CROSS-WALKS, FIRE GEOGRAPHY, AND GIS AT MESA VERDE NATIONAL PARK: A WATERSHED APPROACH

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled:

CROSS-WALKS, FIRE GEOGRAPHY, AND GIS AT MESA VERDE NATIONAL PARK: A WATERSHED APPROACH

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a candidate for the degree of Master of Arts in Geography,

and hereby certify that, in their opinion, it is worthy of acceptance.

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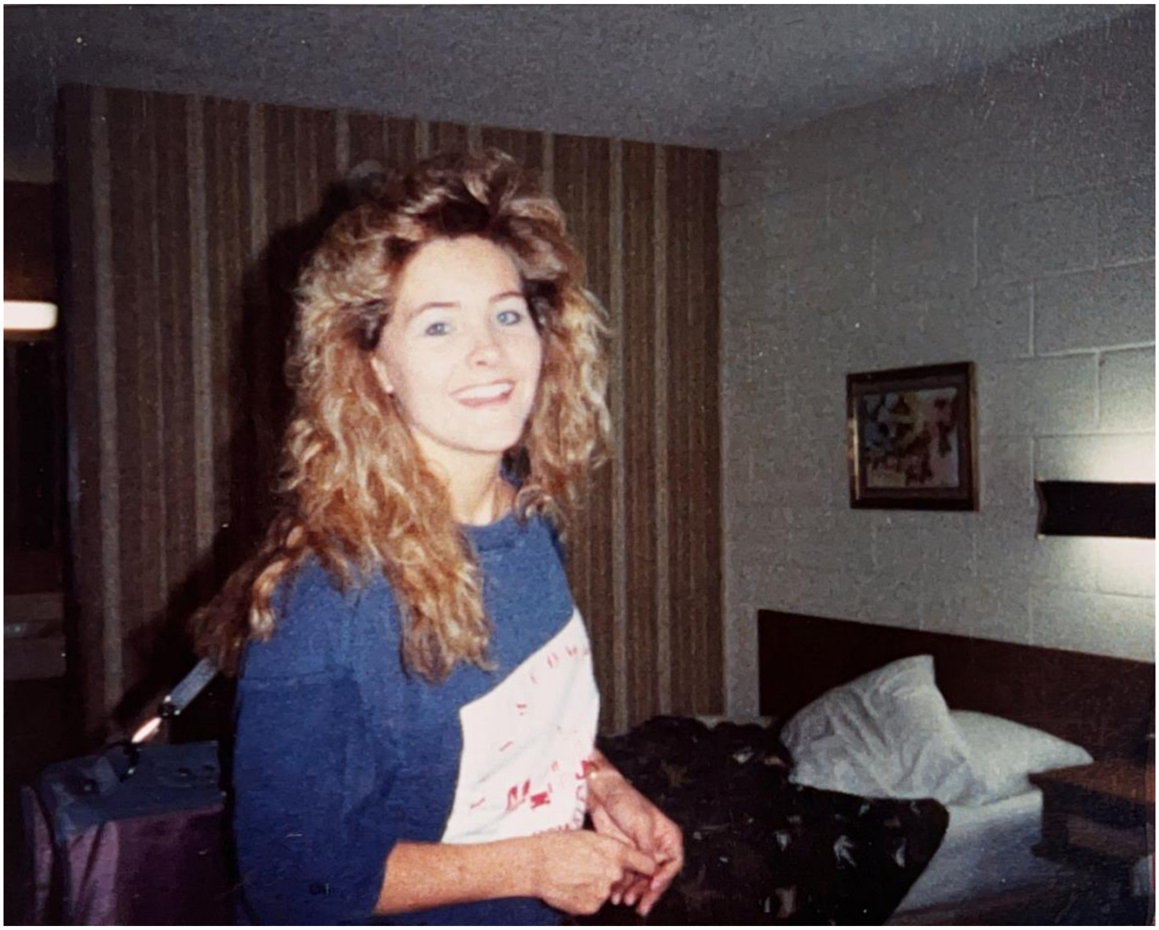
Dedication



For Mom
(1966 – 2022)

Finishing what we started.

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Abstract

Land use and land cover (LULC) data are valuable resources to fire managers making important decisions regarding the future of America's National Parks and forests. The choice of available LULC GIS products varies greatly by the provider. The National Land Cover Database (NLCD) and Landscape Fire and Resource Management Planning Tools (LANDFIRE) Program each represent vegetation at different scales for different reasons. This study utilizes a process known as cross-walking to make the data comparable at a one-to-one scale. The cross-walking process is described in detail. An overlay analysis is conducted which explores the decline, growth, and stationarity of evergreen forest, shrub/scrub, and grassland/herbaceous cover types from 2001 to 2019/2020. The results are analyzed to provide geographic and cartographic comparisons regarding the fire geography of Mesa Verde National Park. Findings include geographic and cartographic differences between datasets, especially where fires larger than approximately 12 hectares (or approximately 30 acres) have previously occurred. This information is valuable to decision-makers regarding the fire geography of Mesa Verde National Park and their GIS knowledge of LULC data such as NLCD and LANDFIRE.

Chapter One

Introduction

Land use and land cover (LULC) information is used for a multitude of resource and environmental management purposes. The Multi-Resolution Land Characteristics (MRLC) consortium consists of 10 federal agencies which utilize Landsat imagery to produce multiple data products including, but not limited to, the National Land Cover Database (NLCD) and Landscape Fire and Resource Management Planning Tools (LANDFIRE) Program (Dewitz & U.S. Geological Survey, 2021; MRLC, n.d.; U.S. EPA, 2023). NLCD was developed as a standardized system for classifying 16 LULC categories (Dewitz & U.S. Geological Survey, 2021; Wickham et al., 2014). LANDFIRE geospatial data was formally chartered in 2004 (LANDFIRE, n.d.). The idea behind LANDFIRE was developed in 2000 in response to the growing frequency, size, and severity of fires (LANDFIRE, n.d.; Wickham et al., 2014). The program's goal was to reduce the impacts of severe fires, aid fire management, and assist firefighters (Wickham et al., 2014). Today it is widely used in fire management applications, offering datasets on fire regimes, fuel characteristics, existing vegetation, and more. LANDFIRE Existing Vegetation Type (LANDFIRE EVT) is the specific product used here and offers users a more detailed level of LULC data than NLCD.

Standardized data is useful for government agencies and researchers because it lessens duplication and offers a stable dataset for addressing resource and environmental issues (J. R. Anderson, 1976). Attempts to standardize LANDFIRE EVT data through a process known as cross-walking have been conducted on a national scale (McKerrow et al., 2016). Cross-walking is the act of simplifying one subject to a similar and comparable level as another subject. McKerrow et al.'s (2016) results show numerical differences between NLCD and LANDFIRE EVT data across LULC types. Importantly, there was no attempt to show the differences cartographically to see how NLCD and LANDFIRE EVT data agree or disagree on the spatial distribution of LULC. Therefore, this research will attempt to study LULC patterns associated with NLCD and cross-walked LANDFIRE EVT data through an overlay analysis using geographic information systems (GIS).

Our interests are associated with the cross-walking of LULC data and center purposefully around southwestern Colorado. Specifically, this study explores the fire geography of Mesa Verde National Park (MEVE) while utilizing a watershed scale of analysis. We further refine our study by focusing on specific vegetation types which can be considered as burnable fuels. The burnable fuels considered within this study include evergreen forests, shrub/scrub, and grassland/herbaceous cover types. From a watershed perspective, this study explores the following question about the fire geography of MEVE:

1. To what spatial extents do NLCD and LANDFIRE EVT datasets geographically and cartographically agree on landscape characteristics in and around Mesa Verde National Park?

The goal of this study is to explore the areal relationships between NLCD and LANDFIRE EVT datasets by examining fire across multiple watersheds within and surrounding MEVE. Our objectives include:

1. To crosswalk and standardize LANDFIRE EVT data using the NLCD legend classifications.

2. To prepare GIS layers of NLCD and cross-walked LANDFIRE EVT data for evergreen forest, shrub/scrub, and grassland/herbaceous to highlight change over time at a watershed scale.
3. To conduct an overlay analysis to compare the geographic and cartographic similarities and differences between the NLCD and cross-walked LANDFIRE EVT data layers.

Chapter Two

Literature Review

Mesa Verde Fire History, Fire Regimes, and Successional Dynamics

Mesa Verde National Park comprises approximately 21,400 hectares (ha) located in southwestern Colorado upon the Mesa Verde cuesta (approximately 53,800 (ha)). It contains and is surrounded by multiple vegetation types. The most abundant vegetation types include evergreen forests and shrub/scrub communities (M. L. Floyd et al., 2000; Herring et al., 2014). *Pinus edulis* (Colorado pinyon pine) and *Juniperus osteosperma* (Utah juniper) are the most common coniferous vegetation within the study area (Thomas et al., 2009). Many stands within the park are pinyon-juniper mixed. Extensive mountain shrublands (commonly referred to as petran chaparral) are also present in the form of *Quercus gambelii* (gambel oak), *Amelanchier utahensis* (Utah service-berry), and *Fendlera rupicola* (cliff fendlerbrush), amongst many others (Colyer, 2003; M. L. Floyd et al., 2000; Herring et al., 2014). These pinyon-juniper woodlands and shrubland communities are the primary fuels being burned in and surrounding MEVE today. Grassland/herbaceous communities are also prevalent, especially near and within the underbrush of shrub/scrub communities (M. L. Floyd et al., 2000). A common grass includes *poa fendleriana* (muttongrass) (Romme et al., 2003). Invasive grasses such as *Bromus tectorum (*cheatgrass) are also common (Romme et al., 2003).

Each of the above-mentioned vegetation types contribute to the fire regime of MEVE. A fire regime consists of distinct properties including: spatial extent, intensity, severity, frequency, seasonality, and type of fire (Bond & Keeley, 2005; Bowman et al., 2009; Medler, 2010). However, defining a 'natural' fire regime is complicated because many forest ecosystems have evolved with human disturbances (Medler, 2010). Throughout history, indigenous populations used fire as a tool for creating desirable conditions. Fire kept the understory cleared for hunting and increased forest production of berries, amongst other purposes (Wessels, 1999). In recent history, common processes which alter the 'natural' fire regime of forests include fire suppression, prescribed burns, mechanical thinning, and burning to create pasture and cropland. These social influences alter amounts of burnable fuel types, intensity, severity, timing/seasonality, and the spatial scale of wildfire (Bond & Keeley, 2005; Medler, 2010).

Nevertheless, the fire regime of MEVE is complicated and not fully understood (M. L. Floyd et al., 2004). This is because pinyon-juniper forest structure and stand dynamics demonstrate complexity and differentiate from one stand to another (M. L. Floyd et al., 2004; Romme et al., 2003). Forest structure alludes to the physical arrangements such as the canopy height, age, and proximity of one tree to another, amongst other factors (Seidler, 2017). Pinyon pine has also proven difficult to study as evidence of previous fire history and visual effects from fire disturbances are hard to recognize (M. L. Floyd et al., 2000). Fire scars are rare as pinyon pine is easily killed by low-severity surface fires (M. L. Floyd et al., 2000). This further enhances the difficulty of placing disturbances before 1906 (MEVE establishment) as limited or inadequate records are available. This is further complicated as pinyon pine has been documented to exceed the age of 1,000 years (M. D. Anderson, 2002).

In recent history, large fires within the park boundaries have been limited and suppressed. It is documented that fire suppression results in a buildup of fuel loads and creates conditions for hotter, more severe, and larger fires which are seasonally inconsistent (Bond & Keeley, 2005; Medler, 2010). MEVE and much of the southwestern United States have traditionally been characterized as having frequent low intensity fires which do not often reach the crowns of the coniferous vegetation (Bond & Keeley, 2005). However, total fire suppression policies and fire exclusion from MEVE have allowed the buildup of fuels and have changed forest structure to become far more dense in some places (M. L. Floyd et al., 2004; Romme et al., 2003). Drought conditions across the southwest exacerbate this by lowering moisture content and increasing opportunities of ignition (Breshears et al., 2005).

Normally, less severe burns would clear the understory and kill shade-intolerant herbaceous plants. Now, when ignition sources combust, these relatively frequent and low intensity fires become large and uncontrollable events (Bond & Keeley, 2005). Debates within MEVE about the role of human activity (e.g. fire suppression) in the prevalence of larger, more intense fires didn't begin until the latter half of the 20th century, when multiple large fires burned throughout MEVE and surrounding areas (M. L. Floyd et al., 2000; NPS, n.d.). These fires marked a shift in fire activity for MEVE.

It is estimated that larger stand-replacing fire disturbances in this area occurred once every 400 years prior to 1995 (M. L. Floyd et al., 2004). These historic and large stand-replacing fires were infrequent and of high intensity (M. L. Floyd et al., 2004). However, a sediment core taken from Prater Canyon (within MEVE) helped reconstruct ancient forests through soil charcoal and pollen assemblages (Herring et al., 2014). It suggested an increase in fire events from AD 500 to 1250 (Herring et al., 2014). This coincides with the rise in Puebloan population within MEVE until their departure around AD 1300 (Herring et al., 2014). This evidence suggests indigenous people impacted the local environment with fire as their culture grew and expanded into the cliff dwellings and mountainside pueblos visible today (Herring et al., 2014). These historic fire practices complicate the current description of what is considered a 'natural' fire regime.

Further, after Puebloan emigrations from MEVE around AD 1300, fire occurred less (Herring et al., 2014). Puebloans possibly left the region due to drought, demands of an increased population, and the exploitation of resources including soil and timber (Cordell et al., 2007; Flint-Lacey, 2003). This is interesting as the Little Ice Age occurred simultaneously on a global scale. That event globally cooled temperatures and increased precipitation (Herring et al., 2014). All of these variables factor into the fire regime and the current 400+ year fire rotation of the area (M. L. Floyd et al., 2000, 2004; Romme et al., 2003). Fire rotation refers to the time it takes an entire area to burn (Dickmann & Cleland, 2002). However, another study speaking on the Uncompahgre Plateau in western Colorado found the fire rotation of pinyon-juniper woodlands to be approximately 200 to 700 years (Eisenhart, 2004).

Today, there is ongoing speculation regarding the historic range of variability of pinyon-juniper woodlands within MEVE (M. L. Floyd et al., 2004). The historic range of variability typically refers to time before the arrival of human influence between natural disturbance events (e.g. drought, wildfire, etc.) which change forest structure within an area (Veblen, 2003; Wohl, 2019). Two possible explanations exist to account for the more frequent, intense, and sizable fires of the mid-1990s into the early 2000s surrounding and within MEVE. The first suggests the park is experiencing unprecedented fire activity; the second is that the park is undergoing stand-replacing burns normal within the historic range of variability of approximately 400 to 500 years (M. L. Floyd et al., 2004). Eisenhart (2004) also suggested that the fires occurring around MEVE are within the historic range of variability.

Once these forests burn, the successional reestablishment of these forests is often slow after a fire disturbance (Baker & Shinneman, 2004). It may take a minimum of 25 years post-fire to regenerate and establish pinyon-juniper forests (Erdman, 1970). It is also recorded that some pinyon-juniper forests take decades to centuries post-fire to regenerate (Erdman, 1970; Hartsell et al., 2020). Sometimes, pinyon-juniper forests do not reestablish at all (M. L. Floyd et al., 2000). This may be because pinyon-juniper woodlands are experiencing drought-induced mortality which limits new recruitment and heightens juvenile forest mortality (Redmond et al., 2015).

Nevertheless, the two primary understory structures aiding in the regeneration of burned pinyon-juniper woodlands are obligate seeding woodlands and sprouting woodlands (M. L. Floyd et al., 2021). Obligate seeding woodlands refers to understory species characterized by their requirement of fire to germinate seeds. Obligate seeding woodlands are dominated by forbs and grasses. Sprouting woodlands consist of understory species with root systems that do not burn and therefore resprout naturally after above-ground vegetation burns away. Sprouting woodlands are dominated by shrubs which also hold a natural ability to resist drought conditions (M. L. Floyd et al., 2021). Interestingly, pinyon pine and Utah juniper have capabilities to be obligate seeders or sprouting woodlands (M. L. Floyd et al., 2021).

However, each of these understory forest structures respond differently to fire disturbance within MEVE. Obligate seeding woodlands experience slow regeneration post-fire, allowing non-native and invasive species to establish in the open understory with limited groundcover. Sprouting woodlands have more resilience to fire disturbance due to their drought resiliency and higher regeneration rate of vegetative cover, which helps prevent the establishment of non-native and invasive species. Because of its slow regeneration, obligate seeding woodlands will be more vulnerable to fire and climate change than sprouting woodlands moving forward (M. L. Floyd et al., 2021). In contrast to pinyon-juniper woodlands, petran chaparral shrublands such as gambel oak are quick to regenerate after disturbance events such as fire (M. L. Floyd et al., 2000). Petran chaparral resprouts abundantly after above-ground portions are burned away (M. L. Floyd et al., 2000). The fire rotation of shrub/scrub in MEVE is approximately 100 years (M. L. Floyd et al., 2000).

Needs: The above-mentioned studies are excellent sources for understanding the fire history of MEVE, but there are no studies that break the MEVE property and surrounding areas into individual watersheds for analysis. It is unclear how wildfire has impacted vegetation types in MEVE versus the surrounding watersheds located immediately outside the park boundaries. Furthermore, there is no research on the use of GIS to compare NLCD and LANDFIRE EVT data in and around the park. An alternative and perhaps more holistic approach to fire management in the future might involve the use of HUC-10 and HUC-12 watersheds as units of analysis and management. Since fire, wind, temperature, water, flora, and fauna are all natural parts of the ecological system, it seems logical to use natural geographic units such as watersheds for analysis and management. One commonality between federal and state agency management and future watershed management models is the use of GIS and LULC data. A first step in the direction of watershed management is to compare LULC data sources, looking for similarities and differences in the data using GIS.

Mapping Mesa Verde Fires with GIS

Multiple studies have utilized GIS while studying fire in MEVE. The research using GIS has been utilized at varying levels. Some have used it to visualize MEVE by satellite imagery or vector information (M. L. Floyd et al., 2000; Herring et al., 2014; Thomas et al., 2009). Others have used GIS to show the locations of fires and vegetation types (M. L. Floyd et al., 2000, 2004, 2021; Herring et al., 2014). A few have explored simulations of fires (Turner et al., 2008). However, no studies have compared LULC data sources or changes in vegetation type using overlay analysis at a watershed level. This section is a light overview of the nevertheless important GIS and fire research within and surrounding MEVE.

Floyd et al. (2000) shows the fire history within the chaparral shrubland vegetation type in MEVE. Their fieldwork involved sampling sites and marking georeferenced information onto USGS topographic maps. They later digitized this information using GIS. The authors cross-referenced their sampled data with maps of historical fires that burned within the park in 1934, 1959, 1972, and 1996. Fire perimeters are also mapped within the MEVE GIS fire atlas. The study finally revealed the amount of vegetation that had been burned during the later half of the 20th century. Floyd et al. (2000) stated:

> … we determined with the GIS that woodland (mostly pinon and juniper) covered 10,960 (ha) within the Park. There was an additional 393 (ha) of woodland prior to the 1934 fires, and fires since 1950 have burned a total of 1,336 (ha) of woodland (Table 2). All of the woodland that burned in the 20th century is now

> dominated by shrubs and herbs, with little or no conifer reestablishment. Because there were no extensive fires in Mesa Verde between the 1880s and 1934, we assumed that the amount of woodland that existed just prior to the 1934 fire was also about the amount that existed at the turn of the century. (p. 1675)

The above statement is a vibrant example of how the vegetation of MEVE and surrounding areas respond after fire.

Floyd et al. (2004) then examined how fire regime information and mapping helps with cross-referencing fire data. For example, they created several maps of pinyon–juniper woodlands stand ages for the entire cuesta.

Additional geospatial information was gleaned from studies that reproduced tree stand age within MEVE. Turner et al. (2008) noted:

> A geographic information system (GIS) interface is provided in MMS [Modular Modeling System] for applying GIS tools to delineate, characterize, and parameterize topographical, hydrological, and biological features for use in a variety of lumped- and distributed-modeling approaches…The modular toolbox design also enables the immediate integration of advances in physical and biological sciences, GIS technology, computer technology, and data resources into the toolbox. Resource-management decision making thus benefits from the ability to constantly refine the models with state-of-the-art scientific information and technology. (p. 25-26)

Needs: MEVE fire maps were excellent sources of fire data and corresponded with existing vegetation types. However, the studies did not directly focus on the use of NLCD and LANDFIRE data for their analysis. Thus, going back to the primary research question, how are NLCD and LANDFIRE EVT data similar or different across space needs to be addressed within GIS fire research.

NLCD and LANDFIRE Data Comparisons

NLCD and LANDFIRE EVT data sets are used in multiple natural resource management applications including forestry, range management, climate studies, fire management, and environmental management (Helmbrecht & Blankenship, 2016; Homer & Et al, 2015; McKerrow et al., 2016; Wickham et al., 2014). Although both datasets map the same geographic features, there are vast differences between the classification system of NLCD and LANDFIRE EVT. It is recognized that NLCD consists of 16 land cover classes and LANDFIRE data consists of more than 600 land cover classifications within the conterminous United States (NatureServe, 2018; Nelson et al., 2013; Wickham et al., 2014). In other words, LANDFIRE data contains much more detailed information for land cover than NLCD.

McKerrow et al. (2016) is the only study which compared the areal extent of both NLCD and LANDFIRE EVT data across the United States using a data cross-walking method. Findings showed that:

> NLCD and LANDFIRE land cover indicate discrepancies related to differences in structure (for example, scrub/shrub versus forest in the west, scrub/shrub versus herbaceous in the Midwest), phenology (for example, evergreen versus mixed forest), or definition (for example, open space developed pixels in NLCD being reclassified to Medium Intensity Developed for pixels proximal to roads. (pp. 4-5)

Needs: McKerrow et al. (2016) noted that the differences in NLCD and LANDFIRE EVT data are important when considering the geography of land cover and the mapping of the data. However, the authors did not provide cartographic representations of the differences between NLCD and LANDFIRE EVT data. As a result, there is a research need to conduct a cross-walking experiment while overlaying the resulting NLCD and LANDFIRE EVT GIS layers to look for cartographic similarities and differences.

Chapter Three

Methodology

Data Collection

LULC data was collected from the Multi-Resolution Land Characteristics (MRLC) consortium (MRLC, n.d.). NLCD data was collected for 2001 and 2019 (Dewitz & U.S. Geological Survey, 2021; LaMotte, 2016). Finer land cover classifications were obtained from LANDFIRE EVT. LANDFIRE EVT data was collected for both 2001 and 2020 (LANDFIRE, 2011, 2022). These data products are not produced and released annually. Therefore, it is not always possible to collect data featuring the same year. All collected data were projected to NAD 1983 Contiguous USA Albers. This projection was used as it is an equal area projection.

The United States Geological Survey (USGS) was used to collect ten-digit and twelve-digit Hydrologic Unit Codes (HUC-10 and HUC-12) boundary data from the Watershed Boundary Dataset (Jones et al., 2022).

Fire data was collected from the National Interagency Fire Center (NIFC). Data was collected from the "InterAgencyFirePerimeterHistory All Years View" shapefile (NIFC, 2022).

The MEVE political boundary was collected from the National Park Service (NPS) open data boundary shapefile titled "NPS – Land Resources Division Boundary and Tract Data Service" (NPS, 2019). The MEVE boundary was selected and extracted to a new individual shapefile.

Scale of Analysis

Our analysis was taken at a watershed level, which is a novel way to consider LULC data and fires within and surrounding a National Park. We began by identifying three HUC-10 watersheds. Each watershed held a portion within the MEVE boundary (Figure 1).

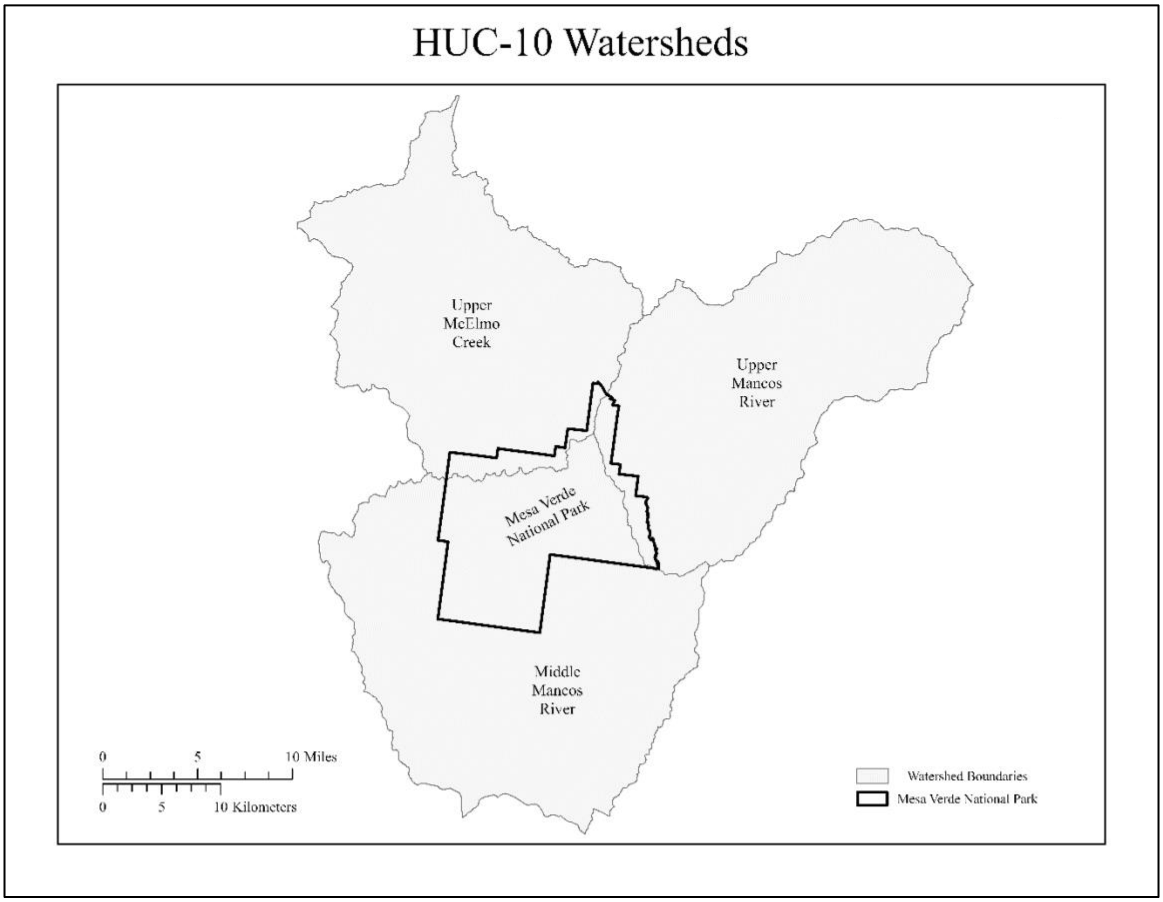

Figure 1: HUC-10 Watersheds

These watersheds defined the outer perimeter of our study area. To be ecologically consistent we utilized the twenty-six HUC-12 subwatersheds that exist within the HUC-10 watershed study perimeter (Figure 2). The smaller scale of the HUC-12 subwatersheds allowed a finer analysis of land cover change within and surrounding the park.

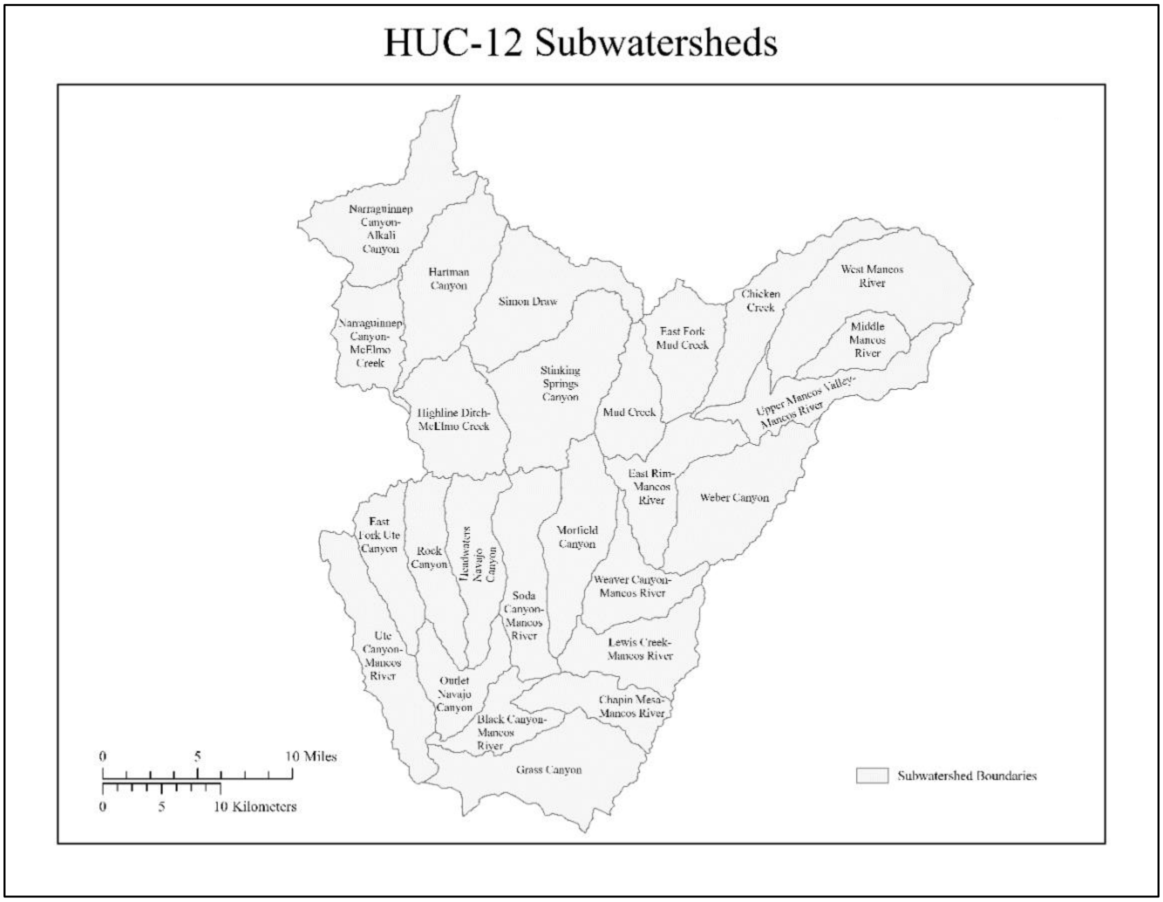

Figure 2: HUC-12 Subwatersheds

Fires which burned within the HUC-12 boundaries were separated depending on two factors: 1) All recorded fires which occurred from 1989 to 2021 (n=730), and 2) All recorded fires which occurred from 1989 to 2021 larger than 30 acres (n=18) (NPS, n.d.) (Figure 3). Having an approximate 30-year history of fire aligns with how climate is measured. This is an attempt to climatically explain the fire history of the area and includes future potential to include temperature, rainfall, and other data variables. Acres were used instead of hectares to define “Major Fires” as per documentation by the NPS (NPS, n.d.). It is important to note that the collected NIFC data has many gaps and does not include data for fires in 1990 to 1995, 1997 to 1999, 2004, or from 2014 to 2019. This equates to 16 years of missing fire information. This is a major data issue which was not remedied or proxied by alternative data.

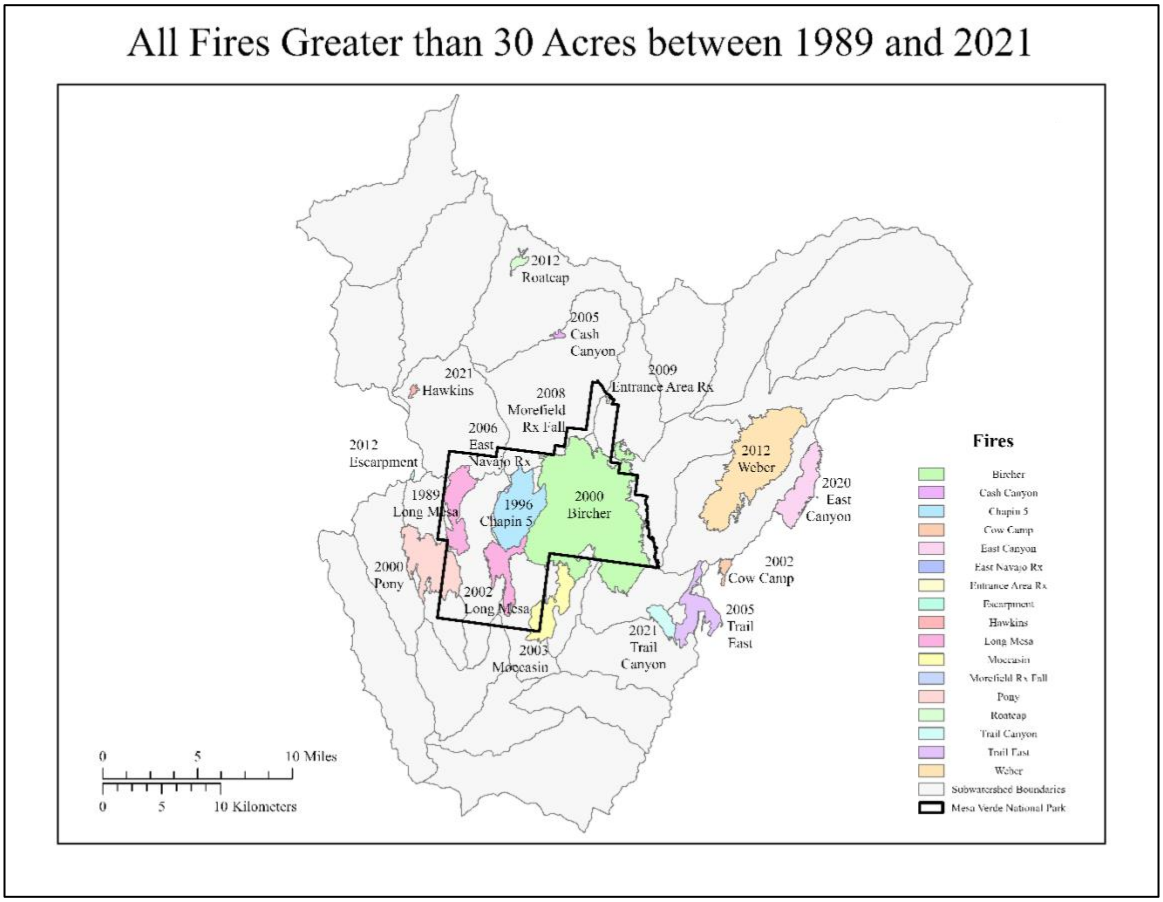

Figure 3: All Fires Greater than 30 Acres between 1989 and 2021

Cross-walking Approach

Cross-walking is a process that aids in comparing one LULC dataset against another. Preparing cross-walked LULC data requires a predetermined LULC classification system as a baseline, such as NLCD, to make equal comparisons across sources. Once the baseline is defined, any other classification system must be coded to correctly represent cover types which reflect the baseline.

After collecting the LULC data it was necessary to crosswalk the LANDFIRE EVT data to a broader hierarchical scale to aid data visualization (Appendix A). Preparing the data as such helped undertake the cross-walking process. Both NLCD and LANDFIRE EVT data were edited to show all developed lands (e.g. buildings, roads, impervious surfaces, etc.) as a single LULC type (NLCD Code #21) for simplicity and generalization. This was in effort to avoid visualizing development across four separate types (NLCD Code #21, #22, #23, #24). Additionally, woody wetlands (NLCD Code #90) was excluded from the LANDFIRE EVT crosswalk because of complexity within naming conventions. All wetlands in the crosswalk are listed as emergent herbaceous wetlands (NLCD Code #95).

The remaining LANDFIRE EVT cover classes were cross-walked manually by myself following McKerrow et al. (2016) and LANDFIRE EVT documentation (NatureServe, 2018). As LANDFIRE EVT naming conventions were complex and often difficult to convert into broader classification levels we primarily used LANDFIRE EVT subclasses to aid in crosswalk final decision-making.

Before beginning the process, a series of steps was taken to prepare the data for analysis. This was completed through ArcGIS Pro:

Step 1: Collect NLCD and LANDFIRE EVT data.

Step 2: Use the Extract by Mask tool. The ‘input raster’ included the land cover data. The HUC-12 watershed boundary shapefile was used as the ‘feature mask data’.

Step 3: Use the Polygon to Raster tool. Insert the HUC-12 watershed boundary shapefile as the ‘input feature’. Each watershed is then given a numbered value (1 through 26). This makes calculations easier going forward as land cover data will easily reside within its appropriate watershed (or bin).

Step 3: Use the Combine tool. Use the newly created raster watershed boundary layer and the raster LULC data for the appropriate year as 'input rasters.' This merges the land cover data into one of their respective twenty-six watersheds.

Step 4: Use the Export Table tool. Output the table as 'filename.csv' and examine the new raster layer attribute table. Ensure that the LULC data is sorted amongst the twenty-six watersheds.

Nested functions (e.g. =IF(D2=7011, "Rocky Mountain Aspen Forest and Woodland") were created using .txt files (notepad) to add detailed information to the exported Microsoft Excel documents. Each formula is placed at the top of the appropriate column and double clicked to apply throughout the entire dataset. To begin the cross-walking process of LANDFIRE EVT data to NLCD hierarchal scale, these steps were taken:

Step 5: Use .txt file to assign the numbered HUCs their actual name:

=IF(E2=1, "Middle Mancos River", IF(E2=2, "Upper Mancos Valley-Mancos River"))

Step 6: Use .txt file to assign LANDFIRE EVT codes to their appropriate LANDFIRE EVT Class Names:

=IF(D2=7011, "Rocky Mountain Aspen Forest and Woodland", IF(D2=7016, "Colorado Plateau Pinyon-Juniper Woodland"))

Step 7: Use .txt file to assign LANDFIRE EVT Classes to their subclasses. All final cross-walking decisions were based upon the subclass designation:

=IF(D2=7011, "Deciduous open tree canopy", IF(D2=7016, "Evergreen open tree canopy"))

Step 8: Use .txt file and McKerrow et al. (2016) to crosswalk LANDFIRE data to any applicable NLCD values. Attributes listed as "Fiquet" signify a need for manual determinations of classification:

=IF(G2="Rocky Mountain Aspen Forest and Woodland", 41, IF(G2="Rocky Mountain Lower Montane-Foothill Riparian Woodland", "Fiquet"))

Step 9: Use .txt file and manually assign cross-walked NLCD values to any attributes that McKerrow et al. (2016) did not cover:

=IF(G2="Rocky Mountain Aspen Forest and Woodland", 41, IF(G2="Rocky Mountain Lower Montane-Foothill Riparian Woodland", "43"))

Step 10: Use .txt file to assign the crosswalked NLCD values their appropriate NLCD Cover Type Names (e.g. 41 to Deciduous Forest)

=IF(J2=11,"Open Water", IF(J2=42,"Evergreen Forest"))

Step 11: Convert pixel count to hectares by multiplying 'count' column in excel by 0.09

Step 12: Add the excel sheet back into ArcGIS Pro. Use the Join Field tool to permanently add the cross-walked information to the appropriate raster dataset. Repeat this process for each data source and year of data collected (e.g. NLCD 2001 and 2019; LANDFIRE 2001 and 2020).

Then, symbology of the cross-walked data was updated:

Step 13: Within symbology, select unique values. The field should be set to either the cross-walked NLCD code names or numbers.

Step 14: Add original NLCD data into the viewer. The cartographic color information stored in this dataset will allow the cross-walked data to be viewed comparably.

Step 15: Within the cross-walked LANDFIRE raster symbology edit the colors of each LULC type to be the same as NLCD. This can be done using the color eye dropper or importing the color map of NLCD.

Chapter Four

Results

NLCD vs Cross-walked LANDFIRE EVT

The results of the 2001 crosswalk are visually striking (Figure 4). NLCD shows shrub/scrub and grassland/herbaceous better than LANDFIRE EVT. On the other hand, the extent of evergreen forest in NLCD is less visible than LANDFIRE EVT. In addition,

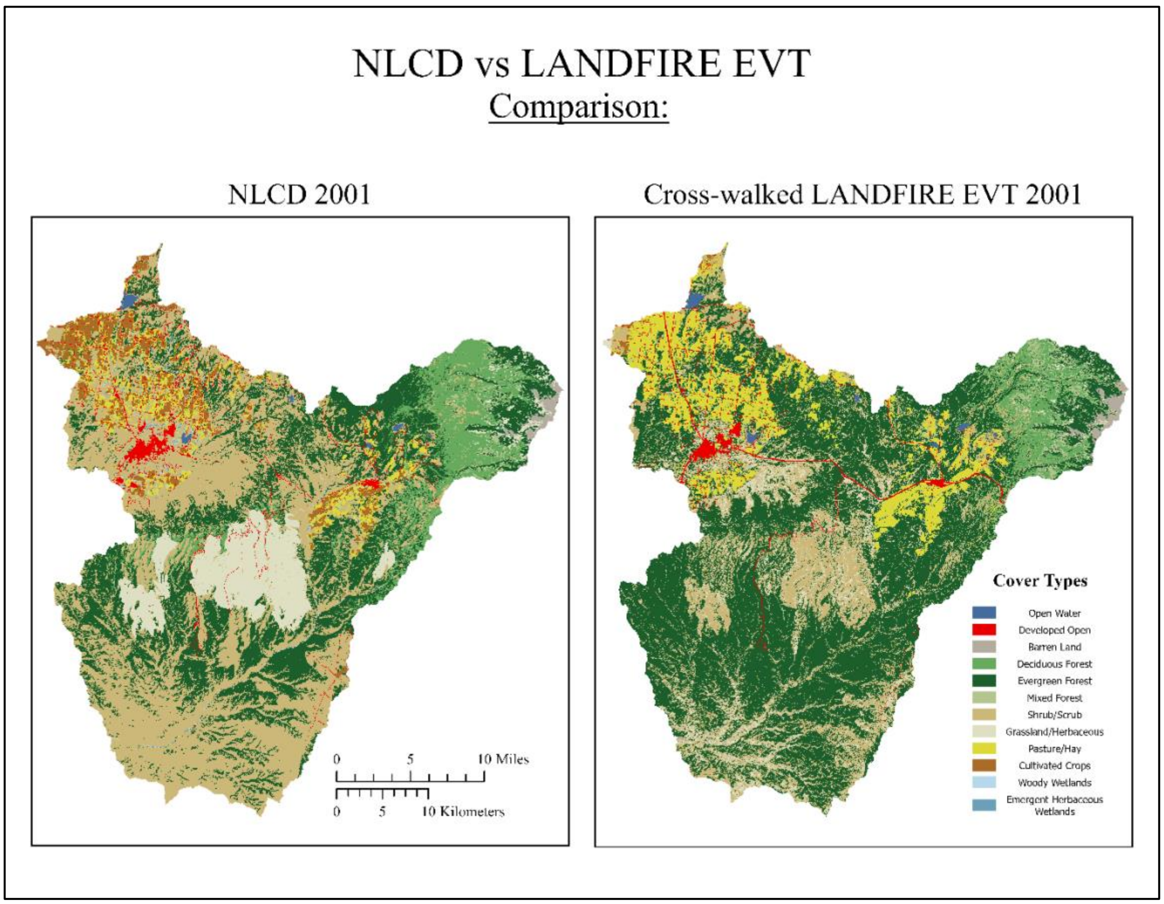

Figure 4: 2001 NLCD vs LANDFIRE EVT Comparison

the cartographic representation of cross-walked LANDFIRE EVT data presents a real or perceived larger spatial extent and richness of LULC within the HUC 10 and 12 boundaries. Information is further separated by examining burnable fuels (Appendix B1 and B2). Both datasets provide environmental and fire managers with different visual information.

Findings from the 2019/2020 crosswalk data show visual differences (Figure 5). For instance, NLCD shows a greater extent of shrub/scrub and grassland/herbaceous cover types than LANDFIRE EVT. However, LANDFIRE EVT visually pulls the map

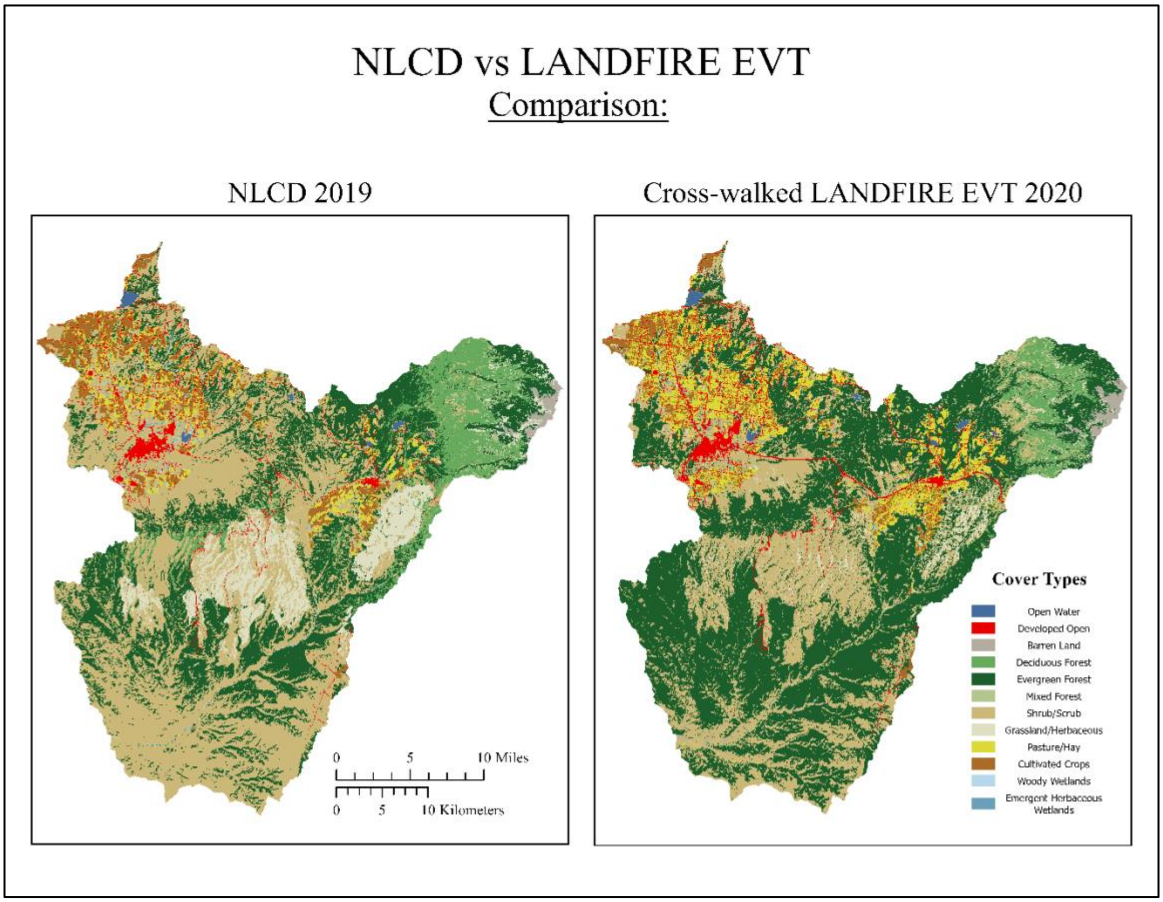

Figure 5: 2019 NLCD vs 2020 LANDFIRE EVT Comparison

reader towards evergreen forest extent as a primary cover type. The overall information displayed is different between both datasets, including by burnable fuels (Appendix B3 and B4). Again, LANDFIRE EVT data appears to reveal greater extent and richness of vegetation within the watersheds. The cartographic differences can provide environmental and fire managers with two unique visualizations of LULC data. To further understand the cartographic differences between NLCD and LANDFIRE EVT, an overlay approach was employed to cartographically identify differences in spatial extent of vegetation as burnable fuels. The vegetation types will be separated as discrete objects for analysis.

Overlay Analysis of NLCD and Cross-walked LANDFIRE EVT of Burnable Fuels

Overlay analysis was used to visualize changes in burnable fuels including evergreen forest, shrub/scrub, and herbaceous/grasslands types. Both NLCD and cross-walked LANDFIRE EVT data were analyzed. The process involved overlaying recent data (e.g. 2020) over the older data (e.g. 2001) of a particular vegetation type. The data shows decline, growth, or stationarity of a specific burnable fuel. Below, cover types are described from those more prevalent in western portions to those more prevalent in eastern portions of the study area.

Evergreen Forest

Visually, there are significant differences for evergreen forests between the NLCD and LANDFIRE EVT (Figure 6). The primary vegetation type of evergreen forest in the study area is pinyon-juniper woodland. Evergreen forest was the second-largest burnable fuel type within the NLCD dataset by hectares (Table 1). It was the largest within LANDFIRE EVT by hectares.

NLCD data displays areas of no change as the primary finding. Small areas of decline were visible in Headwaters Navajo Canyon, Soda Canyon-Mancos River, and Morefield Canyon. Those three subwatersheds contain the most area encompassed by the park boundaries. Additional decline is seen within the eastern subwatersheds of Upper

Mancos Valley-Mancos River, Weber Canyon, Weaver Canyon-Mancos River, and Lewis Creek-Mancos River. Little growth is seen anywhere.

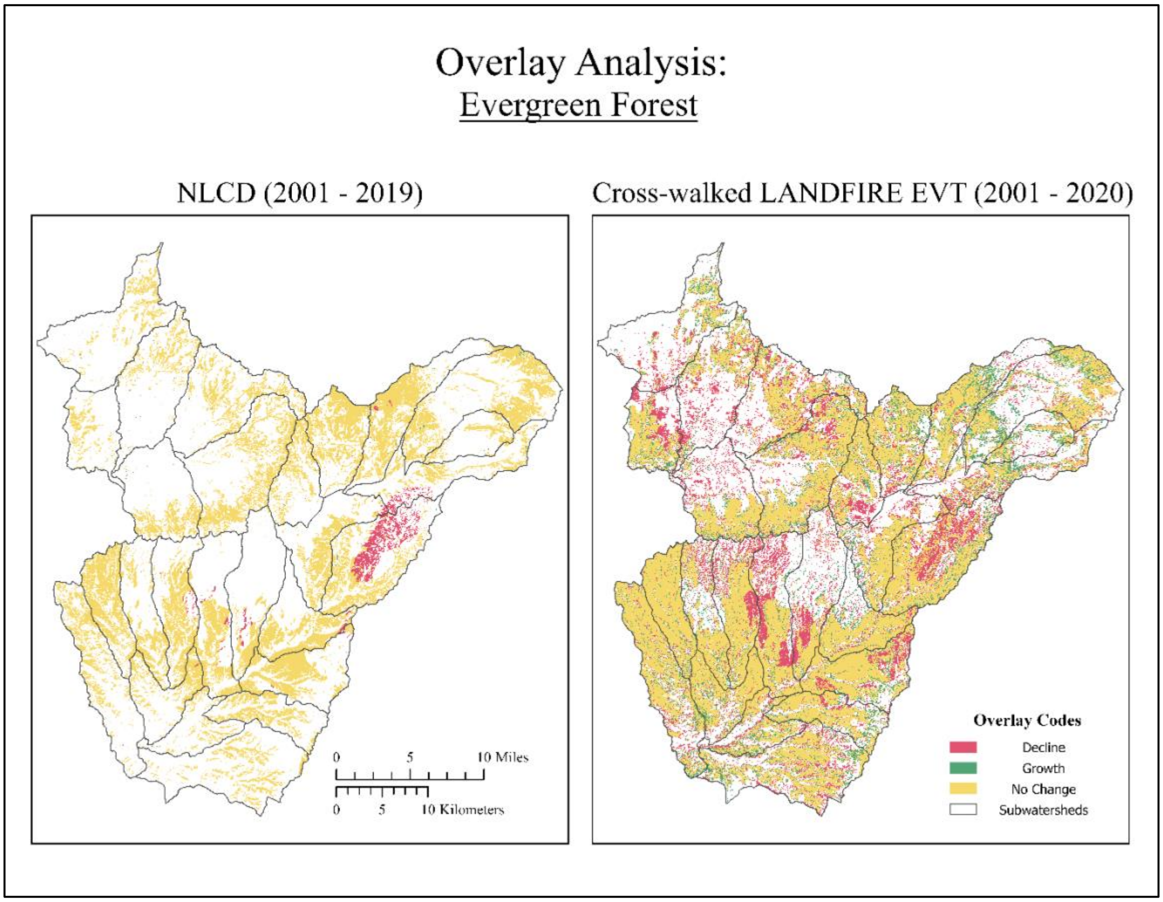

Figure 6: Overlay Analysis: Evergreen Forest

LANDFIRE EVT shows more dense evergreen forest cover by hectares than NLCD. No change in evergreen forests was the primary result. The western side of the study area shows scattered decline within the central to northern areas of Rock Canyon and Headwaters Navajo Canyon. Within the central subwatersheds of Soda Canyon-Mancos River and Morefield Canyon there is a significant decline. The eastern subwatersheds of Upper Mancos Valley-Mancos River, Weber Canyon, and Lewis Creek-Mancos River also reveal a significant decline in evergreen forest cover. Scattered growth is seen throughout the study area with the most visual difference found within the northeast sections of the map.

Table 1

Overlay Analysis – Burnable Fuels Results

	Evergreen Forest (ha)	Shrub/Scrub (ha)	Grassland/Herbaceous (ha)
NLCD	47,942	76,657	12,767
LANDFIRE EVT	82,842	48,366	5,325
Difference (±)	-34,900	+28,291	+7,442

Note: Values represent growth and no change throughout the entire study area for each burnable fuel cover type. Difference values were determined by subtracting LANDFIRE EVT by NLCD.

Shrub/Scrub

Visually, there are differences for shrub/scrub between the NLCD and LANDFIRE EVT datasets (Figure 7). The primary vegetation type of shrub/scrub within the study area is a mix of different shrubs. Shrub/Scrub is the largest burnable fuel type by hectares within NLCD (Table 1). It is the second largest burnable fuel type by hectares within LANDFIRE EVT. Shrub/Scrub land cover shows more commonalities between datasets than the other maps.

The NLCD shows growth across most of the central subwatersheds for shrub/scrub. The primary areas of shrub/scrub decline within the central subwatersheds are seen within Headwaters Navajo Canyon, Soda Canyon-Mancos River, and Morefield Canyon. Decline is also dispersed across Upper Mancos Valley-Mancos River, Weber Canyon, Weaver Canyon-Mancos River, and Lewis Creek-Mancos River. No change is the dominate result for the more northern and the more southern subwatersheds.

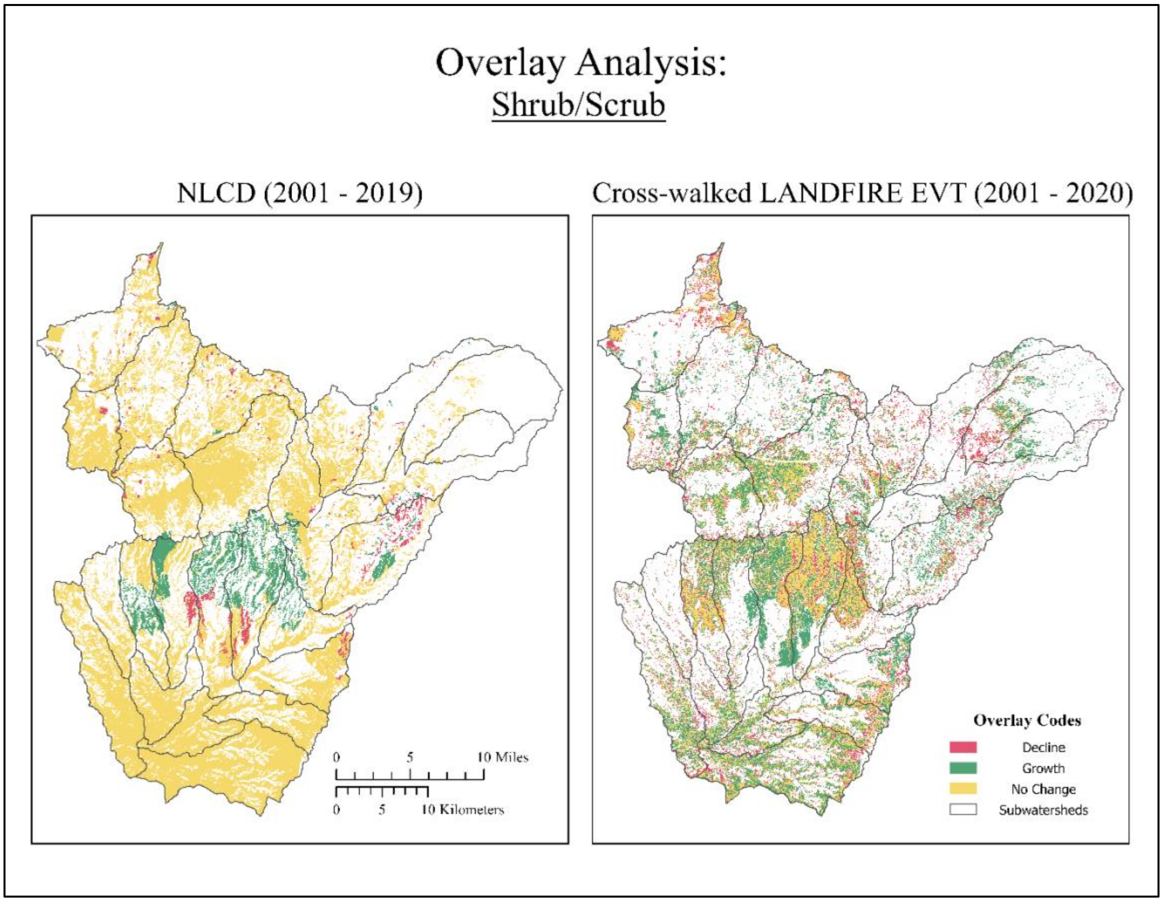

Figure 7: Overlay Analysis: Shrub/Scrub

LANDFIRE EVT shows complexity between areas of decline, growth, and no change. It appears that shrub/scrub has experienced growth, decline, and no change over time. Areas of growth characterize distinct portions of Rock Canyon, Soda Canyon-Mancos River, and Morefield Canyon. The central subwatersheds of Soda Canyon-Mancos River, Morefield Canyon, and Weaver Canyon-Mancos River show another mix of growth, decline, and no change. Eastern subwatersheds including Weber Canyon and Weaver Canyon-Mancos River share an area displaying growth with some decline. This all contrasts with the NLCD data.

Grassland/Herbaceous

Visually, there are major differences for grassland/herbaceous between NLCD and LANDFIRE EVT data (Figure 8). The primary vegetation type of grassland/herbaceous in the study area includes multiple grasses such as muttongrass and cheatgrass.

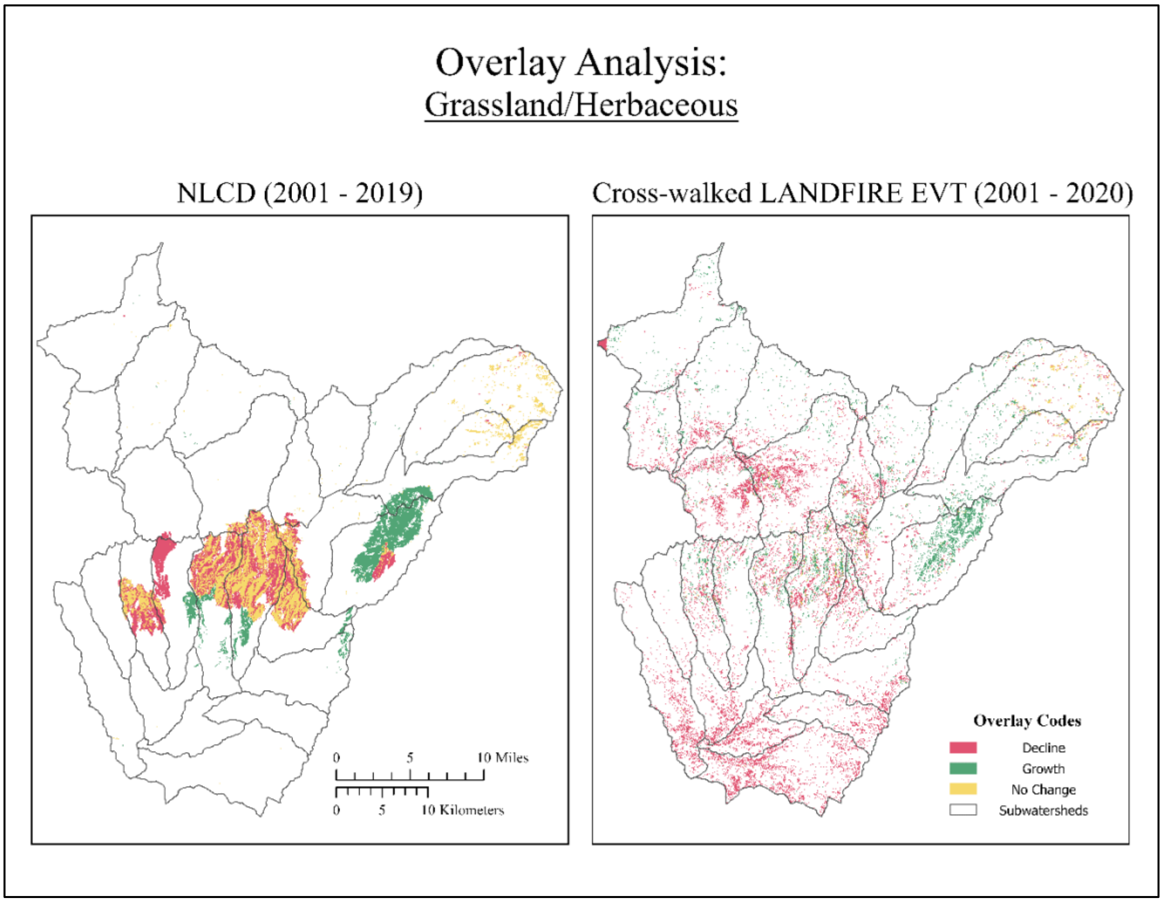

Figure 8: Overlay Analysis: Grassland/Herbaceous

Grassland/herbaceous was the third-largest burnable fuel type by hectares within both the NLCD and LANDFIRE EVT (Table 1). Although the spatial extent of grassland/herbaceous areas is different across datasets, commonalities do exist. Each dataset shows growth within Upper Mancos Valley-Mancos River and Weber Canyon.

The major difference includes the lack of decline or growth shown by NLCD outside of the central subwatersheds.

The western subwatershed of Rock Canyon shows a mixture of no change and decline. Headwaters Navajo Canyon displays clear signatures of decline and growth. The central subwatersheds of Soda Canyon-Mancos River and Morefield Canyon display a majority shared between no change and decline. Growth is clearly defined in the southern reaches of each. Moving eastward, growth is the primary finding across Upper Mancos Valley-Mancos River, Weber Canyon, Weaver Canyon-Mancos River, and Lewis Creek-Mancos River.

LANDFIRE EVT is visually more dispersed across all subwatersheds regarding grassland/herbaceous areas. Across the entire central study area from Rock Canyon, Headwaters Navajo Canyon, Soda Canyon-Mancos River, Morefield Canyon, Weaver Canyon-Mancos River, East Rim-Mancos River, and Weber Canyon a mix of decline and growth is experienced. The largest area of grassland/herbaceous growth is seen in Weber Canyon.

Fires (1989-2021)

The total area burned from 1989 to 2021 (n = 730) totaled 21,918 (ha) (Table 2). The total area burned from 1989 to 2021 by fires larger than 30 acres (n=18) totaled 21,534 (ha) (Table 3). The column 'Fire Count' in each table does not equal the sample size of each fire dataset as some fires occurred in multiple subwatersheds and were counted more than once. The most interesting result is that approximately 400 (ha) is the difference between fire datasets while accounting for total burned areas. This is important as many smaller fires, many as prescribed burns, were recorded. However, the dichotomy between small fires less than 30 acres in size and larger fires bigger than 30 acres is displayed.

Additionally, the overlay analysis results above highlight areas where disturbance events have altered vegetation over time. The change witnessed throughout each dataset highlights a region of disturbances we call the fire belt (Figure 9). The fire belt consists of wildfires larger than 30 acres in size. It excludes any prescribed fires, any fires near Cortez within Upper McElmo Creek watershed, and any fires which primarily burned outside of the HUC-10 boundary. The total area burned of the fire belt was 21,499 (ha).

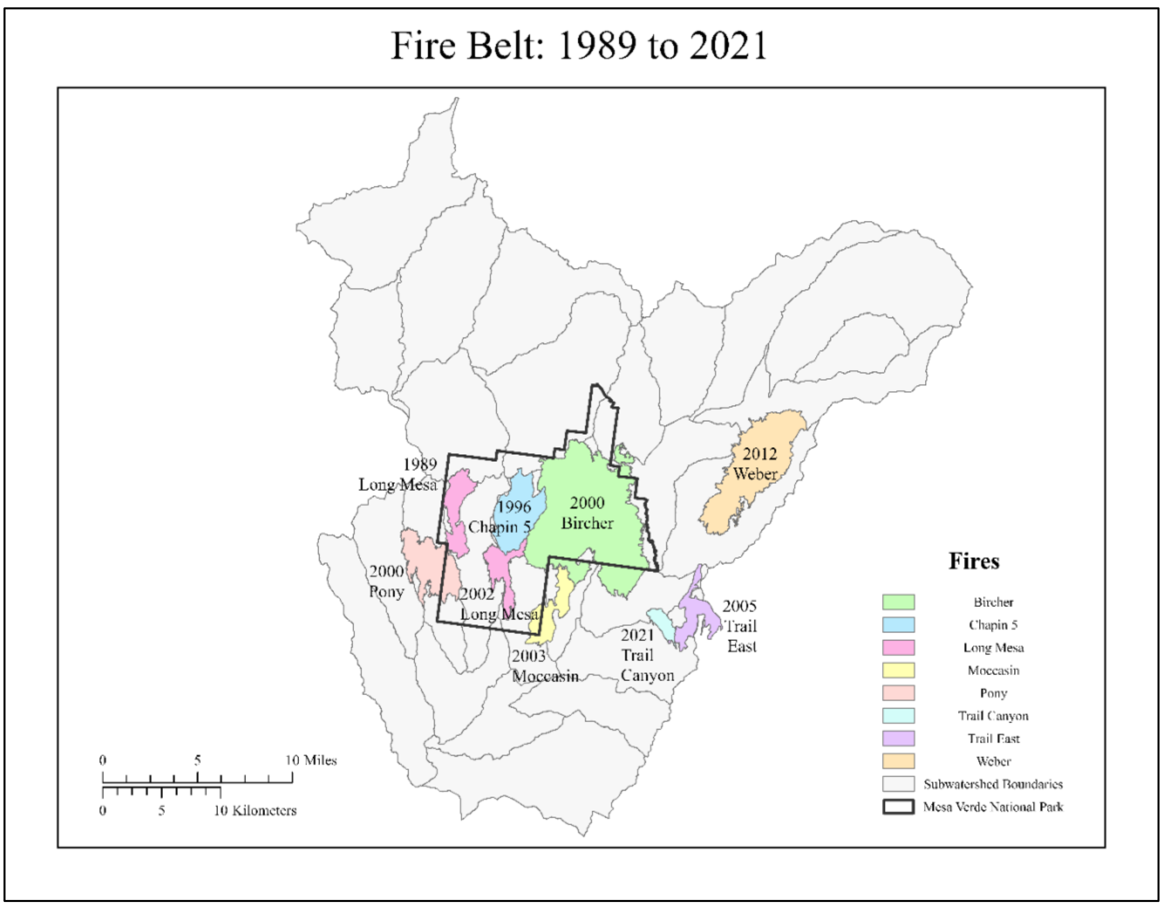

Figure 9: Fire Belt: 1989 to 2021

Table 2

All Burned Areas (1989 – 2021)

Subwatershed	Fire Count	Burned Area (acres)	Burned Area (ha)	Total Area (ha)	Burned Area (ha) (%)
Black Canyon-Mancos River	0	0	0	3,609	0.00%
Chapin Mesa-Mancos River	0	0	0	4,391	0.00%
Chicken Creek	0	0	0	6,659	0.00%
East Fork Mud Creek	0	0	0	5,548	0.00%
East Fork Ute Canyon	2	108	44	4,492	0.98%
East Rim-Mancos River	3	2,599	1,052	6,087	17.28%
Grass Canyon	0	0	0	9,920	0.00%
Hartman Canyon	0	0	0	8,811	0.00%
Headwaters Navajo Canyon	501	4,511	1,825	5,832	31.30%
Highline Ditch-McElmo Creek	3	347	141	7,334	1.92%
Lewis Creek-Mancos River	2	1,938	784	6,151	12.74%
Middle Mancos River	0	0	0	3,211	0.00%
Morefield Canyon	101	13,999	5,665	7,128	79.48%
Mud Creek	24	394	160	4,366	3.65%
Narraguinnep Canyon-Alkali Canyon	0	0	0	9,591	0.00%
Narraguinnep Canyon-McElmo Creek	0	0	0	4,981	0.00%
Outlet Navajo Canyon	30	32	13	4,244	0.30%
Rock Canyon	3	4,128	1,671	5,062	33.00%
Simon Draw	2	365	148	8,766	1.68%
Soda Canyon-Mancos River	81	10,001	4,047	6,986	57.93%
Stinking Springs Canyon	13	751	304	10,912	2.79%
Upper Mancos Valley-Mancos River	1	1,995	806	6,427	12.55%
Ute Canyon-Mancos River	1	16	7	7,706	0.08%
Weaver Canyon-Mancos River	3	4,925	1,993	5,140	38.78%
Weber Canyon	8	8,066	3,260	9,207	35.41%
West Mancos River	0	0	0	11,074	0.00%
Totals	**778**	54,177	**21,918**	173,635	12.62%

Note: Data was obtained from using the National Interagency Fire Center (NIFC, 2022). This table also includes prescribed burns.

Table 3

All Burned Areas by Fires Larger than 30 Acres (1989 – 2021)

Subwatershed	Fire Count	Burned Area (acres)	Burned Area (ha)	Total Area (ha)	Burned Area (ha) (%)
Black Canyon-Mancos River	0	0	0	3,609	0.00%
Chapin Mesa-Mancos River	0	0	0	4,391	0.00%
Chicken Creek	0	0	0	6,659	0.00%
East Fork Mud Creek	0	0	0	5,548	0.00%
East Fork Ute Canyon	1	108	44	4,492	0.97%
East Rim-Mancos River	2	2,582	1,045	6,087	17.17%
Grass Canyon	0	0	0	9,920	0.00%
Hartman Canyon	0	0	0	8,811	0.00%
Headwaters Navajo Canyon	5	3,957	1,601	5,832	27.45%
Highline Ditch-McElmo Creek	2	346	140	7,334	1.91%
Lewis Creek-Mancos River	2	1,938	784	6,151	12.74%
Middle Mancos River	0	0	0	3,211	0.00%
Morefield Canyon	3	13,871	5,614	7,128	78.75%
Mud Creek	2	368	149	4,366	3.41%
Narraguinnep Canyon-Alkali Canyon	0	0	0	9,591	0.00%
Narraguinnep Canyon-McElmo Creek	0	0	0	4,981	0.00%
Outlet Navajo Canyon	0	0	0	4,244	0.00%
Rock Canyon	3	4,128	1,671	5,062	33.00%
Simon Draw	2	365	148	8,766	1.68%
Soda Canyon-Mancos River	5	9,871	3,995	6,986	57.18%
Stinking Springs Canyon	3	745	301	10,912	2.76%
Upper Mancos Valley-Mancos River	1	1,995	806	6,427	12.55%
Ute Canyon-Mancos River	0	0	0	7,706	0.00%
Weaver Canyon-Mancos River	3	4,925	1,993	5,140	38.78%
Weber Canyon	4	8,027	3,244	9,207	35.24%
West Mancos River	0	0	0	11,074	0.00%
Totals	**38**	53,227	**21,534**	173,635	12.40%

Note: Data was obtained from using the National Interagency Fire Center (NIFC, 2022). This table also includes prescribed burns.

Chapter Five

Discussion and Conclusion

NLCD vs Cross-walked LANDFIRE EVT

Although similarities exist between the datasets, these maps tell vastly different stories regarding LULC data. When compared against each other it becomes more important to understand discrepancies and limitations amongst data, to recognize the need for ground-truthing, and to make informed decisions regarding environmental and fire management while utilizing the capabilities of GIS.

Fire Belt and Overlay Analysis

The results obtained from the overlay analysis emphasize the complexity of land cover especially as it occurs in relation to fire. NLCD generally showed far less complexity than LANDFIRE EVT. NLCD was far more manicured looking, as well. The general appearance of LANDFIRE EVT appeared to be far more variable and random. Further analyses could be undertaken to provide evidence upon the dispersal, randomness, or clustering of data.

The process of the overlay analysis specifically examined differences in burnable fuel types between datasets from 2001 to 2019/2020. To contextualize results the fire belt is used (Figure 10, Figure 11, Figure 12). This section highlights the major cartographic differences of the examined burnable fuel types between NLCD and LANDFIRE EVT. This discussion provides valuable insights regarding the fire geography and differences between NLCD and LANDFIRE EVT within MEVE and surrounding subwatersheds.

Discussions of LULC changes are characterized by the fire belt following a west to east progression.

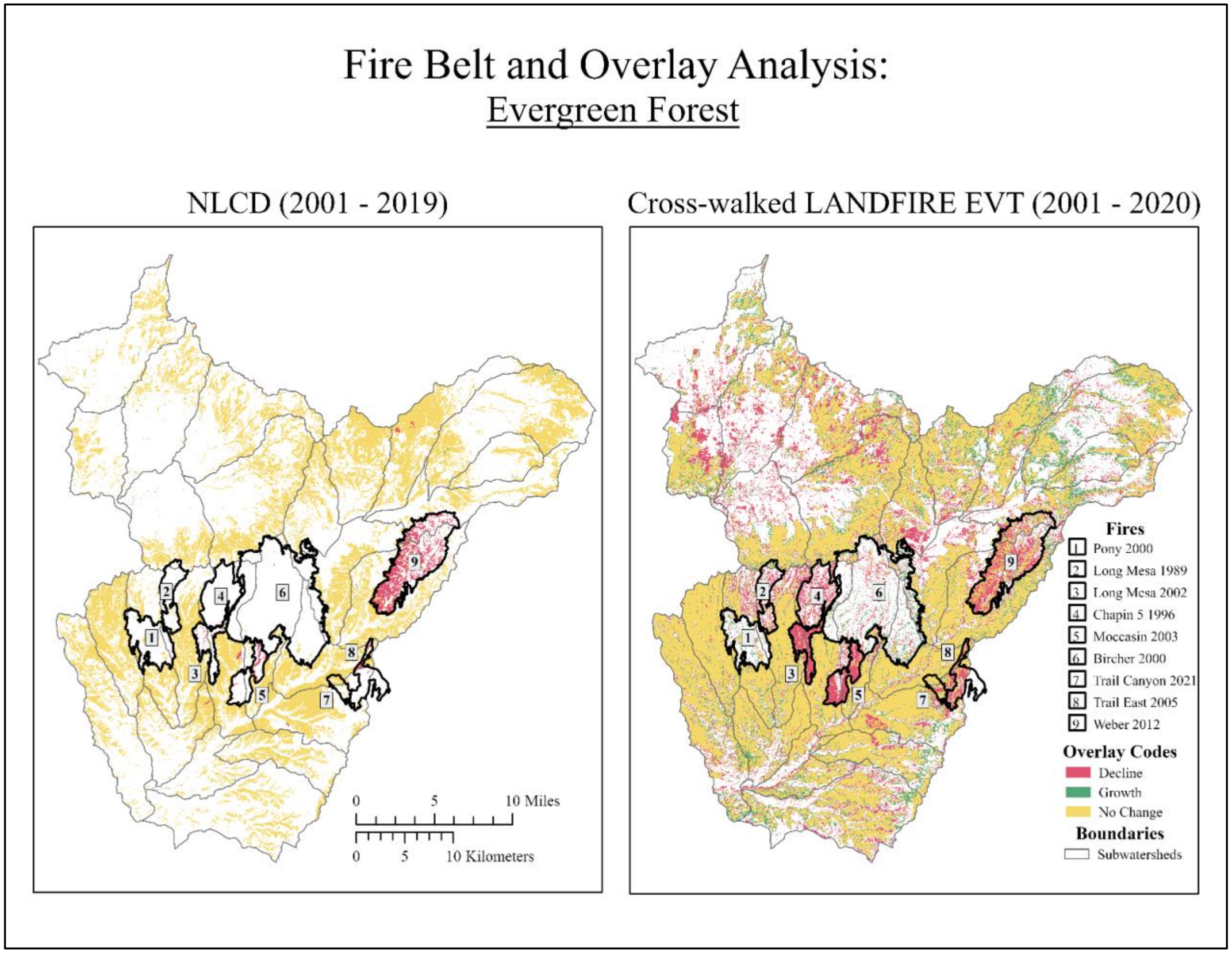

Figure 10: Fire Belt and Overlay Analysis: Evergreen Forest

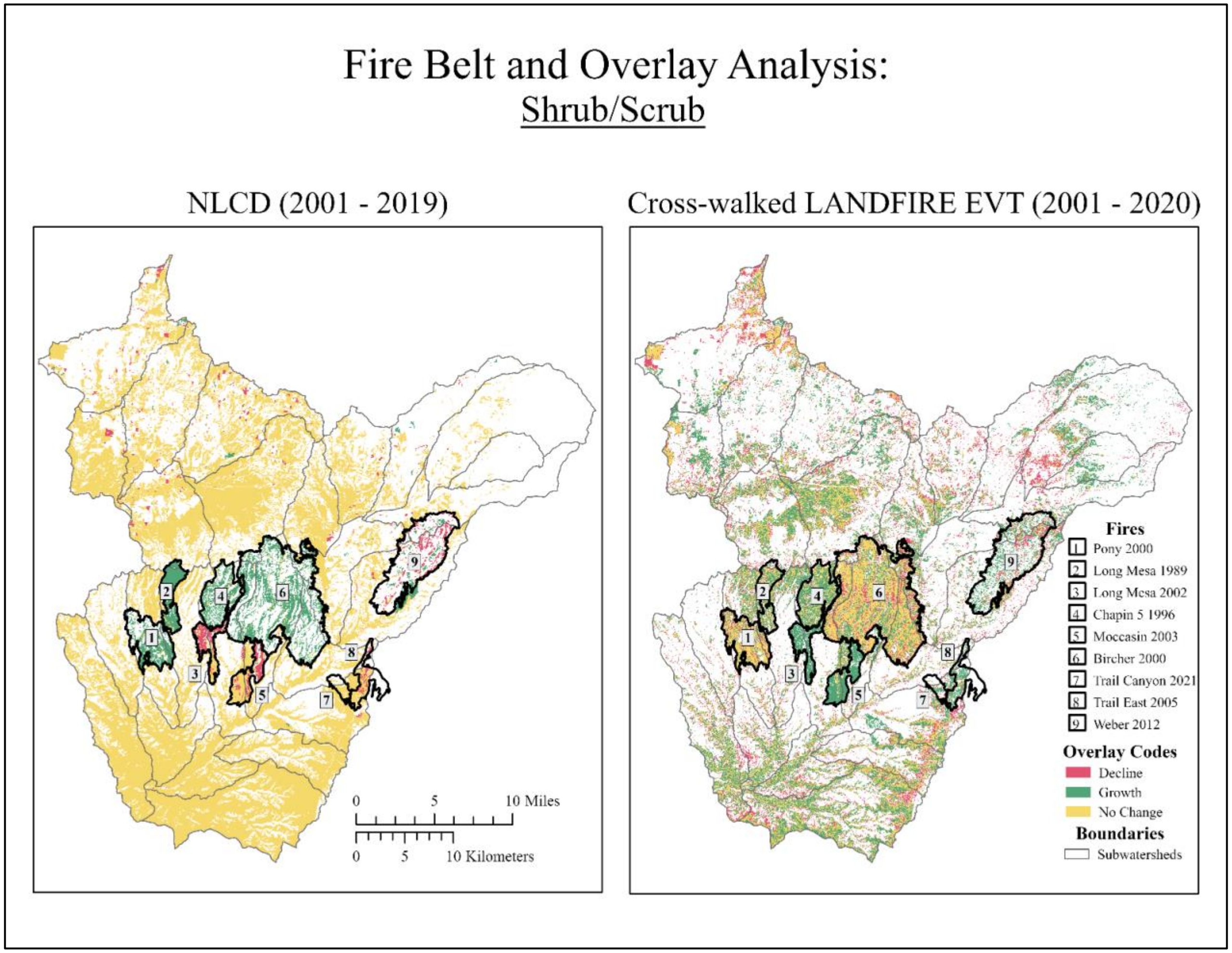

Figure 11: Fire Belt and Overlay Analysis: Shrub/Scrub

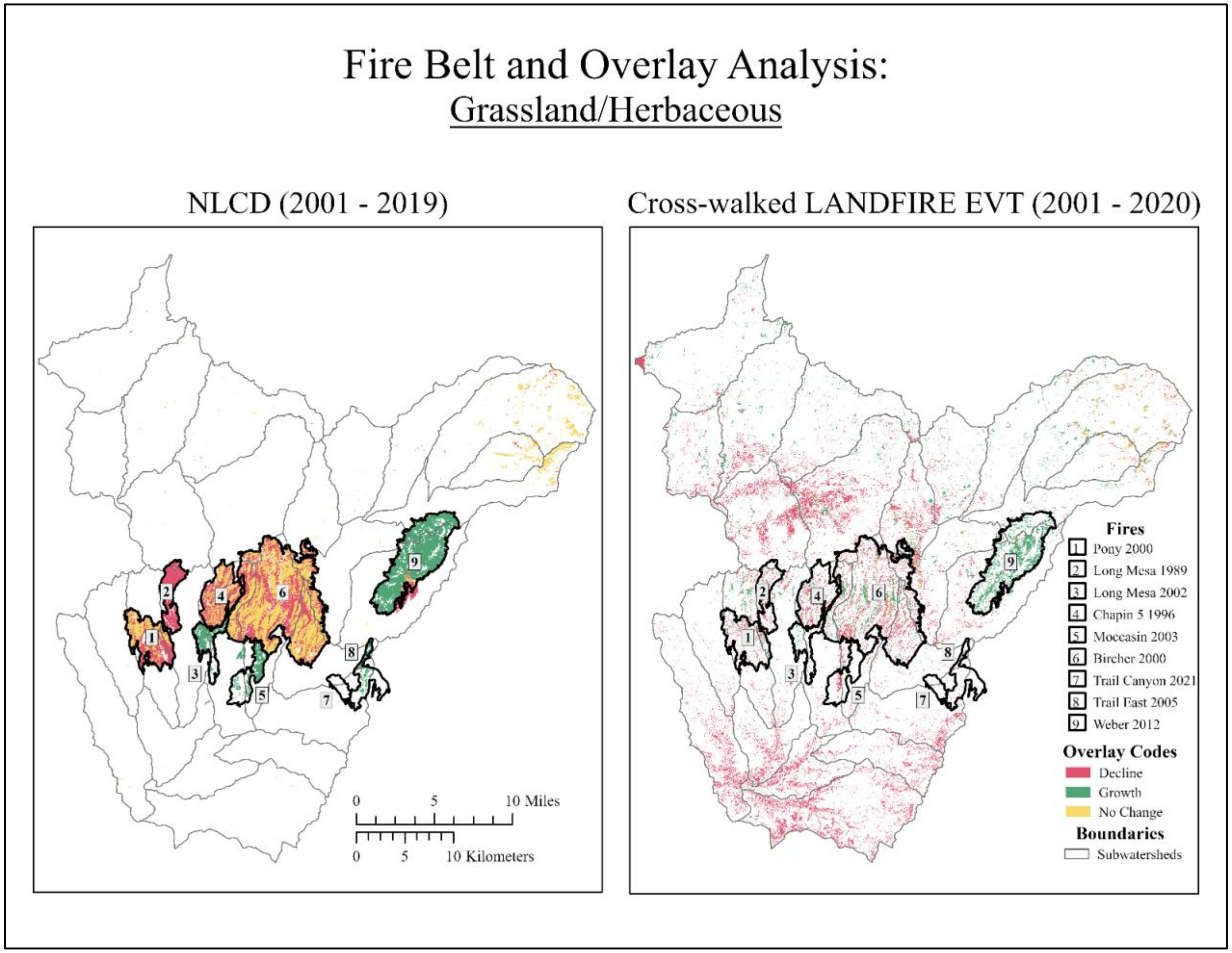

Figure 12: Fire Belt and Overlay Analysis: Grassland/Herbaceous

1. Pony Fire – 2000

The Pony fire affected three subwatersheds including East Fork Ute Canyon, Rock Canyon, and Headwaters Navajo Canyon. The fire also burned portions of land within MEVE. NLCD shows both no change and decline by grassland/herbaceous types. Shrub/scrub growth over time represents successional establishment of this cover type post-fire. Evergreen forests are scarce within the fire burn area. LANDFIRE EVT displays mostly no change in shrub/scrub. Evergreen forests, although scarce, experience a mixture of decline, growth, and no change. Grassland/herbaceous areas experience mostly decline. Nevertheless, each dataset displays a clear effect of the Pony fire. NLCD and LANDFIRE EVT have both similarities and differences between mapping vegetation after the Pony fire.

2. Long Mesa Fire – 1989

The Long Mesa fire of 1989 spanned Rock Canyon, Highline Ditch-McElmo Creek, and Headwaters Navajo Canyon subwatersheds. This fire also burned areas within MEVE. NLCD exhibits the near-complete loss of the grassland/herbaceous cover type. Shrub/scrub experiences near-complete growth during the same period. This may be due to successional growth and limited disturbances. NLCD mostly displays no data for evergreen forests. In comparison, LANDFIRE EVT displays similar growth and no change within shrub/scrub. More decline is witnessed within evergreen forest than grassland/herbaceous cover types. Each cover type within each dataset displays a unique cartographic representation of the fire. This is likely because the fire was 12 years before 2001, making delineations between datasets more difficult. NLCD and LANDFIRE EVT experience a mix of similar and divergent results depicting vegetation decline, growth, and stationarity after the Long Mesa fire of 1989.

3. Long Mesa Fire – 2002

The Long Mesa fire of 2002 burned areas within Headwaters Navajo Canyon and Soda Canyon-Mancos River subwatersheds. This fire also burned portions within MEVE. NLCD shows mostly decline and no change within shrub/scrub. Grassland/herbaceous subsequently shows growth throughout the fire area. Little data is available for evergreen forests within the area of this fire. LANDFIRE EVT is almost completely showing decline for evergreen forest. Shrub/scrub is seen as having heavy growth. Grassland/herbaceous is seen having growth within the area, but it is sparse. A clearly defined burn area is shown by each dataset. The effects of this fire are represented in notably different ways across each dataset after the Long Mesa fire of 2002.

4. Chapin 5 Fire – 1996

The Chapin 5 fire burned within Stinking Springs Canyon, Soda Canyon-Mancos River, and just barely within Headwaters Navajo Canyon subwatersheds. This fire also burned within MEVE. NLCD shows decline and no change of grassland/herbaceous. It then displays considerable growth within shrub/scrub. According to NLCD evergreen forest is not prevalent in the area. LANDFIRE EVT displays considerable decline of evergreen forest, moderate decline of grassland/herbaceous, and growth of shrub/scrub. Although each dataset represents the growth of shrub/scrub to a similar degree, discrepancies between the decline of evergreen forest is a major difference across the datasets after the Chapin 5 fire.

5. Moccasin Fire – 2003

The Moccasin fire burned areas within Soda Canyon-Mancos River and Morefield Canyon subwatersheds. This fire also burned a portion within MEVE. NLCD displays shrub/scrub as having predominately declined and having experienced no change for most of the area. Shrub/scrub growth is seen within the northern reach of the fire area. Evergreen forest experiences some decline in the northern reach. LANDFIRE EVT predominately displays decline in evergreen forest, limited decline of grassland/herbaceous, and a majority of shrub/scrub growth throughout the fire area. Major discrepancies exist between datasets regarding the representation of vegetation after the Moccasin fire.

6. Bircher Fire – 2000

The Bircher fire is the largest fire within the fire belt and burned mostly within MEVE. This fire spread across Soda Canyon-Mancos River, Morefield Canyon, Weaver Canyon-Mancos River, Stinking Springs Canyon, Mud Creek, and East Rim-Mancos River subwatersheds. NLCD shows a mix of no change and decline of grasslands/herbaceous area. The areas of decline were successionally replaced by shrub/scrub. Evergreen forest was nearly non-existent within the fire area. LANDFIRE EVT is far more variable. Shrub/scrub is the dominant vegetation type which experienced no change, decline, and growth. Grassland/herbaceous areas experienced decline and growth. Evergreen forest also contributed decline and growth to the area but not to the same degree as grassland/herbaceous. Ultimately, vegetation is represented differently across the watersheds by each dataset.

7. ***Trail Canyon Fire – 2021***

The Trail Canyon fire burned and was split across Weaver Canyon-Mancos River to the north and Lewis Creek-Mancos River to the south. Importantly, this fire did not burn any area within MEVE. NLCD displayed a mix of no change for both evergreen forest and shrub/scrub. Grassland/herbaceous was not present in the area. Interestingly, no decline or growth was apparent in any of the burnable fuel types for NLCD. LANDFIRE EVT had similar but unique results regarding evergreen forest. The northern subwatershed (Weaver Canyon-Mancos River) experienced mostly no change in evergreen forest. The southern watershed (Lewis Creek-Mancos River) saw a split between decline and no change of evergreen. Shrub/scrub experienced a band of growth across the Lewis Creek-Mancos River. Grassland/herbaceous was largely nonexistent within the area. Similarities are prevalent between each dataset in representing vegetation after the Trail Canyon fire. Discrepancies are also present but are not as prominent as in other areas. Additionally, as this fire burned outside of the data collection window (2001 – 2020) it is possible the changes seen could be due to other fires or other disturbances.

8. Trail East Fire – 2005

The Trail East fire burned areas within Weber Canyon, Weaver Canyon-Mancos River, and Lewis Creek-Mancos River. This fire also did not burn within MEVE. NLCD shows shrub/scrub as being mixed throughout the area with mostly no change and decline, grassland/herbaceous showing growth, and evergreen forest displaying only a small amount of decline in the northern reaches. LANDFIRE EVT shows mostly decline in evergreen forest, growth by shrub/scrub, and little data is associated with grassland/herbaceous. Major discrepancies exist for burnable fuels across datasets where the Trail East fire burned.

9. Weber Fire – 2012

The Weber fire burned areas within Weber Canyon, Upper Mancos Valley-Mancos River, and East Rim-Mancos River subwatersheds. It is important to state that this fire did not burn within MEVE. NLCD represents evergreen forest as having large amounts of decline, shrubs as having mixed growth and decline, and grassland/herbaceous as having considerable growth with some decline. LANDFIRE EVT represents evergreen as having mostly a decline in evergreen forest, a mix of growth and decline in shrub/scrub, and a majority of growth in grassland/herbaceous. There are similarities between datasets accounting for the vegetation before and after the Weber fire.

Overall, it seems that differences between NLCD and LANDFIRE EVT were cartographically significant. Generally, the differences experienced were significant by the contrasting information being displayed by each dataset for each burnable fuel. One reason for these massive differences may be attributable to advances in imagery collection and classification techniques. Change in LANDFIRE EVT does not concentrate on areas of previous fires as much as NLCD.

Much of these areas showing decline and growth have been associated with fire at some point since 1989. It may be that some grasses burned and returned to grassland/herbaceous land cover and stayed that way. It may also be that grasses burned, were replaced by new grasses, and eventually successionally transitioned to shrub/scrub or young evergreen forest. This might explain the changes in grassland/herbaceous land cover due to most of the recorded large fires (>30 acres) occurring before 2012.

Future Research

Future research possibilities working with these datasets around MEVE are abundant. There is potential to ground truth forests, shrublands, and grasslands via sampling points and using methods such as repeat photography. More statistics could be generated looking at change within burnable fuels and other cover types. The utilization of Multi-Distance Spatial Cluster Analysis (Ripley's K Function), Average Nearest Neighbor, and Hot Spot Analysis (Getis-Ord Gi*) could help explain patterns within the LULC data. More fire data could be used to fill the gaps and help to understand the fire geography of MEVE to a better degree. Finally, as MEVE is a cultural World Heritage Site, future research could include the proximity/density analysis of archaeological sites to fires.

Chapter Six

Conclusion

LANDFIRE's purpose in aiding fire management is different than NLCD's purpose in describing land cover characteristics and land cover change over time. The process of cross-walking LANDFIRE data has previously been accomplished by way of using expert opinion (McKerrow et al., 2016), but ultimately is subjective in nature. The expert making choices for the crosswalk may choose differently than another expert, as the naming conventions are justifiably tedious and complex. This issue of non-standardization is a critical component to improving the efforts of cross-walking. It may be of use if developers of LANDFIRE EVT and other data products worked alongside developers of NLCD to produce an attribute value for cross-walking in the future.

For most users, one LULC dataset should be enough. Having two datasets which produce different results complicates the utility between each. It presents a challenge to the user which may suggest one dataset being more useful than another. It may be beneficial to users if developers of NLCD and LANDFIRE products worked more closely together in the future.

Strengths and Weaknesses of Study

The strengths of this study include:

- The power of seeing LANDFIRE at a more manageable scale;
- The ability to visualize land cover change within known fire areas;
- Visual evidence of the differences between NLCD and cross-walked LANDFIRE EVT.

Weaknesses of this study include:

- Complex standardization issues between NLCD and LANDFIRE EVT require more time and detailed classification efforts;
- Lack of ground truthing information within the study area;
- Large gaps within fire dataset;
- Vegetation growth and decline may be influenced by factors other than fire like drought, precipitation levels, herbivory, and elevation.

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Appendices

Appendix A: LANDFIRE EVT Cross-walked Values

Based on McKerrow et al (2016)

*= Decision had to be made by myself as no clear classification could be easily obtained; asteriks are deleted once moved to word document.

2001 LANDFIRE EVT Crosswalk

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=IF(D2= "Open Water", 11,
 IF(D2= "Developed-Upland Deciduous Forest", 21*,
 IF(D2= "Developed-Upland Evergreen Forest", 21*,
 IF(D2= "Developed-Upland Mixed Forest", 21*,
 IF(D2= "Developed-Upland Herbaceous", 21*,
 IF(D2= "Developed-Upland Shrubland", 21*,
 IF(D2= "Developed-Medium Intensity", 21,
 IF(D2= "Developed-High Intensity", 21,
 IF(D2= "Developed-Roads", 21,
 IF(D2= "Barren", 31,
 IF(D2= "NASS-Row Crop-Close Grown Crop", 82,
 IF(D2= "NASS-Row Crop", 82,
 IF(D2= "NASS-Close Grown Crop", 82,
 IF(D2= "NASS-Fallow/Idle Cropland", 82,
 IF(D2= "Herbaceous Semi-dry", 71*,
 IF(D2= "Herbaceous Semi-wet", 71*,
 IF(D2= "Recently Disturbed Forest", 71*,
 IF(D2= "Agriculture-Pasture and Hay", 81,
 IF(D2= "Agriculture-Cultivated Crops and Irrigated Agriculture", 81,
 IF(D2= "Herbaceous Wetlands", 95,
 IF(D2= "Inter-Mountain Basins Sparsely Vegetated Systems", 31,
 IF(D2= "Rocky Mountain Alpine/Montane Sparsely Vegetated Systems", 31,
 IF(D2= "Rocky Mountain Aspen Forest and Woodland", 41,
 IF(D2= "Colorado Plateau Pinyon-Juniper Woodland", 42,
 IF(D2= "Rocky Mountain Foothill Limber Pine-Juniper Woodland", 42,
 IF(D2= "Rocky Mountain Lodgepole Pine Forest", 42,
 IF(D2= "Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland", 42,
 IF(D2= "Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland", 42,
 IF(D2= "Southern Rocky Mountain Ponderosa Pine Woodland", 42,
 IF(D2= "Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland", 42,
 IF(D2= "Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland", 42,
 IF(D2= "Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland", 42,
 IF(D2= "Southern Rocky Mountain Pinyon-Juniper Woodland", 42,
 IF(D2= "Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland", 43,
 IF(D2= "Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland", 41*,
 IF(D2= "Colorado Plateau Mixed Low Sagebrush Shrubland", 52,
 IF(D2= "Inter-Mountain Basins Mat Saltbush Shrubland", 52,
 IF(D2= "Rocky Mountain Alpine Dwarf-Shrubland", 52,
 IF(D2= "Inter-Mountain Basins Big Sagebrush Shrubland", 52,
 IF(D2= "Inter-Mountain Basins Mixed Salt Desert Scrub", 52,
 IF(D2= "Rocky Mountain Lower Montane-Foothill Shrubland", 52,
 IF(D2= "Southern Colorado Plateau Sand Shrubland", 52,
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IF(D2= "Great Basin Semi-Desert Chaparral", 52,
IF(D2= "Mogollon Chaparral", 52,
IF(D2= "Rocky Mountain Gambel Oak-Mixed Montane Shrubland", 52,
IF(D2= "Inter-Mountain Basins Juniper Savanna", 42,
IF(D2= "Southern Rocky Mountain Ponderosa Pine Savanna", 42,
IF(D2= "Southern Rocky Mountain Juniper Woodland and Savanna", 42,
IF(D2= "Inter-Mountain Basins Big Sagebrush Steppe", 52,
IF(D2= "Inter-Mountain Basins Montane Sagebrush Steppe", 52,
IF(D2= "Inter-Mountain Basins Semi-Desert Shrub-Steppe", 52,
IF(D2= "Inter-Mountain Basins Semi-Desert Grassland", 71,
IF(D2= "Rocky Mountain Alpine Turf", 71,
IF(D2= "Rocky Mountain Subalpine-Montane Mesic Meadow", 71,
IF(D2= "Southern Rocky Mountain Montane-Subalpine Grassland", 71,
IF(D2= "Inter-Mountain Basins Greasewood Flat", 52,
IF(D2= "Rocky Mountain Montane Riparian Systems", 43,
IF(D2= "Rocky Mountain Subalpine/Upper Montane Riparian Systems", 43*,
IF(D2= "Introduced Riparian Vegetation", 43*,
IF(D2= "Introduced Upland Vegetation-Annual Grassland", 71,
IF(D2= "Introduced Upland Vegetation-Perennial Grassland and Forbland", 71,
IF(D2= "Introduced Upland Vegetation-Annual and Biennial Forbland", 71,
IF(D2= "Coleogyne ramosissima Shrubland Alliance", 52,
IF(D2= "Arctostaphylos patula Shrubland Alliance", 52,
IF(D2= "Quercus gambelii Shrubland Alliance", 52,
IF(D2= "Artemisisa tridentata ssp. vaseyana Shrubland Alliance", 52

2020 LANDFIRE EVT Crosswalk

=IF(F2="Rocky Mountain Aspen Forest and Woodland", 41,
IF(F2="Colorado Plateau Pinyon-Juniper Woodland", 42,
IF(F2="Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland", 42,
IF(F2="Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland", 42,
IF(F2="Southern Rocky Mountain Ponderosa Pine Woodland", 42,
IF(F2="Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland", 42,
IF(F2="Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland", 42,
IF(F2="Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland", 42,
IF(F2="Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland", 43,
IF(F2="Colorado Plateau Mixed Low Sagebrush Shrubland", 52,
IF(F2="Inter-Mountain Basins Mat Saltbush Shrubland", 52,
IF(F2="Rocky Mountain Alpine Dwarf-Shrubland", 52,
IF(F2="Inter-Mountain Basins Big Sagebrush Shrubland", 52,
IF(F2="Inter-Mountain Basins Mixed Salt Desert Scrub", 52,
IF(F2="Rocky Mountain Lower Montane-Foothill Shrubland", 52,
IF(F2="Southern Colorado Plateau Sand Shrubland", 52,
IF(F2="Colorado Plateau Pinyon-Juniper Shrubland", 52,
IF(F2="Rocky Mountain Gambel Oak-Mixed Montane Shrubland", 52,
IF(F2="Southern Rocky Mountain Ponderosa Pine Savanna", 42,
IF(F2="Inter-Mountain Basins Montane Sagebrush Steppe", 52,
IF(F2="Inter-Mountain Basins Semi-Desert Shrub-Steppe", 52,
IF(F2="Inter-Mountain Basins Semi-Desert Grassland", 71,
IF(F2="Rocky Mountain Alpine Fell-Field", 71,
IF(F2="Rocky Mountain Alpine Turf", 71,
IF(F2="Rocky Mountain Subalpine-Montane Mesic Meadow", 71,
IF(F2="Southern Rocky Mountain Montane-Subalpine Grassland", 71,

IF(F2="Inter-Mountain Basins Greasewood Flat", 52,
IF(F2="Open Water", 11,
IF(F2="Quarries-Strip Mines-Gravel Pits-Well and Wind Pads", 31,
IF(F2="Developed-Low Intensity", 22,
IF(F2="Developed-Medium Intensity", 23,
IF(F2="Developed-High Intensity", 24,
IF(F2="Developed-Roads", 23,
IF(F2="Western Cool Temperate Urban Deciduous Forest", 21,
IF(F2="Western Cool Temperate Urban Evergreen Forest", 21,
IF(F2="Western Cool Temperate Urban Mixed Forest", 21,
IF(F2="Western Cool Temperate Urban Herbaceous", 21,
IF(F2="Western Cool Temperate Urban Shrubland", 21,
IF(F2="Western Cool Temperate Developed Deciduous Forest", 41,
IF(F2="Western Cool Temperate Developed Evergreen Forest", 42,
IF(F2="Western Cool Temperate Developed Mixed Forest", 43,
IF(F2="Western Cool Temperate Developed Shrubland", 52,
IF(F2="Western Cool Temperate Developed Herbaceous", 71,
IF(F2="Western Cool Temperate Row Crop - Close Grown Crop", 82,
IF(F2="Western Cool Temperate Row Crop", 82,
IF(F2="Western Cool Temperate Close Grown Crop", 82,
IF(F2="Western Cool Temperate Fallow/Idle Cropland", 82,
IF(F2="Western Cool Temperate Pasture and Hayland", 81,
IF(F2="Western Cool Temperate Wheat", 82,
IF(F2="Colorado Plateau Mixed Bedrock Canyon and Tableland", 31,
IF(F2="Inter-Mountain Basins Shale Badland", 31,
IF(F2="North American Arid West Emergent Marsh", 95,
IF(F2="Rocky Mountain Alpine Bedrock and Scree", 31,
IF(F2="Rocky Mountain Alpine-Montane Wet Meadow", 71,
IF(F2="Rocky Mountain Cliff Canyon and Massive Bedrock", 31,
IF(F2="Rocky Mountain Lower Montane-Foothill Riparian Woodland", 43,
IF(F2="Rocky Mountain Subalpine-Montane Riparian Shrubland", 52,
IF(F2="Rocky Mountain Subalpine-Montane Riparian Woodland", 43,
IF(F2="Great Basin and Intermountain Introduced Annual and Biennial Forbland", 71,
IF(F2="Great Basin and Intermountain Introduced Annual Grassland", 71,
IF(F2="Great Basin and Intermountain Introduced Perennial Grassland and Forbland", 71,
IF(F2="Interior West Ruderal Riparian Forest", 43,
IF(F2="Interior Western North American Temperate Ruderal Shrubland", 52,
IF(F2="Western North American Ruderal Wet Shrubland", 52,
IF(F2="Great Basin and Intermountain Ruderal Shrubland", 52,
IF(F2="Rocky Mountain Lower Montane-Foothill Riparian Shrubland", 52,
IF(F2="Interior West Ruderal Riparian Scrub", 52,
IF(F2="Interior Western North American Temperate Ruderal Grassland", 71,
IF(F2="Western North American Ruderal Wet Meadow and Marsh", 95

Appendix B: Burnable Fuels Tables

Appendix B1

Available Burnable Fuels by Subwatershed – NLCD 2001

Watershed	Burnable Fuels (ha)	Total Area (ha)	Burnable Fuels (%)
Black Canyon-Mancos River	3,530	3,609	97.81%
Chapin Mesa-Mancos River	4,342	4,391	98.89%
Chicken Creek	3,973	6,659	59.66%
East Fork Mud Creek	5,121	5,548	92.31%
East Fork Ute Canyon	4,409	4,492	98.16%
East Rim-Mancos River	4,494	6,087	73.83%
Grass Canyon	9,916	9,920	99.97%
Hartman Canyon	4,741	8,811	53.81%
Headwaters Navajo Canyon	5,337	5,832	91.51%
Highline Ditch-McElmo Creek	5,401	7,334	73.64%
Lewis Creek-Mancos River	5,965	6,151	96.98%
Middle Mancos River	1,005	3,211	31.30%
Morefield Canyon	6,904	7,128	96.85%
Mud Creek	3,967	4,366	90.85%
Narraguinnep Canyon-Alkali Canyon	4,354	9,591	45.39%
Narraguinnep Canyon-McElmo Creek	3,979	4,981	79.88%
Outlet Navajo Canyon	4,237	4,244	99.83%
Rock Canyon	4,779	5,062	94.43%
Simon Draw	5,919	8,766	67.53%
Soda Canyon-Mancos River	6,710	6,986	96.05%
Stinking Springs Canyon	10,429	10,912	95.57%
Upper Mancos Valley-Mancos River	2,673	6,427	41.59%
Ute Canyon-Mancos River	7,678	7,706	99.64%
Weaver Canyon-Mancos River	5,032	5,140	97.89%
Weber Canyon	6,868	9,207	74.59%
West Mancos River	5,098	11,074	46.03%
Totals	136,862	173,635	78.82%

Note: Burnable fuels include Evergreen Forest (42), Shrub/scrub (52), and Grassland/herbaceous (71)

Appendix B2

Available Burnable Fuels by Subwatershed – LANDFIRE 2001

Watershed	Burnable Fuels (ha)	Total Area (ha)	Burnable Fuels (%)
Black Canyon-Mancos River	3,542	3,609	98.15%
Chapin Mesa-Mancos River	4,314	4,391	98.23%
Chicken Creek	3,942	6,659	59.20%
East Fork Mud Creek	4,467	5,548	80.51%
East Fork Ute Canyon	4,435	4,492	98.75%
East Rim-Mancos River	4,370	6,087	71.78%
Grass Canyon	9,878	9,920	99.58%
Hartman Canyon	4,431	8,811	50.29%
Headwaters Navajo Canyon	5,615	5,832	96.27%
Highline Ditch-McElmo Creek	5,487	7,334	74.81%
Lewis Creek-Mancos River	6,047	6,151	98.31%
Middle Mancos River	1,221	3,211	38.02%
Morefield Canyon	7,008	7,128	98.31%
Mud Creek	4,077	4,366	93.38%
Narraguinnep Canyon-Alkali Canyon	4,009	9,591	41.80%
Narraguinnep Canyon-McElmo Creek	3,942	4,981	79.14%
Outlet Navajo Canyon	4,217	4,244	99.37%
Rock Canyon	4,957	5,062	97.93%
Simon Draw	5,294	8,766	60.39%
Soda Canyon-Mancos River	6,721	6,986	96.20%
Stinking Springs Canyon	10,420	10,912	95.49%
Upper Mancos Valley-Mancos River	3,040	6,427	47.30%
Ute Canyon-Mancos River	7,634	7,706	99.07%
Weaver Canyon-Mancos River	5,083	5,140	98.88%
Weber Canyon	8,169	9,207	88.73%
West Mancos River	5,519	11,074	49.84%
Totals	137,839	173,635	79.38%

Note: Burnable fuels include Evergreen Forest (42), Shrub/scrub (52), and Grassland/herbaceous (71)

Appendix B3

Available Burnable Fuels by Subwatershed – NLCD 2019

Watershed	Burnable Fuels (ha)	Total Area (ha)	Burnable Fuels (%)
Black Canyon-Mancos River	3,530	3,609	97.82%
Chapin Mesa-Mancos River	4,342	4,391	98.89%
Chicken Creek	3,973	6,659	59.51%
East Fork Mud Creek	5,121	5,548	91.66%
East Fork Ute Canyon	4,409	4,492	98.16%
East Rim-Mancos River	4,494	6,087	73.88%
Grass Canyon	9,916	9,920	99.97%
Hartman Canyon	4,741	8,811	53.12%
Headwaters Navajo Canyon	5,337	5,832	91.55%
Highline Ditch-McElmo Creek	5,401	7,334	72.41%
Lewis Creek-Mancos River	5,965	6,151	96.81%
Middle Mancos River	1,005	3,211	31.27%
Morefield Canyon	6,904	7,128	96.93%
Mud Creek	3,967	4,366	90.17%
Narraguinnep Canyon-Alkali Canyon	4,354	9,591	43.86%
Narraguinnep Canyon-McElmo Creek	3,979	4,981	78.51%
Outlet Navajo Canyon	4,237	4,244	99.83%
Rock Canyon	4,779	5,062	94.43%
Simon Draw	5,919	8,766	66.24%
Soda Canyon-Mancos River	6,710	6,986	96.16%
Stinking Springs Canyon	10,429	10,912	95.32%
Upper Mancos Valley-Mancos River	2,673	6,427	47.68%
Ute Canyon-Mancos River	7,678	7,706	99.64%
Weaver Canyon-Mancos River	5,032	5,140	98.23%
Weber Canyon	6,868	9,207	81.96%
West Mancos River	5,098	11,074	45.96%
Totals	137,366	173,635	79.11%

Note: Burnable fuels include Evergreen Forest (42), Shrub/scrub (52), and Grassland/herbaceous (71)

Appendix B4

Available Burnable Fuels by Subwatershed – LANDFIRE 2020

Watershed	Burnable Fuels (ha)	Total Area (ha)	Burnable Fuels (%)
Black Canyon-Mancos River	3,421	3,609	94.78%
Chapin Mesa-Mancos River	4,299	4,391	97.91%
Chicken Creek	4,508	6,659	67.70%
East Fork Mud Creek	4,549	5,548	81.99%
East Fork Ute Canyon	4,486	4,492	99.86%
East Rim-Mancos River	4,100	6,087	67.36%
Grass Canyon	9,858	9,920	99.38%
Hartman Canyon	3,687	8,811	41.85%
Headwaters Navajo Canyon	5,714	5,832	97.97%
Highline Ditch-McElmo Creek	4,980	7,334	67.91%
Lewis Creek-Mancos River	5,855	6,151	95.19%
Middle Mancos River	1,696	3,211	52.82%
Morefield Canyon	6,874	7,128	96.43%
Mud Creek	3,673	4,366	84.12%
Narraguinnep Canyon-Alkali Canyon	3,440	9,591	35.87%
Narraguinnep Canyon-McElmo Creek	3,618	4,981	72.63%
Outlet Navajo Canyon	4,212	4,244	99.24%
Rock Canyon	5,029	5,062	99.35%
Simon Draw	4,762	8,766	54.33%
Soda Canyon-Mancos River	6,771	6,986	96.91%
Stinking Springs Canyon	10,258	10,912	94.01%
Upper Mancos Valley-Mancos River	3,311	6,427	51.51%
Ute Canyon-Mancos River	7,583	7,706	98.41%
Weaver Canyon-Mancos River	5,071	5,140	98.64%
Weber Canyon	8,414	9,207	91.38%
West Mancos River	6,363	11,074	57.47%
Totals	136,532	173,635	78.63%

Note: Burnable fuels include Evergreen Forest (42), Shrub/scrub (52), and Grassland/herbaceous (71)