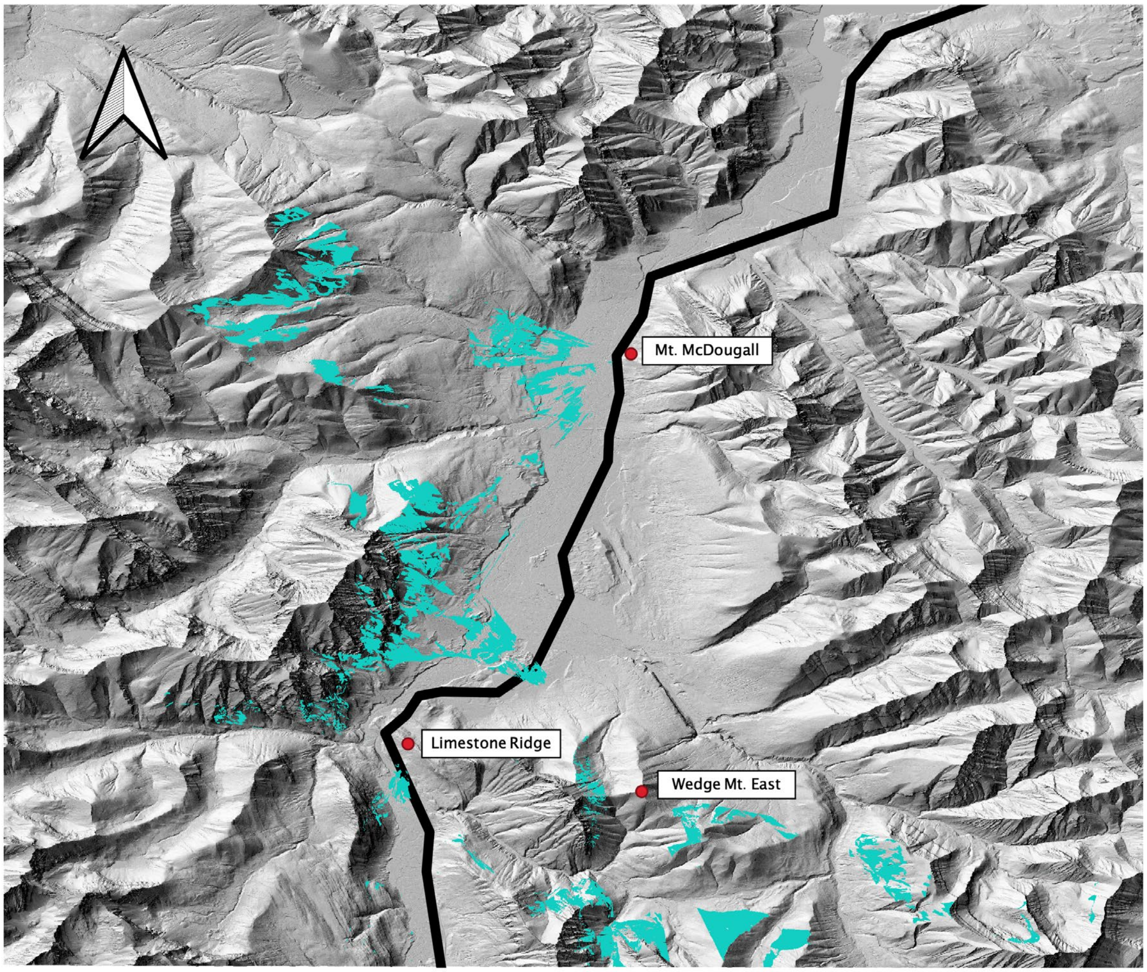


Figure 5.3.5. *The georeferenced viewsheds from the case study in this thesis, but with only areas of vegetation change highlighted in blue. The highlighted areas show where vegetation has shifted to a later seral stage in the past century.*

5.4 Photo analysis using artificial intelligence & Georeferencing

The changes noted in landcover were observed working with oblique photos to generate estimates of landcover. The estimates of landcover generated by the georeferenced photos generated similar numbers, with at most a 2% difference in landscape cover estimate from the oblique images. The average total area that was visible in the photos in the

Georeferencing case study was 6.6 hectares, or 66 000m^2. A 2% difference in landcover estimate represents a real-world difference of about 1320m^2, or about 1/5 the size of a standard American football field. Therefore, except for studies where high precision surrounding landcover estimates or location of change is important, oblique photos can provide a reasonably accurate estimation of landcover and change.

These results - that landcover estimates generated by oblique imagery are similar to those derived from spatially accurate orthogonal imagery - was also found by Fortin et al (2018), who researched landcover estimates generated by oblique photography to those generated by satellite imagery. There are some advantages and drawbacks to both oblique and orthogonal images for rarer landcover types, but at the landscape level, both oblique and orthogonal imagery estimate similar proportions of landcover (Fortin et al., 2018). This offers a promising future of research into oblique images, as oblique images can provide unique data even without the laborious task of georeferencing.

In this study, it was found that georeferenced image predicted slightly higher proportions of coniferous forest, barren rock, and snow/ice coverage. These are similar to results found by Fortin et al. (2018), who found that satellite imagery estimated higher coniferous coverage and lower herbaceous coverage than oblique imagery. These patterns are likely due to the inherent properties of oblique imagery. When estimating landcover, oblique images tend to prioritize landcover types that are closest to the camera and therefore occupy the most pixel space. In mountainous images, the categories likely to be close to the camera are typically the landcover types found at a lower elevation, like herbaceous vegetation and regenerating areas. Landcover types that are typically farther away on high-up mountain peaks include coniferous forest, barren rock, and snow/ice. Due to their distance from the camera, these three landcover types will occupy less pixel area and be underestimated in oblique imagery. When designing future studies using oblique imagery, understanding which landcover types are of interest to the study and these biases that may be present in using oblique imagery is useful. However, all major landcover types present in the oblique and georeferenced images (conifer, barren rock, snow/ice, and upland herbaceous) showed a strong correlation between oblique and georeferenced landcover predictions - despite these small discrepancies, it appears oblique images are useful for estimating landcover percentages.

The landcover predictions made by PyLC used in this study were quite highly correlated with the predictions made with the human corrected masks, with an r^2 value of 0.94. This indicates that PyLC does a good job in general of creating masks that predict similar landcover proportions that a human would. When the individual landcover categories are separated out, the strongest categories for PyLC (those with the highest correlation between ML and human generated masks) are broadleaf, conifer, barren rock, and regenerating area. The weakest categories were snow/ice, upland herbaceous, wetland, and water. Wetland and water were by far the most troublesome categories as both were consistently underpredicted by PyLC. This is likely due to the reflectivity of these categories, as PyLC tended to categorize water and wetland as the category that was reflected in the water, instead of classifying it as water.

5.5 Limitations

One main source of error - errors that arise from mask creation and correction - has already been addressed in section 4.2.1. There are two other main sources of error that are present in this study in the georeferencing process that cannot be entirely measured. In future studies that utilize georeferencing of images and their corresponding landcover masks, these sources of error should be addressed to increase accuracy and confidence in results.

In section 4.2.1, the error in the PyLC-generated masks was analyzed. PyLC was the most accurate at predicting conifer, regenerating area, barren rock, and upland herbaceous. These categories, coincidentally, are also the most abundant landcover types - so it is possible that PyLC is better at these landcover categories because it simply has more data and training on these categories. The categories that PyLC was the weakest at were water, snow/ice, and wetland. Issues with water were previously discussed in section 2.6 - water has the potential to be reflective, and the artificial intelligence classifies the reflection, instead of the water itself. An issue with snow/ice that I noticed is that the patches of snow or ice on the landscape were often quite small and were simply lumped into the larger category surrounding them, likely due to the minimum sampling size used by PyLC. Finally, wetland is both one of the least common landcover types and also one of the least distinctive in a photograph, as it often looks similar to upland herbaceous. With more training masks and improved versions of the PyLC software, these errors should be improved upon in the future.

One main source of error in the georeferencing process comes from the creation of the virtual photo and its alignment with the optical image. Both of these processes are checked only through visual observation. The user who creates the virtual image and does the alignment visually inspects both elements to ensure they are as accurate as possible before proceeding to the next step: the complex nature of these processes, images, and data (such as the underlying DEM) makes it difficult to create a perfectly accurate virtual image, or a perfect alignment. The user must simply decide when the virtual photo and the alignment are as close to accurate as possible. Unfortunately, there is currently no way to quantify any errors that appear during these steps or to know how this error affects the final results. While it may never be possible to have a completely perfect virtual photo or alignment, the Image Analysis Toolkit software would be improved by the inclusion of some form of error quantification to help researchers understand the nature of the errors present in their images.

Along the same vein are errors that may arise from georeferencing and projection of the final viewsheds in the GIS program. These errors may come from errors found in the underlying DEM, hillshade, or projection used in the GIS software. Errors in georeferencing can be compounded by errors that arise in the virtual image creation and alignment process or during mask creation, making it difficult to correct errors once the viewsheds have been projected as it is difficult to pinpoint where exactly the error arose. Errors in georeferencing of the viewsheds can be checked against existing landcover data, but this also depends on the scale and precision of other available landcover data. The categories used by PyLC for classifying oblique images are based on a modified LANDSAT classification system, so checking the projections against another land classification system would likely require a re-classification of that system to align with the PyLC categories, which would have its own error associated with it. The introduction of these errors would also be difficult to track and quantify, introducing further uncertainty into the results. Some researchers have already begun to develop methods to address these errors, such as the methods described by Bayr (2021).

Another major issue with PyLC is the lack of a human infrastructure category. In many images in this region, there has been substantial development including houses, mines, roadways, and other amenities. With no category for human infrastructure, PyLC classified these as rock, water, and ice most often. These images required the most substantial human correction, without which there would have been significant errors. While there is room for PyLC to improve, especially with the inclusion of an infrastructure category and in classification of water and wetlands, it provides a solid starting point for future researchers. The use of my masks as training models can inform the future versions of PyLC's software that will have fewer errors and require less human correction.

Finally, the study area presented some challenges generating spatial signatures of Indigenous burning. Unfortunately, due to the sample of photos that was available for this research, much of the images captured elevations that were too high for Indigenous burning. Indigenous burning was most common in the foothills region (<1200m) and up into the montane region (1300m - 1500m). In this study, all image station locations were above 1500m except for 2 stations (Lady McDonald Bench & Georgetown). Although many overlooked areas of lower elevation there are no areas below ~1200m captured by this study area, which means the areas where Indigenous burning was most likely to occur were not captured. However, the discussion generated from this analysis are a useful starting point for further analysis of Indigenous burning in images and a visually appealing way to bring awareness to this important factor in landscape management and change.

6.0 Conclusion

Overall, this study set out to develop novel methods of examining landcover changes and explore how these changes relate to indigenous burning on the landscape. Two novel methods, ML classification of images and the georeferencing of oblique images using the Image Analysis Toolkit, were used and their accuracy, efficiency, and shortcomings were determined. These tools were used to examine landscape changes in the Kananaskis Valley over the past century and relate that change to Indigenous burning through collaboration and literature review. Spatial features of Indigenous burning that will be useful to future researchers who are studying Indigenous burning were determined, explained, and demonstrated.

While fire is the key disturbance in the forests of Kananaskis Country, another key disturbance that has been missing for the past century is herbivory. Bison, along with other ungulates such as elk, used to roam the foothills in numbers that were estimated to be as high as 30 million (Isenberg, 2001). Bison were important in preventing forests from overtaking grasslands through not just herbivory, but also through the trampling of saplings as their vast herds passed through the grasslands (Stockdale et al., 2019b). Bison have been extinct from Banff and Kananaskis since the 1880s (Isenberg, 2001); however, they have been recently reintroduced in the hopes of reducing tree and shrub encroachment in grassland ecosystems (Keery, 2019). Future studies into the re-introduction of historic fire regimes in this area should consider the status and impacts of ungulate herbivores on forest encroachment as well.

Future studies into Indigenous burning should use the spatial features laid out in this study when choosing their study area. For example, photo stations that are at lower elevations and near bodies of water are preferential to high elevation stations that were unlikely to be regularly inhabited by humans. Through the collaboration with local Indigenous communities, maps or traditional ecological knowledge can guide the selection of stations that are near traditional habitation, travelling, or camping sites. Additionally, while the study area in this research was limited by available DEM data and processing time, the time-saving techniques (such as using PyLC to classify images) described in this research should allow future researchers to greatly increase the number of images that can be analyzed in one study.

Overall, further study into Indigenous burning in the Rocky Mountains should be conducted at lower elevations and focused in places with known human habitation. Since oblique photos provide roughly the same estimates of landcover as georeferenced photos, the limitation of data availability for georeferencing should not be an issue. The Mountain Legacy Project has images that span the entire Rockies, including into the foothills/transition zone to the prairies. With the use of ML classification and the sheer volume of images available through the Mountain Legacy Project, quite a comprehensive look at the foothills/montane region of the eastern Rockies could be conducted to help inform the reintroduction of the traditional fire regime of Kananaskis Country.

One way that the traditional fire regime of Kananaskis Country has been reintroduced is through prescribed burning. The practice of prescribed burning is one fuel management strategy used by governments to help reduce wildfire severity that is based on the knowledge that the forests in a particular area evolved with a regular fire regime. Prescribed fires help land managers achieve a variety of goals, including fuel management, pest management, ecological restoration, and wildlife habitat enhancement. The burns are usually conducted in late fall or early spring, when the fire will burn at a lower intensity, produce less smoke, and generally have a lower risk of escaping than if it was done under warmer and drier conditions. In Kananaskis Country, prescribed fires have been taking place since 2010 to restore ecosystems and reduce the potential for large-scale, out of control wildfires.

Many Indigenous communities and tribes are seeking to use their traditional knowledge in a modern context to reduce hazardous fuel buildup and reintroduce fire into ecosystems to protect valued resources (Gilles, 2017). This often takes the form of Indigenous participation in prescribed burning plans, or creating, implementing, and leading burning plans for their own lands that are based on their traditional knowledge (Snow, personal communication, Oct 13, 2012). There is also an increasing interest by Western governments and land managers to include Indigenous knowledge in land management plans and many Indigenous communities do have a desire to use their knowledge to participate in contemporary wildland fire management (Lake et al., 2014); research by Stockdale et al. (2019b) has shown that the restoration of historical burning patterns based on Indigenous management can reduce the probability of high intensity wildfires by almost half.

However, there can be issues with cross-jurisdictional conflict when creating prescribed burning plans. These jurisdictions can include tribal, federal, provincial, and park management entities (Lake et al., 2014). Issues can arise when cultural resources, such as sacred sites, gathering areas, traditional travel routes, plants, animals, and fungi are at risk of being disturbed by fire crews or prescribed burns (Lake et al., 2014). If fire management teams do not include Indigenous communities in their plans, or do not take input that they receive seriously, irreparable damage may be done (Welch et al., 2012). Therefore, local communities should always be involved in management plans, and strategies should be used to ensure that the community is able to protect their cultural resources without disclosing precise locations of these resources (McBride et al., 2017).

In addition, it is important for western land managers to broaden their perspective on the potential benefits of prescribed burns. While prescribed burns can be used to reduce hazardous fuel buildup, it can also be used to promote culturally important species, habitats, and traditions (Lake et al., 2014). Therefore, when working in collaboration with Indigenous communities, it is important for land managers to include and prioritize how the prescribed burning techniques will be used to meet both ecological and cultural objectives (Lake et al., 2014). The involvement of local communities directly in building prescribed burning plans can ensure that these cultural objectives are considered and met.

There is clearly a need for the inclusion of all relevant partners, especially local Indigenous communities, when creating plans for prescribed burns. It is important for land managers to collaborate to create plans and to consider community intellectual property rights, data sharing, and ownership agreements over the traditional knowledge that is shared to create plans (Lake et al., 2014). It is also important to create a sense of inclusion during the collaboration process - managers and researchers should avoid using technical jargon that can lead to misunderstandings or entire shutdowns of communication (White and McDowell, 2009). Traditional knowledge is important and those who hold it view it as a responsibility, and it is key that researchers and managers take the appropriate time to build a relationship with local communities that is based on trust, communication, and respect (Lake et al., 2014).

While prescribed burning has the potential to mitigate extreme wildfires in a warming climate, there are two main challenges to the implementation of prescribed burning plans: ecological concerns and social concerns. Ecologically speaking, the result of over a century of fire suppression has been an unprecedented level of fuel loading on the landscape that exceeds levels that were present at the turn of the century (Ryan et al., 2013). The rate at which a fire grows and spreads is directly related to the amount of fuel that is available to be consumed (Ryan, 2002). Additionally, the transition of the landscape has significant consequences on fire behaviour; pre-fire suppression forests were patchy with natural firebreaks, but the current dense conifer forests produce a continuous, uniformly flammable fuelbed for fires (Knapp and Keeley, 2006). Therefore, initial fires after a long period of suppression can have negative, unanticipated effects, like killing large remnant trees that are normally fire resistant (Ryan and Frandsen, 1991).

There are complex discussions around how we should restore fire-starved ecosystems in the face of climate change. Some argue that in the future, fire-resistant ecosystems will be more resilient to increased global temperatures, and the homogenous forests of the Rocky Mountains that have been emerging over the past century are concerning because they provide less diverse habitat for wildlife and increase the risk of intense wildfire (Flatlet and Fule, 2016; Arno and Gruell, 1983; Stockdale et. al., 2019). Others, however, argue that nature will 'regulate itself,' where severe wildfires were burn back forests that have encroached into shrublands and grasslands (Holden et al., 2010). Regardless, it seems that we need to come to accept fire as a natural, healthy part of our ecosystems.

From a sociological standpoint, many people have persistent views of fire as negative, destructive, and unsafe. Even though over 99% of prescribed burns remain inside their planned perimeter (Dether and Black, 2006), it just takes one or two high profile cases of a fire escaping and causing loss of property or life to fuel public fear and skepticism (Ryan et al., 2013). Prescribed burns can also cause public annoyance or health consequences through the release of smoke - although smoke was likely a common occurrence in the pre-European landscape, decades of fire suppression has resulted in a public that is uncomfortable with landscape burning and the associated smoke (Stephens et al., 2007). Land managers often receive public praise for extinguishing wildfires and 'saving' the forests, but there is little notice or recognition for a successful prescribed burn (Ryan et al., 2013), and this combined with societal intolerance of risk and tendency toward short-term planning, means that prescribed fires are not conducted as frequently or at the scale that is necessary to truly reduce the risk of large wildfires.

Studies like this one can help with the reintegration of Indigenous burning through prescribed burns by bringing awareness to both the benefits of fire and the catastrophic consequences of fire suppression. Using images is an effective way to help diverse publics see the changes that have occurred on the landscape throughout fire suppression and make connections between fire suppression, landscape change, and other associated negative consequences. Using a visualization technique such as the one employed in this study to show how Indigenous burning might have shaped the landscape can also help people to understand the large contribution of Indigenous burning to maintaining healthy landscapes and hopefully influence opinion to be in favour of larger, more frequent prescribed burns on the landscape. This research will act as the groundwork for future studies to do more in depth, collaborative research on Indigenous fire regimes and explore pathways for re-integrating fire into our mountain landscapes.

7.0 References

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Appendix 1

PyLC is run from the terminal on a MacOS (10.15) computer using Python. The following lines of code set up and run PyLC:

```
cd/Users/mountainlegacyproject/Documents/Maya/PyLC/PyLC-master
```

This code sets the directory for the terminal as being the PyLC-master folder. The location of this file will vary depending on where it has been saved onto the computer.

```
conda install pytorch torchvision -c pytorch
```

This code uses anaconda (which must be installed onto the computer) to install the Pytorch library which is used for machine learning in python.

```
pip3 install opencv-python
```

This line installs the python library that solves computer vision problems - this is what CV stands for.

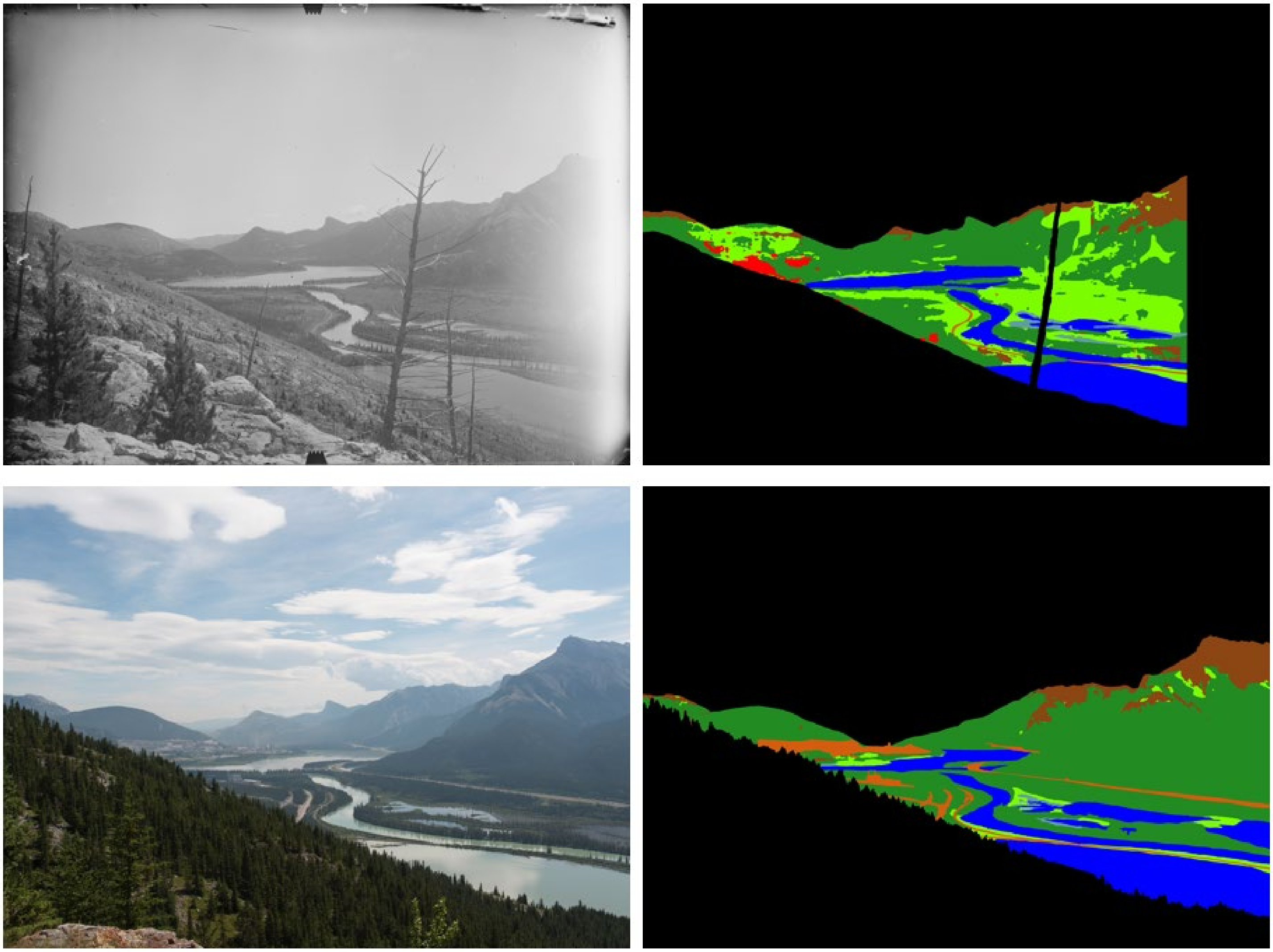
```
python -c “import cv2”
```

This opens the computer vision library that was just installed so that the computer has access to it when running PyLC.

```
python PyLC.pc  test --PATH_TO_MODEL  --img PATH_TO_IMG --
scale(0.1-1)
```

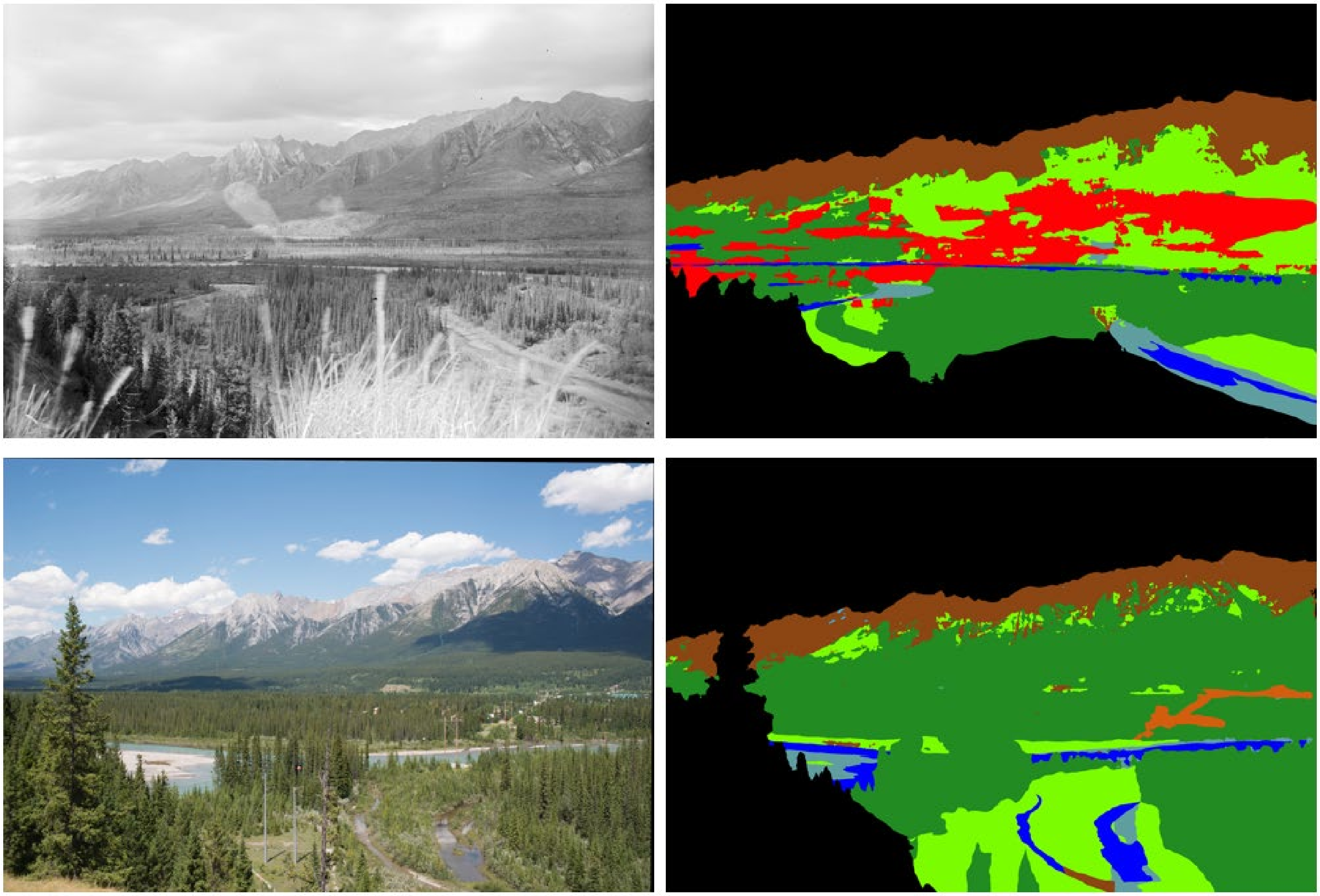
This is the general format for running PyLC. You must fill in the path to the model you are running, the path to the image, and choose a scale. Once the model is running, changes cannot be made until it is done. PyLC will automatically save the generated mask to an output folder.

Appendix 2



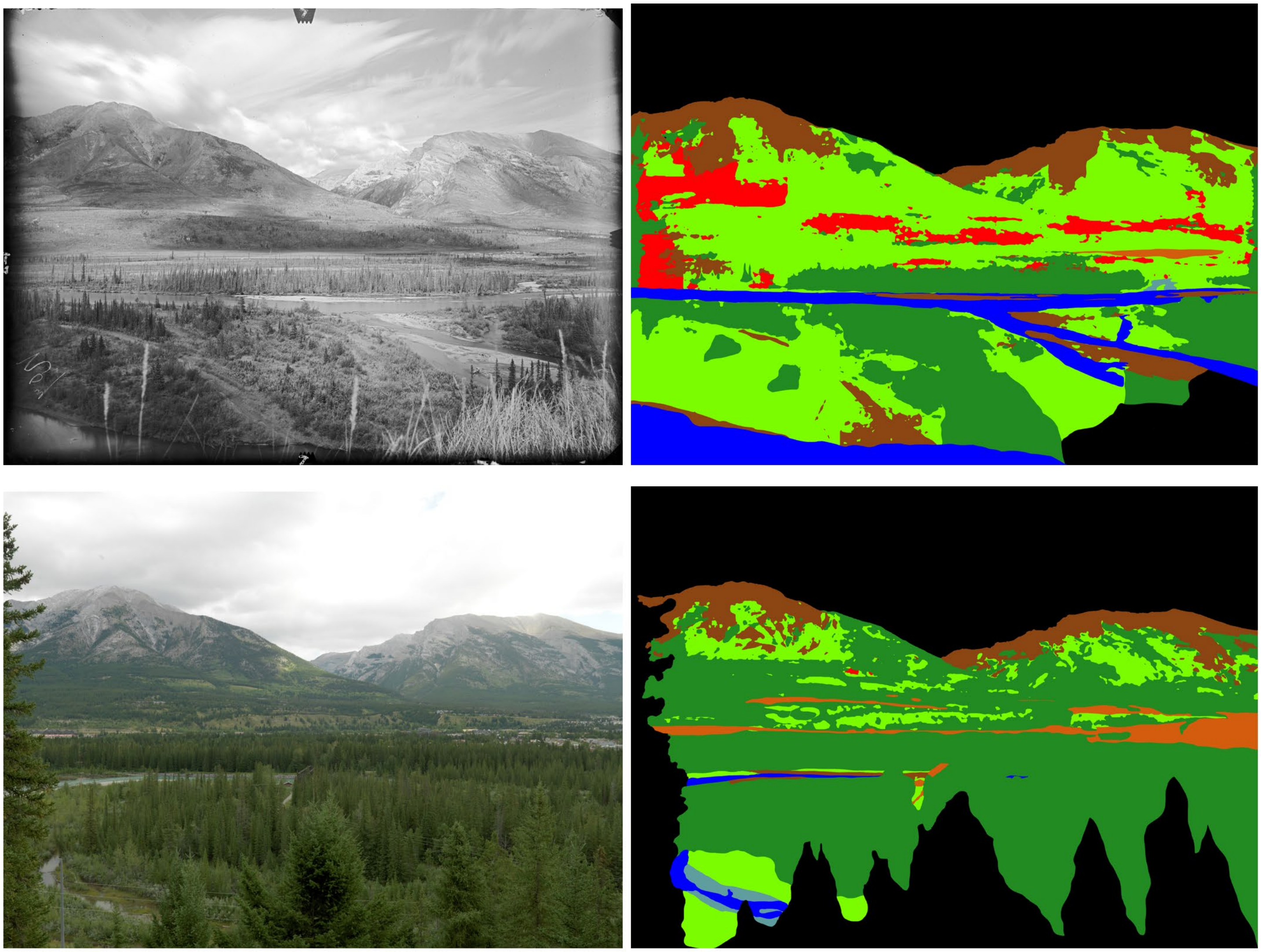
Gap Lake (1890 - 2009, Elevation: 1545m, Az: 72)

Foreground shows evidence of burnt sticks, but this was not classified due to the proximity to the camera. In the mid-ground of the image, along the river/lake, there is definitely clearing with some trees interspersed throughout, but not much in terms of black sticks. This image doesn't overlook any important habitation areas for the Stoney Nakoda.



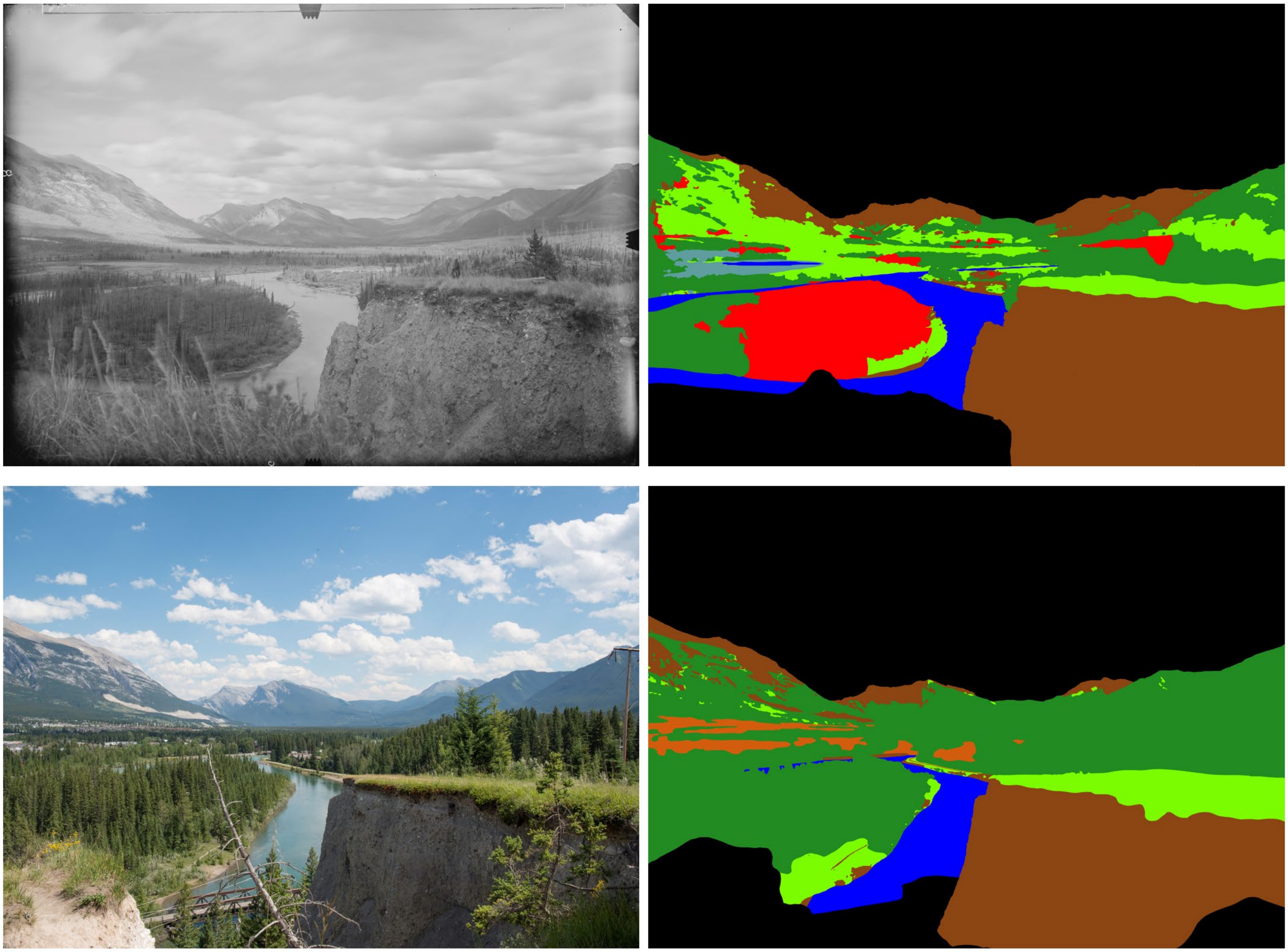
Georgetown (1889 - 2009, Elevation: 1334m, Az: 0)

This image set overlooks a huge swath of regenerating area in the historic photo that is, upon close inspection, completely covered in black sticks. This area also is not in close proximity to any traditional campsite or travelling route of the Stoney Nakoda. Due to these facts, it is not likely that the area shown in this image set was managed by Indigenous burning, and the infill of conifer is likely what existed in the area before the fire that swept through and left behind the sticks in the historic image.



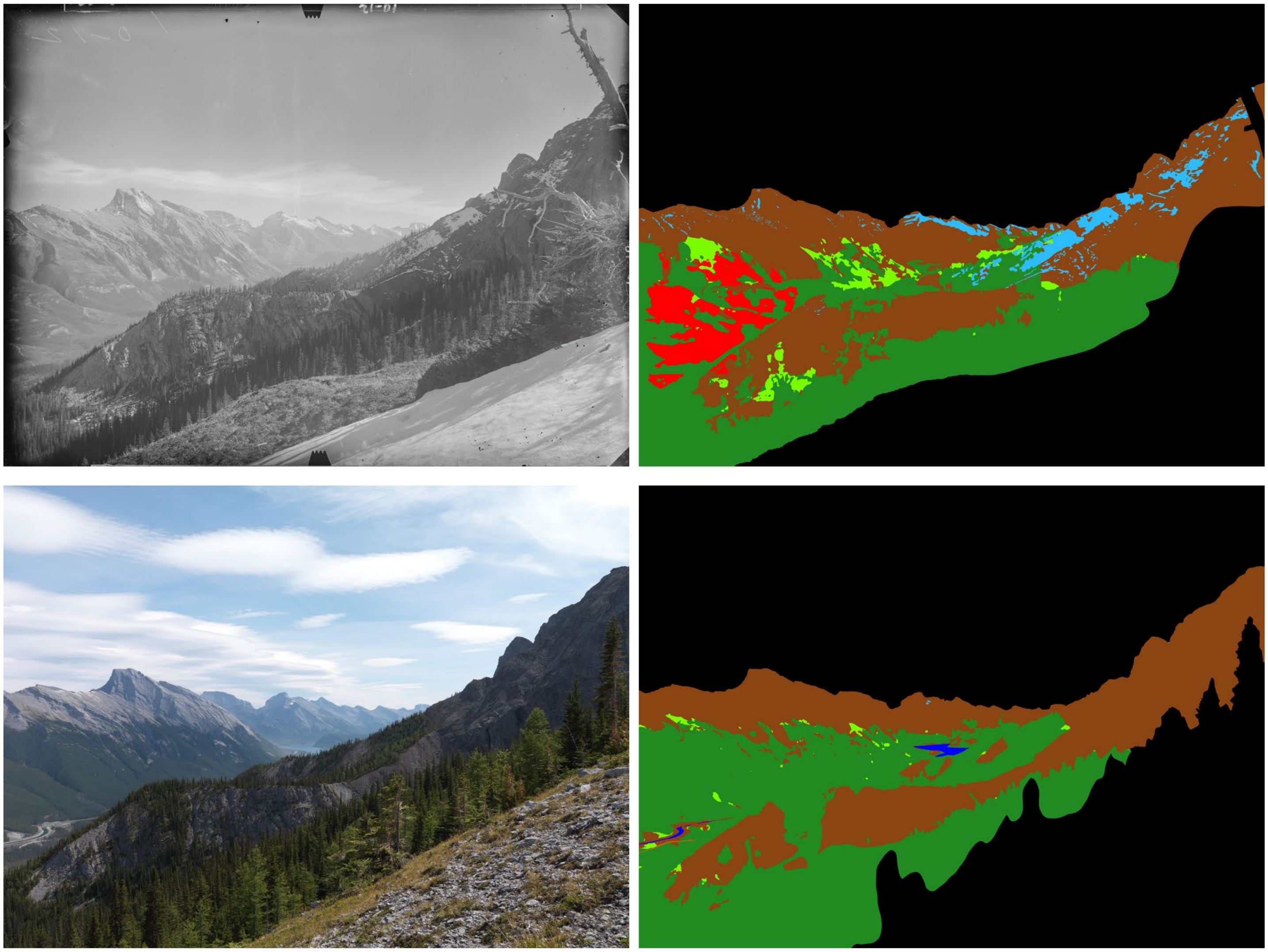
Georgetown (1889 - 2009, Elevation: 1334m, Az: 38)

This image looks slightly northeast, toward a traditional campsite of the Stoney Nakoda. There is a large swath of regenerating area and herbaceous terrain along the mountain slopes, which are marked with black sticks and fallen logs of a previous fire. This, like in the previous Georgetown image, indicates that this area was not regularly burned, which allowed conifer trees to grow to substantial size before the fire came through.



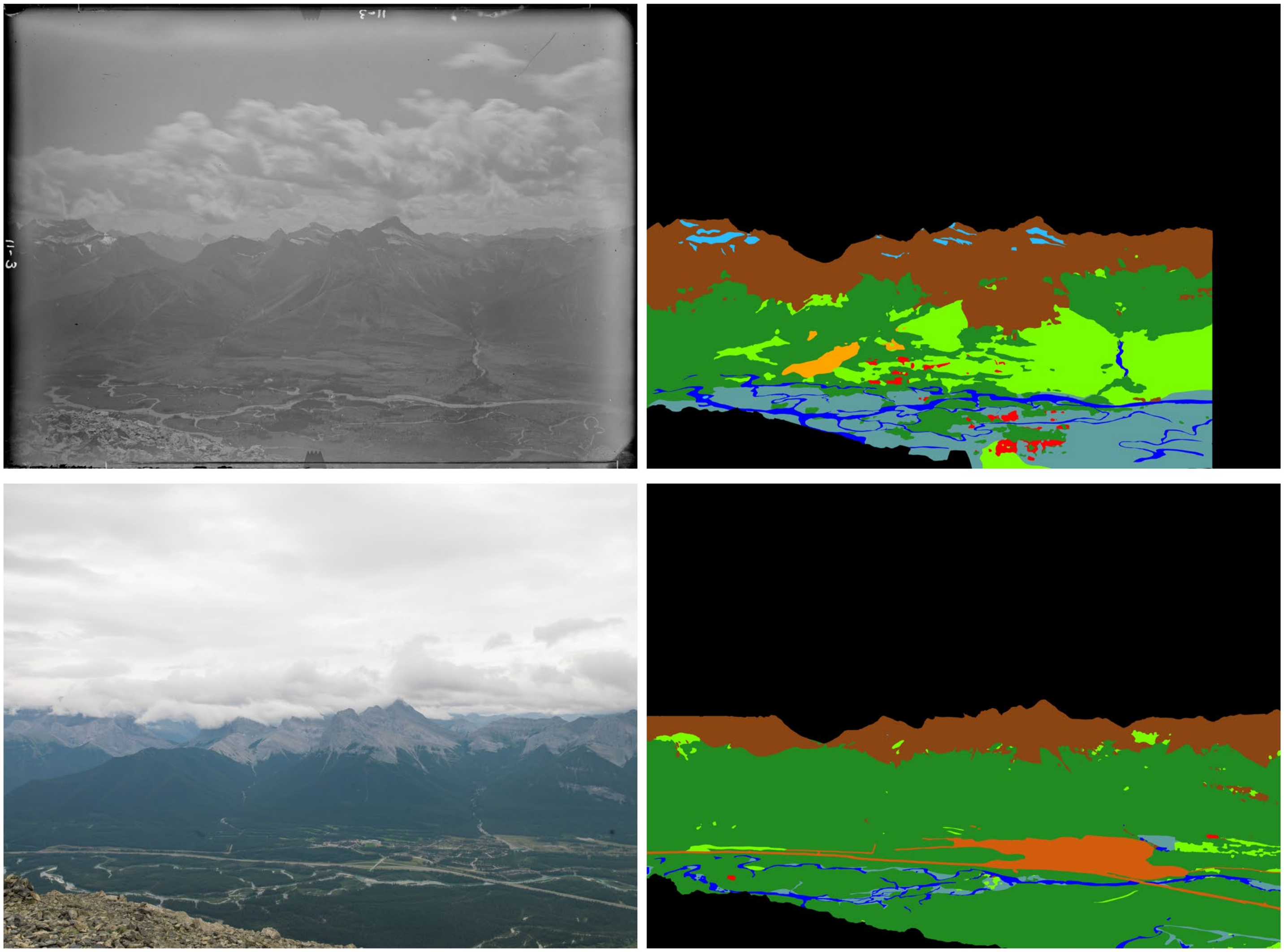
Georgetown (1889 - 2009, Elevation: 1334m, Az: 98)

On the left side of the image, the small island in the middle of the river can be seen to be clearly marked by blackened sticks and logs, indicating yet again that this area was not likely burned regularly. However, on the right side of the image, it should be noted that the peaks/valet in the distance are near to a traditional campsite of the Stoney Nakoda. It is difficult to ascertain in the historical image if there is evidence of blackened sticks keeping this area open - they don’t appear to be present, but due to the quality of this image and the distance away from the camera, it is difficult to be certain.



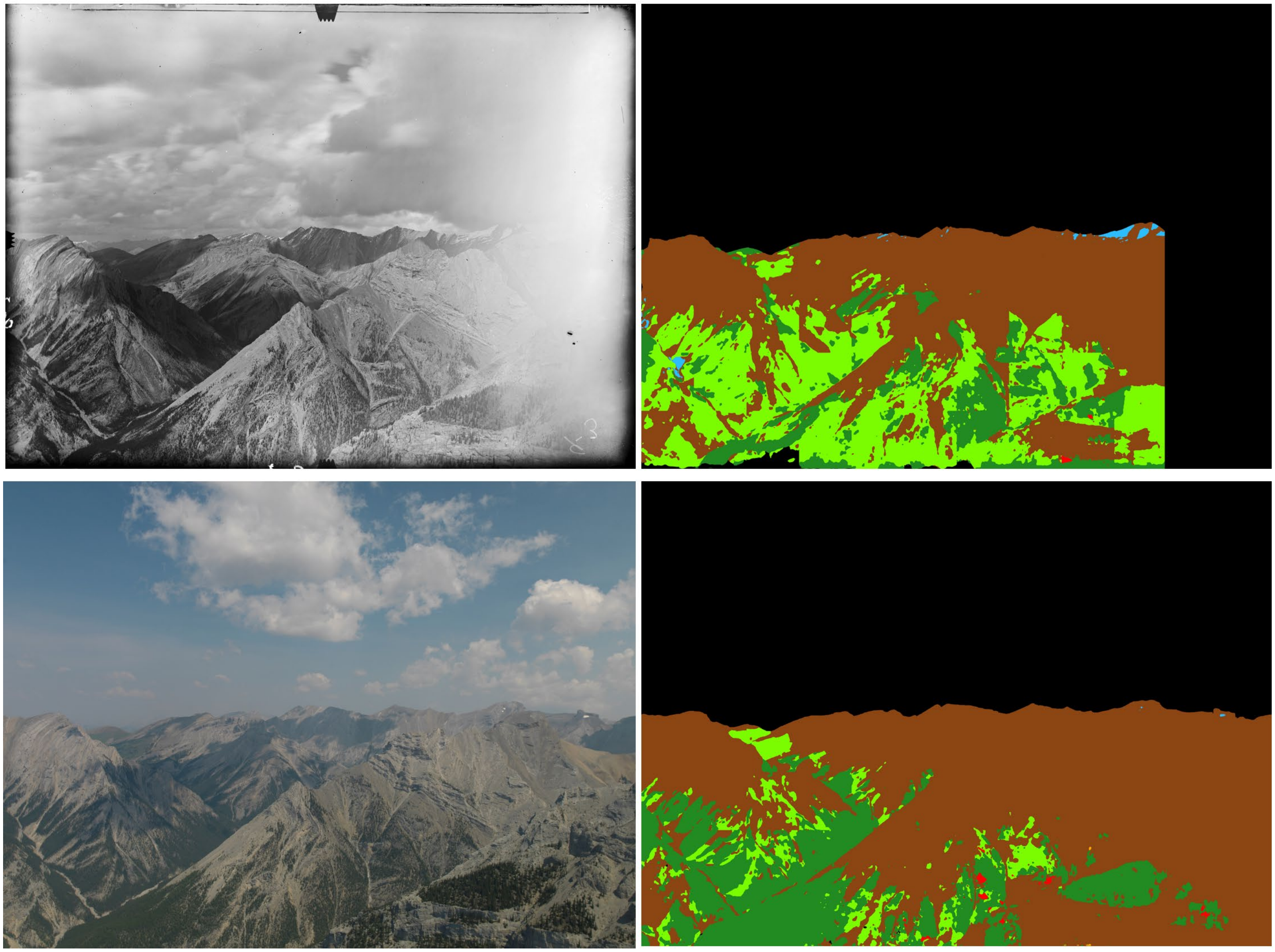
Goat Range North (1889 - 2009, Elevation: 1783m, Az: 129)

This image is not located close to any traditional campsite or travelling route of the Stoney Nakoda. The large regenerating area on the left side of this image shows a high number of sticks and deadfall, indicating that this area was likely not regularly burned prior to European colonization.



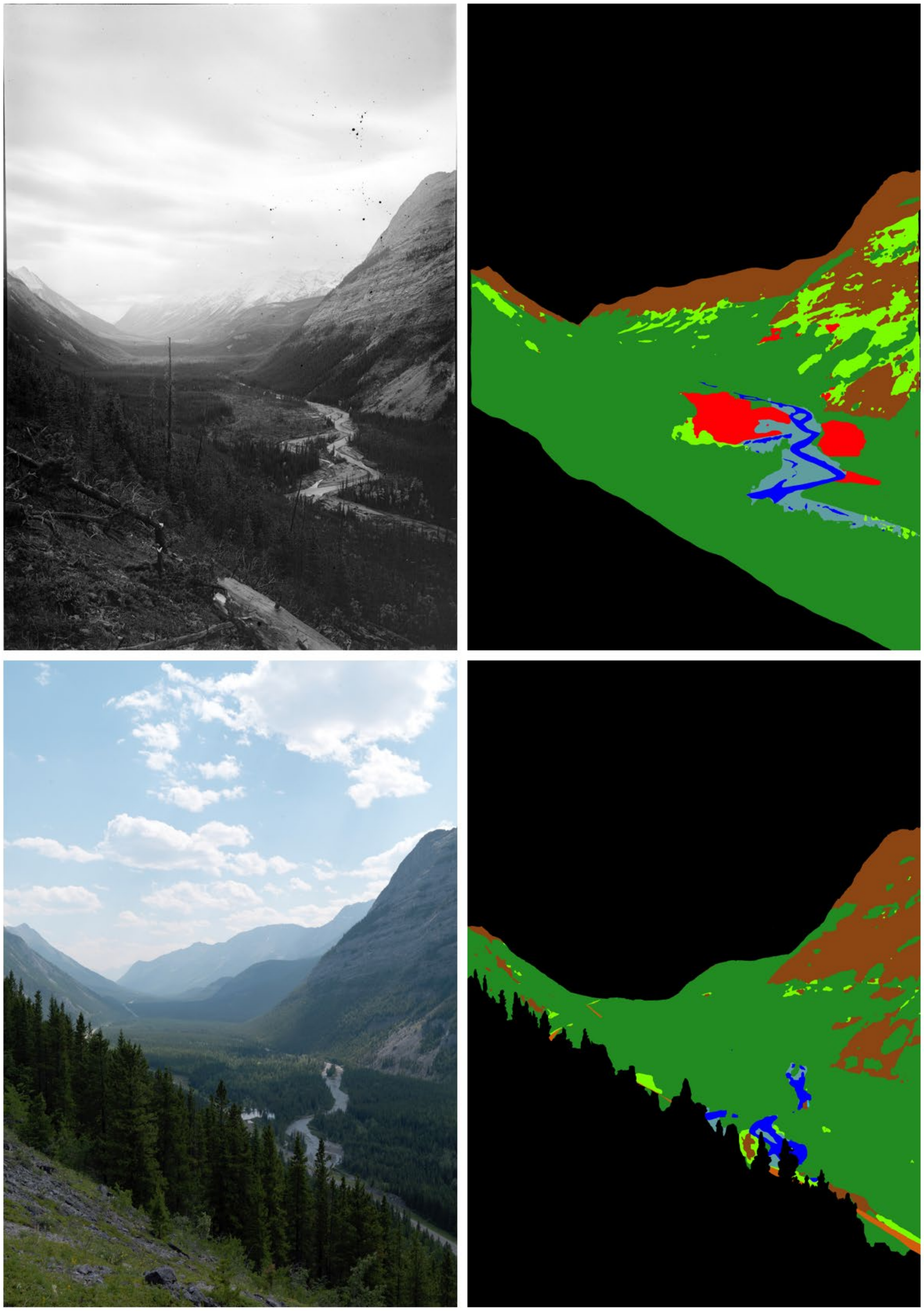
Grotto Mt (1889 - 2014, Elevation: 2492m, Az: 201)

This image directly overlooks a traditional Stoney Nakoda campsite. The regular inhabitation of this area is quite clear, as the shrubby and herbaceous areas of the historic image, especially on the right of the image closest to the traditional campsite, shows no evidence of black sticks or fallen logs. It is likely that the area depicted in these images was burned very frequently to maintain easy access to the river and wetlands, as well as to maintain clearings for camp.



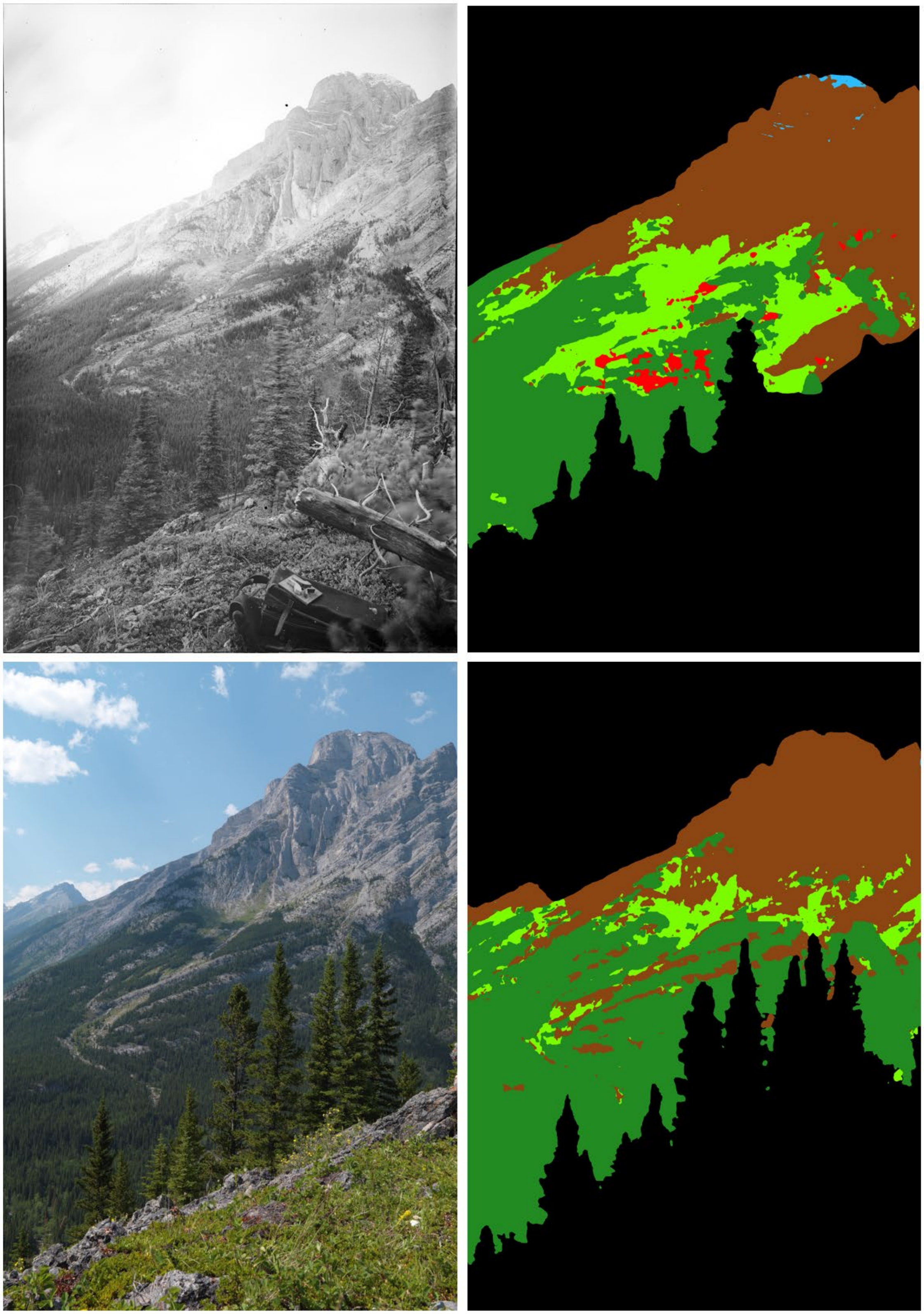
Grotto Mt (1889 - 2014, Elevation: 2492m, Az: 351)

While these images are near a traditional Stoney campsite, they face away from the campsite toward nearby mountain peaks, where there was no known regular human travelling or habitation. There is little regenerating area to examine and the herbaceous area that exists in the historic image is free from black sticks. However, as this is a high elevations station, we must consider that elevation was likely a strong factor controlling conifer growth in the past.



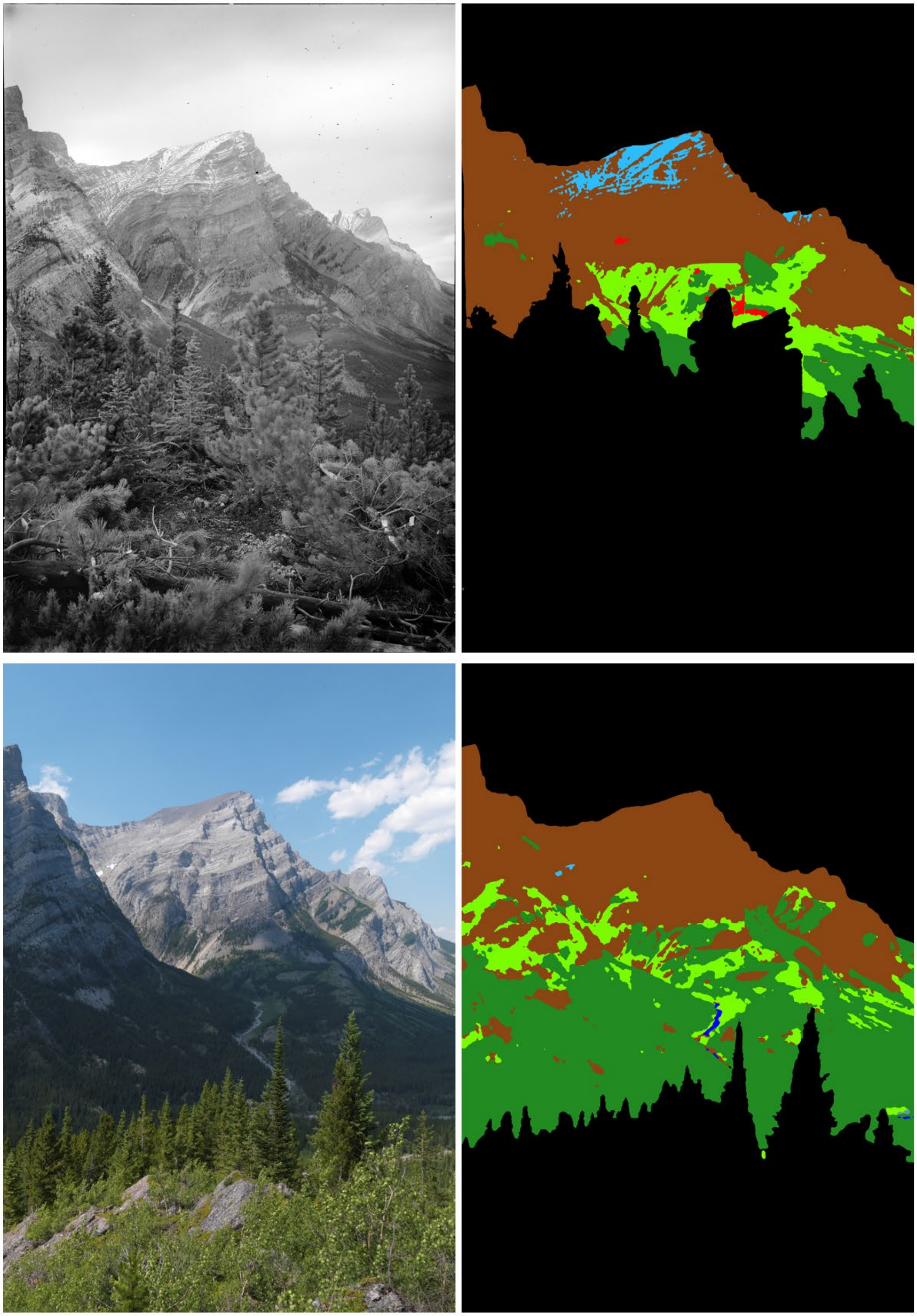
Limestone Ridge West (1905 - 2009, Elevation: 2397m, Az: 168)

This image set looks away from the normal traditional travelling route of the Stoney Nakoda but is still nearby. The open, regenerating area in the centre of the historic image overlooks a small wooden building likely built by colonizers, and this area that is cleared around the building is filled with dead sticks. It is noteworthy that the area surrounding this is largely conifer in the historic image, and everywhere that has not recently been burned is already a thick blanket of conifer. This area was likely not heavily managed by Indigenous burning prior to colonization.



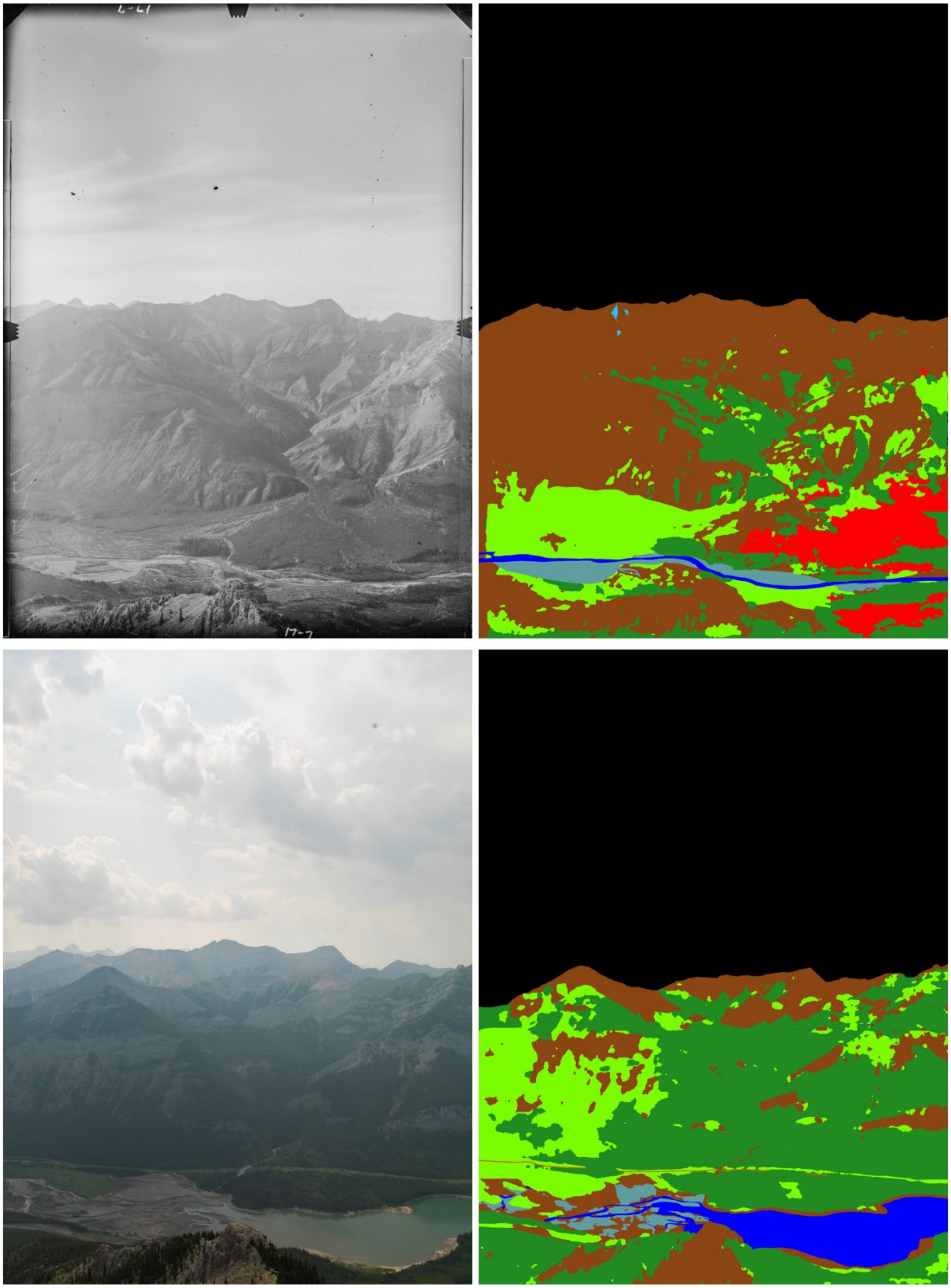
Limestone Ridge West (1905 - 2009, Elevation: 2397m, Az: 282)

While this image station is located near a traditional travelling route of the Stoney Nakoda, it overlooks a mountainside and misses the valley below, where travel was most likely to take place. There is limited shift to conifer in this image, and much of this shift was likely controlled by climatic factors as the elevation of the shift is quite high.



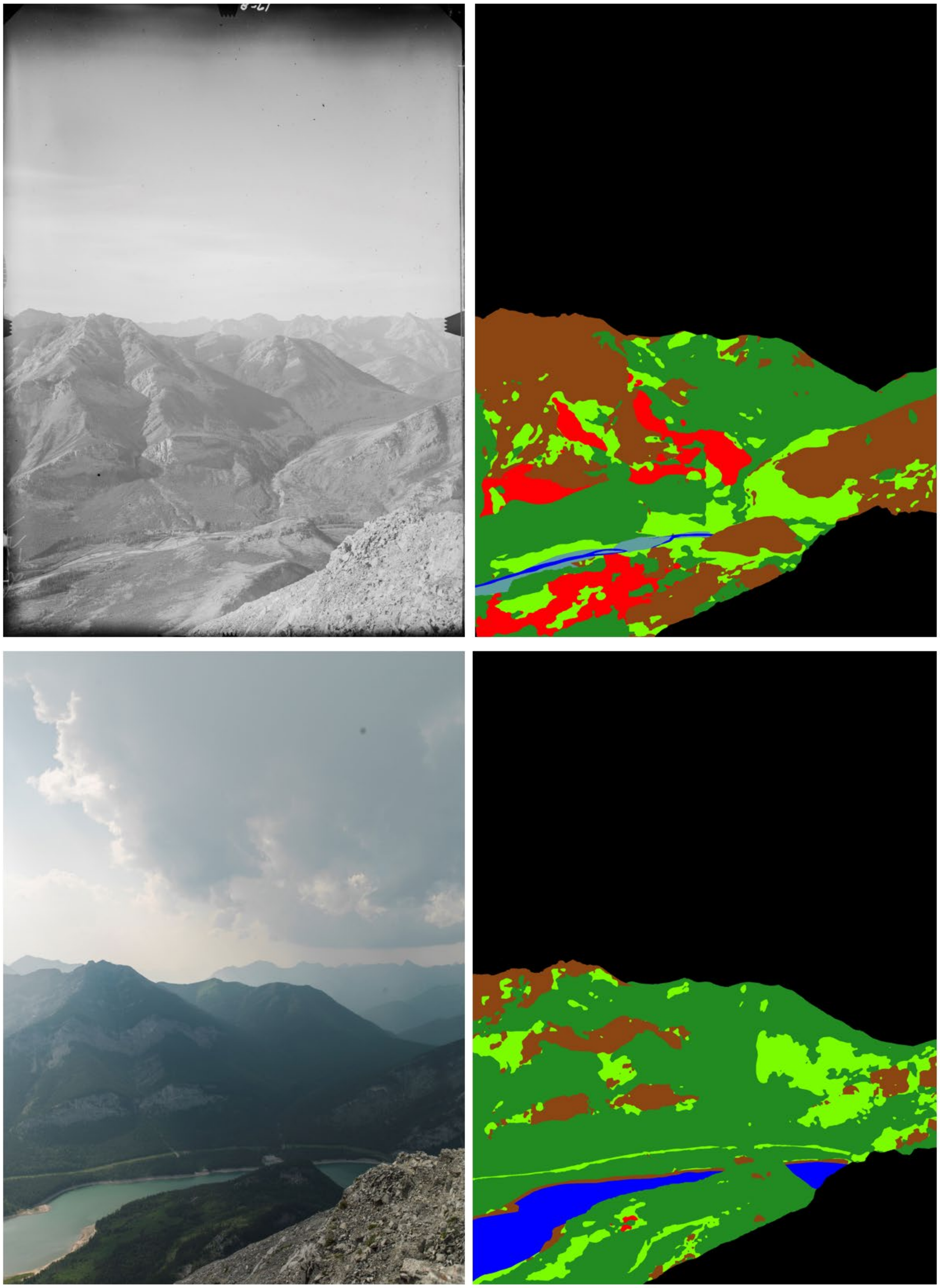
Limestone Ridge West (1905-2009, Elevation: 2397, Az: 332)

This site looks northwest toward the *Ozade Châgu* traditional travelling route, but again the angle of this image occludes a good view of the valley where travel would have occurred. Therefore, the limited shift in vegetation that is noted in these images is likely due to climatic conditions, as again these mountainsides are quite high in elevation. While it’s certainly not impossible that Indigenous management played a roll in this landscape, it seems less likely in the view captured by this image set.



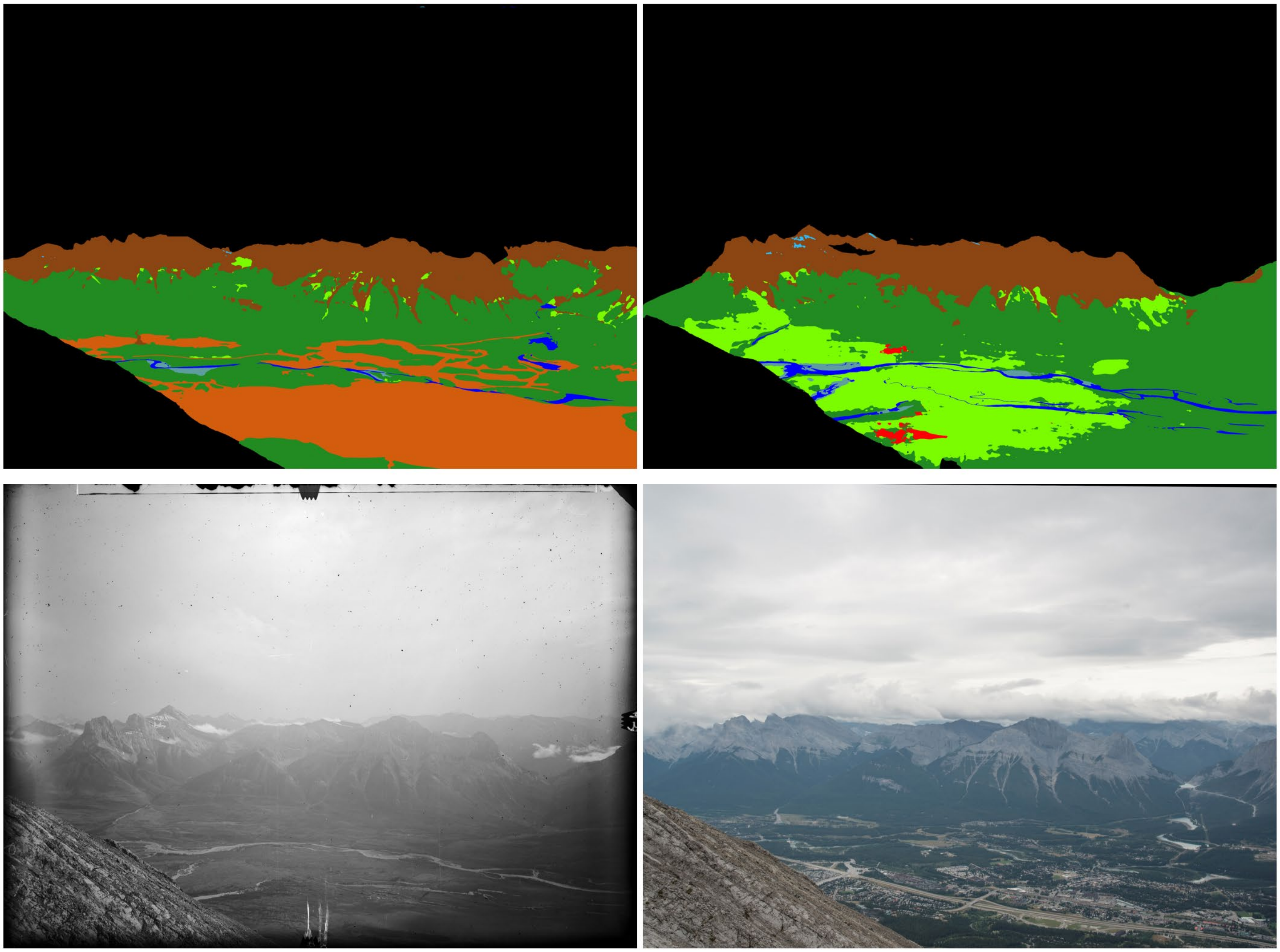
Mt Baldy (1889 - 2014, Elevation: 2191m, Az: 244)

This station overlooks directly the *Ozade Châgu* traditional travelling route, over the section that was traditionally the main entrance into the Kananaskis Valley. Not only was this site used frequently for travel, but camp would be set near this location to watch who was entering the Valley. All of the open rocky, herbaceous, and regenerating area in the historic image were likely well maintained by Indigenous burning, as there is no evidence of blackened sticks or deadfall in these open areas.



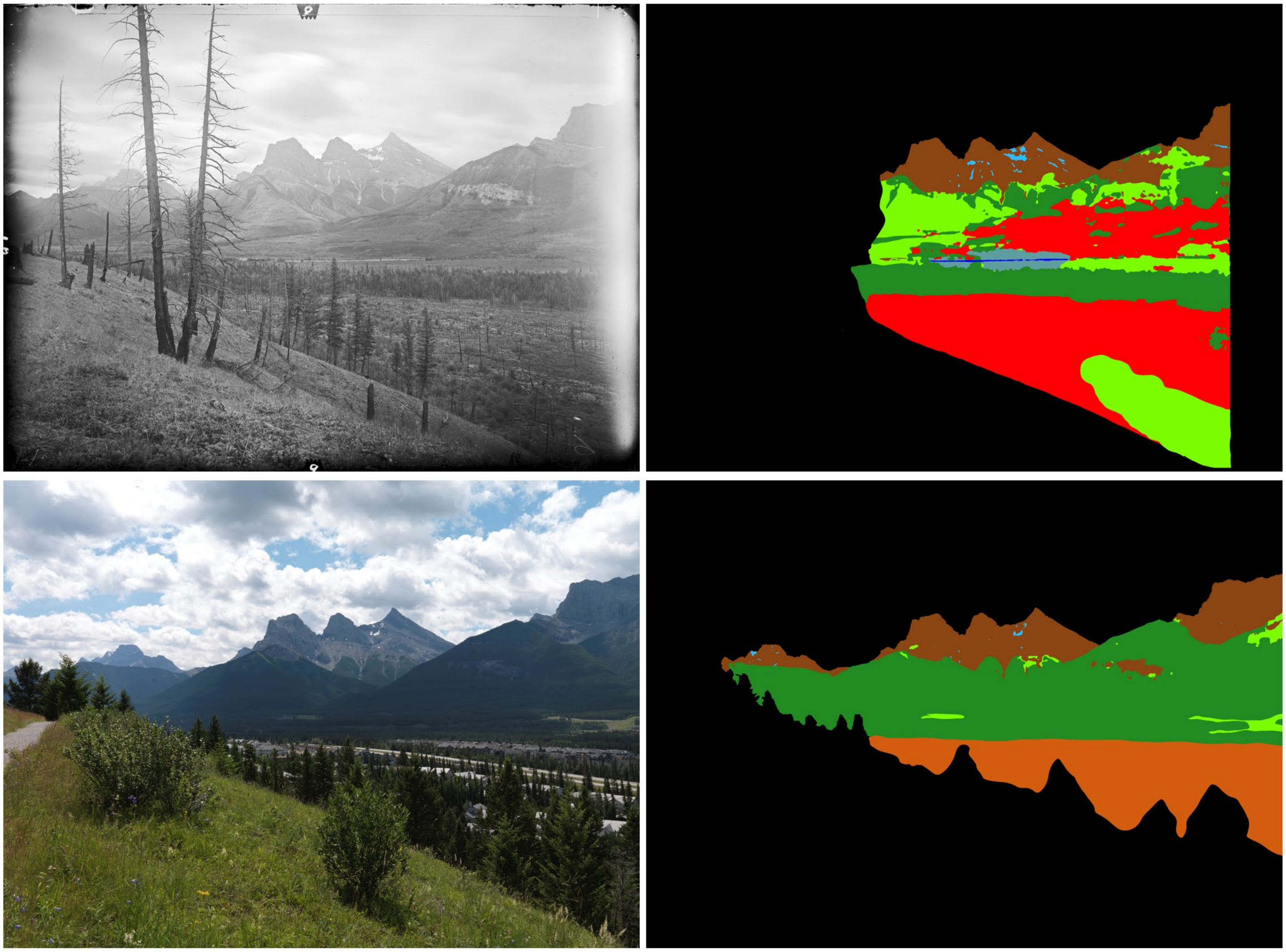
Mt Baldy (1889 - 2014, Elevation: 2191m, Az: 290)

This photoset from the 290 azimuth at Mt Baldy is looking slightly more east than the above set but looks over the same travelling route and entrance to Kananaskis Valley. The open herbaceous, regenerating, and barren rock areas in the historic image are completely free from black sticks or other indicators of large wildfire, indicating that this area was likely well maintained by Indigenous burning.



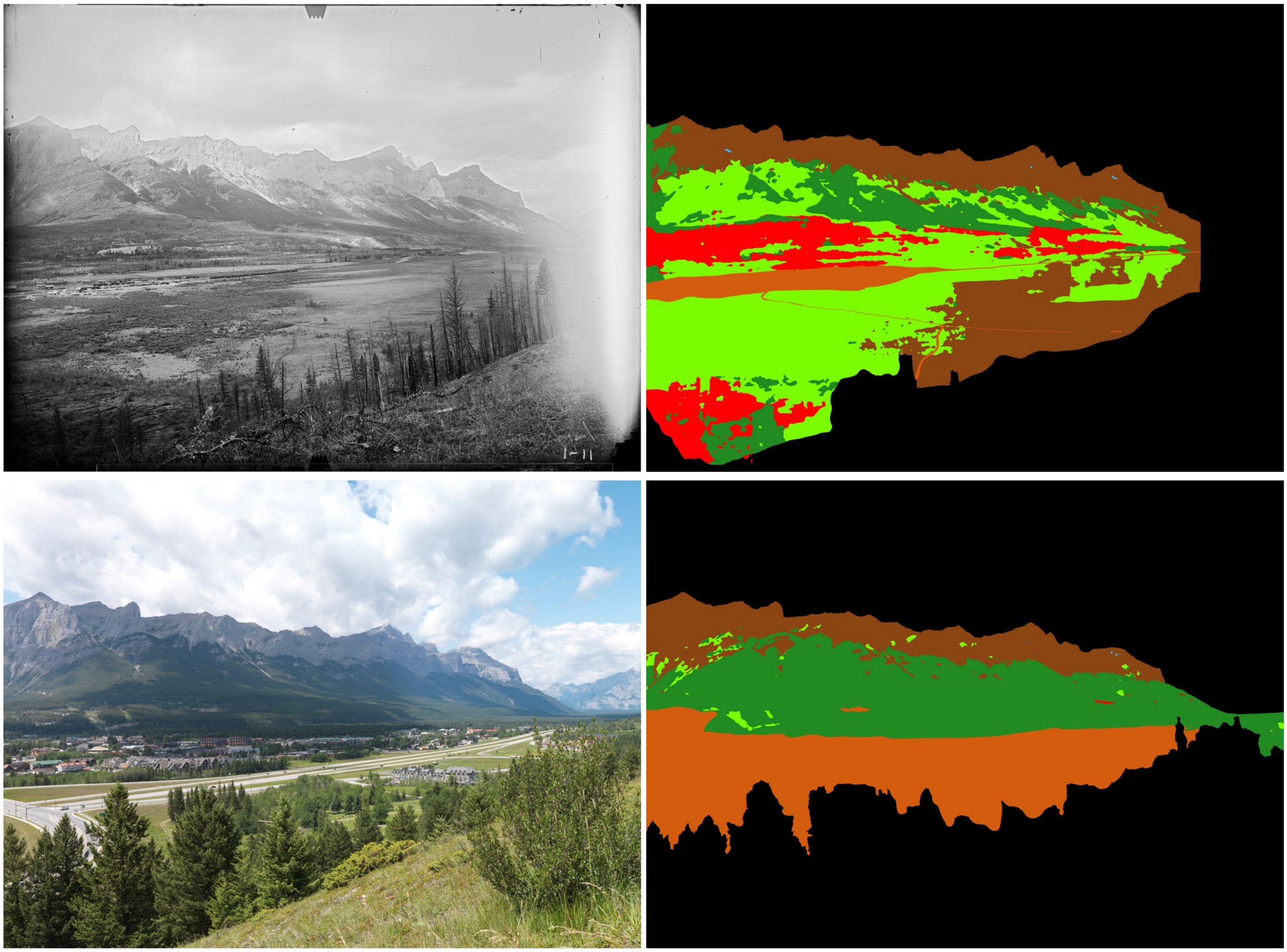
Mt Lady McDonald (1890 - 2014, Elevation: 2613m, Az: 192)

This high elevation station overlooks what is now Canmore, but what used to be a traditional Stoney Nakoda Campsite. The area around Canmore was used in the past by the Stoney Nakoda for hunting bison. Overall, this area has been used by people for many centuries. The valley bottom in the historic images is very open and completely clear of any black sticks or other indicators of large burning, which makes sense was this area was likely heavily managed by Indigenous burning.



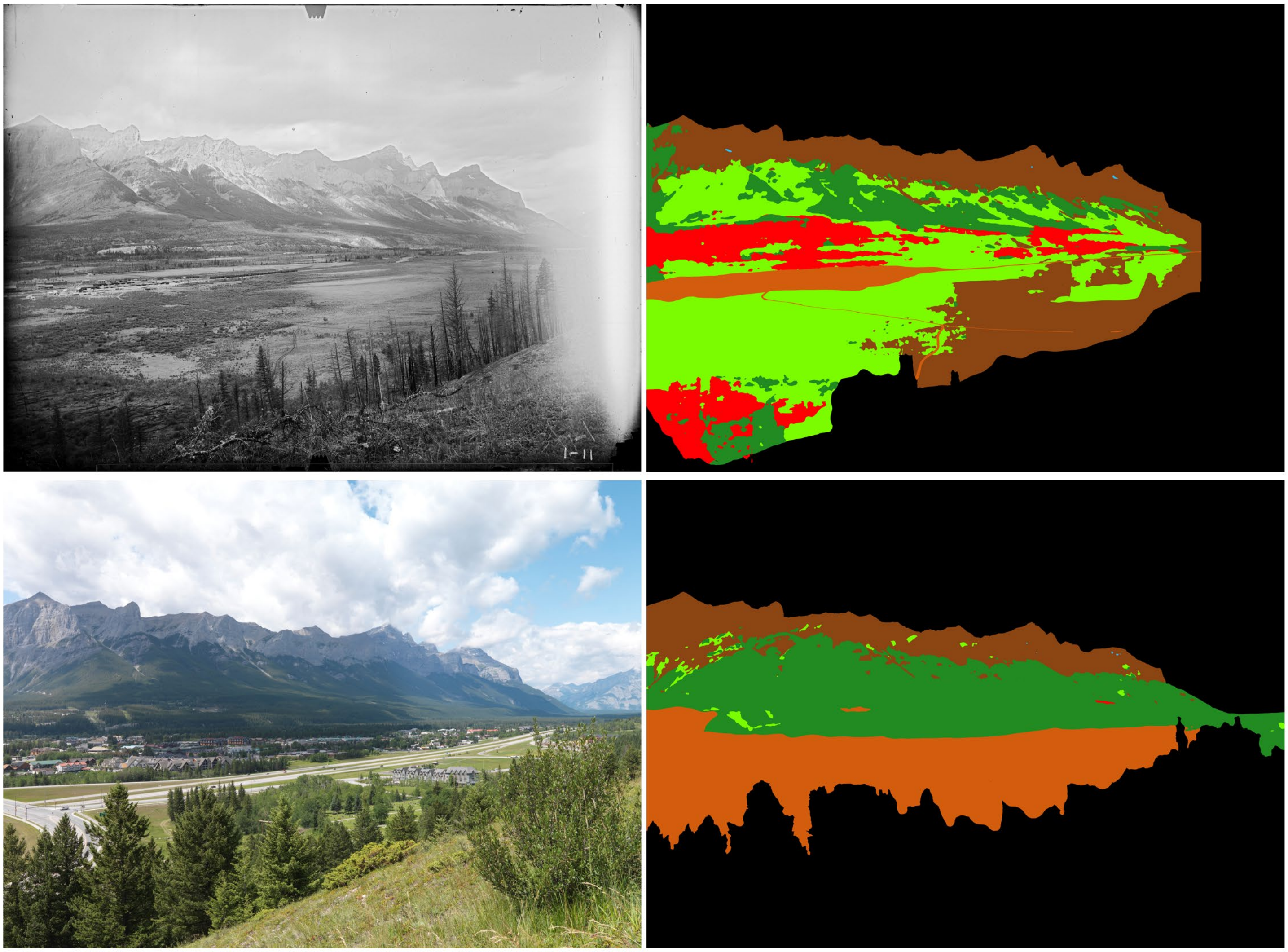
Mt Lady McDonald Bench (1889 - 2009, Elevation: 1351m, Az: 175)

This station is down in the valley that the previous station was overlooking. This camera location is only ~4km from the traditional campsite in this area, so the area in this image's viewshed was likely heavily managed by Indigenous burning. However, this image looks slightly back toward the mountains and away from the traditional campsite. There are dead trees in the foreground, but they are not blackened, so it is difficult to ascertain if they were burned. The clear areas further away from the camera have no such snags, so it is difficult to be sure just how much Indigenous burning took place in the area seen in these images.



Mt Lady McDonald Bench (1889 - 2009, Elevation: 1351m, Az: 270)

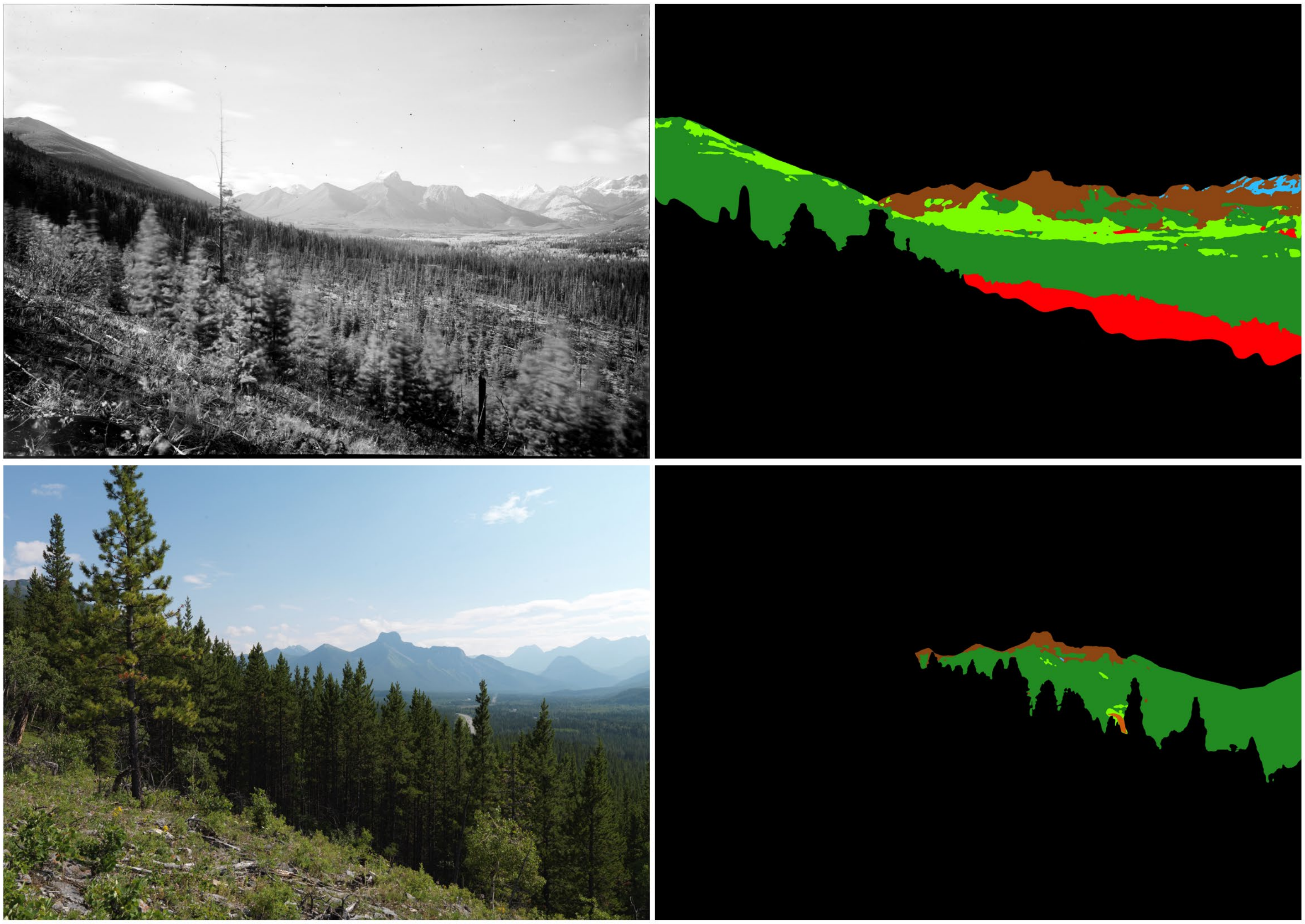
This image set looks west, directly away from the traditional campsite and hunting area captured by the other Mt Lady McDonald Bench - however, it is only ~4km away from that location. There are small buildings of the early Canmore settlement present in the historic image, as well as the railway, which was built only 5 years prior to this image. The open regenerating and herbaceous areas in this image are completely free of any trunks or black sticks, indicating that this cleared area was likely well maintained by Indigenous burring.



Mt Lawrence Grassi South (1889 - 2014, Elevation: 2178m, Az: 79)

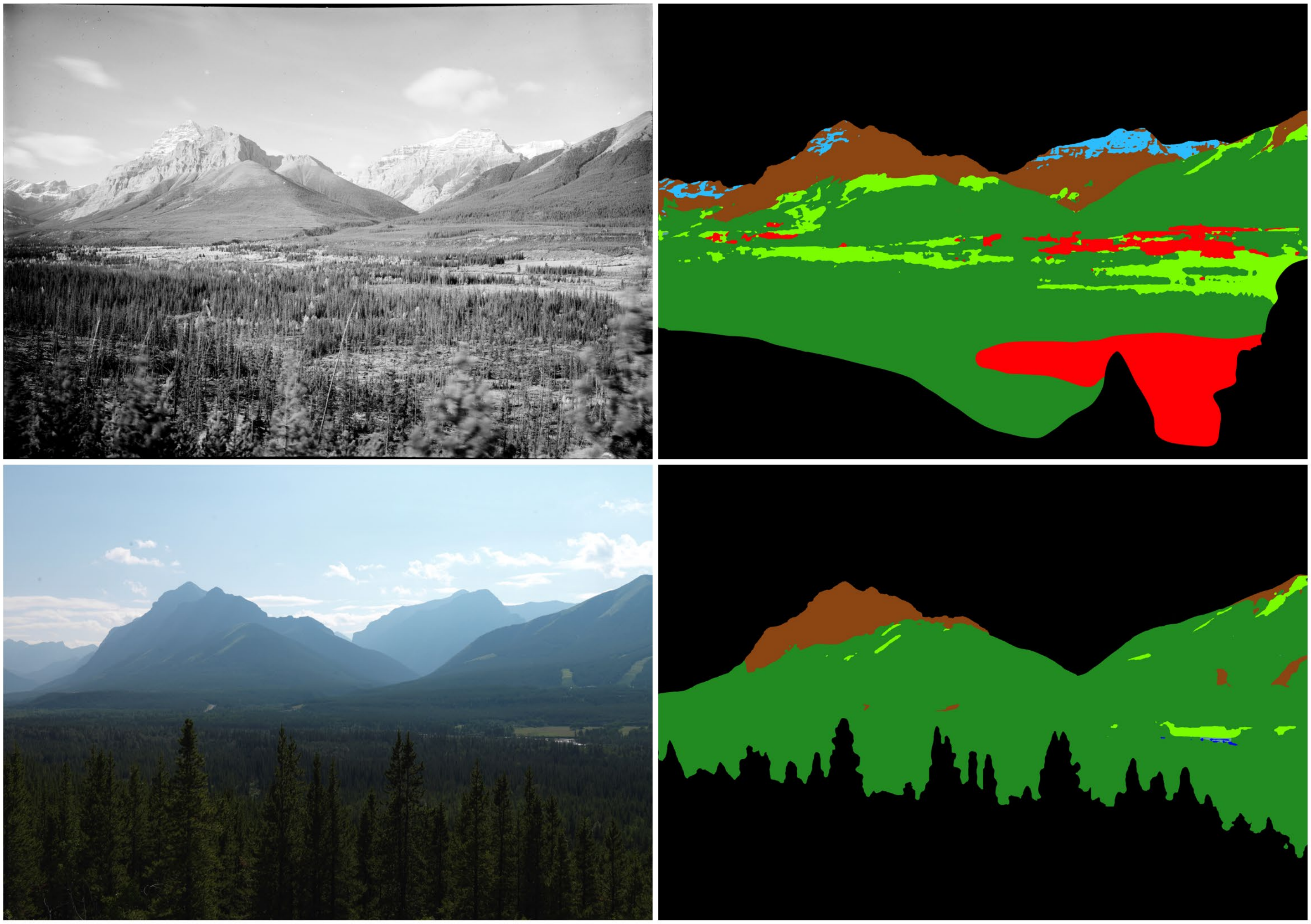
This station is located directly west of the previous two stations, overlooking the same valley that is home to a traditional campsite and hunting ground. Most of the clear areas in this historic photograph are unmarked by blackened sticks. There is one small section of dead trees that was captured by the first Mt Lady

McDonald Bench image set. As this area has been well inhabited by humans, it is likely that Indigenous burning was used to maintain these open areas.



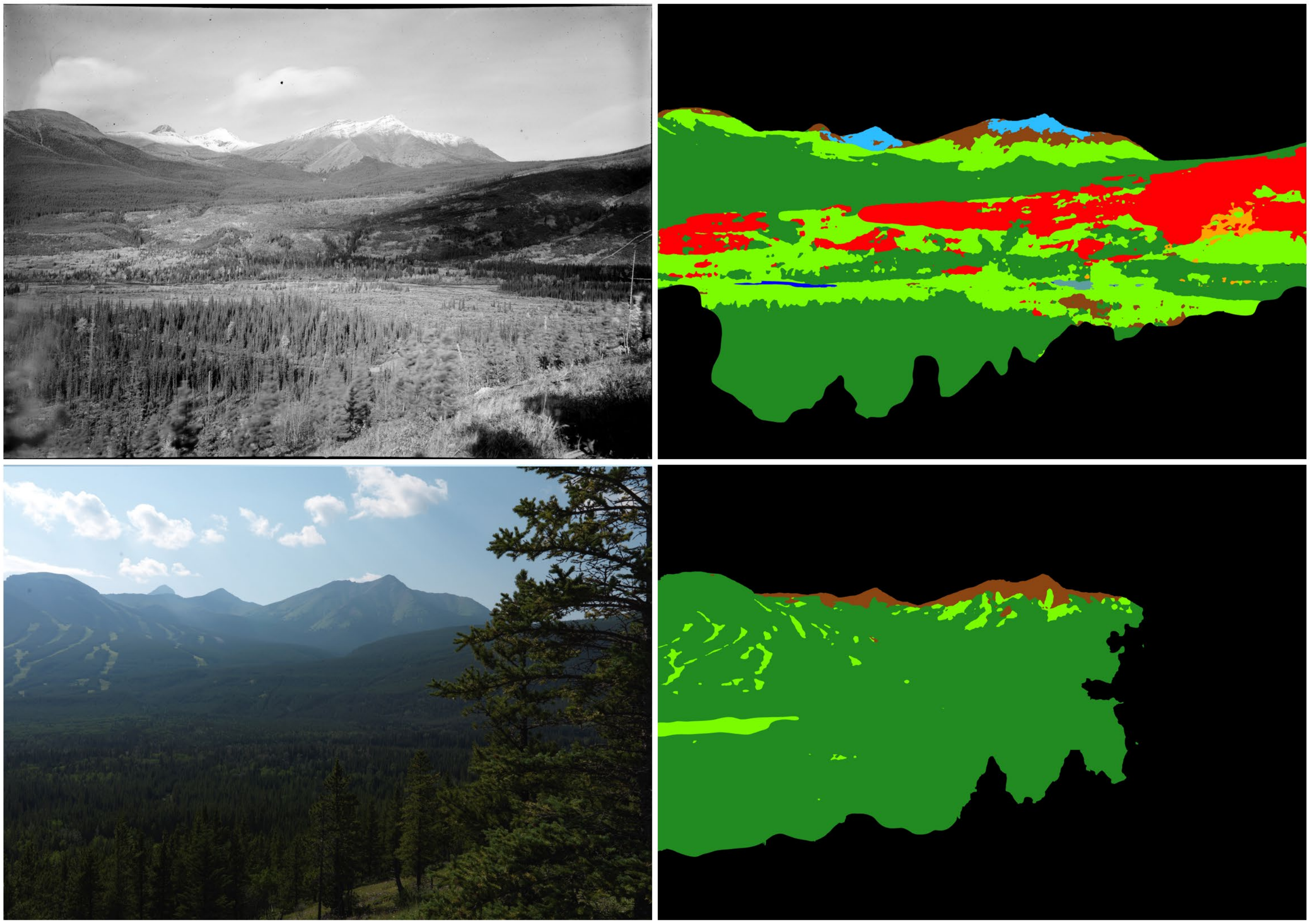
Mt McDougall North (1905 - 2009, Elevation: 1514m, Az: 158)

This station is located right along the *Ozade Châgu* traditional travel route but looks back toward the mountains with quite a bit of foreground. There is not much that can be meaningfully determined from this image due to its limited viewshed. However, in the historic image, we can see quite a bit of tree coverage, which may indicate the viewshed captured here was not regularly burned.



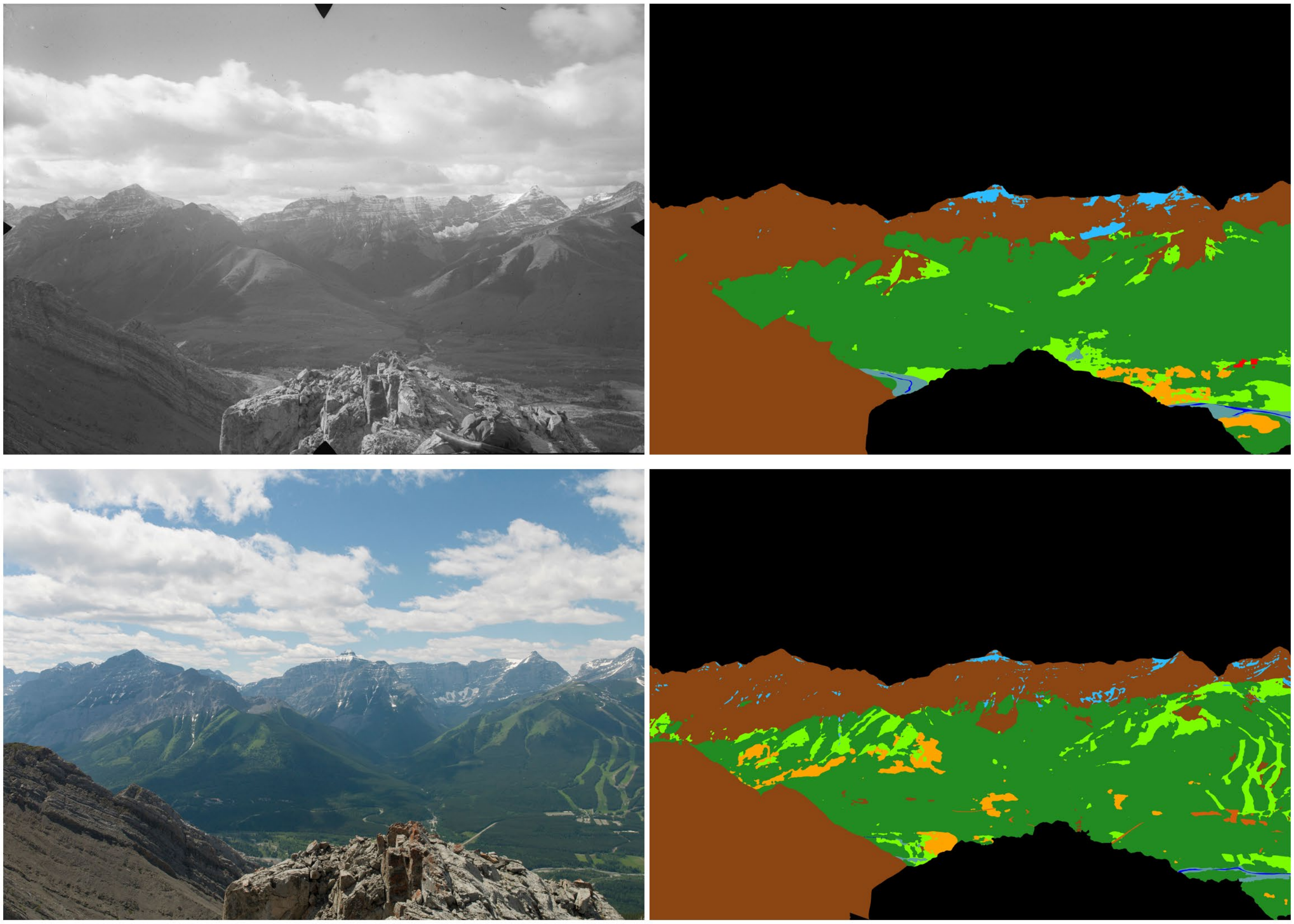
Mt McDougall North (1905 - 2009, Elevation: 1514m, Az: 211)

This station, still along the *Ozade Châgu* travel route, looks along the mountainsides that surround this traditional travelling route. While most of the area is treed, there is a clearing in the center, which was likely the travelling route along the river. The absence of any sort of black stick, the infilling of all herbaceous and regenerating area to conifer, and the knowledge that this looks out at a traditional travelling route, makes it likely that this area was managed by Indigenous burning.



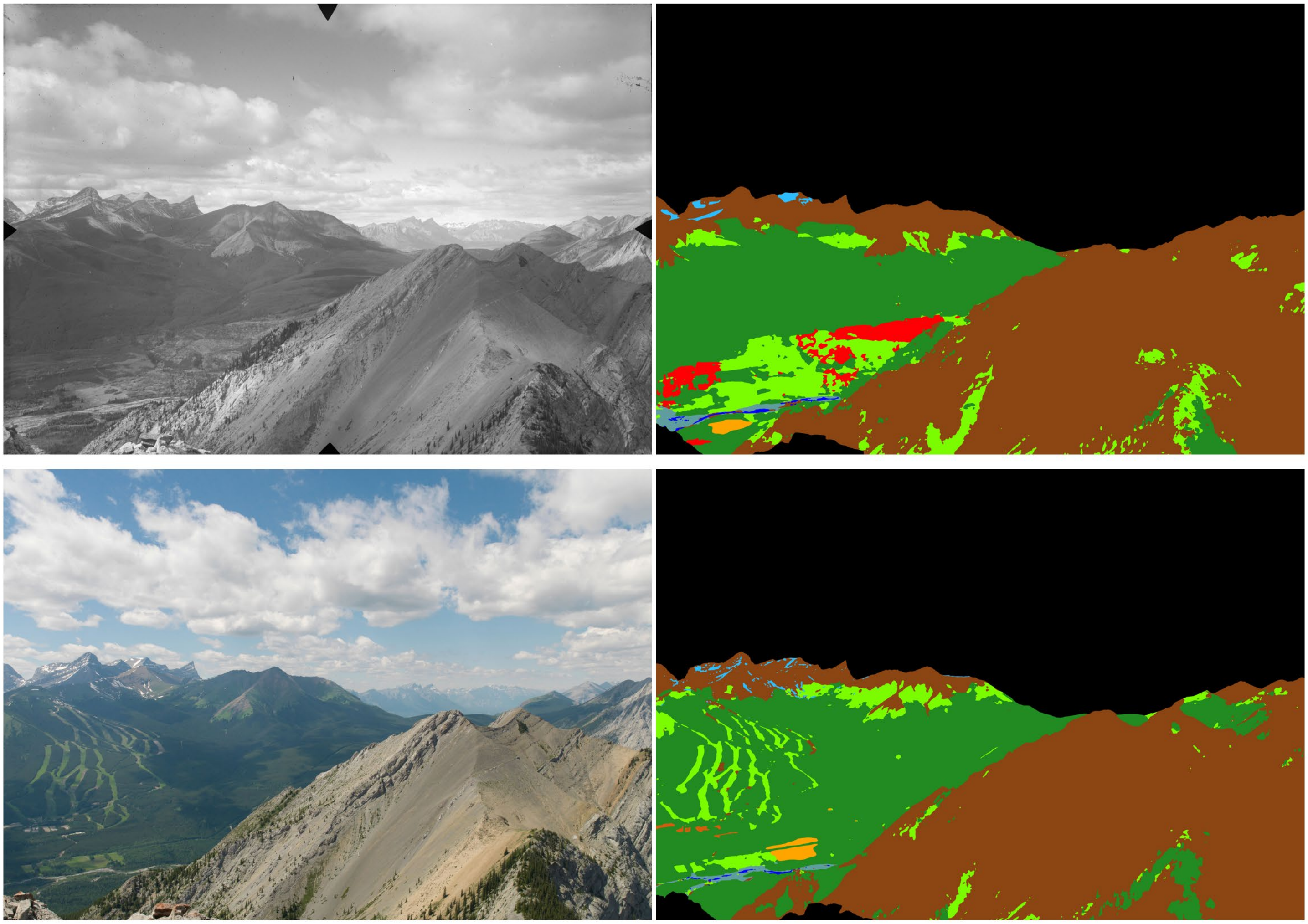
Mt McDougall North (1905 - 2009, Elevation: 1514m, Az: 272)

This image set has the best look at the *Ozade Châgu* travel route. The clearings maintained for this travelling route are completely free of black sticks, indicating they were likely maintained by regular burning.



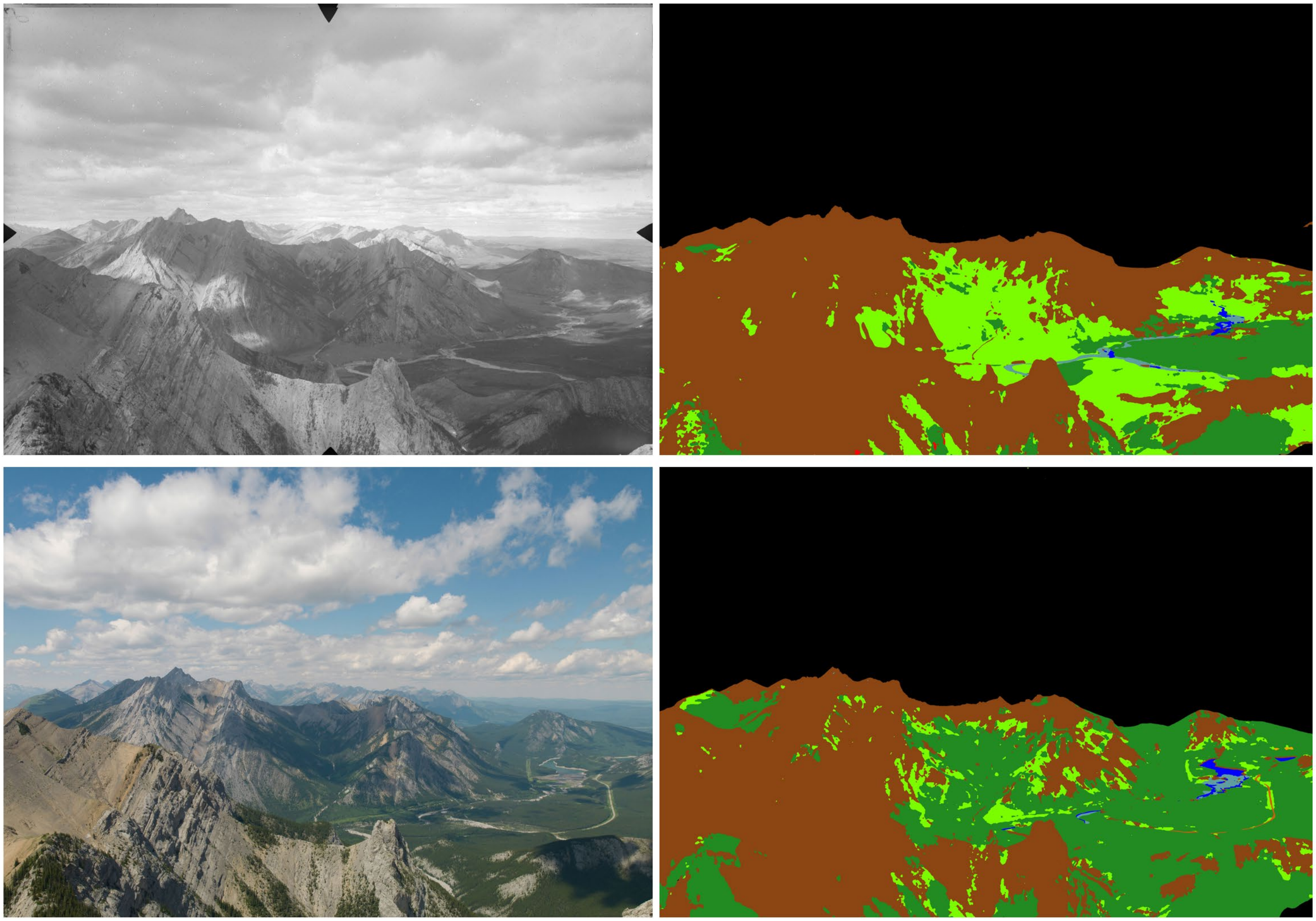
Stn 54 Kananaskis Ridge (1916 - 2014, Elevation: 2369m, Az: 240)

This overlooks the Ozade Châgu traditional travelling route. Although much of the valley bottom in this image set is taken up by the foreground, close inspection of what is visible along the valley bottom shows a mixed herbaceous/mixedwood travelling path with no evidence of black sticks or other signs of fire. This area was likely well maintained by the Stoney Nakoda, as this section of the Ozade Châgu is quite close to a major traditional campsite.



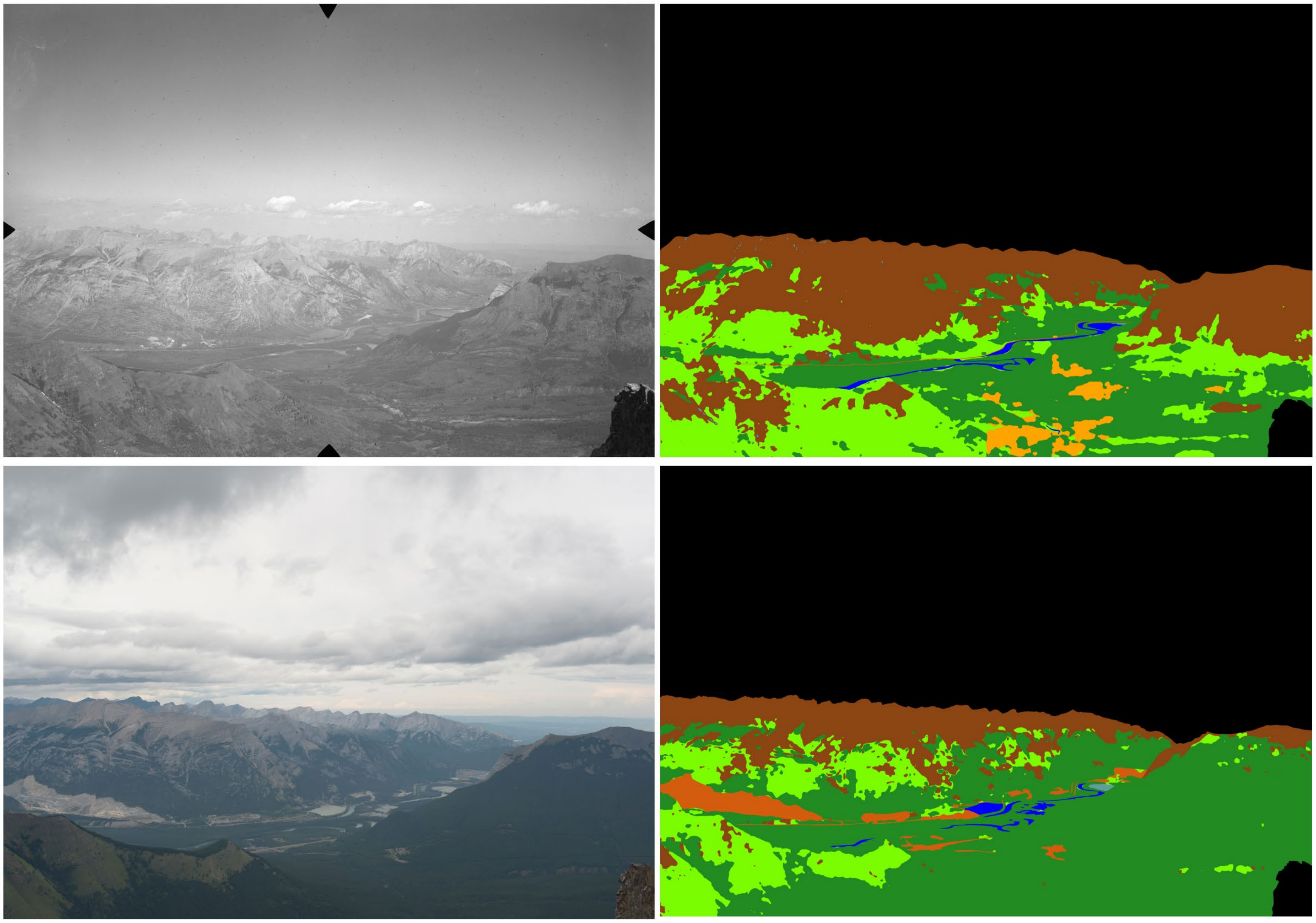
Stn 54 Kananaskis Ridge (1916 - 2014, Elevation: 2369m, Az: 282)

This image set, like the one above it, directly overlooks the Ozade Châgu travelling route in an area very close to a major traditional campsite of the Stoney Nakoda. The valley bottom visible in the lower left of the historic image shows an open, easily-traversable trail with no evidence of burn or black sticks. As this area has filled in with conifer in the modern images, except where areas have been cleared for the ski hill, this area can be assumed to have been one that was regularly maintained by Indigenous burning.



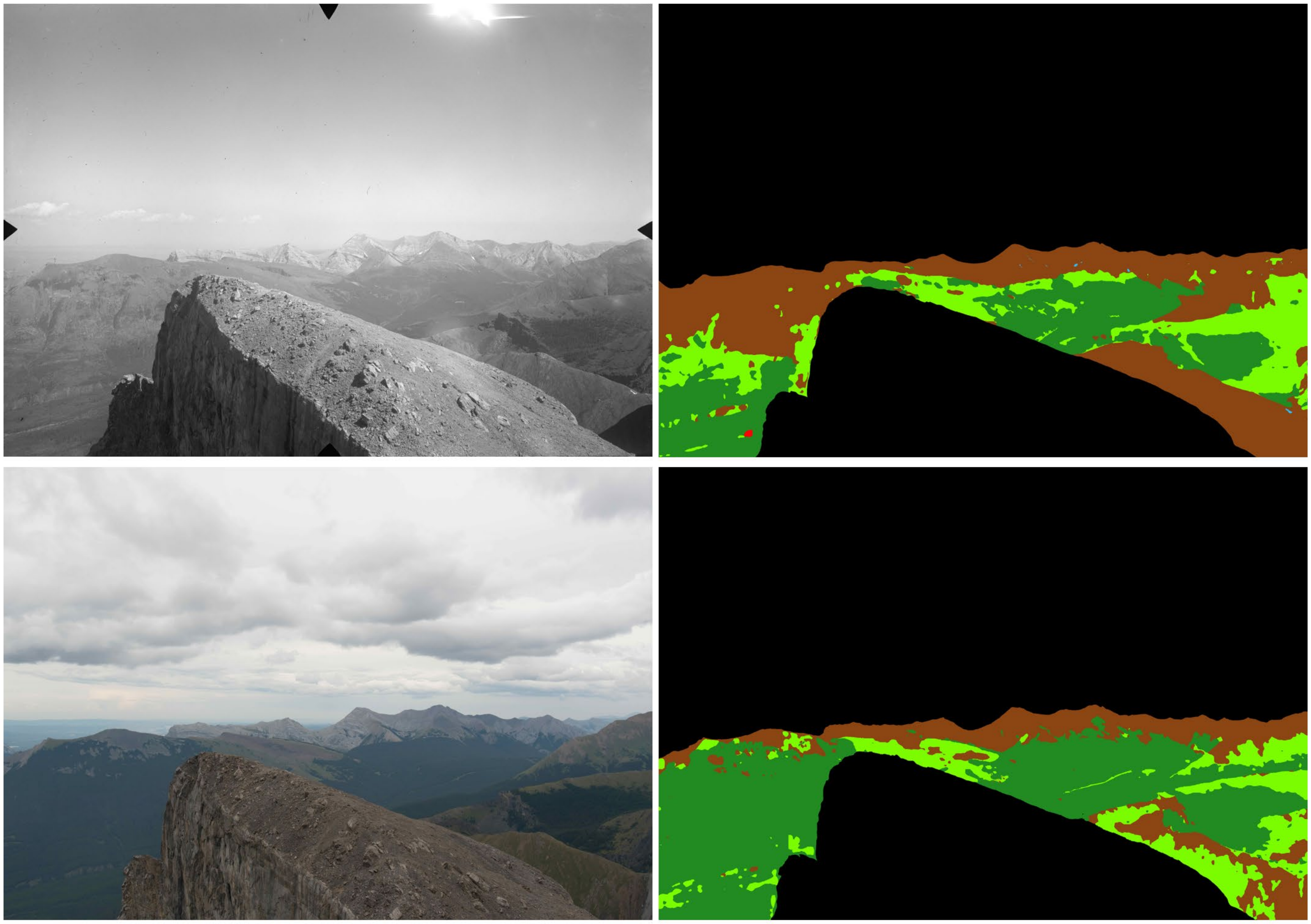
Stn 54 Kananaskis Ridge (1916 - 2014, Elevation: 2369m, Az: 326)

This image set follows the same pattern as the other two from this station, discussed above. This overlooks the Ozade Châgu near a major traditional campsite, and the open herbaceous valley bottom reflects that this was an area of heavy Indigenous management.



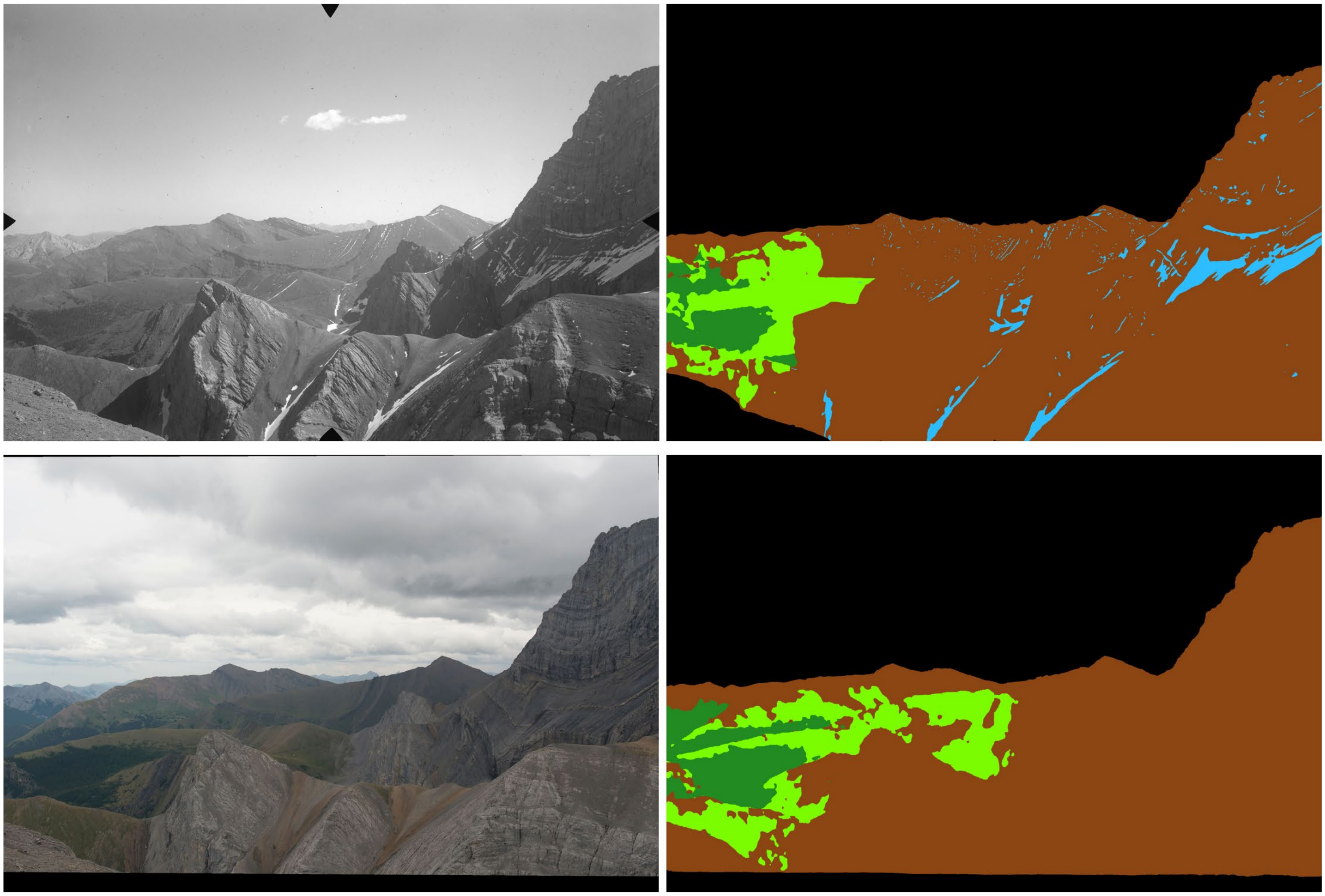
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 14)

While the Rimwall station is located over ten kilometres from a traditional campsite or travelling route, this azimuth does overlook a traditional campsite and travelling route. As this image has a long viewshed, it is still able to capture this highly managed area, which shows no evidence of burning in the historic image and conifer infill in the modern image.



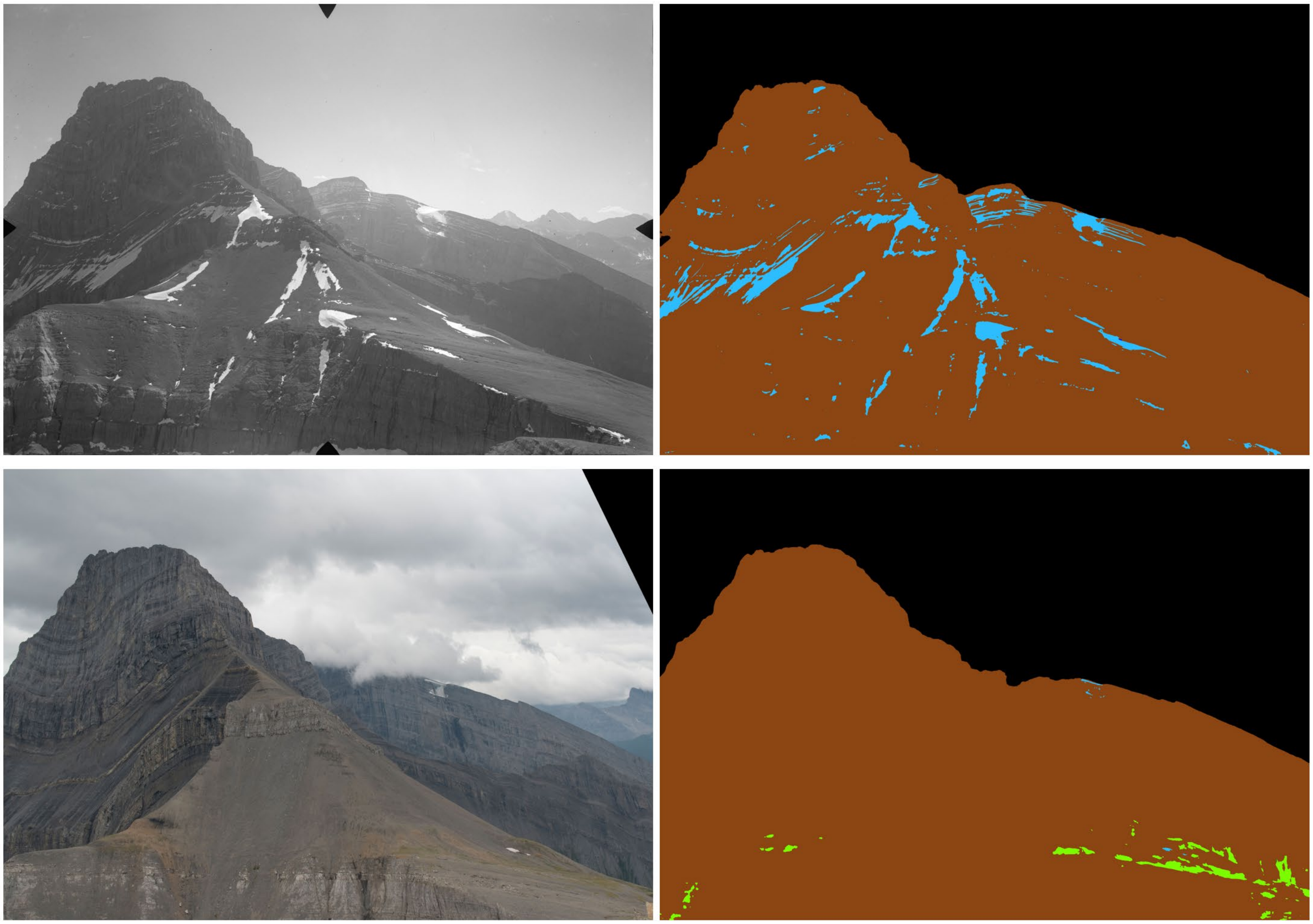
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 58)

This station and azimuth do not overlook any area that is significant to the Stoney Nakoda. Most conifer infill visible in this station takes place on the sides of mountains, which indicates that these changes are more likely to be a result of climate or other changes rather than Indigenous management.



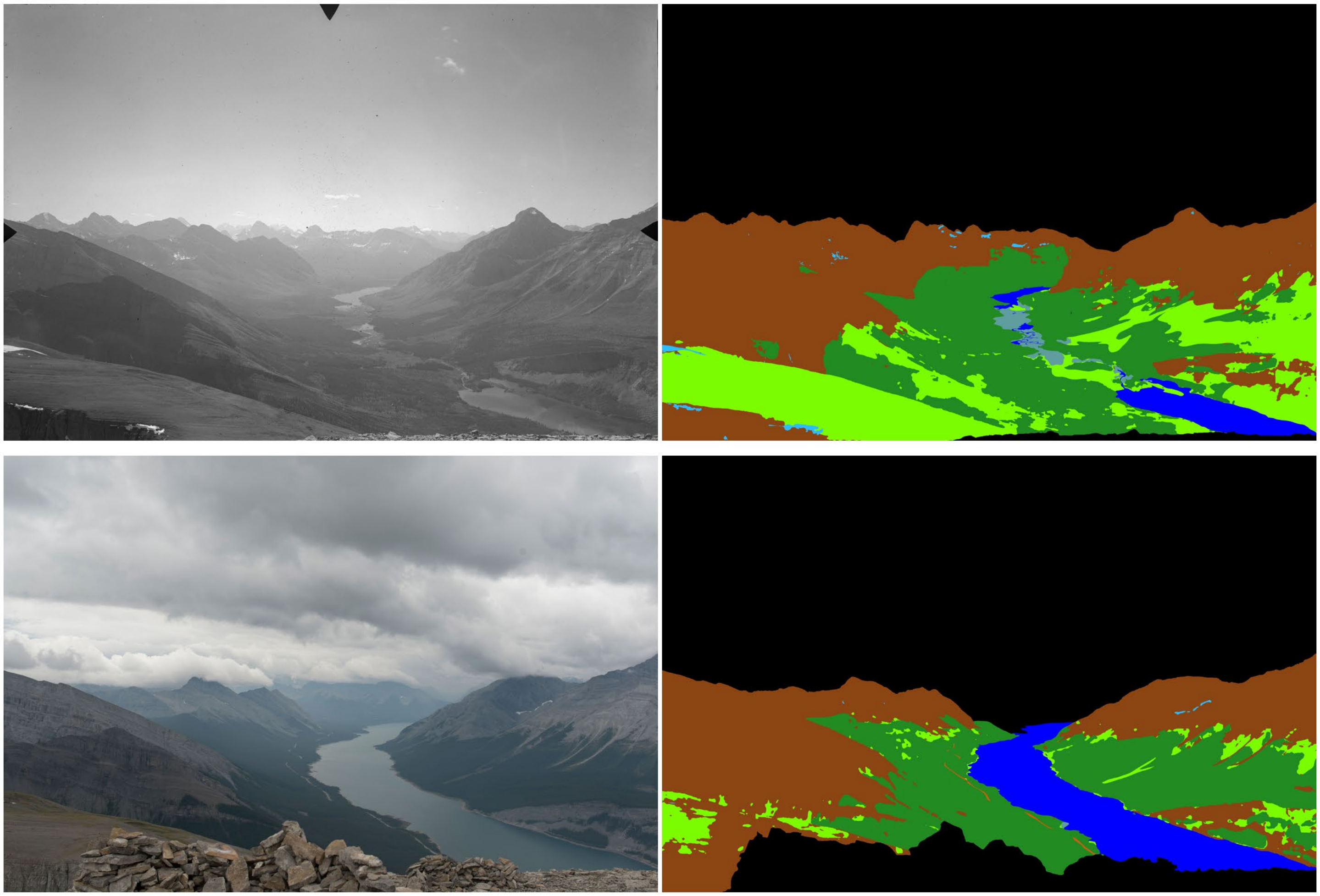
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 98)

This high-elevation station and azimuth largely looks over mountain peaks that had no regular use or inhabitation by people, meaning that most changes that have occurred here are not related to the removal of Indigenous people from the landscape.



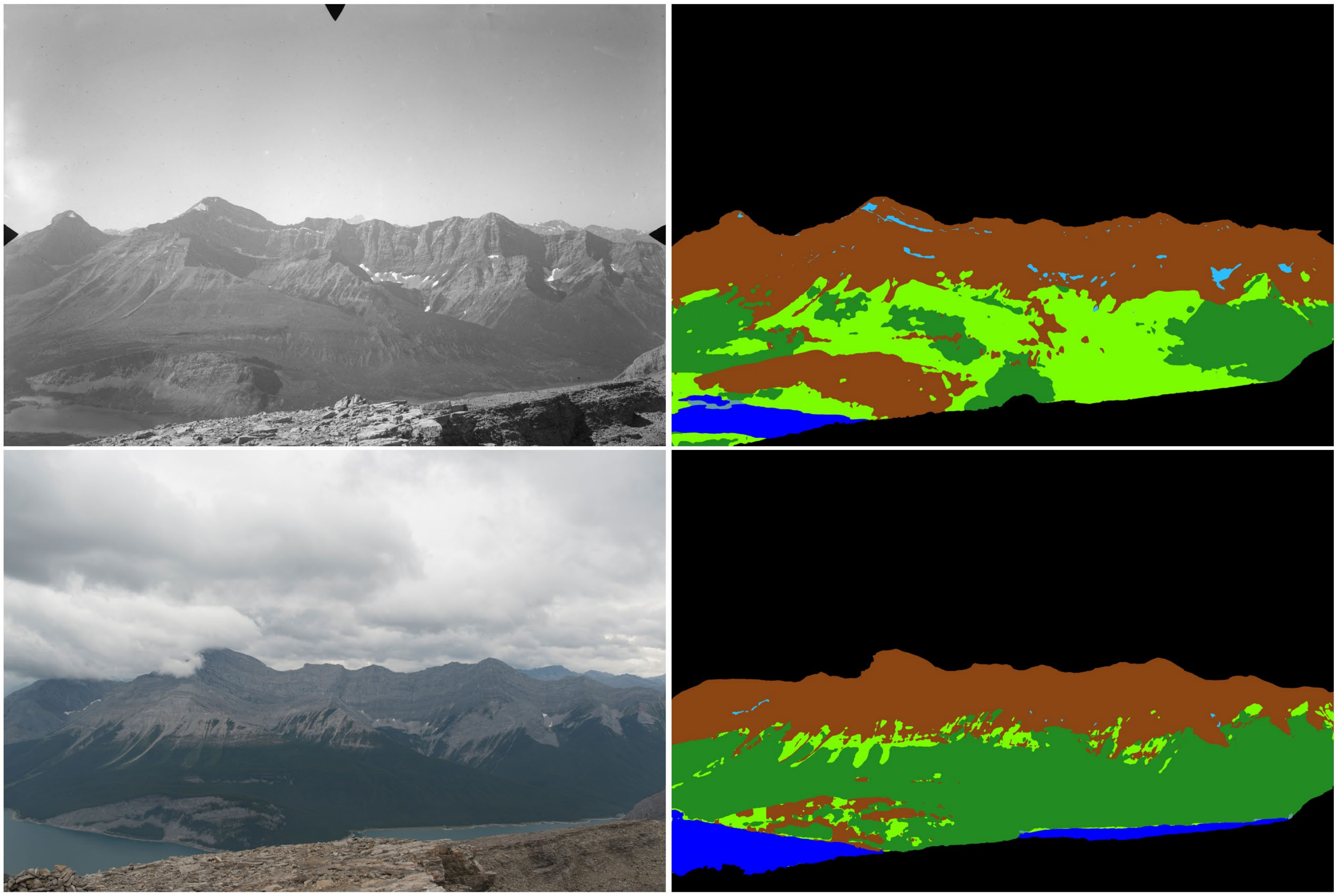
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689, Az: 140)

This station and azimuth, which only overlooks one mountain peak, shows very little evidence of change and no evidence of any human inhabitation or management.



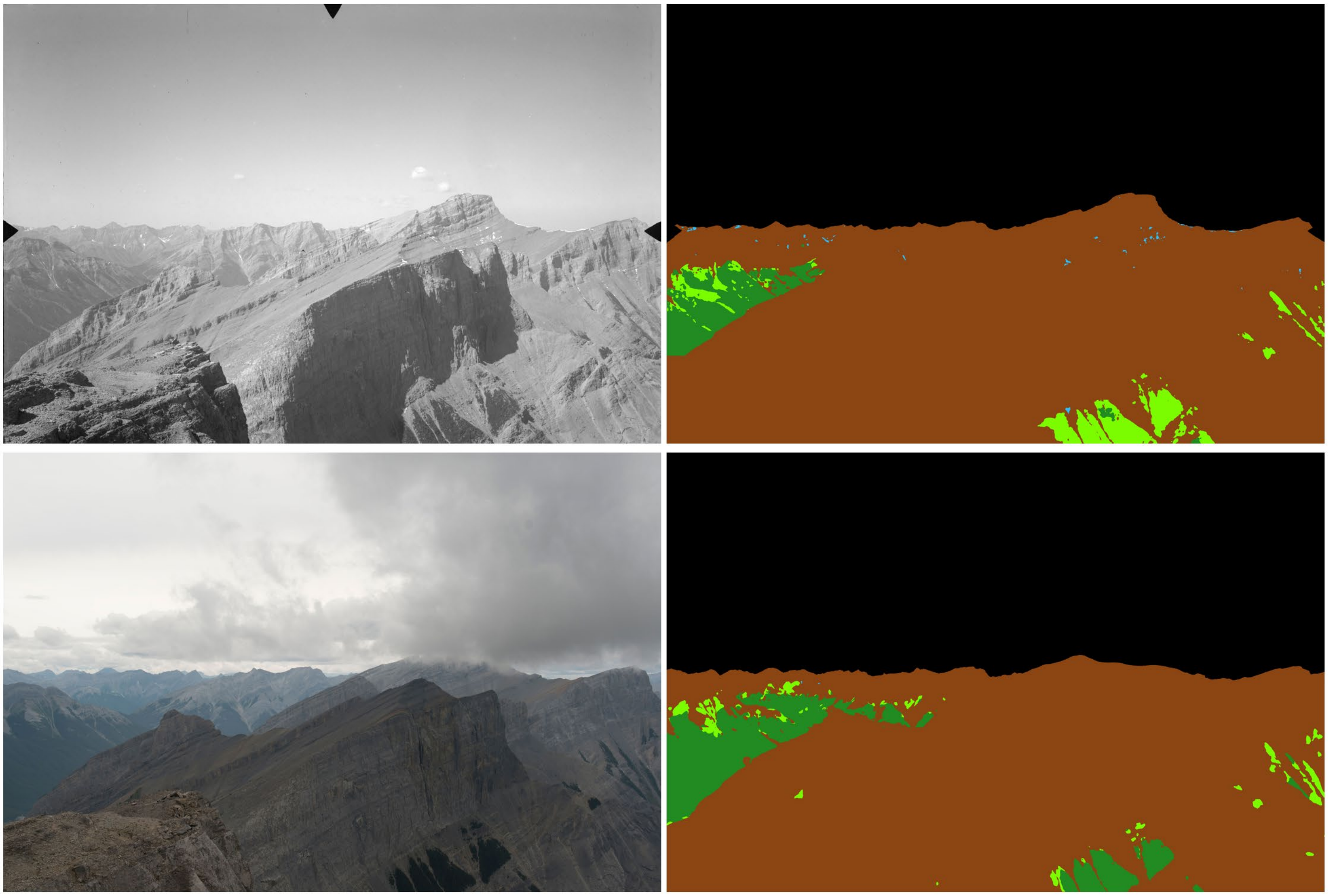
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689, Az: 180)

This image set overlooks Spray Lake, which was dammed in 1950, which caused the lake to increase to an area of about 20km^2 and the water level to rise by 50m. This heavy alteration of the landscape makes it difficult to know if any of the change seen in the vegetation patterns was related to the removal of Indigenous burning, or whether the huge increase in water in this area was a driving factor.



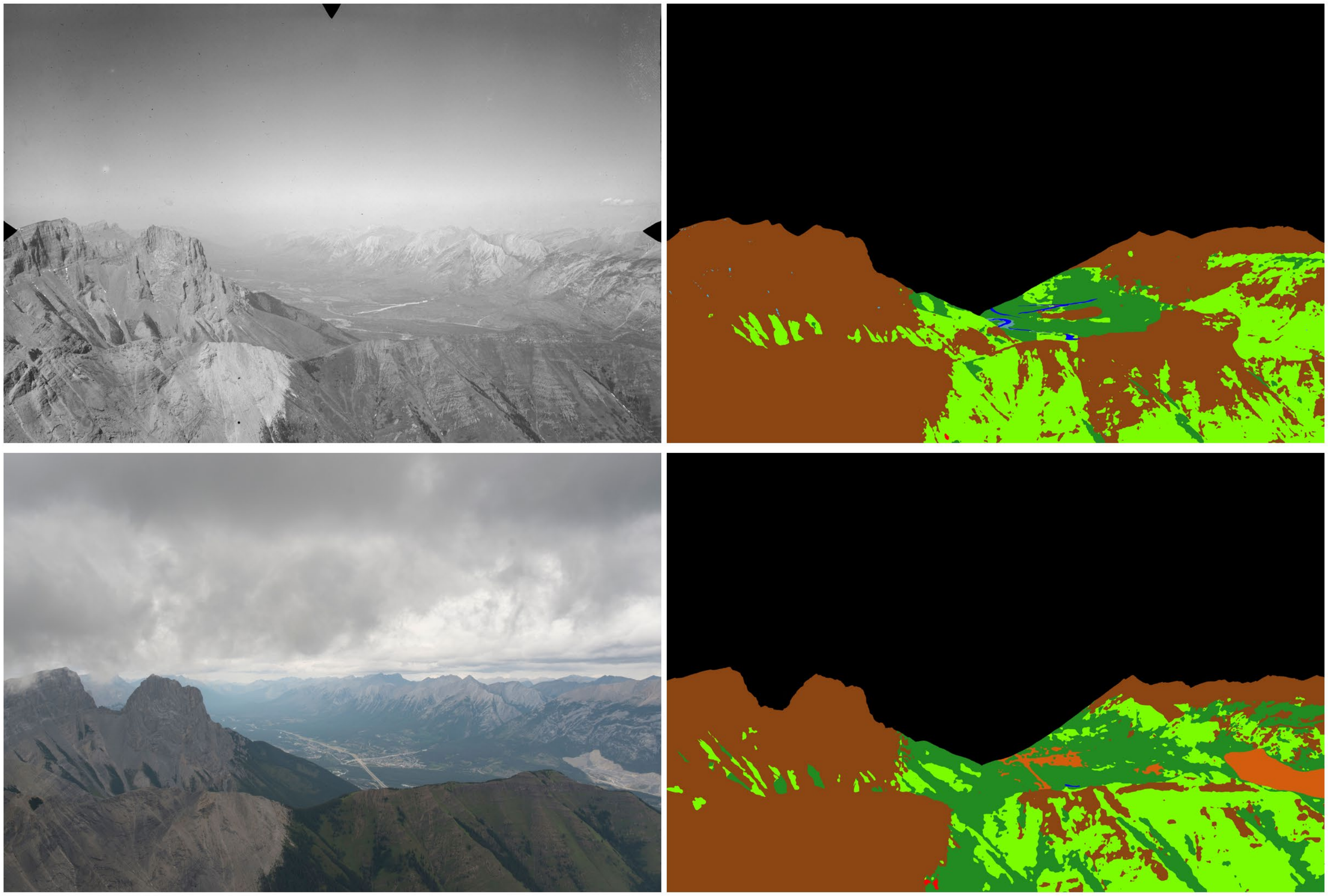
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 225)

This image set, as above, shows Spray Lake. The conifer infill in this set is mostly on the mountainside, which may have been related to Indigenous burning due to the lack of black sticks in the clearings, or it could be related to the increase in water in the area.



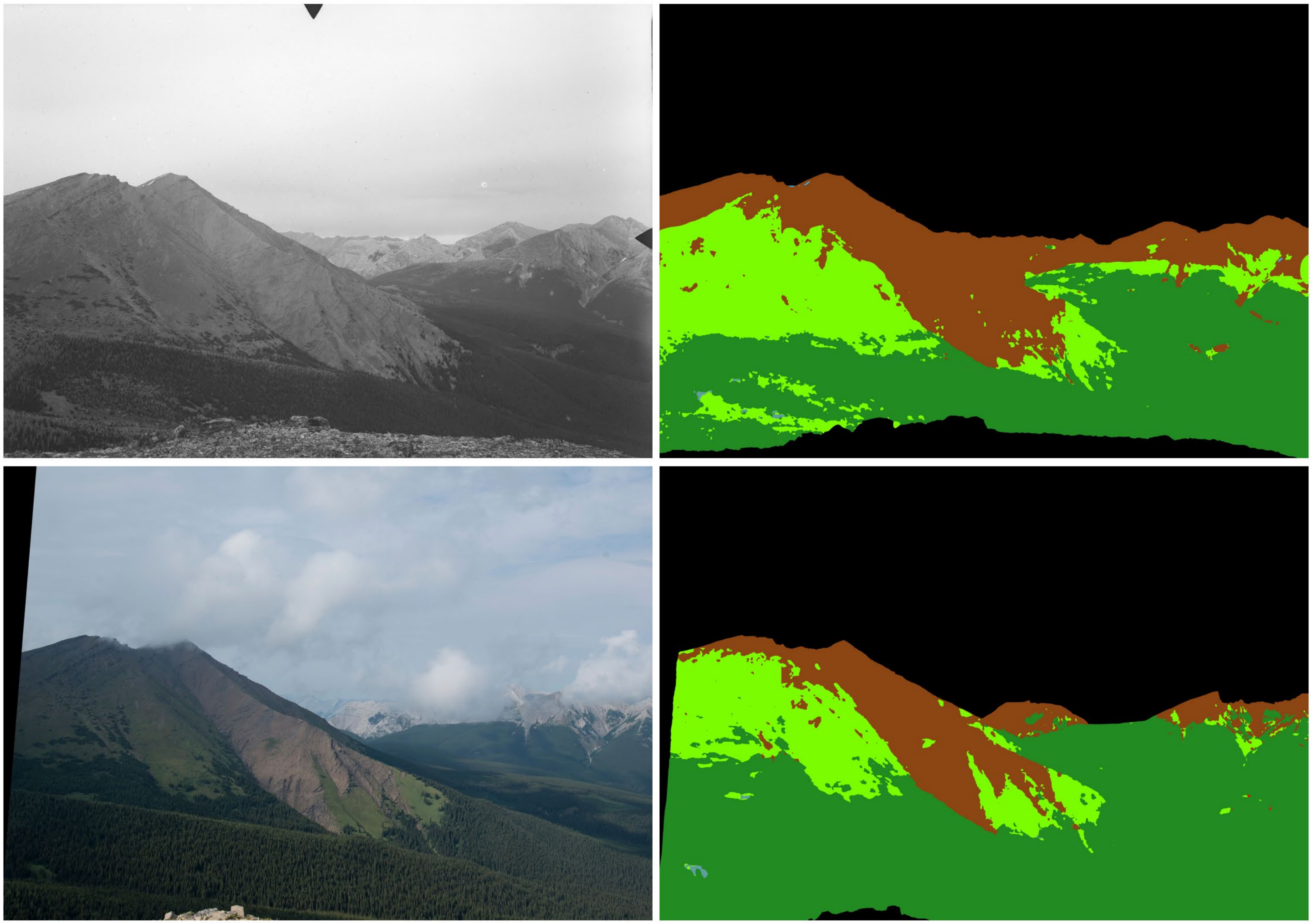
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 274)

This station, as with other Rimwall stations discussed above, largely shows rocky mountain peaks that have no large evidence of change, human inhabitation, or Indigenous management.



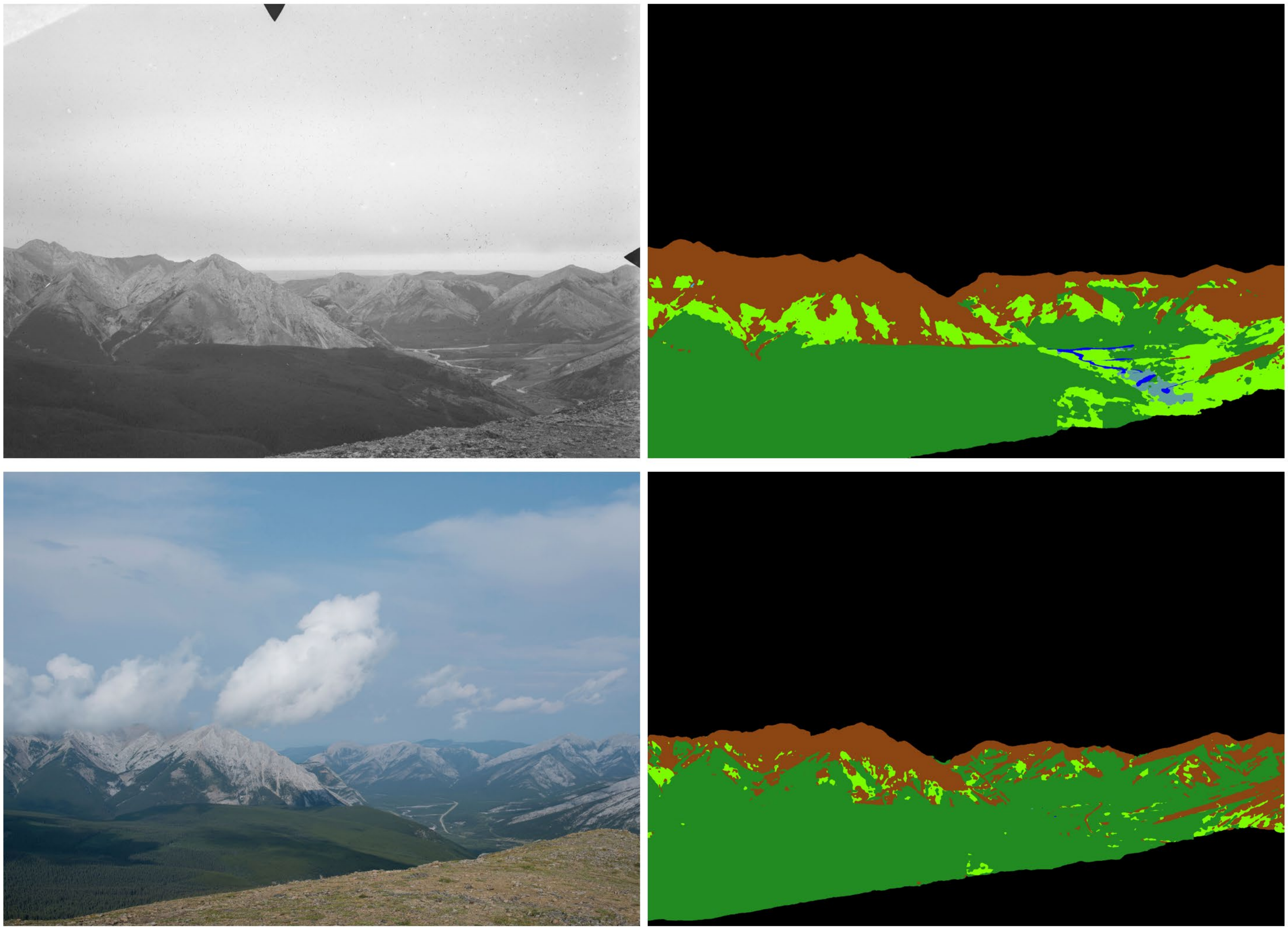
Stn. 45 Rimwall (1916 - 2014, Elevation: 2689m, Az: 320)

This image looks back toward a traditional travelling route of the Stoney Nakoda, but as this is quite far away from the camera, it is difficult to see any evidence of blackened sticks or other burn signatures to determine if this area was regularly maintained by Indigenous burning.



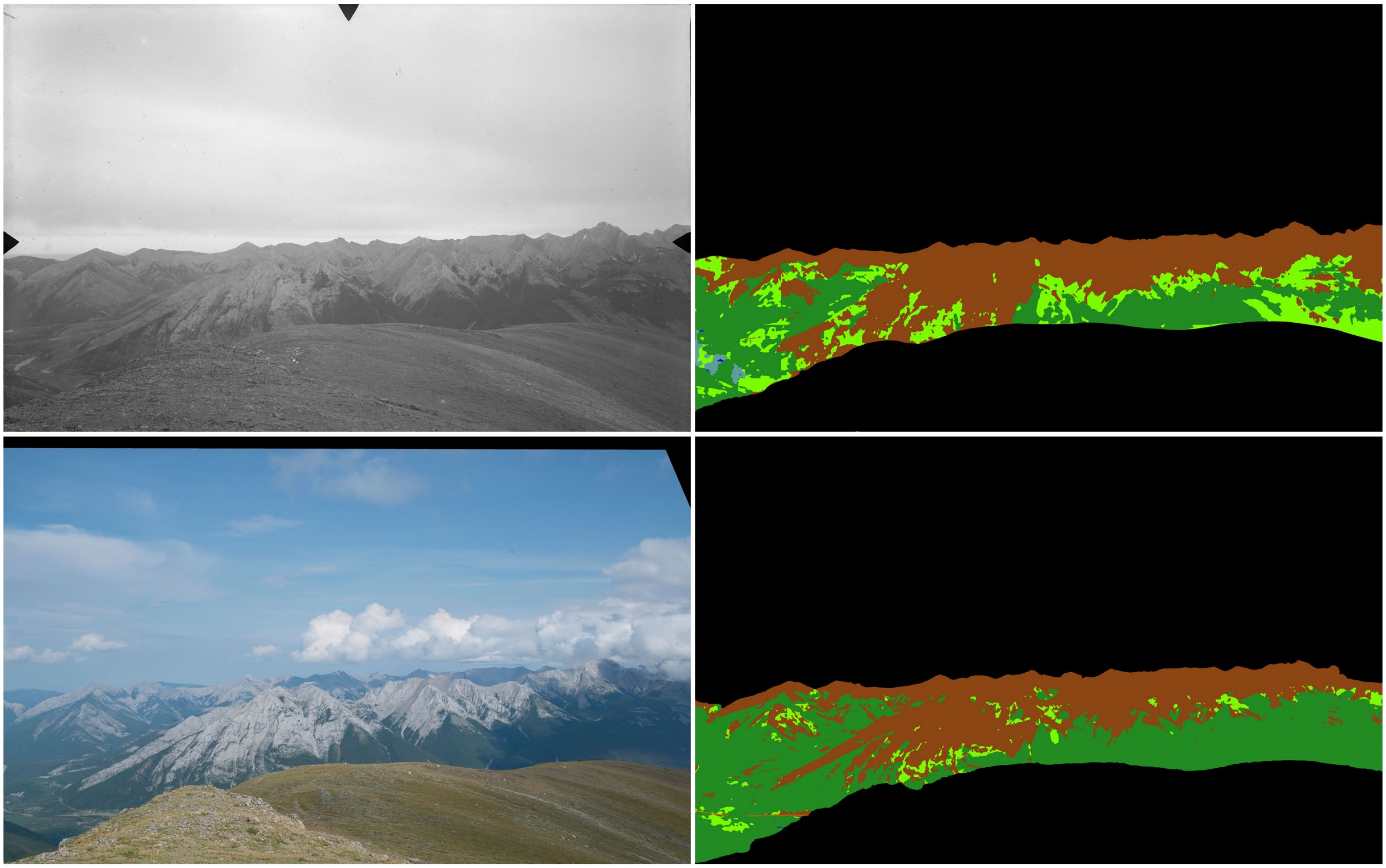
Stn. 6 Mt Allan (1916 - 2014, Elevation: 2473m, Az: 10)

This photoset looks almost directly north, pointing it away from any traditional travelling routes or campsites. The historical photo is thick, dense conifer, which is relatively unchanged in the modern repeat. It's likely that this area was not regularly burned by Indigenous people.



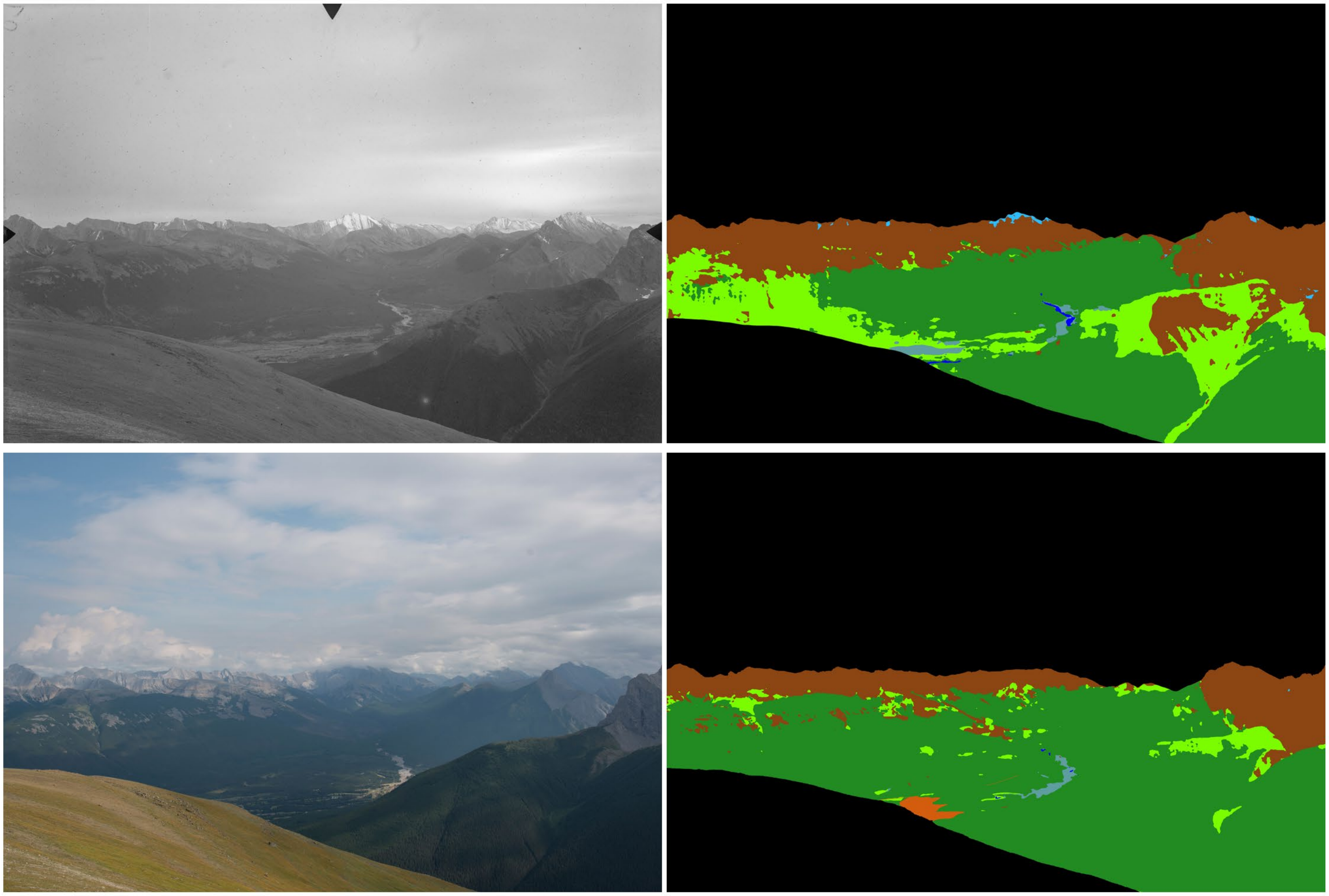
Stn. 6 Mt Allan (1916 - 2014, Elevation: 2473m, Az: 40)

This image set faces northeast. The left side of the image shows the coniferous pass that was relatively unused and uninhabited, while the right side begins to show the Ozade Châgu travelling path. It is too far away in this image to be clear enough to determine the presence of any black sticks or other burn signatures, but it is likely that this section was managed due to the presence of the travelling route.



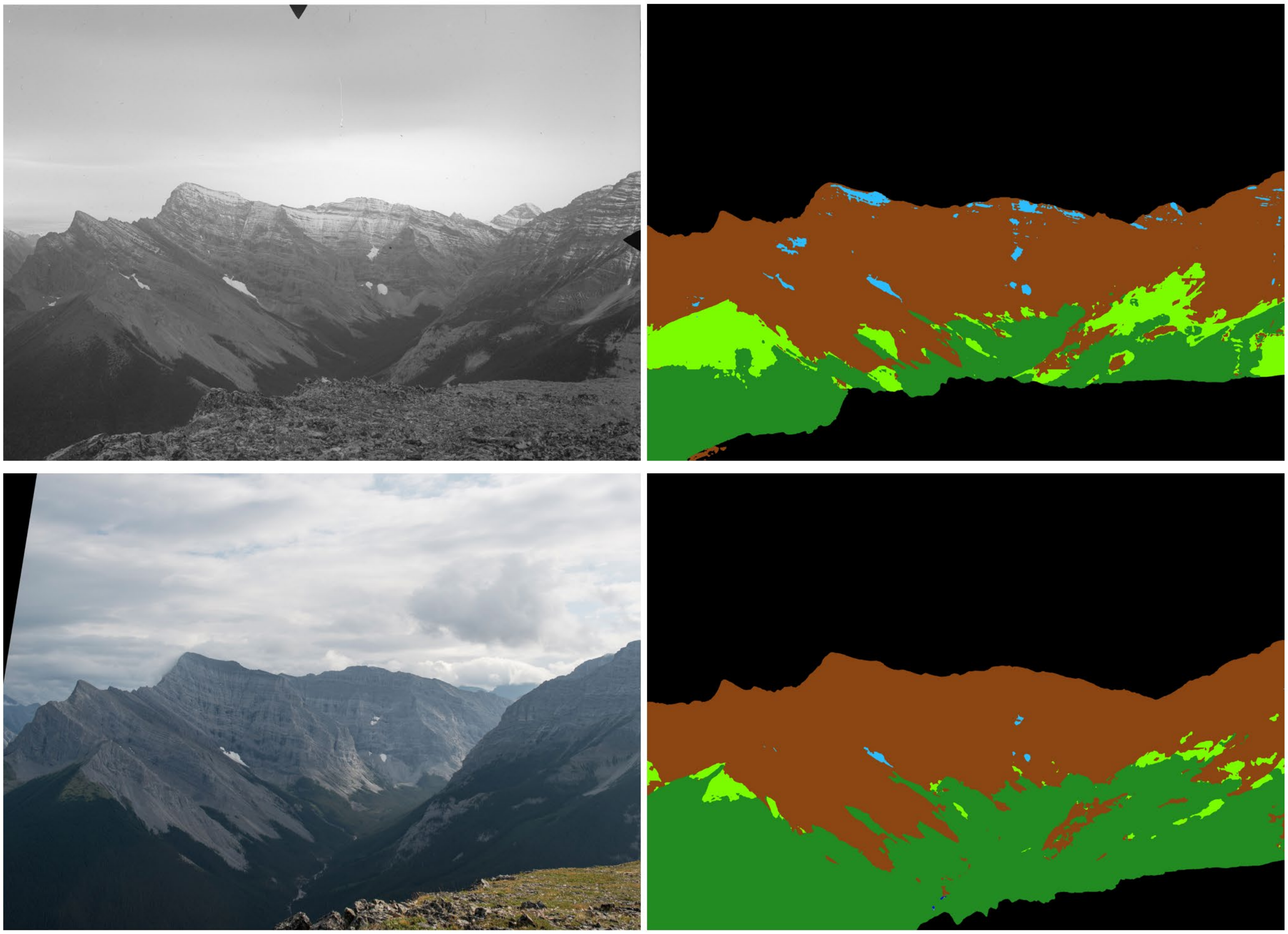
Stn. 6 Mt Allan (1916 - 2014, Elevation: 2473m, Az: 76)

This image has quite a lot of foreground obscuring the valley bottom, where the Ozade Châgu traditional trail is located, which makes it difficult to look for any evidence of Indigenous burning or management.



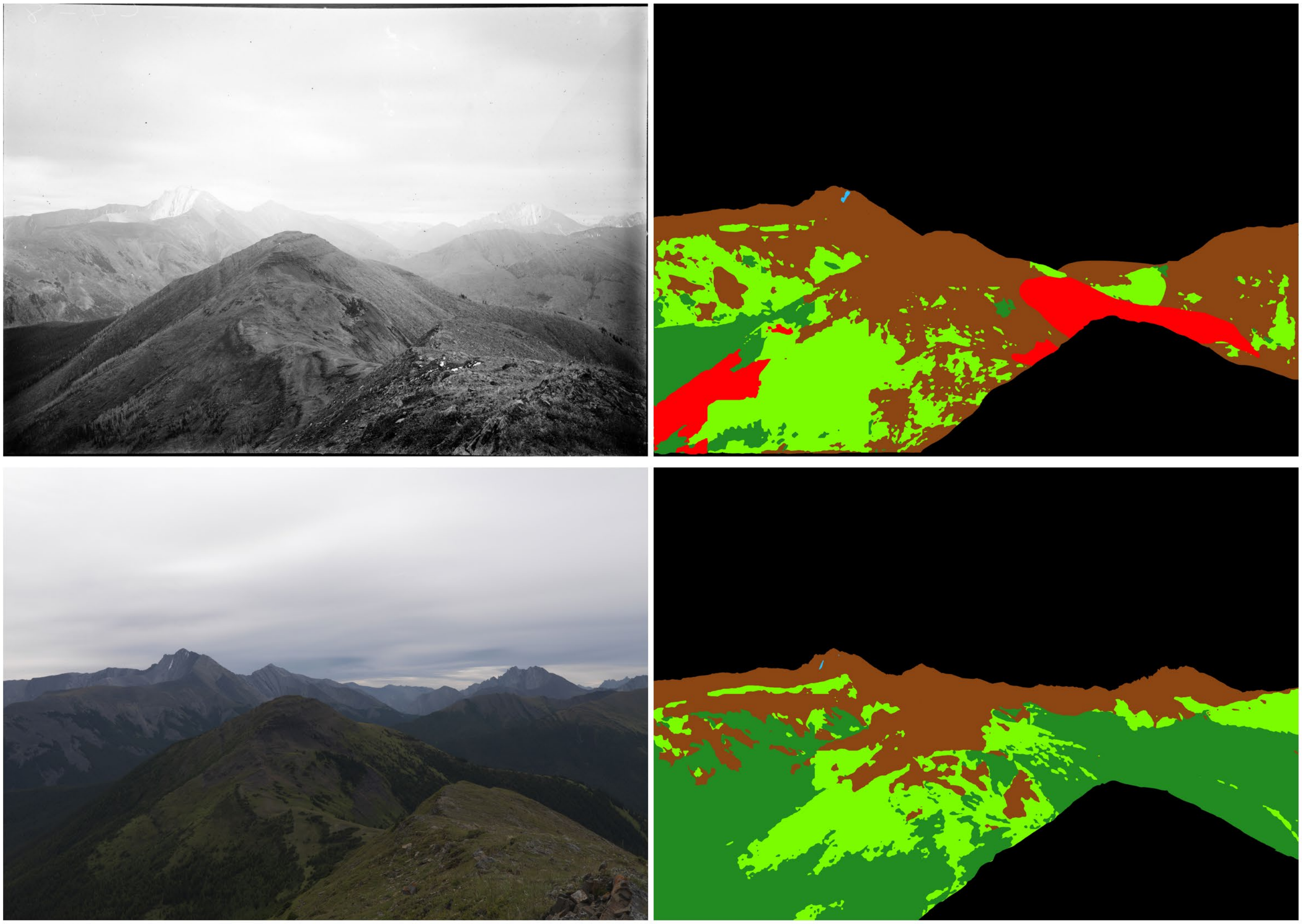
Stn. 6 Mt Allan (1916 - 2014, Elevation: 2473m, Az: 132)

This photoset directly overlooks the Ozade Châgu traditional travelling route. The clearing in the valley bottom is wide and free from thick trees, and with no evidence of fire, it appears as if it was regularly maintained by Indigenous burning, which would make sense for such a major travelling route.



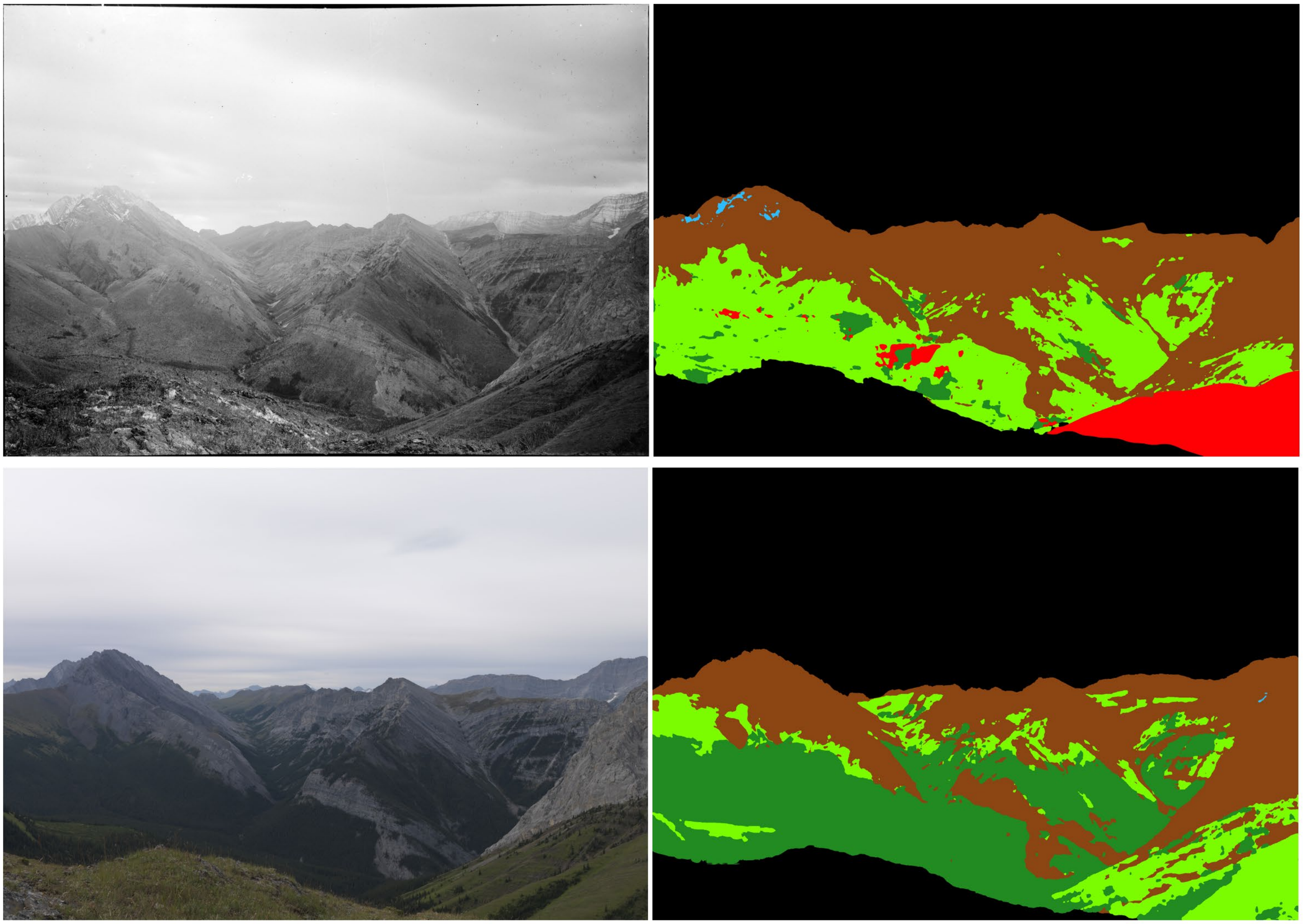
Stn. 6 Mt Allan (1916 - 2014, Elevation: 2473m, Az: 180)

This image pair overlooks an elevated plateau between Mount Bogart and Mount Kidd. This area was not associated with any traditional campsite or travelling route and in both the historic and modern image is covered in fairly dense conifer. This area was likely not managed by Indigenous burning.



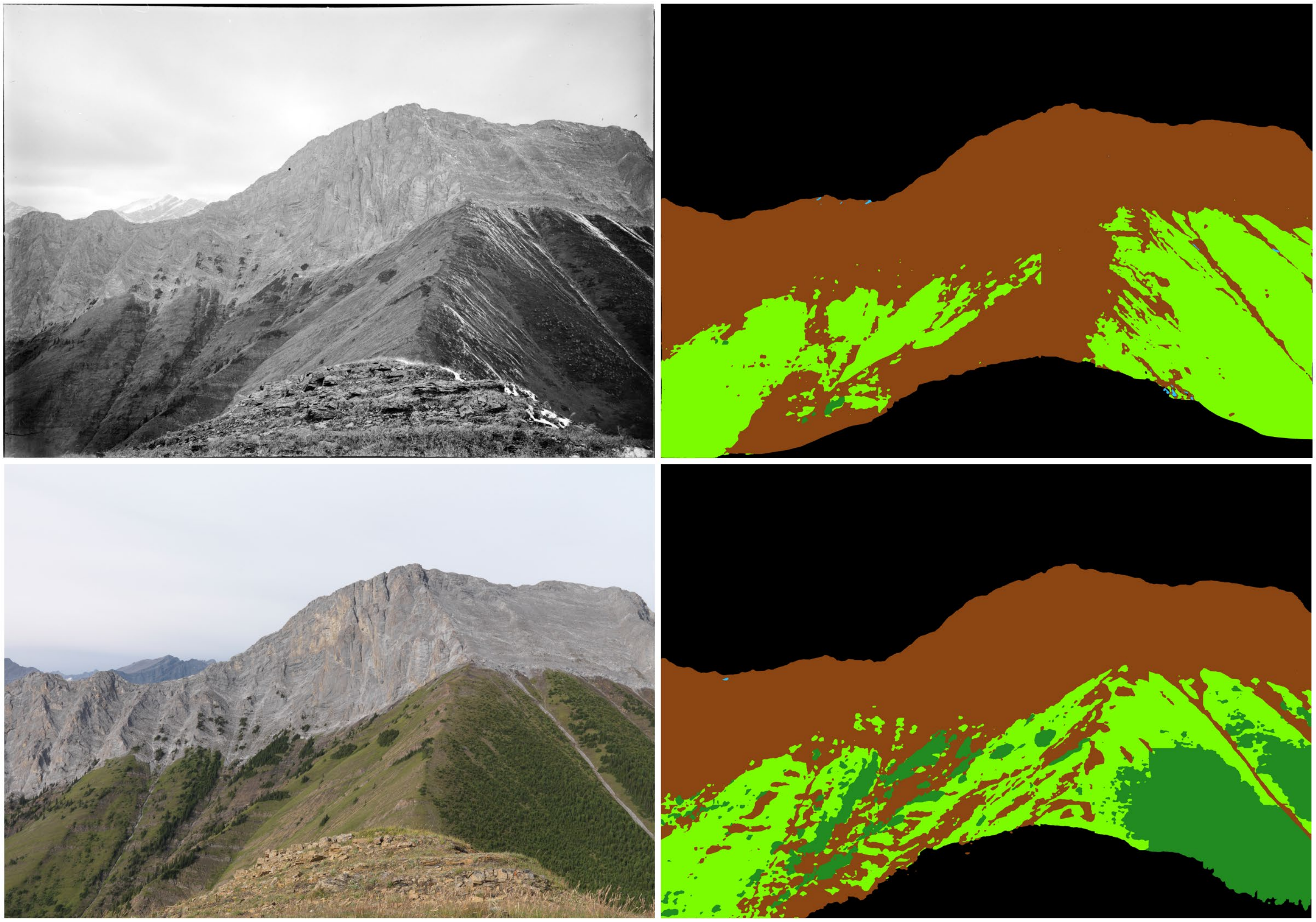
Wedge Mt East (1905 - 2009, Elevation: 2431m, Az: 118)

This photo set overlooks the *Îthorhan Oda Châgu* traditional travelling route, but the foreground obstructs any view of the valley bottom. Instead, this image set primarily looks on the eastern peak of the Wedge Mountain. On the historical image on the south slopes of the Wedge, burned sticks are clearly visible. This mountainside, despite being near a travelling route, was likely not regularly managed by Indigenous burning due to the evidence of large-scale burn seen there.



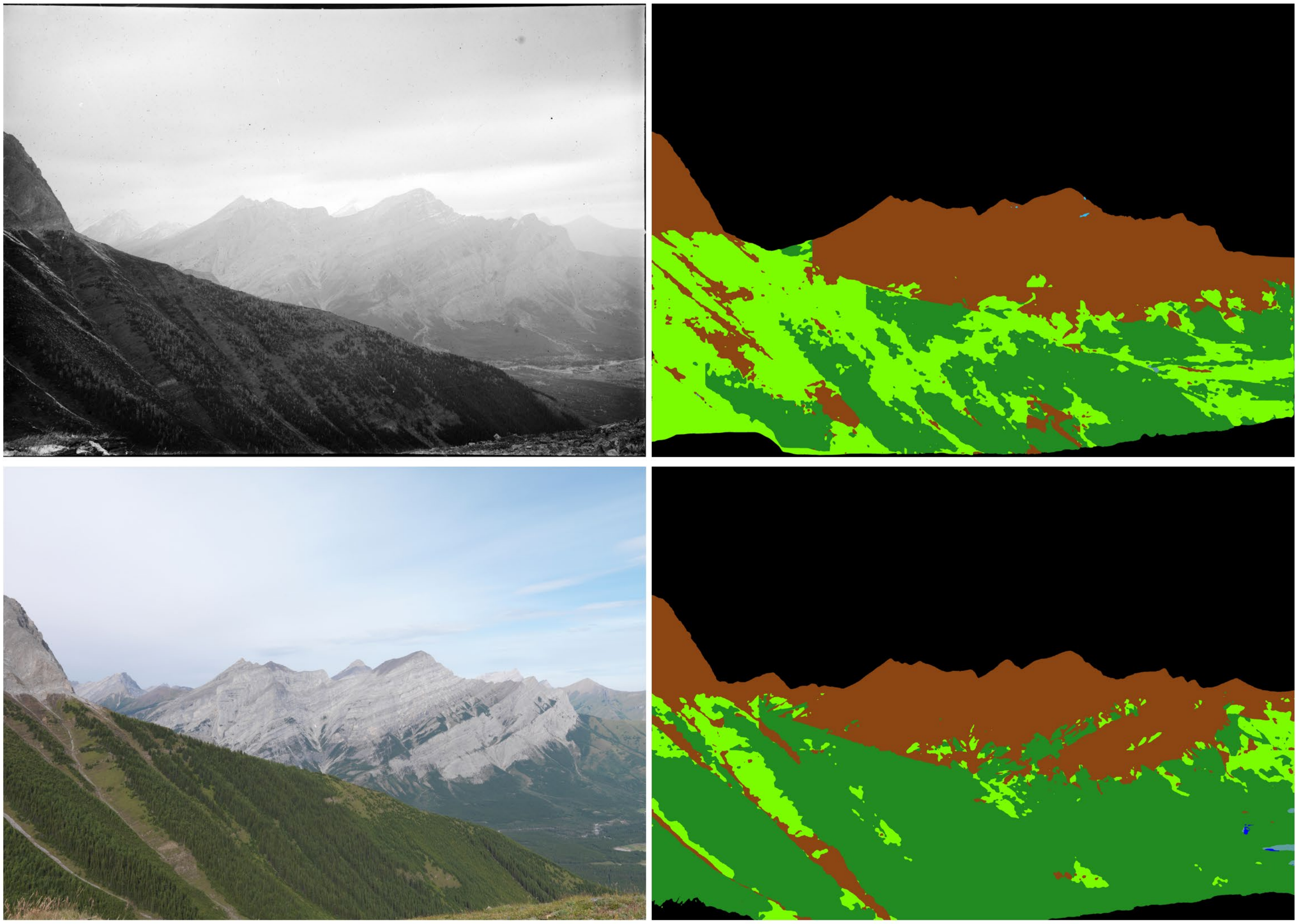
Wedge Mt East (1905 - 2009, Elevation: 2431m, Az: 176)

This image set, which looks south over the Wedge, shows more signs of the large-scale burn captured in the above image set. This area was likely not managed by Indigenous burning due to the elevation, the fact that it is not a traditional travelling route or campsite, and the evidence of large scale burn in the form of dead tree trunks in the right hand side of the image.



Wedge Mt East (1905 - 2009, Elevation: 2431m, Az: 236)

This image looks back toward the western peak of the Wedge. This image set does not capture any area that would have been managed by Indigenous burning, due to the high elevation and distance from any travelling route or traditional campsite.



Wedge Mt East (1905 - 2009, Elevation: 2431m, Az: 290)

In this right side of this image, the *Îthorhan Oda Châgu* traditional travel route is visible. There is no burnt sticks visible, indicating that this area was likely managed by Indigenous burning.