THESIS

PRIORITIZATION OF BEAVER (*CASTOR CANADENSIS*) REINTRODUCTION SITES WITHIN SEMI-ARID GRASSLAND RIVERS IN THE GREAT PLAINS

Submitted By

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ABSTRACT

PRIORITIZATION OF BEAVER (*CASTOR CANADENSIS*) REINTRODUCTION SITES WITHIN SEMI-ARID GRASSLAND RIVERS IN THE GREAT PLAINS

River restoration has become more of a concern with human influence on natural systems on the rise. Beaver provide a relatively inexpensive and natural opportunity to restore rivers to a pre-settlement state. Quantitative models can be used to better understand where beaver reintroduction should occur to maximize the odds of a reintroduced beaver population establishing an ideal habitat to thrive in. The Beaver Restoration Assessment Tool (BRAT) is a quantitative model that uses elevation, hydrology, and vegetation inputs to estimate the carrying capacity of beaver. The primary objective of this project is to develop baseline data that can inform river restoration of the Dale Creek watershed on Old Elk Ranch, a northern tributary to the Poudre River in Northern Colorado, although the methods used in this study are broadly applicable to other watersheds. This objective was addressed during two phases of work – the channel and riparian condition assessment during summer 2018 and the assessment of historic and contemporary potential beaver habitat using BRAT and field surveys during summer 2019. Through the utilization of BRAT, survey mapping, and remote sensing, I was further able to determine the best methods for estimating potential beaver population density, as well as the accuracy of the BRAT results relative to the field survey results.

Remote sensing provides a unique opportunity to increase the accuracy of BRAT through image classification and analysis. A national vegetation dataset produced by LANDFIRE, with a

spatial resolution of 10m, is not as spatially accurate as vegetation datasets derived though supervised classification of NAIP imagery with a 1m spatial resolution. Due to its coarser spatial resolution and being a product of generalized models and field data, LANDFIRE data missed important details in vegetation, such as riparian willows along valley bottoms and variabilities within the floodplain that are crucial for beaver survival. Furthermore, this increase in vegetation accuracy led to increasing the accuracy of BRAT predictions for beaver carrying capacity relative to ground-based mapping of past beaver occupation, allowing for better assessment of where beaver should be reintroduced.

Historical BRAT estimates revealed that zero and 1^{st} order channels had the highest carrying capacity of dams historically, accounting for 56% of reaches capable of the highest BRAT classification (15+ dams/km). According to the field survey and historical vs contemporary BRAT estimates, carrying capacity has been greatly reduced post human settlement, primarily in zero and 1^{st} order channel valleys where cattle were introduced. The 2018 condition assessment confirmed that while riparian vegetation was healthiest in higher-order channels, zero and 1^{st} order channels were heavily browsed by cattle, deer, and elk. Based on the distribution of riparian vegetation health, and carrying capacity estimates from BRAT and field surveys, stream restoration would be most effective on 0^{th} and 1^{st} order streams.

ACKNOWLEDGMENTS

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1. Introduction

1.1. Impacts of Beaver Engineering on Fluvial Environments

Channel incision has been a documented problem that has led to the degradation of ecosystems across the globe (Wang et al., 1997). Incision can result from diverse causes, including changes in base level, increased runoff, decreased sediment load, or changes in bed roughness. Incision can also results from overgrazing from cattle, deer, and elk, which is a problem in a large portion of northern Colorado and southern Wyoming. During the past two centuries, there has been a major change in land use across North America (Kanianska, 2016). Forests and wetlands have and continue to be removed and drained to make room for an ever-growing industry: agriculture. The increasing population of cattle is having a noticeable effect on the ecosystems in which they graze. Overgrazing has led to decreased riparian and floodplain vegetation, increased soil erosion and the incision of channels, and altered nutrient levels (Hubbard et al., 2004; Trimble and Mendel, 1995). It is only in recent years that the impacts of these activities have been mitigated through the implementation of rotating pastures and riparian and river restoration projects (Bernhardt et al., 2005; Swanson et al., 2015).

Beaver (Castor canadensis) have a unique influence on river morphology and riparian vegetation in that they cut trees down to create dams across portions of a river or stream. Beaver dams increase sediment storage within the channel and floodplain while decreasing stream power and flow velocity, diminishing the ability of flow to incise and erode the channel (Pollock et al., 2014). Furthermore, there is evidence that the presence of beaver engineering increases the entrapment of fine sediment, creating a positive feedback leading to more multithread channel planforms and valley bottoms with greater spatial heterogeneity and ability to retain water, sediment, and organic matter (Polvi and Wohl, 2012). Dam-building also has a profound influence on the annual stream discharge regime, decreases flow velocity, creates a channel with a stair-step gradient profile, and increases flood area inundation (Naiman et al., 1988). Beaver dams increase lateral connectivity by promoting the inundation of adjacent floodplains and uplands, increasing longitudinal discontinuities downstream (Burchsted et al., 2010). The fact that this transition into a more complex multi-thread network can be expedited in as little as a decade after re-introduction makes beaver a likely candidate for river restoration (Bouwes et al., 2016). Unfortunately, there has been a dramatic decrease in the North American beaver population in the past 150 years due to changes in land use and increased trapping (Naiman et al., 1988).

1.2. Changes in Beaver Populations

Biotic influences on an ecosystem's structure and complexity have been extensively studied for several decades. Changes in the North American beaver (*Castor canadensis*) population is one of the most evident examples of how human activities can alter an ecosystem. Presently, there are an estimated 6 to 12 million beaver in North America (Naiman et al., 1988), but prior to European settlement and the expansive fur trade, beaver were found in nearly all aquatic habitats from the arctic tundra to the deserts of northern Mexico, with an estimated population of 60-400 million individuals in North America (Naiman et al., 1988). As a result of the rapid decline in the beaver population since the 19th century, approximately 195,000 km^2-260,000 km^2 of US wetlands have dried up (Shaw and Fredine, 1971). Although beaver populations have increased and decreased during the past century, there is evidence that beaver populations are now slowly increasing due to increased environmental management and decreased trapping (Busher and Lyons, 1999). However, due to increasing elk and moose populations in northern Colorado, overgrazing of woody vegetation such as willows has inhibited beaver population growth (Polvi and Wohl, 2012).

1.3. Histosol Presence and Beaver Dams

A reliable way to identify past beaver occupation of river corridors is through analysis of the soil in areas of past or current fluvial activity. Studies of contemporary beaver dams indicate decreased flow velocities, increased sediment storage, and increased overbank flows that promote saturation of floodplain soils (Polvi and Wohl, 2012). Histosols form in organic soil materials that are completely saturated and in low lying areas, such as bogs or swamps where drainage is low, leading to high levels of decomposition (Stephens et al., 1984). Soil is generally classified as a histosol if half or more of the upper 80 cm of the unit is organic material (Survey Staff Soil, 1999). A dominant suborder of histosols is Saprists or wet histosols in which organic materials are well decomposed (Survey Staff Soil, 1999). The soil type haplosaprist, a subset of histosols, is largely found in areas of either seeps and springs or ponded water and overbank flows that are typically associated with beaver engineering (Johnston, 2014). This makes haplosaprists an excellent indicator for past beaver engineering in semi-arid environments, as these soils are commonly associated with springs/seeps and sites of historic beaver ponds (Stephens et al., 1984). Specifically, in semi-arid environments with moderate relief, such as the Dale Creek watershed, histosols are only found in association with beaver engineering or seeps and springs.

1.4. Restoration

Interest in stream restoration and recovery of degraded river ecosystems is currently a heavy focus throughout North America and is continuing to gain momentum (Bernhardt et al., 2005). With numerous restoration projects being implemented every year, resources and funding are always a concern during project design. The North American beaver presents an inexpensive and effective method for implementing river restoration if the location and conditions are correct. By better understanding factors that control where beaver thrive within a region, we can more effectively manage active beaver re-introduction projects that lead to a higher success rate for river restoration.

1.5. Objectives

This study will compare historic (pre-intensive land use approximately 1850 A.D.) and contemporary beaver-carrying capacities as estimated using field evidence of past beaver occupation and a numerical model, respectively. The methods used in this study are broadly applicable to other watersheds. The primary objectives of this study are to (i) determine the farthest upstream and downstream extent of past beaver ecosystem engineering within the Dale Creek watershed, (ii) assess the accuracy of the model results relative to field indicators, and (iii) develop baseline data that can inform river restoration on Old Elk Ranch. These objectives were addressed during two phases of work – the channel and riparian condition assessment during summer 2018 and the assessment of historic and contemporary potential beaver habitat using quantitative models and field surveys during summer 2019. I will first discuss a quantitative model used to predict beaver carrying capacity, as well as the factors that go into calculating those estimates. I will then describe the study site and field methods used in both the 2018 condition assessment and 2019 survey, along with the parameters used in the quantitative model and how I modified those parameters to increase estimation accuracy.

1.6. Beaver Restoration Assessment Tool

Knowing exactly where beaver can thrive is the first step toward a successful beaver reintroduction restoration project. Although beaver have been found to occupy many sections of a forested environment, beaver prefer low gradient (<6%) alluvial channels, without coarse or bedrock substrates, with minimal stream power (Mccomb et al., 1990; Pollock et al., 2003). The animals also have surprisingly simple requirements: they need a sustainable and reliable water source, as well as enough vegetation for food and building material (Macfarlane et al., 2017). Allen (1983) found that vegetation within 100 m of the channel was most commonly used as a resource by beaver.

One way to better understand the factors that influence the beaver population is through numeric modeling and estimation of beaver carrying capacity. A model developed at Utah State University known as the Beaver Restoration Assessment Tool (BRAT) is used to estimate beaver carrying capacity. BRAT incorporates watershed characteristics such as vegetation, elevation, peak and baseflow stream power, and river channel size into a single model to predict carrying capacity (Macfarlane et al., 2017). These estimations fall into one of five categories based on the number of dams per kilometer: *None*: 0 dams/km, *Rare*: 0-1 dams/km, *Occasional*: 1-4 dams/km, *Frequent*: 5-15 dams/km, and *Pervasive*: 15+ dams/km.

A primary advantage of BRAT is that it uses only publicly-available data sets and does not require any fieldwork as input to complete. These datasets include NHD (the National Hydrograph Database of streams), LANDFIRE (the national vegetation data layer), USGS base flow and peak-flow equations (StreamStats), and national DEMs produced by the USDA (Macfarlane et al., 2017). National datasets have the added benefit of being widely available and free to use for most purposes, but they may not be the best candidate for smaller, more localized studies due to the decreases in spatial resolution and over-simplification of fine details. Figure 1 demonstrates how datasets of various spatial resolutions compare. Hence, creating more spatially detailed inputs such as vegetation and precipitation layers may be useful.

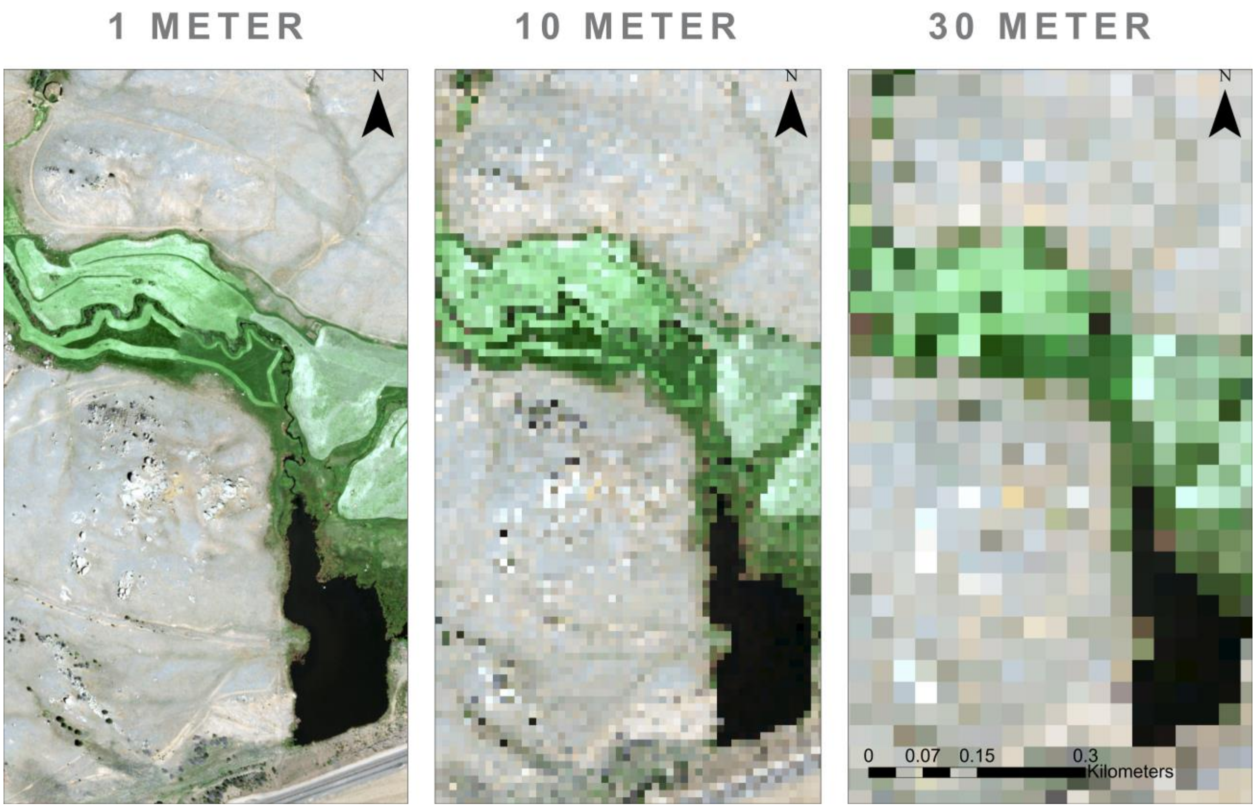


Figure 1: Spatial Resolution Comparison. From left to right: 1 meter spatial resolution aerial imagery, 10 meter spatial resolution of the same area, 30 meter spatial resolution of the same area.

Remote sensing opens up a new realm of possibilities when it comes to how scientists can use BRAT for beaver re-introduction site estimations. Through image classification, localized and spatially accurate vegetation and land-use layers can be created as inputs to BRAT.

1.7. Image Analysis

Image analysis and classification were used to help improve the spatial representation of riparian vegetation that forms a significant input for the BRAT model. Image classification is a technique that involves automatically grouping pixels to desired classes or themes that the user specifies (Lillesand et al., 2015). This is a popular method for looking at the land cover, vegetation, or geologic features/structures due to being able to automatically classify large areas (Lu and Weng, 2007). There are two main types of classification techniques, pixel-based and object-based image analysis. Object-based image analysis (OBIA) examines localized groups of pixels when assigning a pixel to a class (Lillesand et al., 2015). These segments take into account both the shape and the spectral response of a group of pixels, allowing for a more "real-world" classification that resembles actual objects on Earth's surface (Lillesand et al., 2015). Pixel-based image analysis uses spectral patterns to identify pixels with similar spectral reflectance or emissivity and groups them together in the same class (Lillesand et al., 2015).

Image analysis can be broken down further into two subtypes of classifications: supervised and unsupervised. Unsupervised classification techniques analyze unknown pixels in an image and cluster them into natural classes based on their spectral responses and/or shape (Lillesand et al., 2015). The analyst then observes the classes and assigns them names from prior knowledge of the field site (Lu and Weng, 2007). Supervised classifications are distinguished from unsupervised classifications in that, rather than clustering pixels into classes, a training dataset of known classes are specified prior to classification (Lillesand et al., 2015). Classes are then created using the training data by looking for similar properties of the training samples (Lillesand et al., 2015).

One widely used supervised technique is support vector machines (SVM). SVM classification is a form of supervised image classification and is a per-pixel, non-parametric technique (Lu and Weng, 2007). Unlike other popular classification algorithms such as maximum likelihood and minimum distance, SVM is non-parametric, meaning a Gaussian distribution doesn’t have to be assumed due to the absence of statistical calculations to determine classes (Lu and Weng, 2007). Instead, SVM creates linear hyperplanes that maximize the margin between classes (Chapelle et al., 1999). Because SVM does not rely on a Gaussian distribution, smaller, skewed training sets can be used for classifications (Lu and Weng, 2007).

2. Study Area

Dale Creek is located almost entirely on privately owned land southeast of Laramie, Wyoming, and west of I-80, extending south into Colorado. The Dale Creek watershed forms the northernmost part of the Cache la Poudre River watershed. Dale Creek has a drainage area of approximately 162 km^2, where 61% of this area was accessible. The site is at approximately 2500 m in elevation and ranges between 2100 and 2600 m. There is minimal road access (as seen below in Figure 2) throughout the ranch properties and access is permitted only on Old Elk Ranch property. The site is mainly a semi-arid grassland underlain primarily by Precambrian-age Sherman Granite, a coarse-grained hornblende-biotite granite (Ver Ploeg and McLaughlin, 2010). There are many outcroppings of this granite throughout the Dale Creek watershed (Figure 3B). Specifically, there are two main locations along the Dale Creek study site where these outcroppings create narrow canyons approximately 30-40 m wide and 1 km long (Figure 3E).

Areas surrounding Dale Creek, including terraces/floodplains, are poorly consolidated alluvial deposits ranging from clays to gravel. Within the Dale Creek catchment, the primary soil types consist of the Hapjack-Rogert-Amesmont complex for 3-25% slopes, Rogert-Rock Outcrop-Amesmont complex for 5-25% slopes, Rock outcrop-Rogert complex for 25-99% slopes, and Silas, gravelly substratum-Vensora loams for 0-6% slopes. Soils in the Dale Creek watershed primarily consist of Silas, gravelly substratum-Vensora loams, alluvium derived from granite which ranges from a loam to a stratified very gravelly loamy sand. Soils in the granitic canyons within the catchment are composed of the Rock outcrop-Rogert complex, primarily residuum weathered from granite that ranges from gravelly fine sandy loam to unweathered bedrock. Most of the grasslands and surrounding uplands are a combination of the Hapjack-Rogert-Amesmont complex, which is very similar to the Rock Outcrop-Rogert complex only at lower slopes, and the Rogert-Rock Outcrop-Amesmont complex, which is primarily residuum weathered from granite and ranges from a gravelly sandy loam to bedrock. The above soil units are the primary units of the catchment and make up approximately 85% of the field site (Survey Staff Soil, 1999). Haplosaprists are rare compared to the above soils and not typically found throughout the Dale Creek field site.

The dominant vegetation is grasses and shrubs, with willows and aspen (*Populus tremuloides*) as the primary riparian vegetation farther north. Farther south, the landscape becomes more mountainous with coniferous trees (*Pinus* spp., *Juniperus* spp.) as the dominant vegetation and willows (*Salix* spp.) as the primary riparian vegetation. The Dale Creek region has a mean annual temperature of 5°C, mean annual precipitation of 277 mm, and mean annual snowfall of 1262 mm (Young et al., 2017). This suggests predominantly a snowmelt flow regime, although there are occasional thunderstorms during the summer months. The Dale Creek catchment is located in a montane region (1750-2450 m) and is susceptible to high winds and natural fires caused by lightning because of the openness of the region (Veblen and Donnegan, 2005). Morphology of channels in the Dale Creek watershed varies from shallow swales and marshes with very fine, cohesive sediment substrate to step-pool channels with cobble and bedrock beds (Figure 3A). The 2-year peak estimated flow at the most downstream end of the study area is 3.2 cms (USGS StreamStats, 2016). The channels are single-threaded and either meandering or straight with a mean width-to-depth ratio of 3 and a median of 2

(Figure 3C) and range from zero to fourth Strahler stream order. For this project, a zero-order stream was defined as any portion of the drainage network that consists primarily of shallow, wetland swales where no clearly defined channel is present but where downslope flow is present at the surface. These reaches consist of mostly grasses, with sporadic multi-stemmed willows. See Appendix 2 for an example of a zero-order reach on the Old Elk Ranch.

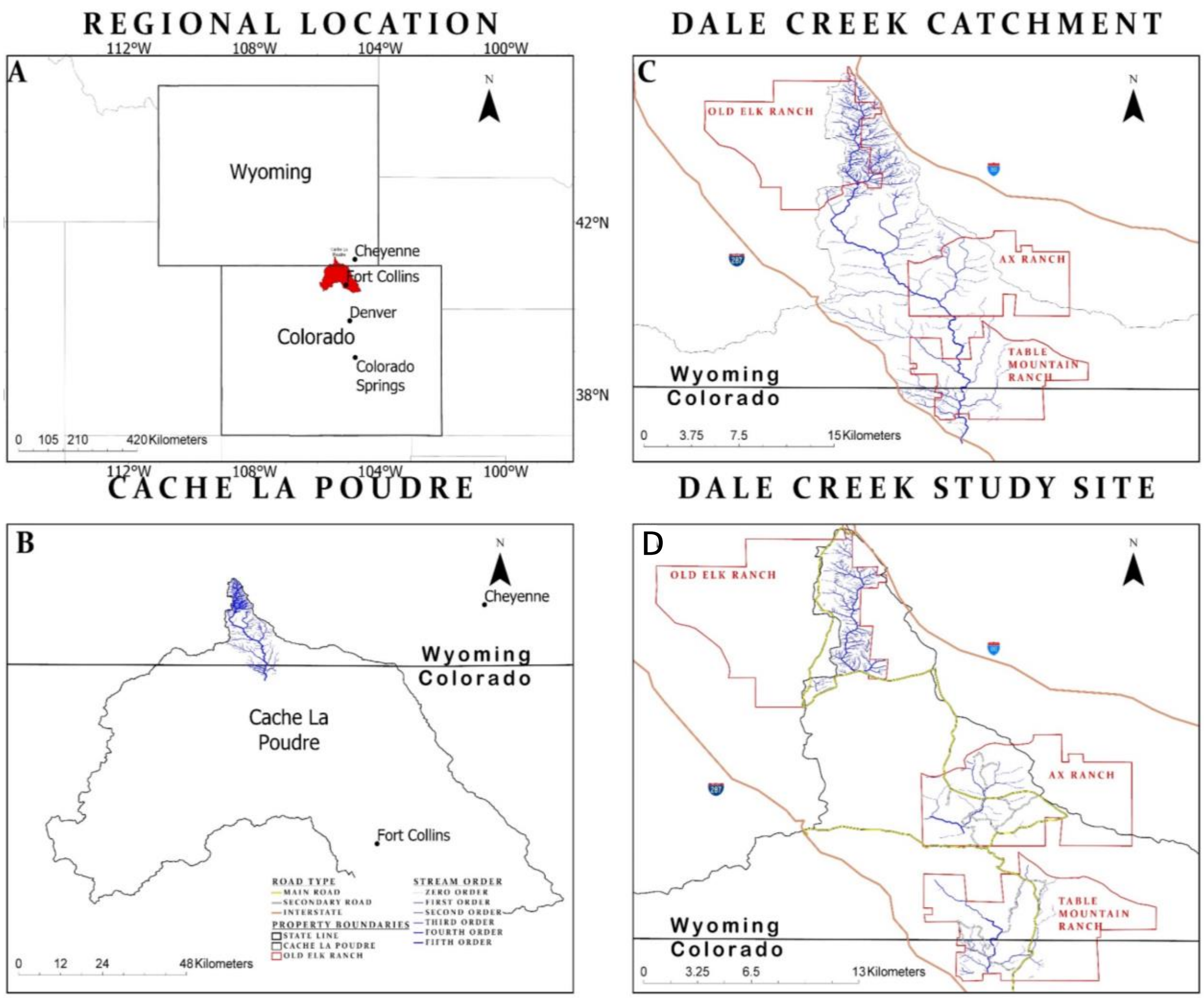


Figure 2: Dale Creek Study Site – Regional and Local Overview. A. Regional location of the Cache la Poudre watershed within the United States, Colorado, and Wyoming. B. Location of Dale Creek catchment within the Cache la Poudre watershed. C. Close-up view of the Dale Creek Catchment showing stream orders 1-3 in blue and 4-5 in red. D. Dale Creek study site within ranch property boundaries. Road access is seen throughout the site in yellow and white.

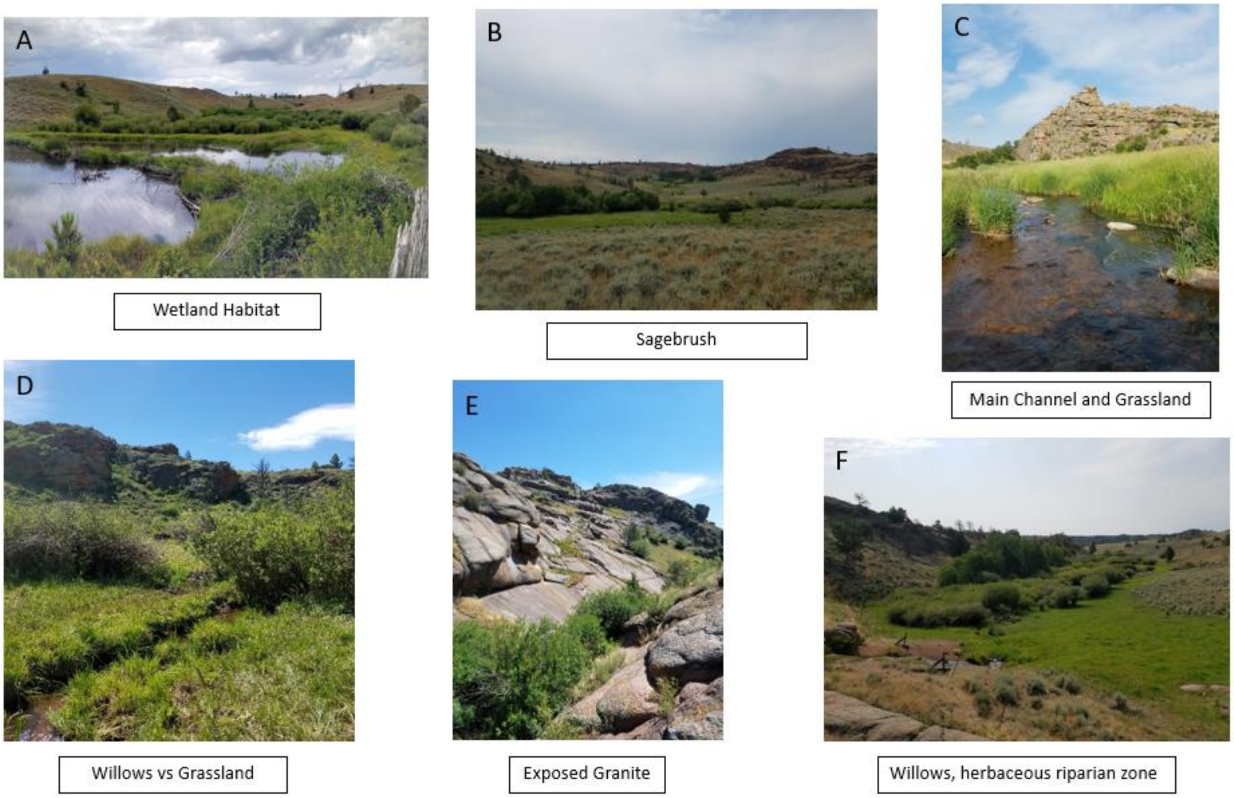


Figure 3: Dale Creek Field Site Overview. A. Wetland habitat containing abandoned beaver dams on the Old Elk Ranch property. B. Old Elk Ranch property with visible sagebrush and Sherman granite outcrops, and riparian willows. C. Dale Creek at the northern border of Table Mountain Ranch. D. The portion of XX Ranch that has pasture within riparian and floodplain zones of Dale Creek. E. Granitic canyon at the southernmost part of Old Elk Ranch. Narrow bedrock channel with thick riparian willows. F. Example of the primary condition of riparian willows along Dale Creek. Willows and grasses are in close proximity.

Pre-settlement of Colorado, approximately 1850, there was a healthy balance between predator and prey when wolves were present in this region. Riparian forests were healthy and thriving with the absence of cattle. There is physical evidence (old beaver dams and meadows and histosols) throughout the catchment of historic beaver activity, suggesting beaver once populated this region extensively. During the late 1800s, ranchers moved west into Wyoming and started what is known as the Range Cattle Boom (Rico, 1998). Overhunting of wolves by ranchers led to increased grazing by cattle, elk, and moose. This has led to overgrazing in many areas along Dale Creek, leading to complete degradation of riparian vegetation in some places and channel incision up to 2 meters. Much of the riparian zone of Dale Creek has been browsed and is under great stress, as indicated by dying and grazed willow and trampled banks. Some efforts have been made to cut back on grazing with the removal of cattle within specific pastures, but much of the riparian vegetation remains in a degraded state. In the early fall of 2018, a beaver reintroduction project was initiated along four segments of Dale Creek. Prior to reintroduction, only a single active beaver segment was present throughout the watershed. As of October 2019, there are 3 active beaver segments with dam densities greater than 15 dams/km channel.

3. Field Work and Modeling

3.1. Dale Creek Condition Assessment

During the spring of 2018, I assessed channel and riparian conditions in the Dale Creek watershed. The landowners, who own approximately 162 km^2 of ranch land known as the Old Elk Ranch in southern Wyoming/northern Colorado, plan to reduce degradation of Dale Creek through a multitude of methods, including revegetation, reduction of cattle, and beaver reintroduction. Throughout the summer of 2018, I conducted a spatially extensive assessment along the entirety of Dale Creek on Old Elk Ranch property. The assessment included approximately 280 sample sites across 35 reach segments that were divided by geographic and geologic characteristics. Each reach location was randomly chosen based on stream order, where the upstream and downstream points were chosen to sufficiently represent that stream segment. Sites were 100 meters apart, starting at the most upstream point of the reach and walking downstream.

At each site, valley and channel characteristics were recorded. These characteristics included dimensional data such as valley width, channel width and depth, and riparian width; floodplain and riparian information including types of vegetation, habitat, connectivity and longitudinal continuity. An important note about riparian vegetation collection is that it was spatially simplified during observation. For example, if only a portion of a sample reach contained willow trees while the remainder is grass, the entire reach is still classified as having willow trees. This may lead to an over-estimation of willows in a sample reach. Channel properties collected included planform, bedform, substrate, bank properties, and classifying flow regime as ephemeral, intermittent, or perennial. In addition to physical characteristics collected, the overall health of the riparian zone was recorded. If there was a culvert, spring, or channel head at a site, the coordinates and characteristics were recorded. See Appendix 1.1 for the report outline of the data collected at each site and for a description of terminology.

3.2. Mapping of Beaver Dams

During the summer of 2019, I extensively mapped both active and abandoned beaver dams throughout the Dale Creek watershed. A total of 135 sample reaches at varying lengths were randomly selected based on geographic location and Strahler stream order. Sample reaches of 133 m long were selected in 10 randomly assigned segments of zero-order channels on each of the three properties. This process was also followed with 1st, 2nd, 3rd, and 4th order channels, where sample reaches were 125 m, 70 m, 50 m, and 50 m, respectively. Sample reach lengths were chosen to ensure at least 5% of the total length of zero-order channels and 10% of the total length of 1st, 2nd, 3rd, and 4th order channels were sampled in the Dale Creek Watershed. The Old Elk property did not have any 2nd order channels due to its location within the Dale Creek watershed. Five sample reaches were inaccessible due to physical/wildlife restrictions.

When identifying abandoned beaver dams, numerous indicators were used to distinguish man-made features, such as stock ponds or fence rows, from beaver habitat. The first and most obvious signs observed were gradually elevated ridges or hills located either within the floodplain or the channel itself. Being on either an active or once-active ranch, it was important to distinguish stock ponds from beaver dams. Stock ponds are typically much more prominent and larger compared to beaver dams, but some dams were so large that other indicators were needed. Chewed wood was seen among many willow trees and cottonwoods, either within dams or in nearby forest. In places where beaver activity occurred so long ago that these indicators were gone, other indicators such as vegetation and channel meanders were used. Characteristic wetland species growing on infilled beaver ponds and ridges of multi-stemmed willow trees growing on berms formed by abandoned dams suggest pooling of water caused by dams. Ponded water will also cause the formation of histosols that can be identified if no vegetation is present. Histosols resulting from beaver ecosystems were differentiated from histosols resulting from seeps and springs primarily by the depth of the black soil. Histosols created from ponding water are typically thicker, whereas histosols resulting from seeps and springs are primarily shallow. This coupled with the presence of any seeps or springs nearby helped determine the source of the histosol. If no other indicators are present, the channel geomorphology can be an indicator that a dam was once present. Beaver dams are typically constructed of more stable material compared to surrounding areas, which can cause channels to meander around them rather than cut through them.

Each sample reach and the surrounding areas were observed for evidence of either past or current beaver presence. Both abandoned and active beaver dams were documented with GPS coordinates, as well as how the dam was identified, if it was active or abandoned, and whether histosols were present. Only dams within the sample reach were mapped; areas just up or downstream were only used as an aid to determine if the stream segment could support beaver habitat and were not mapped. Active beaver habitat (dams, lodges, and ponded water) within a sample reach was also mapped by documenting any active dams present.

3.3. BRAT Overview and Inputs

BRAT is a numerical model that uses four main inputs to estimate beaver dam density along stream networks: digital elevation model (DEM), drainage network, vegetation cover, and regional regression equations for base and peak flow. Each of these datasets were clipped to only cover the Dale Creek drainage area. DEM and vegetation inputs with different spatial resolutions are utilized independently from each other on a per stream segment basis and do not require resampling. DEM attributes are independent from vegetation attributes for each stream segment.

3.3.1. Digital Elevation Model (DEM)

The DEM is a critical component of BRAT. Elevation data for the network provide BRAT with valley geometry, including valley bottom width, slope, and drainage area. The DEM used in this study was acquired through the USGS National Elevation Dataset (NED). This is a national dataset with approximately 10 m spatial resolution and was last updated in 2017 (USGS, 2017). The DEM spatial resolution has a limited impact on the BRAT results. As seen below in Figure 4, when using a 30 meter DEM, we see a maximum of 9% of total stream length changing when compared with contemporary BRAT results with a 10 meter DEM. This contrasts with historical BRAT output, where 5% of total stream length changed.

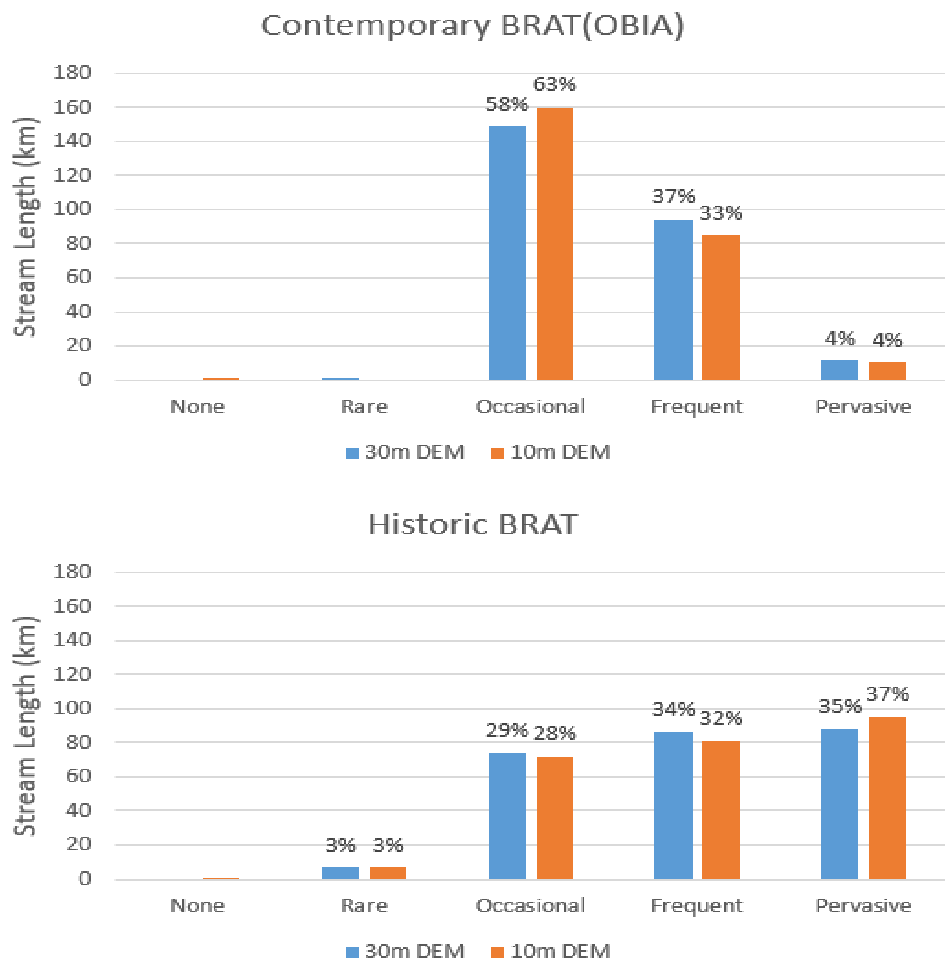


Figure 4. BRAT Sensitivity to DEM Spatial Resolution. BRAT was ran multiple times with OBIA vegetation, with all inputs held constant except for the DEM, where a national 10 meter DEM and national 30 meter DEM was used. The top graph represents differences in BRAT results when using OBIA vegetation. The bottom graph represents differences in BRAT when using LANDFIRE historic vegetation. Values may not sum to 100 due to rounding.

3.3.2. Drainage Network

BRAT requires stream network layers, including stream flowlines, water bodies, and area features classes to run successfully. The drainage network dataset was acquired through the USGS National Hydrograph Dataset (NHD) and was last updated in March of 2019. Each of the above layers were segmented into 300 m lengths and then simplified to only include the desired streams: perennial and intermittent, excluding ephemeral streams, which typically do not provide suitable beaver habitat (Macfarlane et al., 2017).

3.3.3. Vegetation Layer

Beaver rely on certain types of vegetation as a food source and for building materials for use in their dams. Knowing the vegetation cover around the stream helps estimate how many beaver dams could be built. This vegetation is divided into how suitable it is for beaver, as seen below in Figure 5. The control layer was provided through LANDFIRE, a national program aimed at wildfire management. This dataset has a spatial resolution of 30 m and was last updated in 2016 (U.S. Department of Interior, 2017b).

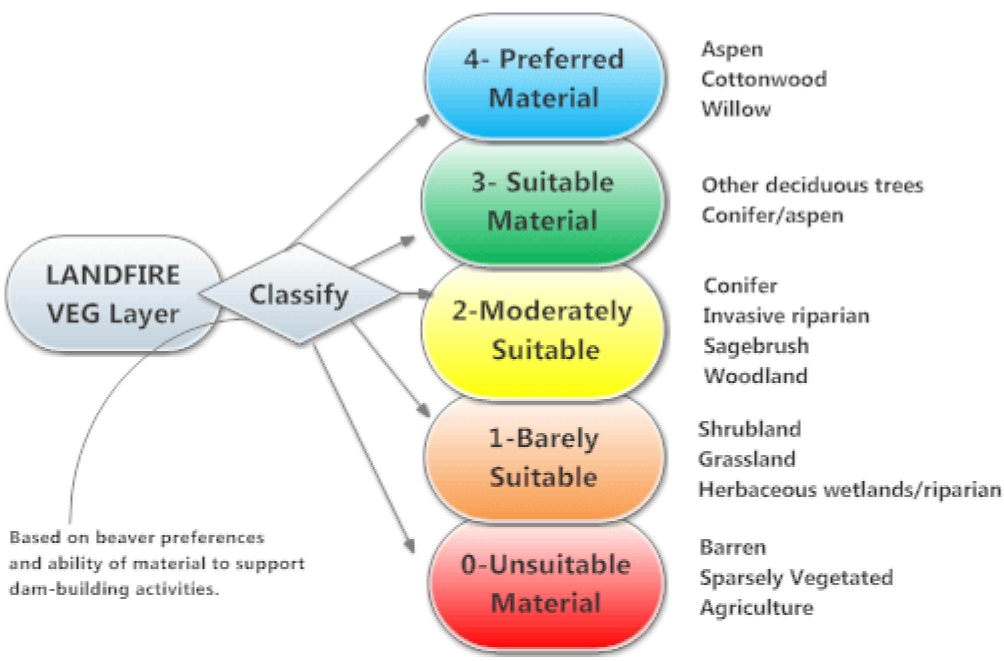


Figure 5: A breakdown of vegetation species used for specific classes to determine beaver preference. With prior knowledge of Dale Creek, the above vegetation species were used to create the training dataset used in both the OBIA SVM and pixel-based SVM classifications (BRAT-Riverscapes, Utah State University).

While BRAT is useful for contemporary analysis, it also provides insight into past beaver populations. To do so, I used a historic vegetation dataset that estimated vegetation and land cover layers prior to intensive human alteration, and then used this dataset to produce additional BRAT model runs. This estimated vegetation layer was produced by LANDFIRE and is a national dataset containing 30 m spatial resolution. It is composed of the current environmental properties, as well as an approximation of the historical disturbance regimes (U.S. Department of Interior, 2017a). This dataset can be referred to as a Biophysical setting and was derived from models that describe vegetation, geography, biophysical characteristics, succession stages, and disturbance regimes. These models were based on extensive field data, satellite imagery, and biophysical gradient layers (U.S. Department of Interior, 2017a). The primary difference between this and contemporary vegetation is the presence of preferred material within the entire riparian zone in historical vegetation. See Appendix 3 for an example of LANDFIRE existing and historical vegetation layers.

3.3.4. Regional Regression Equations

The regional regression equations are used to determine both base and peak stream power and vary depending on the characteristics of the study watershed. The equations were gathered from the USGS StreamStats database. Dale Creek was delineated from an outlet point at 40.96243, -105.36738 to gather specific drainage characteristics used in the peak and base flow equations. Due to StreamStats being used solely for the calculation of peak and base annual flow, variations in the outlet point are not as important as an outlet point that is representative of the interest area.

3.4. Modification of BRAT Inputs

Vegetation layers were acquired using three different techniques. The control layer was provided through LANDFIRE, which has a spatial resolution of 30 m and was last updated in 2016 (U.S. Department of Interior, 2017b). The next vegetation layer was created using SVM pixel-based supervised classification on a principal component analysis (PCA) of National Agriculture Imagery Program (NAIP) imagery from 2017. NAIP has a spatial resolution of 1 m and is flown every two years (National Geospatial Data Asset (NGDA) NAIP Imagery 2015) . I created a training dataset from the PCA according to beaver preferences of material, as seen in Figure 5. The third vegetation layer was created using SVM OBIA supervised classification on the same PCA NAIP imagery. The same training dataset used in the SVM pixel-based classification was used in the SVM OBIA. Several segment attributes were used in determining classes, including the color, mean raster digital number, standard deviation, number of pixels, compactness, and rectangularity. Accuracy of each classification was assessed using visual interpretation of NAIP imagery along with prior knowledge of the field site.

4. Results

4.1. 2018 Dale Creek Condition Assessment

When evaluating the overall health of the Dale Creek Watershed, I used three main indicators: the health of the riparian vegetation, the presence of wetlands within the floodplain, and the flow regime. The data collected in the assessment were divided according to the reach stream order to determine how the above factors vary across different stream orders. See Appendix 1.2 for a detailed breakdown of the above factors according to stream order.

When looking at the impact of grazing on the watershed, the riparian health status was a primary indicator. Across all 280 sites, 22% were browsed and only 11% healthy, while two-thirds of the sites were stressed. Generally, riparian vegetation was healthiest in higher-order channels, but 4^{th} order streams only had 19% of sites considered healthy. Overall, the riparian vegetation is considered to be stressed. For a description of terminology, reference Appendix 1.1.

The largest portion of a river valley and an indicator of river health is the floodplain. The main characteristic examined in the floodplain was wetland presence. The historical dam survey suggests an abundance of wetlands throughout the Dale Creek catchment in the past, but only 17% of sites had an abundance of wetlands, which were primarily along the 0^{th} and 1^{st} order channels. Higher-order channels had a significant decrease in the number of wetlands, with 4^{th} order channels having no wetlands in the floodplain.

Flow regime gives an idea of where most of the flow is occurring within a watershed. At Dale Creek, 79% of sites had perennial flow and 12% were ephemeral, primarily 0^{th} and 1^{st}

order streams. Zero and 1st order streams also made up most of the intermittent streams, while almost all of the 2nd, 3rd, and 4th order streams were perennial.

4.2. Image Classified Vegetation Layers vs National Layers

There were mixed results between the three different vegetation layers, depending on the classification method employed. Based on ground observations and confusion matrices, the vegetation layer derived from LANDFIRE showed the poorest classification of vegetation at Dale Creek compared to the pixel-based and OBIA SVM (Table 1, Figure 6). The pixel-based SVM classification did a much better job of distinguishing the vegetation than LANDFIRE. However, the classification technique with the highest performance and accuracy of classifying vegetation was the OBIA SVM method (Table 1, Figure 6). Table 1 illustrates the overall accuracy measurements of each method from confusion matrices, where accuracy relates to how well vegetation was classified correctly according to BRAT vegetation class. Table 1 shows an increase in accuracy by 12% from LANDFIRE to pixel-based and 30% from LANDFIRE to OBIA. The complete confusion matrices can be found in Appendix 4. Based on the field observations from the 2018 condition assessment and the field survey, as well as satellite imagery and confusion matrices, the OBIA vegetation layer best represents the vegetation communities across the Dale Creek watershed when compared to the LANDFIRE and pixel-based vegetation layers.

Table 1. Confusion Matrix Accuracy for LANDFIRE, pixel-based, and OBIA vegetation Classification Summary.

	LANDFIRE	Pixel-Based	OBIA
Vegetation Accuracy	52%	64%	82%

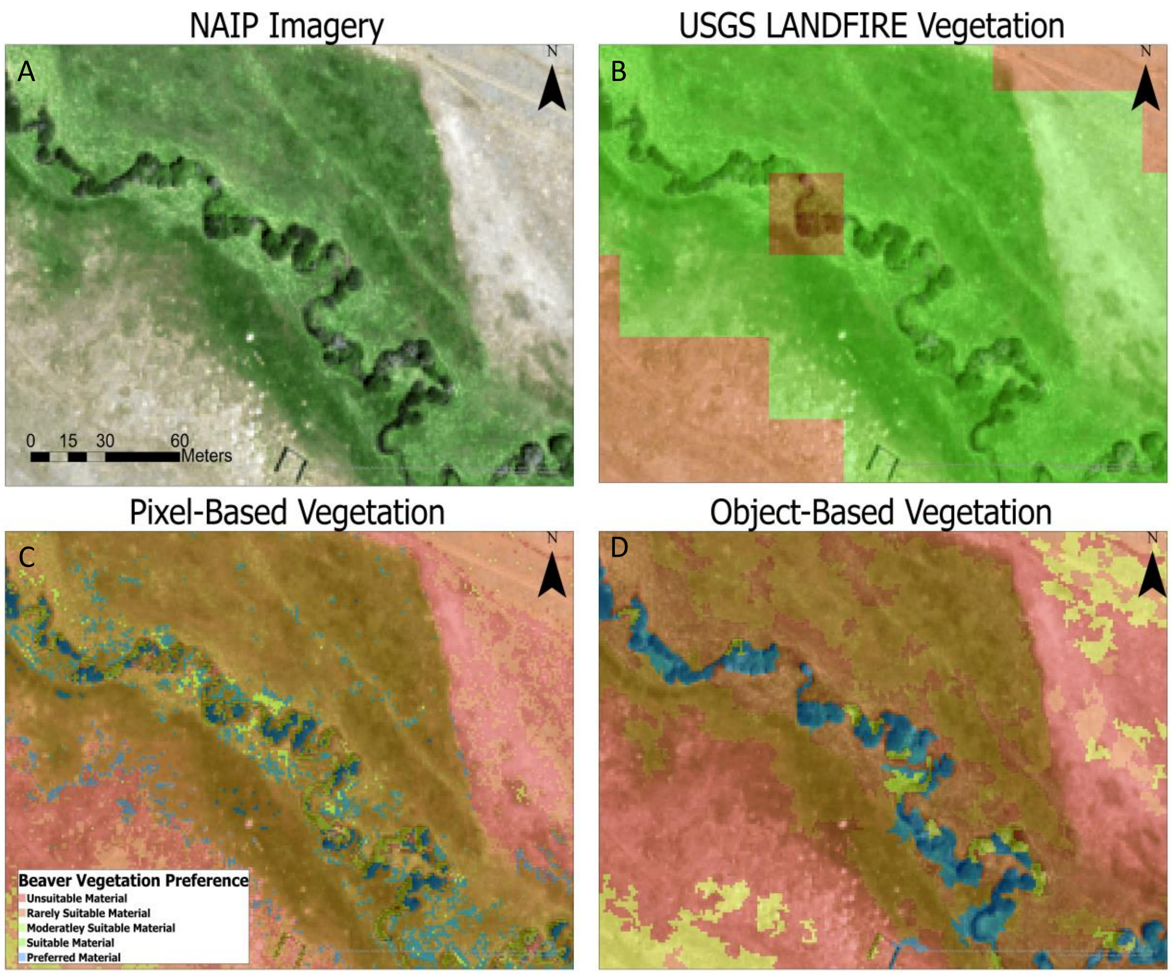


Figure 6: A. NAIP imagery from 2017. B. LANDFIRE vegetation layer from the USGS. C. Vegetation layer created using the pixel-based SVM classification approach. D. Vegetation layer created using the OBIA SVM classification approach.

Below in Figure 7, proportions of riparian vegetation within each BRAT vegetation class is shown. Proportions are compared between LANDFIRE, pixel-based, OBIA, and ground observations from the 2018 field assessment. An important consideration for Figure 7 is the difference between how data were collected for the image analysis methods compared to ground observations. Image analysis allows for high spatial resolution, depicting a single willow tree from a grassy floodplain. This contrasts with the 2018 riparian assessment, which, as mentioned earlier, was simplified during collection. Comparing the three vegetation layers to the 2018 ground observations, the OBIA has the highest proportion (12%) of preferred material compared to LANDFIRE (5%) and pixel-based (7%) vegetation. According to ground-based observations, 81% of sampled segments were preferred material for beavers, comprised mainly of willows.

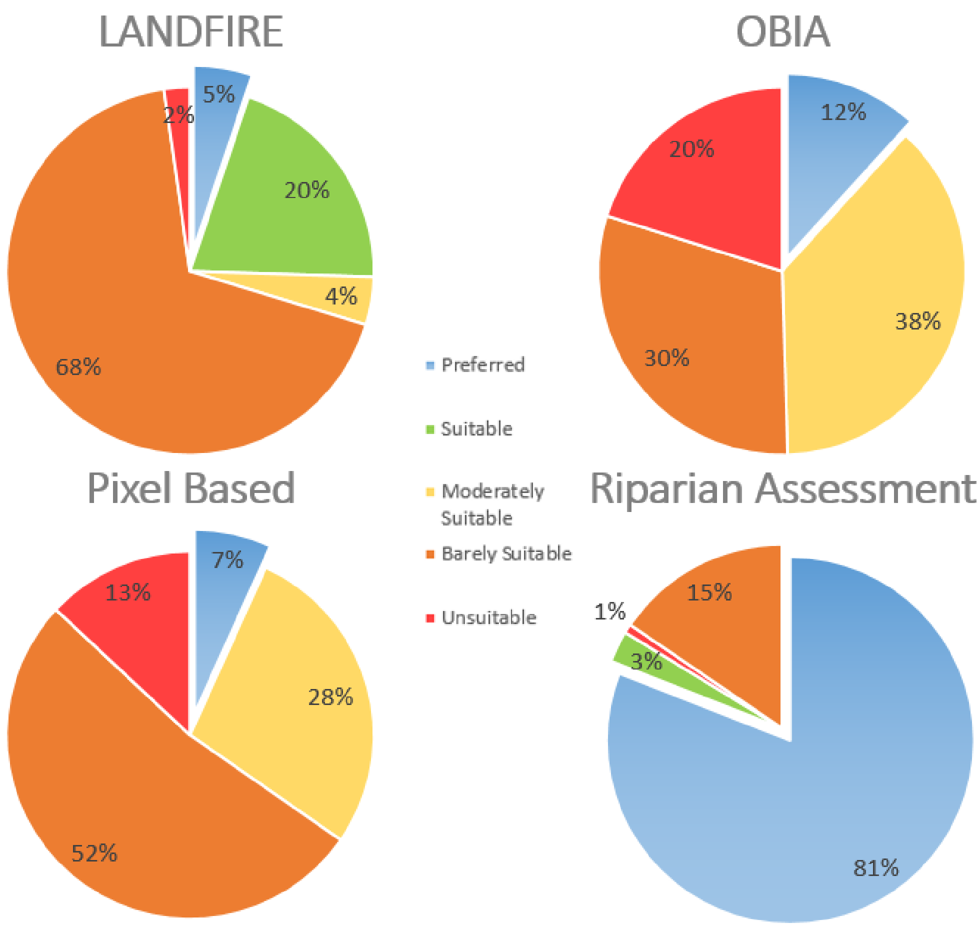


Figure 7: The proportions of vegetation in reference to how suitable the material is for beaver use compared between LANDFIRE, OBIA, Pixel image classification, and ground observations from the 2018 field assessment.

Due to the variations in vegetation layers, there were varying degrees of change between the three iterations of BRAT with different sources of the vegetation input. The BRAT results from the LANDFIRE contemporary vegetation input produced the most diverse group of results, with 54% of the segments in Dale Creek falling in the *occasional* category, 34% in the *frequent* category, 9% in the *rare* category, and 3% as *pervasive* (Figure 6). The pixel-based vegetation input produced estimates with 81% in the *occasional* category and 19% in the *frequent* category. The OBIA vegetation input produced results with 63% of the segments in Dale Creek falling in the *occasional* category, 33% in the *frequent* category, and 4% as *pervasive*. The historic BRAT results have 3% being *rare* segments, 28% *occasional,* and 69% between *frequent* and *pervasive.* The 2019 survey is similar to historical estimates with the exception of 18% of segments having no dams.

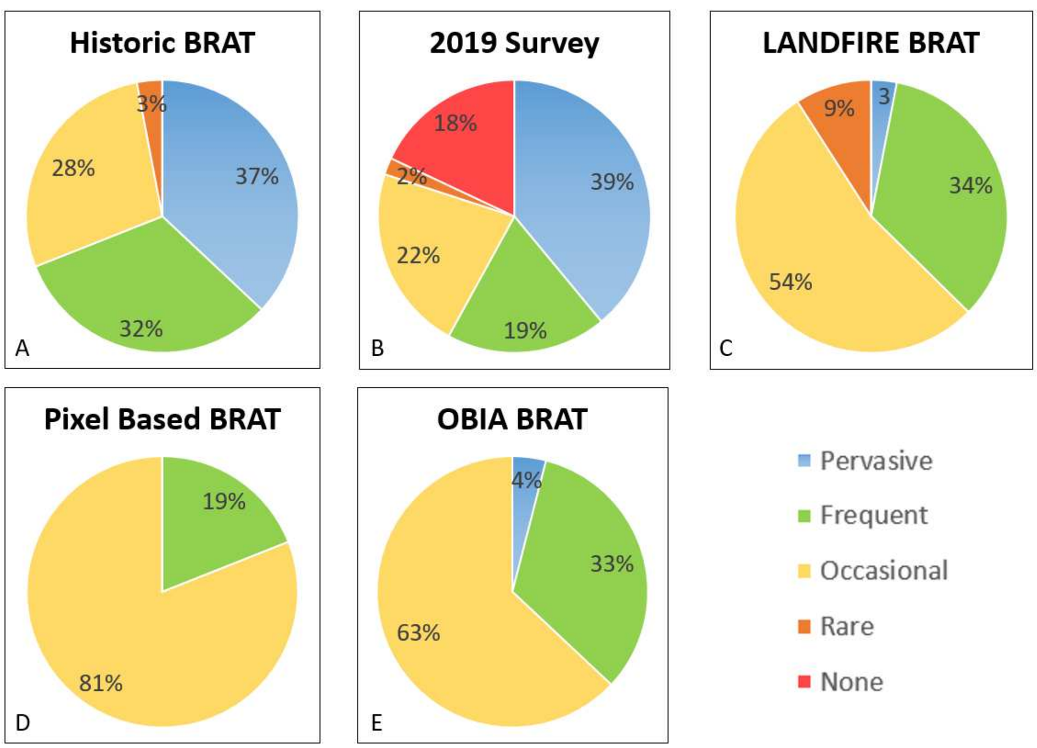
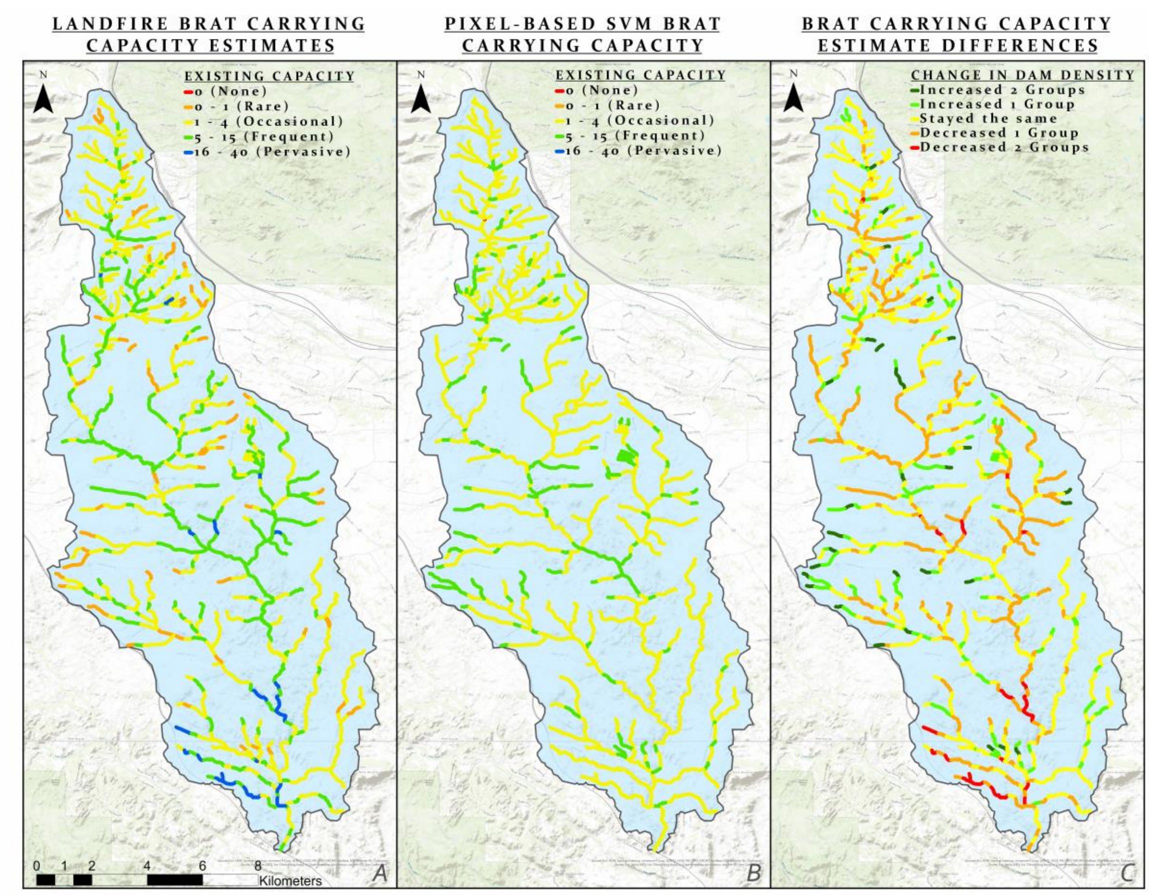


Figure 8: Proportions of Beaver Dam Densities for Each Iteration of BRAT. A. Proportions of dam density groups in Dale Creek after running BRAT with LANDFIRE pre-settlement dataset. B. Proportions of dam density groups in Dale Creek from mapped abandoned dams within sample reaches. C. Proportions of dam density groups in Dale Creek after running BRAT with contemporary LANDFIRE dataset. D. Proportions of dam density groups in Dale Creek after running BRAT with pixel-based SVM dataset. E. Proportions of dam density groups in Dale Creek after running BRAT with OBIA SVM dataset.

By taking the difference of each segment's dam per density category, we can visualize the changes between LANDFIRE and the respective SVM method in the BRAT results. Figure 9 shows the changes in BRAT results based on how many categories a segment changed from model to model. For example, if a segment was *pervasive* in LANDFIRE results and *occasional* in the OBIA results, then that segment would have decreased by two groups.



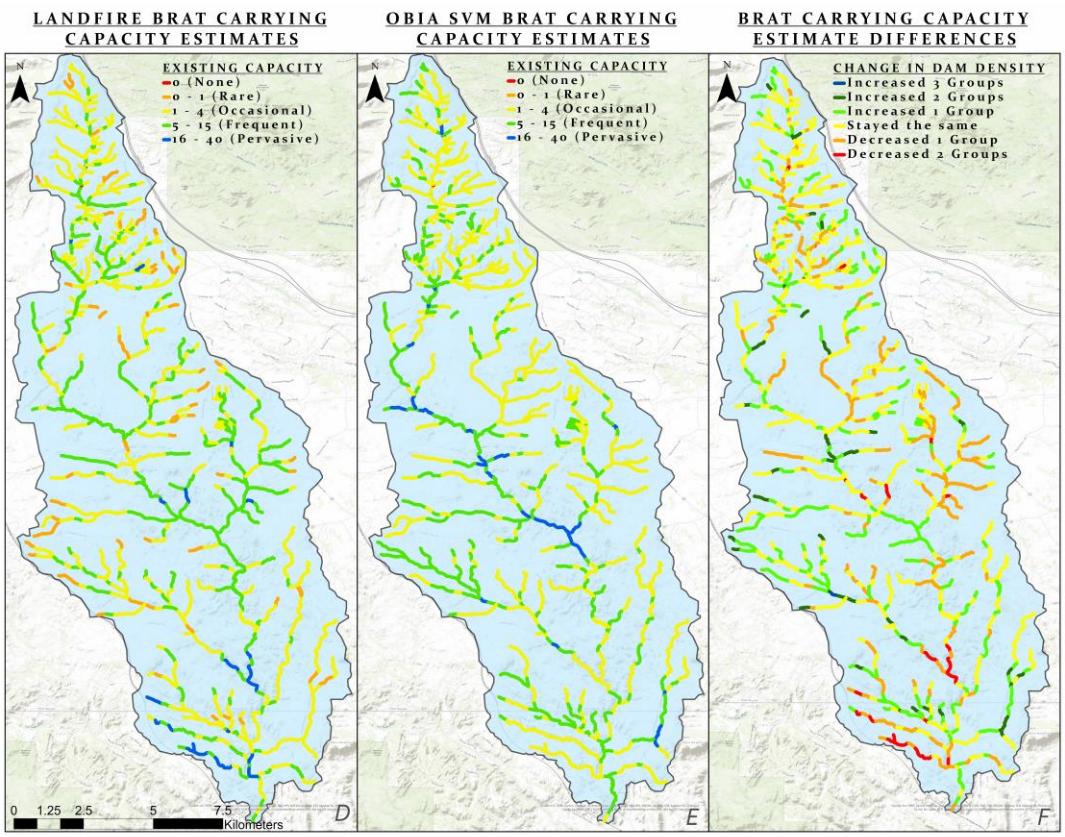


Figure 9: A & D. BRAT results using LANDFIRE vegetation input. B. BRAT results using pixel-based vegetation input. C. Change in dam densities between LANDFIRE and pixel-based BRAT results. E. BRAT results using OBIA vegetation input. F. Change in dam densities between LANDFIRE and OBIA BRAT results.

Figure 9A and 9F are represented below in Figure 10, where the distributions of changes in BRAT class are shown with respect to total stream length. We can see that when looking at the pixel-based changes from LANDFIRE, the majority of Dale Creek either stayed the same or decreased in BRAT class. This contrasts with the OBIA vs LANDFIRE, where the majority either stayed the same or increased in BRAT class.

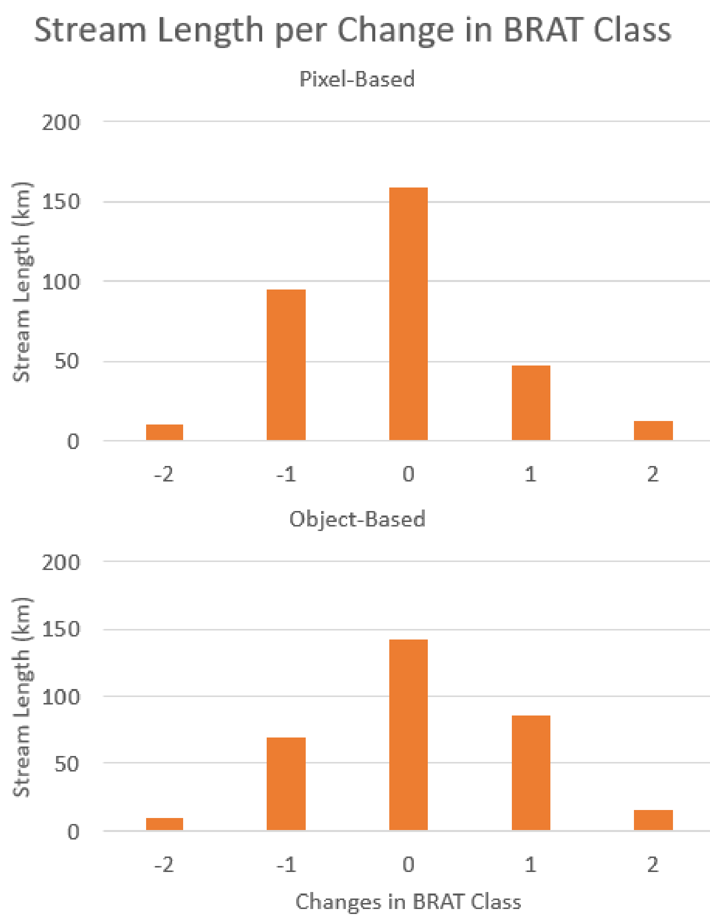


Figure 10. Total stream length that changed relative to LANDFIRE BRAT results. The top figure summarizes the differences in LANDFIRE and pixel-Based BRAT results and the bottom figure summarizes the differences in LANDFIRE and OBIA BRAT results, where the total stream length per magnitude of change is shown.

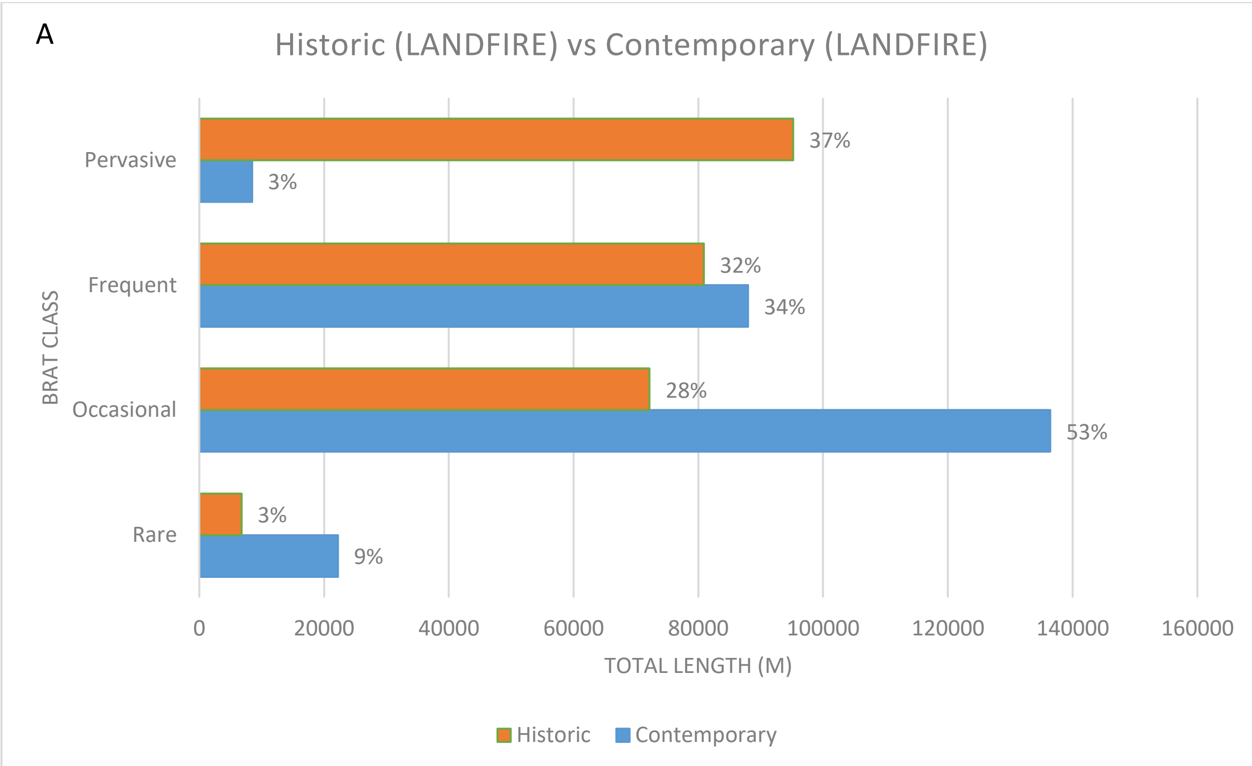
The differences in the BRAT results when using different vegetation input data are easily observed. Capacity both increased and decreased in different stream segments throughout Dale Creek, as well as remaining constant in the majority of segments. Changes ranged over +/- two groups when comparing the LANDFIRE results to the pixel-based and OBIA results (Table 2). The pixel-based classification resulted in an increase in 19% of the network and a decrease in 32%. The OBIA resulted in a 32% increase and a decrease in 25% of the network.

Table 2
Percent change from LANDFIRE per change in BRAT classification.

Change in BRAT Classification	*Percent Change from LANDFIRE*	
# of Classes	Pixel-Based	OBIA
+ 2	4%	5%
+ 1	15%	27%
0	49%	44%
- 1	29%	22%
- 2	3%	3%

4.3. BRAT Estimates of Historic vs Contemporary Beaver Carrying Capacity

Two comparisons were quantitatively analyzed to determine what differences existed between BRAT's historical and contemporary estimates. The first comparison involved LANDFIRE vegetation data for both the historic and contemporary carrying capacity estimates. Figure 11A illustrates the LANDFIRE historic and LANDFIRE contemporary proportions of each BRAT class within the Dale Creek Watershed BRAT results. The second comparison involved LANDFIRE vegetation data for the historic estimates and OBIA for the contemporary estimates. Figure 11B illustrates the LANDFIRE historic and OBIA contemporary proportions of each BRAT class within the Dale Creek Watershed BRAT results. Currently, the majority (87% and 96%) of channels in Dale Creek fall either within the *occasional* or *frequent* BRAT category for both sets of vegetation data, compared to pre-settlement conditions with 37% of channels within the *pervasive* category and only about 60% within the *occasional* and *frequent* categories. Both datasets agree that currently, there is a much smaller potential for a high density of beaver dams compared to pre-settlement. See Appendix 3 for a map view of historic and contemporary vegetation.


A
Historic (LANDFIRE) vs Contemporary (LANDFIRE)
Pervasive
Frequent
Occasional
Rare
BRAT CLASS
37%
3%
32%
34%
28%
53%
3%
9%
0
20000
40000
60000
80000
100000
120000
140000
160000
TOTAL LENGTH (M)
Historic
Contemporary

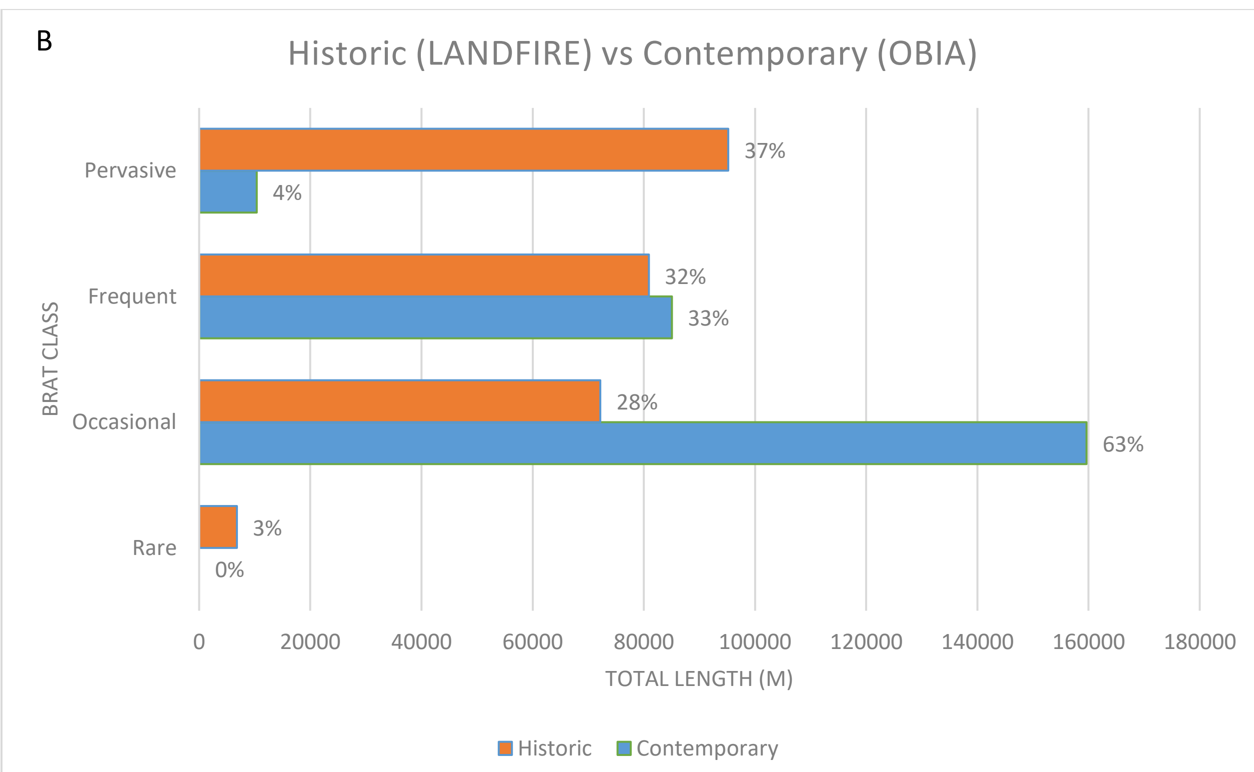

B
Historic (LANDFIRE) vs Contemporary (OBIA)
Pervasive
Frequent
Occasional
Rare
BRAT CLASS
37%
4%
32%
33%
28%
63%
3%
0%
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
TOTAL LENGTH (M)
Historic
Contemporary

Figure 11: A. A comparison of the proportion of each BRAT class within the watershed between historic and contemporary BRAT results using LANDFIRE vegetation data for both. B. A comparison of the proportion of each BRAT class within the watershed between historic and contemporary BRAT results using LANDFIRE vegetation data for historical estimates and OBIA for contemporary estimates.

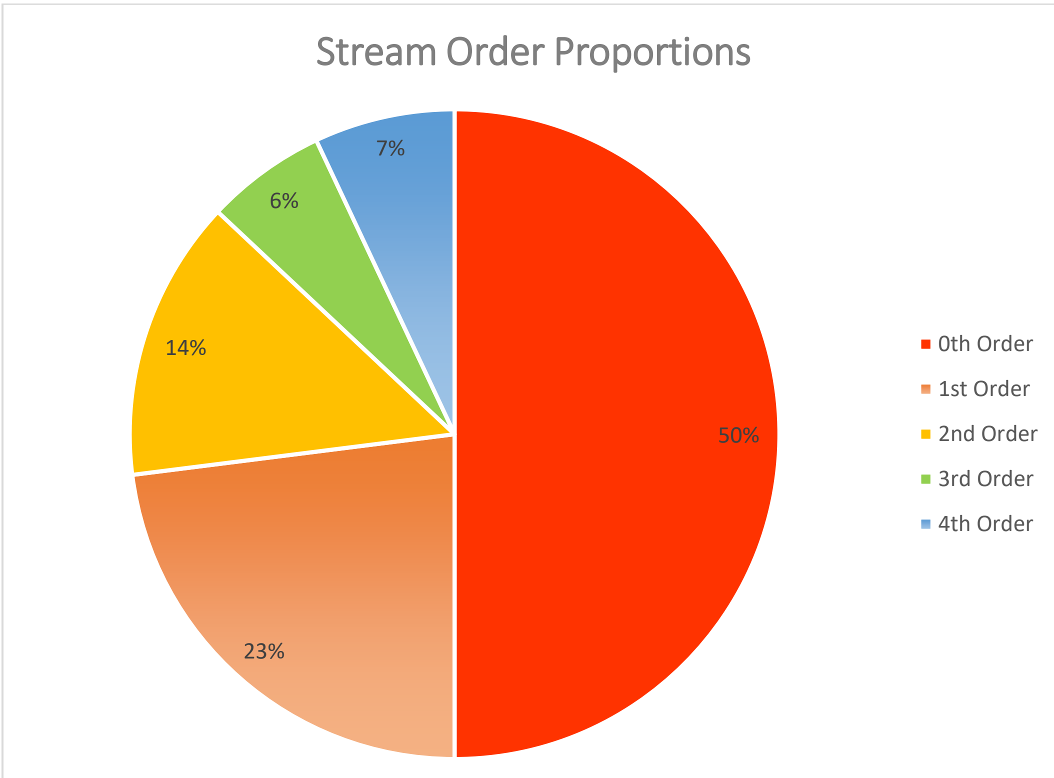


Figure 12: The proportions of total stream length within each stream order throughout the Dale Creek watershed.

Figure 12 illustrates the proportions of total stream length within each stream order throughout the Dale Creek watershed. Zero order and 1st order channels comprise nearly 75% of all streams, whereas only 7% of streams are 4th order channels. Tables 3 and 4 illustrate the proportion of the total length of all streams within each stream order, listed with respect to each BRAT category. Currently, both datasets agree that channels in the *pervasive* category are either found above zero-order channels, which make up roughly 50% of all segments within the

Dale Creek watershed, or make up less than 5% of each stream order. This is compared to the historical data, where pervasive streams comprise 22% of zero-order stream and at least 43% of all other stream orders. The lower limit in which a high density of dams (15+/km) can be built pre-settlement is along zero order channels, compared to contemporary estimates, in which most pervasive streams are only along 4th order channels. Historically, most 2nd, 3rd, and 4th order streams were pervasive, whereas both datasets estimate these orders are primarily occasional streams.

Table 3

LANDFIRE Historic and Contemporary Vegetation. Proportion of the total length of all streams within each stream order, listed with respect to each BRAT category.

	Historic				*Contemporary*			
Order	Rare	Occasional	Frequent	Pervasive	Rare	Occasional	Frequent	Pervasive
0th	5%	42%	31%	22%	12%	57%	28%	3%
1st	1%	18%	38%	43%	6%	51%	38%	5%
2nd	1%	7%	34%	58%	6%	48%	43%	3%
3rd	0%	4%	45%	51%	4%	56%	40%	0%
4th	1%	3%	19%	77%	5%	45%	46%	4%

Table 4
LANDFIRE Historic and OBIA Contemporary Vegetation. Proportion of the total length of all streams within each stream order, listed with respect to each BRAT category.

	Historic				*Contemporary*			
Order	Rare	Occasional	Frequent	Pervasive	Rare	Occasional	Frequent	Pervasive
0th	5%	42%	31%	22%	0%	70%	29%	1%
1st	1%	18%	38%	43%	0%	64%	33%	3%
2nd	1%	7%	34%	58%	0%	60%	34%	6%
3rd	0%	4%	45%	51%	0%	36%	60%	4%
4th	1%	3%	19%	77%	0%	33%	46%	21%

4.4. The Accuracy of BRAT vs Field Mapping

By comparing the historic BRAT results to the field survey conducted in the summer of 2019, we can further assess the accuracy of the pre-settlement land cover from LANDFIRE. Table 5 illustrates the historic and field survey proportions of each BRAT class within the Dale Creek Watershed BRAT results. The field survey resulted in many more reaches that had no dams compared to the BRAT results. As a result, the survey also had a more even distribution across the categories of BRAT compared to the BRAT results. Not including "*None*," the distributions between classes are similar when comparing the survey to BRAT. There were also several cases during the field survey where histosols were present without any evidence of past beavers.

Table 5
Historic and field survey proportions of each BRAT class.

BRAT Class	*Field Survey*	*Historic*
None	18%	0%
Rare	2%	3%
Occasional	22%	28%
Frequent	19%	32%
Pervasive	39%	37%

Table 6 lists the differences between the proportions of the total length of all streams within each stream order, listed with respect to each BRAT category of the 135 sample reaches. The main difference is that the survey once again includes many sample reaches that have no evidence of dams, whereas the BRAT results show every sample reach having at least one dam. The survey also shows a significantly higher percentage of pervasive streams within each stream order, with a lower limit of zero order streams at 17%. The BRAT results show pervasive streams are nearly absent in all order but 4^{th} order.

Table 6
Proportions of stream length per BRAT class within each stream order.

Order	*Field Survey*					*Historic BRAT*				
	None	Rare	Occasional	Frequent	Pervasive	None	Rare	Occasional	Frequent	Pervasive
0th	40%	3%	26%	14%	17%	0%	0%	70%	29%	1%
1st	10%	3%	30%	24%	33%	0%	0%	64%	33%	3%
2nd	8%	0%	19%	19%	54%	0%	0%	60%	34%	6%
3rd	0%	0%	10%	25%	65%	0%	0%	36%	60%	4%
4th	0%	0%	0%	10%	90%	0%	0%	33%	46%	21%

5. Discussion

5.1. 2018 Dale Creek Condition Assessment

Based on the distribution of riparian vegetation health, wetlands, and flow regime, stream restoration could improve channel and riparian condition throughout the watershed. On the one hand, BRAT modeling suggests that 0^{th} and 1^{st} order streams exhibit the greatest proportional drop in channel segments categorized as pervasive from historic to contemporary conditions. On the other hand, these low-order streams retain the most abundant wetlands and may therefore have the greatest potential for restoration of wetland habitat. These sections of the watershed are the primary location for cattle grazing throughout the past 150 years, leading to the highest rates of grazing and erosion. They also have the greatest abundance of wetlands and the greatest potential for wetland habitat. However, even Dale Creek's higher-order riparian vegetation is in a stressed state; showing signs of dying willows, exposed roots, and bare soil along the channel. The broad, relatively low-gradient valley bottoms present along many segments of higher order channels also suggest that floodplain wetlands were abundant when beaver populations were higher in the watershed. At locations where cattle are not permitted, there is still an abundance of deer and elk. A significant number of deer and elk were spotted along higher-order channels in willow groves, grazing on willows and grassy vegetation within the floodplain. Due to most of the watershed exhibiting perennial flow, the ability for Dale Creek to sustain beaver populations is high.

5.2. Image Classified Vegetation Layers vs National Layers

Vegetation is one of the primary variables in determining whether a beaver can survive within a given reach, and hence, it makes sense that there would be varying degrees of change between BRAT with different vegetation input layers. The LANDFIRE vegetation classification is much less spatially detailed given its 30-m spatial resolution. It fails to capture finer detail such as a line of willow along the main channel. It also incorrectly classified much of the riparian zone as deciduous trees other than willow and aspen, which are not found anywhere along Dale Creek, as well as incorrectly classifying upland vegetation. The pixel-based classification captured more detail throughout the entire image due to NAIP imagery having 1-m spatial resolution. The pixel-based classification began to detect lines of willow and smaller changes in upland vegetation but failed to recognize continuous groups and therefore contained a lot of noise in the classification, resulting in only a 12% increase in accuracy. The OBIA classification performed the best at Dale Creek. The ability to segment pixels into groups based on objects allowed for a more accurate classification with minimal noise. Willows and aspens were correctly identified, and the upland vegetation was more accurately classified. There was a 30% increase in the accuracy of OBIA classified vegetation compared to the LANDFIRE dataset.

These differences in vegetation were evident in the BRAT results, and most evidently where the LANDFIRE vegetation was incorrect. The ability to distinguish fine details allowed BRAT categorization to incorporate lines of willows and aspens, a beaver's most preferred source for food and building material. In locations where this vegetation was corrected from LANDFIRE, there was an increase of at least one dam density category. Similarly, where upland vegetation was correctly classified as sagebrush rather than brushland, dam density increased as well. Decreases in carrying capacity were also observed where the floodplain grasslands were corrected from deciduous trees to herbaceous grasslands.

When comparing BRAT results produced with pixel-based and OBIA vegetation, OBIA BRAT results had a higher percentage of the total network increasing its carrying capacity. Similarly, OBIA caused a lower percentage of the total network to experience a decrease in carrying capacity. This is most likely due to the increased classification of the aspen and willow in the OBIA, an area where the pixel-based classification did not perform well. OBIA has the added benefit over pixel-based of looking at overall size and shape of clusters. Beaver are not interested in small patches of preferred vegetation, rendering much of the fine variations seen in the pixel-based vegetation irrelevant. Further evidence supporting OBIA being the most accurate comes from seeing how well it agrees with ground-based vegetation observations compared to LANDFIRE and pixel-based vegetation. OBIA had the highest proportion of preferred material compared to the other methods and agreed with ground observations the closest, but OBIA was still nearly 70% less than ground observations. I interpret this to reflect how the in situ data were collected: Simplification of vegetation in ground observations results in an increased percentage of preferred material. Accounting for this over-estimation, along with satellite imagery, OBIA provides the highest accuracy of vegetation at Dale Creek.

5.3. Historic vs Contemporary Activity

The historical and contemporary BRAT model runs demonstrate that the maximum carrying capacity is much lower today than it was pre-settlement. This change is best seen when comparing the proportion of stream length within each BRAT class. Currently, both datasets estimate the entirety of Dale Creek can support beaver, although nearly two-thirds can only support 1-4 dams per kilometer and only 3-4% can support 15+ dams per kilometer. This can be compared to historic capacities, where 37% of Dale Creek could support 15+ dams per kilometer. This change is primarily a result of changing land use, either from cattle grazing or human development. Many portions of Dale Creek experienced heavy cattle grazing throughout the past 150 years. As a result of this constant trampling and grazing of the riparian zones from cattle, as well as deer and elk, beaver lost too much of their habitat to survive the Wyoming winters and either died or left. This is further supported by data in Tables 3 and 4 and the 2018 condition assessment, which shows that 0^{th} order streams have been impacted the most in terms of riparian health and beaver carrying capacity.

5.4. The Accuracy of BRAT vs Field Mapping

The main difference between the field survey and BRAT was that the survey accounts for many sample reaches that have no evidence of dams, whereas the BRAT results show every sample reach having at least one dam. Field surveys indicated 18% more reaches without dams than the BRAT simulation. This difference could reflect the destruction of evidence of past beaver presence and the fact that BRAT estimates the maximum carrying capacity. Many of the types of evidence used when mapping dams are dynamic and can change or be destroyed in unstable environments. The introduction of cattle may have resulted in the trampling of evidence used to identify dams. Most likely there were dams present at some of these sites, but they were no longer visible at the surface. To counter this, there were also cases where histosols were present without evidence of past beavers. This was common in locations where seeps and springs saturated the soil over many years, producing organic-rich soil similar to that from ponding water behind dams. Another factor to consider is that BRAT estimates to maximum capacity and very rarely do populations exist at the maximum capacity. This, coupled with destroyed evidence, means that some reaches classified as none in the survey may have had dams, while some reaches may have had the potential for dams, but did not have any. Accounting for these two potential errors, 0^{th} and 1^{st} order channels had the highest carrying capacity of dams historically, but according to the field survey, dams existed throughout all stream orders.

6. Conclusion

Interest in stream restoration and recovery of these degrading systems is currently a heavy focus throughout North America and is continuing to gain momentum (Bernhardt et al., 2005). With numerous restoration projects being implemented every year, resources and funding are always a concern during project design. The North American beaver presents a relatively inexpensive and effective method for implementing river restoration due to their ability to naturally maintain dams and adapt to environmental changes I have explored three methods with which to prioritize beaver reintroduction for the purposes of river restoration: a riparian condition assessment, quantitative modeling (BRAT), and conducting a field survey of past beaver occupation.

The initial condition assessment was developed to gain insight into the health of the Dale Creek watershed. It involved recording physical characteristics across the watershed, including riparian health, the health of the floodplain, and the flow regime. The areas with the most damage due to grazing were 0^{th} and 1^{st} order streams, but Dale Creek as a whole was stressed at all orders by recent cattle grazing and continuing grazing by deer and elk. Due to the distribution of grazing, the primary ways to help restore the stressed riparian vegetation would be to i) either entirely remove cattle or substitute cattle for a species less destructive of riparian vegetation, such as bison, and ii) to fence off stressed areas to limit deer and elk access.

There were two primary analyses using BRAT carrying capacity estimates: historic vs contemporary and historic vs a field survey. When comparing the historic and contemporary estimates, the overwhelming conclusion was that beaver carrying capacity is significantly lower today. Most of this decrease was seen within 0^{th} and 1^{st} order channels, agreeing with the conclusions from the condition assessment. The comparison between BRAT with historic LANDFIRE data and the field survey tested the accuracy of the historic BRAT estimates. While most estimates were correct, based on the survey, there was a drastic underestimation by BRAT of segments with no dams. This is most likely due to destroyed evidence and the possibility that these segments were not at full capacity. This analysis also produced evidence that suggests 0^{th} and 1^{st} order streams had the highest capacity for beavers.

To aid in the historic vs contemporary analysis, the contemporary vegetation layer was modified using image classification. Some of the benefits to BRAT may also be some of the disadvantages. National datasets are great in that they are nationally available no matter where the field site is located, but that large coverage comes at the price of spatial resolution. While there are ways to balance the two more effectively, they tend to be methods that require increased funding, time, or both. Image classification is a cheap and readily available method that can be used on any image to produce classified layers of interest.

When I implemented supervised classification to replace datasets used as input for BRAT, there was a significant change in the results. Increased spatial resolution resulted in a 30% increase in the accuracy of vegetation that was present. Also, the ability to verify classification using knowledge of the field site ensures an accurate representation of the field site. After comparing the BRAT results across several vegetation inputs, more accurate vegetation meant more accurate estimates of carrying capacity. This accuracy was strongest when using the OBIA classification, agreeing with literature that OBIA is a more robust and accurate technique to classify imagery (Lillesand et al., 2015).

Dale Creek has a high potential to support a beaver population, as seen from the above analyses. Both BRAT and the field survey indicate a previously high density of beaver throughout the watershed. The condition assessment, along with BRAT results, shows the highest potential within 0^{th} and 1^{st} order streams, which are the locations that have been damaged the most. Introducing beaver in these locations, along with a change in livestock and fencing riparian zones, would provide the best habitat for survival, as well as the largest potential for the restoration of Dale Creek.

7. Future Work

BRAT is a useful tool for quick estimation of historical and current beaver carrying capacities for a given watershed and using image analysis greatly improves the quality of the vegetation input. If funding allows it, using LiDAR data to produce a DEM of the target watershed would give spatial resolutions much greater than 10 m. This could then be used to delineate the watershed and calculate more accurate flow accumulation and drainage area, leading to higher accuracy in BRAT. LiDAR could also aid in the mapping of vegetation and abandoned beaver dams through multiple returns. Incorporating a precipitation raster into the regional regression equations would improve peak and base flow calculations, further improving BRAT estimations. When working with watersheds analogous to Dale Creek, a supervised classification is simple and takes little time to process. Detailed image analysis improves the accuracy of BRAT beyond what LANDFIRE is capable of producing. I recommend using manual image analysis for watersheds under 500 km^2 or those that have little variability in vegetation to minimize processing time. However, when working on restoration projects over much larger areas, such as a river basin or statewide, other approaches may be more efficient. Variability in vegetation across classes may be too complex over larger areas, making classification difficult. LANDFIRE vegetation can be used to identify potentially high value watersheds, with image analysis then used on those areas to get a more accurate representation of watersheds with high potential. When planning to restore beaver, it is important to consider both historical and contemporary vegetation. Following additional validation, historical vegetation indicates what is possible and can be used to identify river segments of high potential for beaver reintroduction, while contemporary vegetation identifies areas where beaver can currently survive.

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Appendices

1.1 2018 Field Assessment Form

Dale Creek Watershed Assesment			
Date:	Site # :	° ' " N	° ' " N

Valley		Floodplain		Riparian	
Width:	m	Connectivity:	High/Moderate/Low	Vegetation:	herbs/willow/decid/conifer
Geology:		Habitat Diversity:	Diverse/Mod/Homogenous	Condition:	browsed/stressed/healthy
		Wetlands:	Abundant/Sparse/Absent	Width:	m
				Long. Cont.	Cont/Discont/Sparse

Channel

Planform		Bedform		Substrate		
Straight	Meandering	Step-pool	Plane-bed	L. Boulder	Cobble	Sand
Anastomosing	Braided	Pool-riffle	Dune-ripple	S. Boulder	Pebble	Silt-Clay

Bank Condition		Width/Depth Ratio		Flow Regime		
Angle:		Width:	m	Perennial	Intermittent	Ephemeral
Exposure:		Depth:	m			
Substrate:						

Culverts		Channel Head		Springs	
Angle:		Coordinates:	° ' " N	Coordinates:	° ' " N
Exposure:		Causal Process:	Surface/Subsurface		
Substrate:					

Description of Terminology

Floodplain

Floodplain Connectivity: The lateral hydrologic connectivity between a stream channel and floodplain (Beck et al., 2019).

High – Experiences frequent and extensive inundation
Moderate – Small levels of channel incision with less frequent inundation
Low – Areas with high channel incision, almost no inundation

Floodplain Habitat Diversity: The variability in habitat throughout the floodplain.

Diverse – Showing 3+ vegetation types
Moderate – Showing 2-3 vegetation types
Homogenous – Showing only one vegetation type

Floodplain Wetlands: The presence of continuously inundated habitat throughout the floodplain.

Abundant – The entire floodplain is inundated
Sparse – Parts of the floodplain are inundated
Absent – No wetlands are present

Riparian

Riparian Condition: The health status of riparian vegetation within the riparian zone.

Healthy – Minimal grazing, willows are full, lush vegetation
Stressed – Evidence of some grazing, vegetation is beginning to die off
Browsed – High rates of active or recent grazing, vegetation is sparse

Riparian Longitudinal Connectivity: The density of riparian vegetation along the channel within the riparian zone and the hydrologic connectivity up and downstream.

Continuous – Riparian vegetation is uninterrupted along the banks.
Discontinuous – Areas with gaps within the riparian vegetation
Sparse – Riparian vegetation is almost non-existent

Bank

Bank Exposure: The level of protection from vegetation or armoring along the channel banks.

Low – No protection from erosion. Bare Soil
Medium – Presence of some grass and or rocks
High – High presence of vegetation or rocks

1.2 Stream Characteristics According to Stream Order

Table 1 — *Riparian Health Status*

Stream Order	**Browsed**	**Stressed**	**Healthy**
0	56%	39%	5%
1	38%	51%	11%
2	3%	90%	7%
3	8%	75%	17%
4	0%	81%	19%
Total	**22%**	**67%**	**11%**

Table 2 — *Presence of Floodplain Wetlands*

Stream Order	**Absent**	**Sparse**	**Abundant**
0	27%	54%	19%
1	32%	34%	34%
2	67%	29%	4%
3	73%	11%	16%
4	100%	0%	0%
Total	**56%**	**27%**	**17%**

Table 3 — *Flow Regime*

Stream Order	**Ephemeral**	**Intermittent**	**Perennial**
0	26%	17%	57%
1	26%	21%	53%
2	3%	2%	95%
3	0%	0%	100%
4	0%	0%	100%
Total	**12%**	**9%**	**79%**

Table 4 — *Floodplain Habitat diversity*

Stream Order	**Diverse**	**Moderate**	**Homogenous**
0	2%	51%	47%
1	21%	49%	30%
2	16%	33%	51%
3	14%	39%	47%
4	19%	0%	81%
Total	**15%**	**39%**	**46%**

1.3 2019 Mapping Guidelines

Abandoned Dam Mapping Guidelines

Vegetation

1. Pond Infill Sedges or grasses
2. Willow Trees on Berms or forming a "wall" across the valley

Elevated Ground

1. Gradual incline then decline moving downstream
2. Stock Pond dams are much larger in comparison

Chew Marks

1. Chewed willows near and around the berms
2. Chewed Cottonwood near and around the berms
3. Chewed wood within berms and surrounding areas

Meandering

1. Best used in areas with older dams that have eroded away
2. May be no other evidence due to grazing/erosion/change in environemnt
3. Sharp channel meanders where the channel wouldn't normally meander

Histosols

1. Organic rich soils (black soils) in the floodplain or berm
2. Can also be associated with seeps/springs

Active Dams

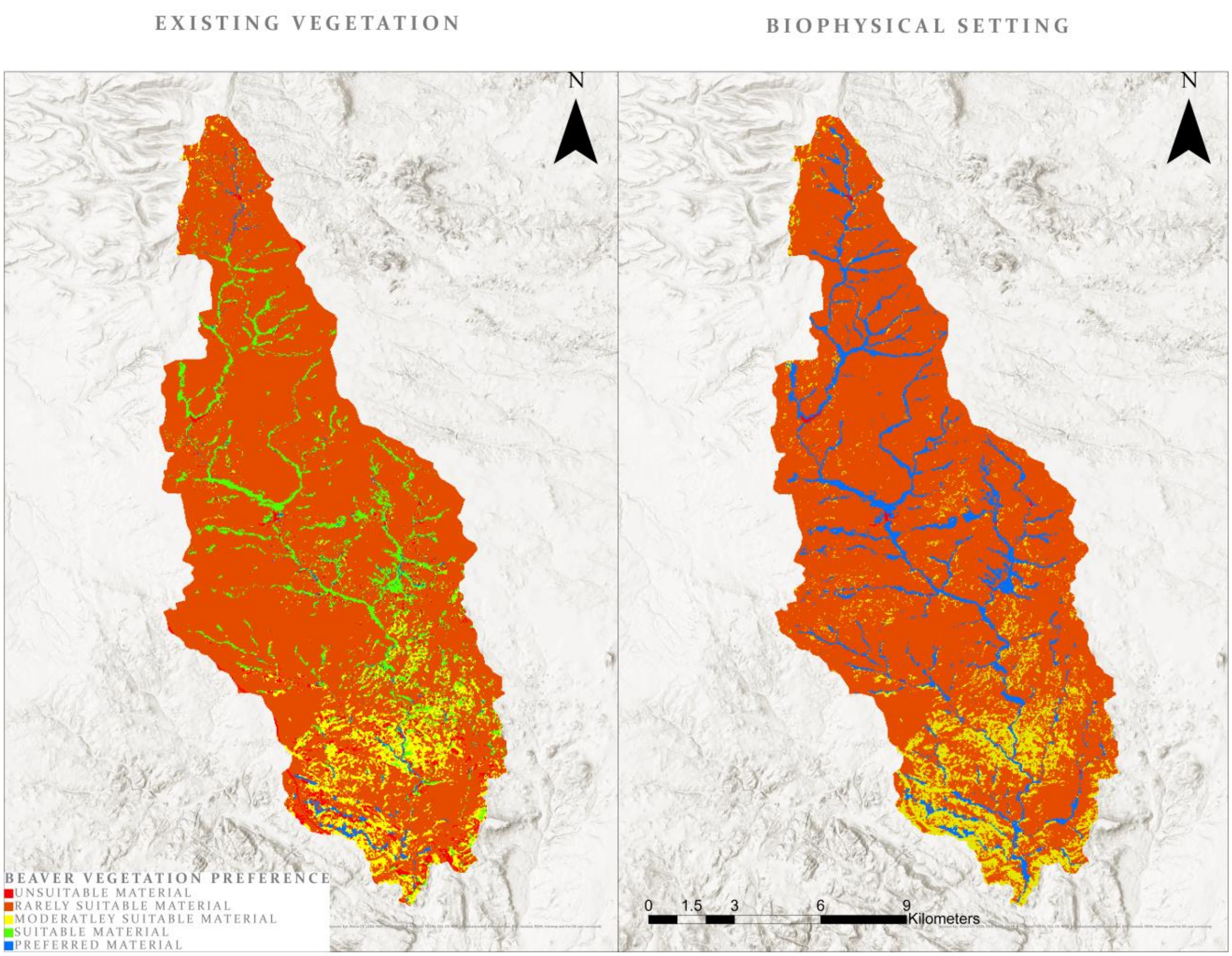
1. Presence of Beaver Lodge/Dams
2. Ponding of water

2. Additional Images

Zero Order Reach Example

Active beaver dam causing river meandering at 90-degree angles along East Sand Creek in Colorado

3. Biophysical Setting Vegetation vs Contemporary Vegetation Matrices



4. Confusion Matrices

LANDFIRE Classification

Vegetation Class	Unsuitable	Barely	Moderately Suitable	Suitable	Preferred	Total	User Accuracy
Unsuitable	6	4	7	0	0	17	35%
Barely	43	229	134	0	5	411	56%
Moderately Suitable	7	6	40	0	0	53	75%
Suitable	0	11	23	0	7	41	0%
Preferred	1	0	6	0	3	10	30%
Total	57	250	210	0	15	532	0%
Production Accuracy	11%	92%	19%	0%	20%	0%	**52%**

Pixel-Based Classification

Vegetation Class	Unsuitable	Barely	Moderately Suitable	Suitable	Preferred	Total	User Accuracy
Unsuitable	33	46	31	0	0	110	30%
Barely	24	173	47	0	8	252	69%
Moderately Suitable	0	27	128		3	158	81%
Suitable	0	0	0	0	0	0	0%
Preferred	0	4	4	0	4	12	33%
Total	57	250		0	15	532	0%
Production Accuracy	58%	69%	61%	0%	27%	0%	**64%**

OBIA Classification

Vegetation Class	Unsuitable	Barely	Moderately Suitable	Suitable	Preferred	Total	User Accuracy
Unsuitable	53	5	24	0	0	82	65%
Barely	3	199	8	0	0	210	95%
Moderately Suitable	1	42	167	0	0	210	80%
Suitable	0	0	0	0	0	0	0%
Preferred	0	4	11	0	15	30	50%
Total	57	250	210	0	15	532	0%
Production Accuracy	93%	80%	80%	0%	100%	0%	**82%**