Evaluating the Relationship between Colorado Elk Hunting Success and Terrain Ruggedness

by

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In memory of my grandmother, Frankye Driggers
1938 - 2016

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List of Abbreviations

ATV	All-Terrain Vehicle
BLM	Bureau of Land Management
CDOT	Colorado Department of Transportation
CPW	Colorado Division of Wildlife
DAU	Data Analysis Unit
DEM	Digital Elevation Model
LSRI	Land Surface Ruggedness Index
OLE DB	Object Linking and Embedding Database
OLS	Ordinary Least Squares
OTC	Over-the-Counter License
RDPH	Recreational Days per Hunter
RMNP	Rocky Mountain National Park
TRI	Terrain Ruggedness Index
USGS	United States Geological Survey
VRM	Vector Ruggedness Measure

Abstract

Colorado is a popular destination for elk hunters. Despite ample opportunities, success rates for elk hunters in Colorado are often low – the combined success rate for all 2016 Colorado elk hunting seasons was only 18 percent. Many variables seem likely to have an impact on hunter success; one possibility is terrain ruggedness. The main research question of this study is whether more rugged topography is correlated with hunter success rates. Such a finding could benefit hunters by showing which areas have higher harvest success rates. Furthermore, this study could benefit wildlife management communities by illustrating which areas need an increase or decrease in hunting licenses in addition to changes in season structure.

Since location of elk harvests are not consistently mapped, regression analysis was utilized to explain spatial patterns. Using ArcMap, this study examines the correlation between terrain ruggedness and hunter success for the 93 Game Management Units (GMU) that offer over-the-counter (OTC) second and third rifle season hunting licenses. The 2012 to 2016 seasons were analyzed in order to account for variation in weather patterns and differences in the number of hunting licenses issued. Average annual GMU success rate was the dependent variable while average elk density, terrain ruggedness, average hunter density, percent of public land, and road density were the exploratory variables. Terrain ruggedness was not a significant variable. Average elk density and public land percentage were the only two significant variables. Future studies should analyze each year separately, analyze public land hunters that hunted OTC rifle seasons, and consider weather variables.

Chapter 1 Introduction

Colorado is one of the first states hunters consider when deciding where to hunt Rocky Mountain Elk (Wapiti, *Cervus canadensis nelson*). Colorado has the highest elk population in North America, the most elk hunters, unlimited over-the-counter (OTC) nonresident licenses, and an abundance of public land. Hunters can choose from many different types of terrain and weather for their hunting trip. This study evaluated the ruggedness of Colorado's Game Management Units (GMU) with OTC rifle second and third seasons against hunter success in order to determine if terrain ruggedness has a negative impact on hunter success.

1.1. Elk Hunting Management

1.1.1. Season Structure

Due to the demand for elk hunting, Colorado Parks and Wildlife (CPW) permits archery, muzzleloader (a firearm in which a projectile and propellant are loaded from the forward, open end of the rifle's barrel), and four separate rifle seasons for elk. Colorado's season structure is designed to help distribute hunting pressure and ensure quality experiences for more hunters (Allan 2017). Table 1 lists the opening and closing dates for Colorado's 2016 elk hunting seasons. The opening and closing dates for the previous four years of this study occurred during the same weeks.

Table 1. Colorado's 2016 elk seasons and dates

Season	Opening and Closing Dates
Archery	Aug. 27 - Sept. 25
Muzzleloader	Sept. 10 - Sept. 18
First Rile	Oct. 15 - Oct. 19
Second Rifle	Oct. 22 - Oct. 30
Third Rifle	Nov. 5 - Nov. 13
Fourth Rifle	Nov. 16 - Nov. 20

Colorado's earliest elk hunting season is the 30-day archery season. Many GMUs are open for archery hunting with two different unlimited OTC licenses: Either Sex or Bull only. These licenses are available to both resident and nonresident hunters. A nine-day muzzleloader season occurs during the middle of archery season. Unlike the archery season, there are no unlimited muzzleloader licenses. Muzzleloader licenses are issued by a lottery system and hunters may only hunt in the GMU explicitly stated on the license (Colorado Big Game Brochure 2017).

The first rifle season lasts just five days and like the muzzleloader season, tags are issued by a lottery system, though cow tags are frequently available as leftovers after the lotteries. The second and third rifle seasons each last nine days. OTC licenses are available for bulls only during the second and third seasons. These licenses are available on a first-come, first-served basis. Finally, the fourth rifle season is a five-day hunt and like the muzzleloader and first rifle seasons, licenses are issued by a drawing and hunters are limited to the GMU listed on their license (Colorado Big Game Brochure 2017).

1.1.2. Elk Hunting Areas

The state of Colorado is divided into 185 GMUs. During the archery season, 137 GMUs offer Either Sex licenses and 58 GMUs offer Bull only licenses. All but five of these areas are west of Interstate 25. Of the aforementioned 137 GMUs, 93 GMUs offer OTC Bull elk licenses during the second and third rifle seasons. Figure 1 illustrates Colorado's GMU (red) boundaries.

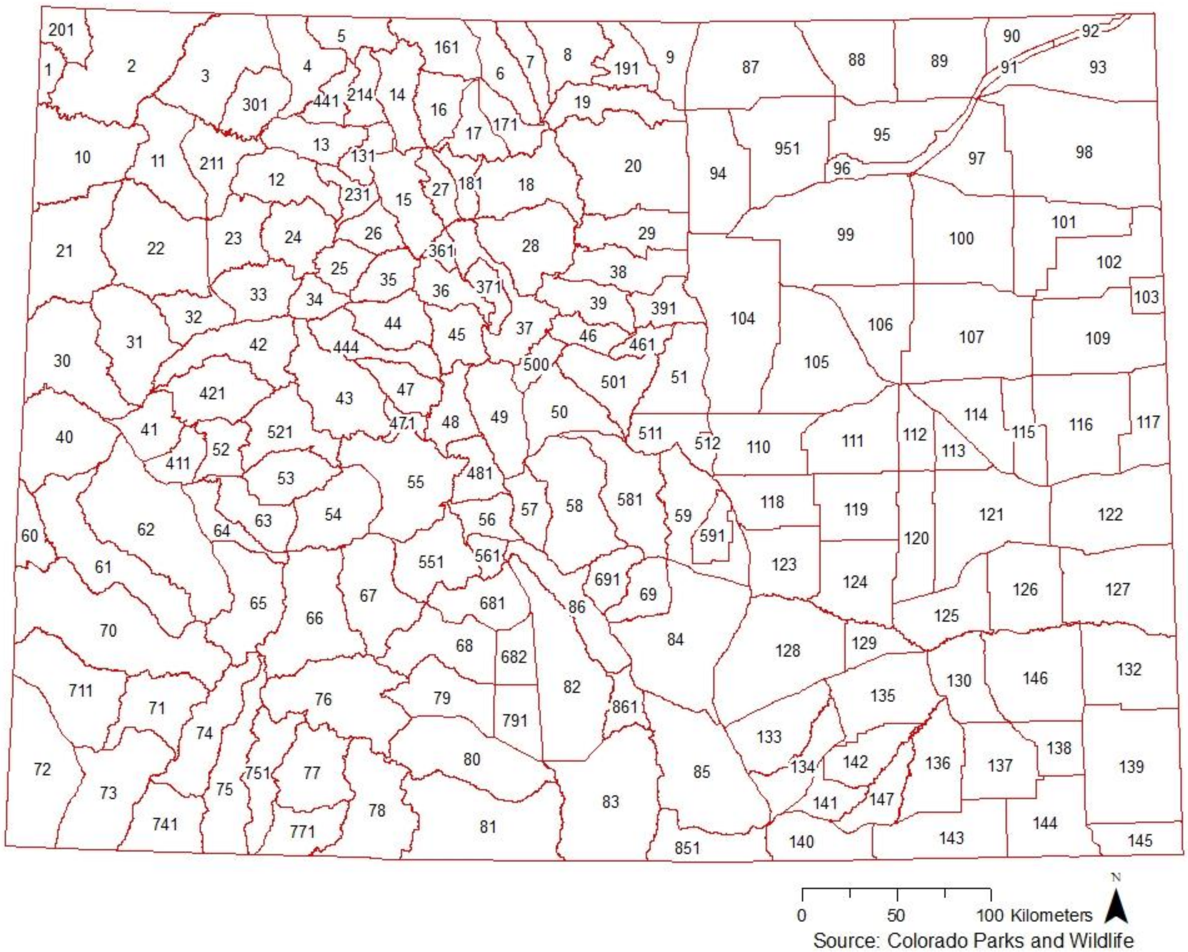

Figure 1. Colorado GMUs

Not all of Colorado's GMUs are equal. Each GMU has varying terrain, vegetation, road densities, land ownership, and numbers of hunters. Hunters must consider these factors prior to selecting a unit to hunt. Elk utilize most terrain and vegetation types throughout western Colorado (Bishop 2017). During summer and early fall, alpine areas at higher elevation can be utilized by elk. As fall advances, rugged areas with Aspen, Oakbrush, Ponderosa Pine, and Mountain Shrub provide optimal forage and cover. Spruce-Fir forests in rugged areas provide good cover from hunters and weather but lack forage. Later in the season, Pinyon-Juniper and

Sagebrush habitat at lower elevation and gentler terrain may be utilized. Figure 2 illustrates how vegetation changes with elevation in western Colorado.

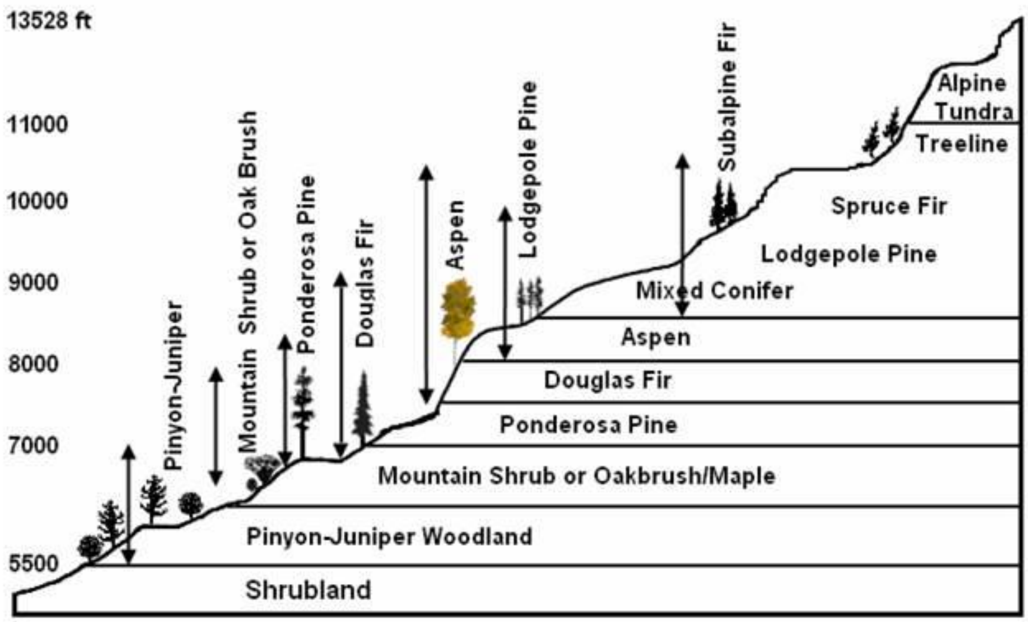

Figure 2. Vegetation changes with elevation in western Colorado (Allan 2017)

1.2. Motivation

1.2.1. Elk Herd Management

This study could benefit CPW and other wildlife management agencies that manage elk herds. Colorado has approximately 300,000 elk spread over millions of acres. CPW manages elk populations by separating elk herds into DAU, geographic areas that represent all of the seasonal ranges of a specific elk herd (Colorado Parks and Wildlife 2017). CPW uses GMUs to control and distribute hunters across the state. One DAU may consist of one or many GMUs. Figure 3 illustrates Colorado’s GMU (red) and DAU (gray) boundaries.

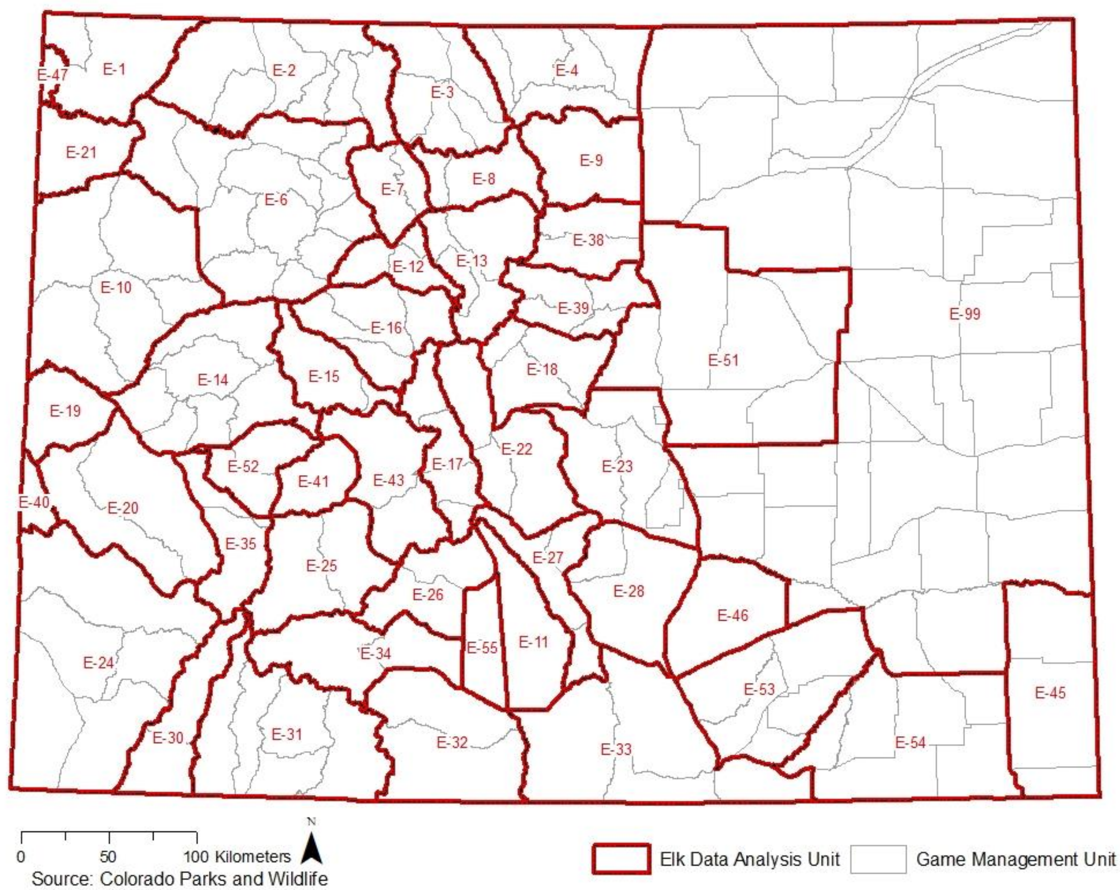

Figure 3. Colorado Elk DAU (red) and GMU (gray) boundaries

Too much hunting pressure forces elk to sanctuaries on lands where either hunting is not permitted or limited hunting is allowed. This results in an increase in elk population. CPW utilizes late season cow depredation hunts to help bring elk herd numbers to population objectives (Finley and Grigg 2008). These hunts often occur in a herd's winter range at lower elevations where terrain is gentler.

Hunting is also used to reduce property damage caused by elk and other game species. CPW is obligated to reimburse landowners for any damages caused by wildlife. In 2016, CPW paid $685,400 for 206 claims; elk were responsible for 64 claims worth $246,738 (Chris Kloster and Bryan Westerberg, Email to author 2018). Figure 4 illustrates the claims and payments made by CPW during the study period. This study may enable CPW and local growers to reduce elk crop depredation. A reduction in elk crop depredation would lead to a decrease in compensation payments, kill permits and distribution hunts, in addition to an increase in public hunting opportunities (Johnson et al. 2014).

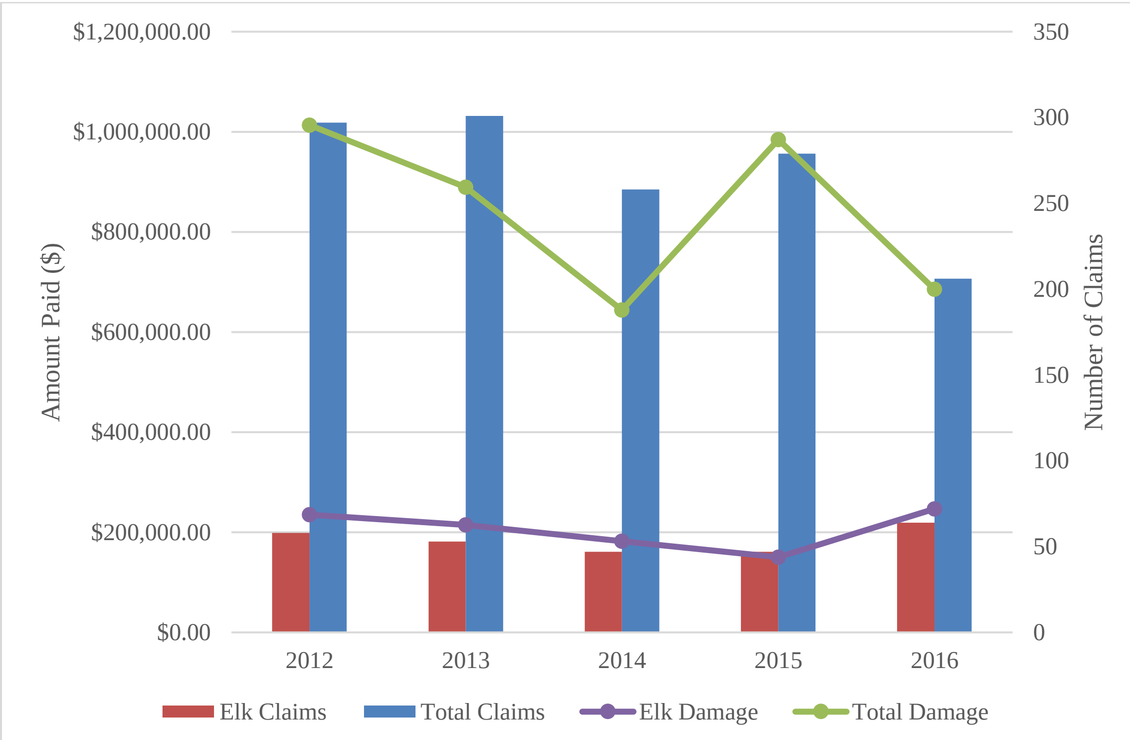

Figure 4. Claims and amount paid by CPW for property damages caused by wildlife

Effective long term management of elk and elk hunting can also help CPW and wildlife management agencies with financial sustainability. CPW does not rely on general tax dollars; instead, it relies on fees collected from hunters and state park visitors. Game tags and licenses account for half of CPW’s budget. In 2016, CPW sold 328,538 hunting licenses accounting for approximately $75 million in revenue (Colorado Parks and Wildlife Fact Sheet 2017). Table 2 shows Colorado Elk Hunting License costs for residents and nonresidents. In addition to purchasing a hunting license, all hunters must also purchase a required $10 habitat stamp.

Table 2. Colorado OTC Elk License Costs (2012 – 2016)

License Type	License Costs per Calendar Year (USD)				
	2012	2013	2014	2015	2016
Resident Adult	$46	$46	$46	$46	$34
Resident Youth	$10.75	$13.75	$10.75	$10.75	$13.75
Nonresident Bull/Fishing Combination	$576	$586	$601	$616	$644
Nonresident Either Sex/Fishing Combination	$576	$586	$601	$616	$644
Nonresident Cow/Fishing Combination	$351	$351	$451	$461	$484
Nonresident Youth/Fishing Combination	$100.75	$100.75	$100.75	$100.75	$103.75

1.2.2. Tourism

Elk and elk hunting also provide economic benefits for the non-hunting communities of Colorado. According to CPW, wildlife viewing and big game hunting contributed nearly $6.1 billion in economic benefits to Colorado in 2016. Colorado's state parks attract more than 12 million visitors that contribute nearly $1 billion to the economy (Colorado Parks and Wildlife Fact Sheet 2017). Many state park visitors hope to view elk and hear bulls bugle during the rut which occurs during the early hunting seasons. If wildlife enthusiasts see elk and other wildlife, they are more likely to return in the future. More visits in the future would provide economic benefit to CPW and local communities.

1.2.3. Elk Hunt Planning

Hunters can use this study to find a GMU in which they can safely hunt and be successful. Despite ample opportunities for elk hunters, success rates are often low – the success rate for all hunting seasons statewide in 2016 was only 18 percent. Figure 5 shows hunting success percentages for each hunting season over the past five years. A successful elk hunter is a happy elk hunter. Reasons that take away from hunting satisfaction generally relate to access and crowding issues. A survey conducted by Responsive Management for the U.S. Fish and Wildlife Service (2011) found that 46 percent of U.S. hunters have been dissatisfied with their hunting experience due to lack of access to game and hunting locations. Approximately 35 percent of hunters have a bad hunting experience due to limited hunting areas being too crowded (Merritt 2017). The methods in this study could be used to determine which GMUs are less crowded and thereby allow hunters to isolate themselves from other hunters, thus providing a more satisfying hunting experience.

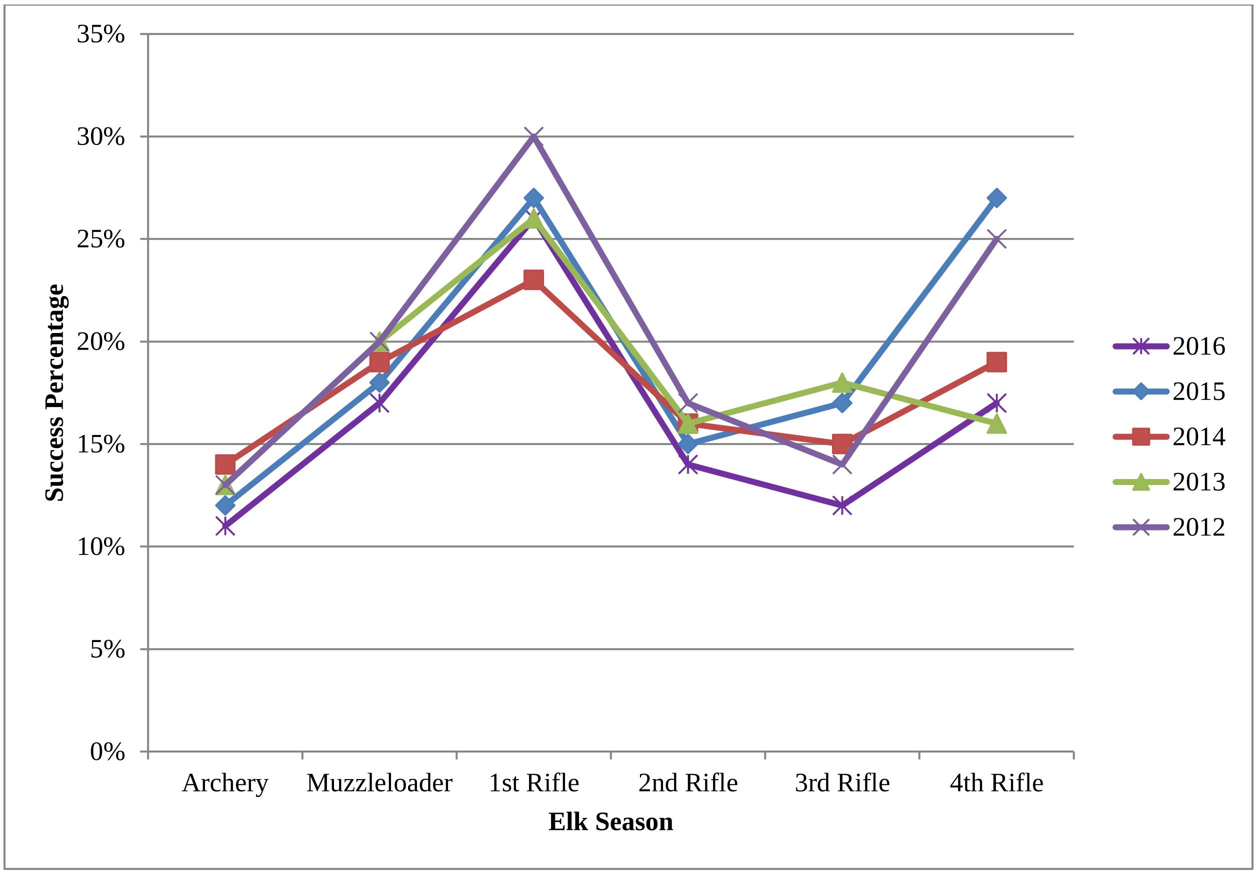

Figure 5. Elk hunting success per season (2012 – 2016)

GMUs with more rugged terrain can be more difficult to hunt in winter weather. Conversely, colder temperatures and snowfall in the appropriate locations can help hunting success rates because snowfall will force elk from their summer ranges in higher elevations with rougher topography to their winter ranges at lower elevations with gentler topography. Hunters that intend to hunt elk at lower elevations during the later rifle seasons will have to climb to higher elevations that are more rugged in order to be successful if mild temperatures and no snowfall occurs. Furthermore, snowfall in the wrong locations can prevent hunters from safely hunting. Roads can be difficult, if not dangerous to traverse; steep slopes can be slippery. This study could help hunters that are not confident in traversing rugged terrain to find a hunting area suitable to their hunting methods.

The ability to identify GMUs with gentler topography and high success rates could benefit disabled, elderly, and youth hunters that do not have the physical capability to traverse rugged, high elevation topography while carrying heavy packs full of hunting and camping gear. Some people prefer to hunt deep into backcountry away from roads and other hunters while other hunters prefer to be able to camp near their truck and hunt a few hours from the vehicle by foot, and also have access to trails for use of all-terrain vehicles (ATV).

1.3. Research Goals

The purpose of this study is to determine if rugged terrain has an impact on Colorado Elk hunting: Do hunters in GMUs with rougher terrain have lower hunting success? The primary prediction for this study is that GMUs with gentler terrain have higher hunting success than GMUs with more rugged terrain. Another goal is to compile statistics for each GMU from differing data types and sources and merge them into one dataset.

The scope for this study includes each of the 93 GMUs that have OTC second and third rifle hunting seasons. These GMUs have the same season structure - archery, muzzleloader, and the four rifle seasons. The green units in Figure 4 represent the scope of this study (gray).

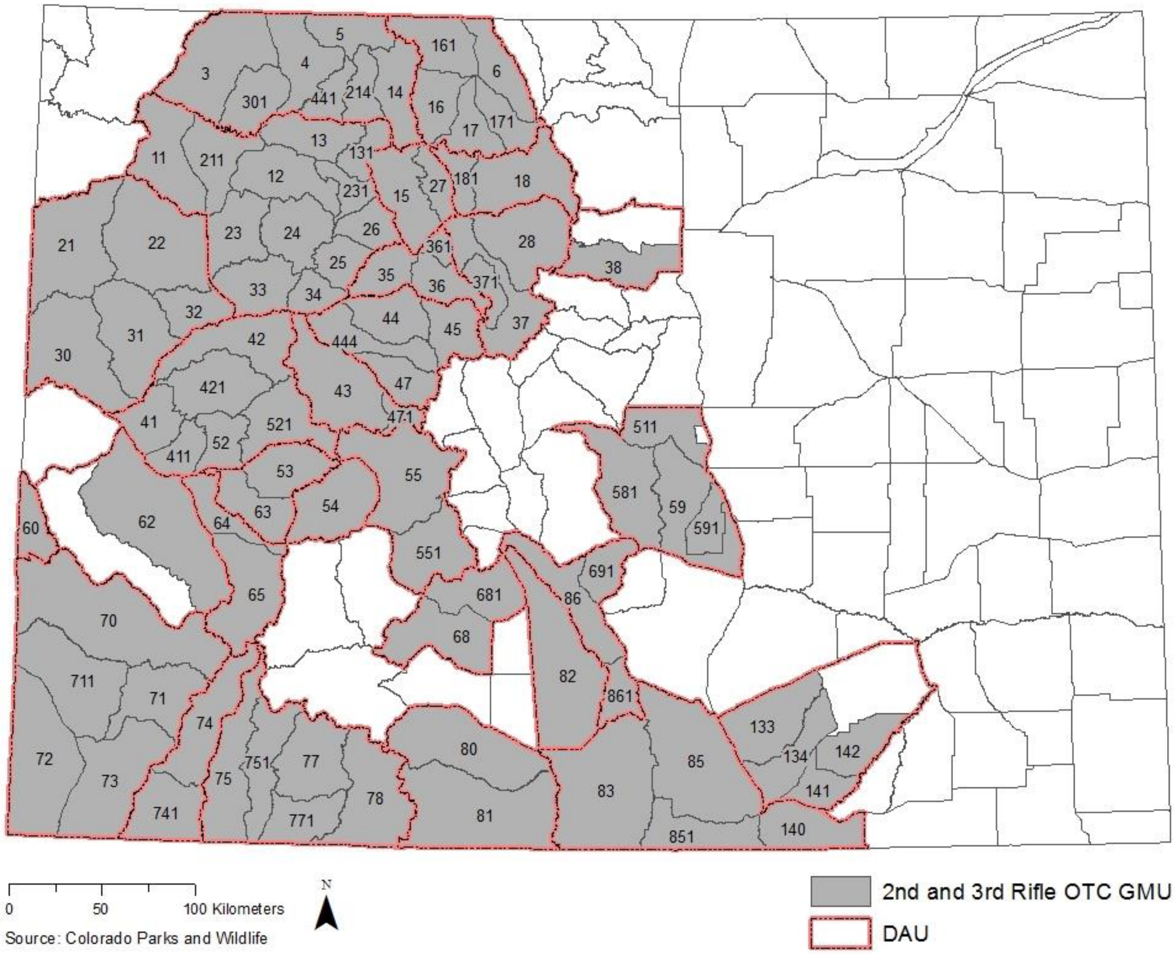

Figure 6. Study Area

1.4. Thesis Methods

Linear regression analysis was used to analyze elk harvest throughout the study area because it can be used to explain the relationship between a dependent variable and one or more explanatory variables. Hunter success was the dependent variable and terrain ruggedness, hunter and elk density, public land percentage, and road density for each GMU in the study area were the explanatory variables.

1.5. Thesis Organization

This thesis contains four additional chapters. Chapter Two provides a review of research regarding terrain analysis and wildlife management, so as to situate this study within the field. Chapter Three presents the methodology employed to determine if elk hunters are more successful in areas with less rugged terrain than their counterparts that hunt in more rugged terrain by comparing the ruggedness of each GMU that offers rifle OTC licenses and hunter success. Chapter Four presents the results and Chapter Five discusses the implications of these results, the limitations of the study, and concludes with future research suggestions.

Chapter 2 Literature Review

This literature review begins by discussing existing studies that perform geomorphometry, the study of terrain by means of quantifying the topography of the Earth. This literature informs the choice of method by which terrain ruggedness was determined for this study. The chapter then summarizes related literature on regression analysis of hunter activity and success. The literature informs the methodology for statistical analysis used herein.

2.1. Geomorphometry

2.1.1. The Hilliness of U.S. Cities

Many methods can be used to determine terrain ruggedness of an area. Using the National Elevation Dataset DEM that was resampled to 90 m resolution and eight different methods, Pierce and Kolden (2015) rank comparative hilliness of the 100 largest cities in the contiguous United States. Two of the indices captured topographic relief independent of scale: the Melton Ruggedness Number (MRN), a scale-independent basin-wide measure which is calculated by dividing the relief by the square root of the basin area (Melton 1965), and the standard deviation of elevation were calculated across all DEM cells within a city's formal incorporated area. Four other indices were used to address urban areas with different population densities by calculating the standard deviation of elevation for all of the DEM cells within 0.5, 1, 2, and 5 km from the city center (Pierce and Kolden 2015). Standard deviations of four buffer calculations were the final methods utilized to calculate slope.

Pierce and Kolden (2015) found that different method provided different rankings at the hilliest end of the spectrum. The first three city methods (MRN, elevation range, and standard deviation) showed a strong bias toward western U.S. cities as the hilliest. The next four methods (the gradually expanding radii from the downtown center) were found to possibly best reflect the experienced hilliness of different classes of cities and are not influenced by spatio-historical differences in cities. For example, the largest radius (5 km) might better reflect cities whose core urban areas are larger because the search radius is larger. The final method, the synthetic slope of the four previous methods, was calculated to see if experiences of hilliness might be usefully captured by the change in hilliness from the center to edges of an urban area. Pierce and Kolden (2015) determined that the standard deviation of elevation over a 2 km radius from the city center was best suited as a benchmark index for further, future research.

2.1.2. Modeling Bighorn Sheep Habitat

Sappington, Longshore, and Thompson (2008) utilized logistic regression, Land Surface Ruggedness Index (LSRI), Vector Ruggedness Measure (VRM), and Terrain Ruggedness Index (TRI) to quantify terrain to model Bighorn Sheep habitat in three different Mojave Desert mountain ranges: The Black, Eagle, and Eldorado Mountain Ranges. Logistic regression analysis in ArcView was also used to examine the importance of slope and ruggedness in determining bighorn sheep habitat (Sappington et al. 2008).

LSRI is a method that quantifies terrain by overlaying a dot grid to contour lines. The number of dot-contour line intersections is the LSRI for that area (Beasom et al. 1983). Sappington et al. (2008) calculated LSRI by using an ArcView script to measure the total length of contour lines within a 90 x 90 m box centered on each random point.

To determine VRM, an ArcView script, obtained from Esri, was used to calculate 3-dimensional dispersion of vectors normal to grid cells that represent each landscape (Sappington et al. 2008) from 30 m DEMs. A 3 x 3 neighborhood was used in order to avoid smoothing. TRI, a measure used to quantify total elevation change across an area that’s calculated from the square root of the sum of the squared differences between the center cell and all eight of its neighborhood cells (Riley et al. 1999), was calculated within a 3 x 3 neighborhood using a different script and 30 m DEMs for each range.

After all three methods of landscape ruggedness were used to quantify the three study areas, logistic regression was used to examine the correlation between ruggedness and sheep habitat. Variables considered in the analysis were VRM, slope, distance to water, and springtime Bighorn Sheep adult female locations (Sappington et al. 2008). Geologic data were utilized to delineate mountainous terrain by identifying intrusive and metamorphic rock.

Sappington et al. (2008) determined that VRM directly measured terrain ruggedness more independently of slope than TRI or LSRI. Importance of slope was found to vary depending on the physiographical characteristics of each mountain range. Furthermore, Sappington et al. (2008) determined that quantifying ruggedness independently of slope is important because bighorn sheep may perceive these characteristics differently when assessing escape terrain (Sappington et al. 2008). Because of this, they found VRM more applicable than TRI or LSRI to their analysis.

Pierce and Kolden (2015) tested many methods that are applicable and demonstrate that different geomorphometry methods produce different results. Their study did not specify which method is better suited to a particular scenario. Sappington et al. (2008) found that TRI was highly correlated with slope in all three mountain ranges while the correlation between VRM and slope was much lower in the Eldorado Mountains and even less in the Eagle and Black Mountains. The study herein utilized TRI to quantify terrain because it is not designed for specific areas and can be used for large area habitat analyses (Riley et al. 1999). As Sappington et al. (2008) used geologic data to identify mountainous terrain, vegetation data was used to identify elk habitat in order to create a more accurate ruggedness number for each GMU.

2.2. Analyzing hunter success with regression analysis

2.2.1. Brown Bear Hunter Success In Alaska

Regression analysis has been used in several studies analyzing hunter success. Albert, Bowyer, and Miller (2001), for example, used stepwise logistic regression, a method in which the choice of predictive variables is determined by an automatic procedure (Hocking 1976) to analyze the motivation, effort, and success of brown bear (*Ursus arctos*) hunters in Alaska. Success was defined as a bear being harvested by a hunter. Data were collected via a survey from bear hunters that participated in the 1985-86 hunting seasons. To compensate for small sample sizes, data for 26 GMUs were merged into five regions. Each region consisted of GMUs with similar climate, vegetation, access type, and level of hunting pressure (Albert et al. 2001).

The analysis found that use of hunting guides, trip objective (i.e., primarily hunting brown bears instead of focusing on other species), and region were the most significant indicators of successful hunting trip. Nonresident hunters were more successful than their resident counterparts. The survey found the greatest percentage of successful resident hunters hunted in south-central and interior Alaska, used automobiles, private boats, and other transportation such as ATVs and snowmobiles. The greatest percentage of successful nonresident hunters focused on hunting brown bears, instead of other species, in southwest Alaska, and used chartered boats and airplanes (Albert et al. 2001).

2.2.2. Analyzing Hunter Distribution Based On Host Resource Selection and Kill Sites to Manage Disease Risk

Another study utilized regression analysis to distribute hunters in order to manage wildlife diseases such as Chronic Wasting Disease and Bovine Tuberculosis. Dugal et al. (2006) used resource selection functions and selection ratios to quantify sex- and age-specific resource selection patterns of collared and hunter-harvested nonmigratory elk in the areas surrounding Riding Mountain National Park and Duck Mountain Provincial Park in Manitoba, Canada.

Dugal et al. (2006) found that distance to protected areas was the most important variable influencing resource selection and hunter harvest sites of elk. The results were also used to map high-risk areas that are under hunted but used by potentially infectious elk. Dugal et al. (2006) proposed that the methods used in this study be used as a tool for distributing hunters in order to manage transmissible diseases in game species.

Like Albert et al. (2001), hunter success in this study was defined as the harvest of an elk by a hunter. The stepwise logistic regression used by Albert et al. (2001) analyzed many variables that impact hunting success without the use of GIS. Dugal et al. (2006) used spatial modeling to analyze collared elk and elk harvest site data.

This study will use linear regression via the OLS Regression tool in ArcMap to analyze variables because linear regression can be used to model a dependent variable's relationship with explanatory variables (O'Sullivan 2010). This phase of the study combines the spatial modeling used by Dugal et al. (2006) with analysis of many variables that influence elk harvest success used by Albert et al. (2001).

Chapter 3 Methods

This chapter describes the methods used to evaluate the relationship between Colorado elk hunting success and terrain ruggedness. First, this chapter describes the overall workflow and input data used in this analysis. The first phase of this analysis involved identifying elk habitat throughout the study area. Next the terrain of the study area was quantified by calculating a Mean TRI for the identified elk habitat in each GMU. After the terrain was quantified, linear regression analysis was used to determine what variables influence hunter success.

3.1. Overall workflow

While the primary purpose of this study is to evaluate the relationship between Elk hunter success and terrain ruggedness, other variables that impact hunter success must be considered. Terrain ruggedness, number of hunters, elk population, public land percentages, and road distance for each GMU in the study area were the explanatory variables chosen for this analysis. The regression equation was:

$$Elk\ Harvest = \beta_0 + \beta_H(Hunters) + \beta_E(Elk\ Pop.) + \beta_P(Public\ Land) + \beta_R(Roads) + \beta_{TR}(Ruggedness) + \varepsilon \qquad (1)$$

Number of hunters was chosen as a variable because hunters like to distance themselves from other hunters in order to see more game. Too much hunting pressure can force elk to seek refuge in sanctuary areas where they are protected from hunting. Elk population was chosen because if no elk are present, no hunter will be successful. Public land extent was chosen because more hunters in Colorado hunt elk on land owned by BLM or USFS than land private land. Road distances were chosen because elk have fewer sanctuary areas in areas with a high quantity of roads; many hunters prefer to hunt near roads (Lyon 1998). The values for each explanatory variable were acquired from varying types of datasets that were converted into the same format.

Explanatory variables were then merged into a single dataset. Figure 7 summarizes the overall workflow for this analysis.

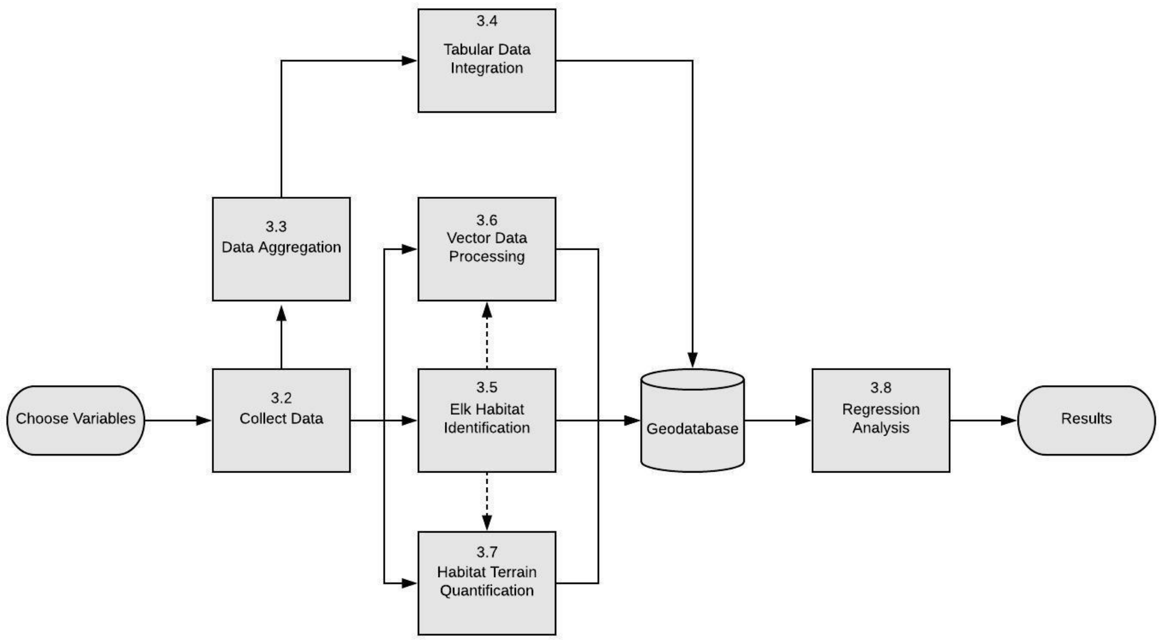

Figure 7. Overall workflow

3.2. Input Data

This study utilized both spatial and nonspatial data. Spatial data used in this analysis were distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83); UTM Zone 13 (meter) was the projected coordinate system used. All of the spatial data needed for this study are available for free from ColoradoView, a site that is part of the U.S. Geological Survey's (USGS) nationwide program, AmericaView. These data were created by CPW, the Colorado Department of Transportation (CDOT), the USGS, and the U.S. Forest Service (USFS).

The nonspatial data came from the Colorado Elk Harvest Reports and post-hunt population estimates published by CPW. Since this study examined hunter success over a five year period, the harvest reports for each year of the study period were used. These reports contain elk harvest per season, number of hunters, and total recreation days for each GMU.

3.2.1. Colorado Basinwide Vegetation Layer

The Colorado Basinwide Vegetation layer package represents vegetation land cover throughout the state of Colorado. This was product of the Colorado Vegetation Classification Project administered by CPW in collaboration with the BLM and USFS. Landsat Thematic Mapper imagery with pixels measuring 25 m on a side was reclassified using an unsupervised classification procedure and field gathered GPS data were used to label and group the classes into the final classification map (Cade et al. 2013).

3.2.2. Colorado Elk Harvest Reports

Harvest reports show how many hunters harvested an elk during each hunting season in each GMU. CPW uses the data from these reports to manage both big game populations and hunters. A third-party vendor contacts hunters via email or telephone to conduct the Big Game Harvest Survey. Licenses with invalid contact information were omitted from the survey. This is a voluntary survey in which vendors obtain harvest and participation data at the DAU level. Because the survey is voluntary, stratified random sampling was used by CPW to more effectively estimate big game harvests. After estimates ware generated, standard error, lower confidence limits, and upper confidence limits were calculated to measure the precision of the estimates (Colorado Parks and Wildlife 2016).

3.2.3. Colorado GMU Boundaries

This is a polygon shapefile that contains administrative boundaries for the 185 GMUs in Colorado. Each feature contains information for the DAUs of each species. These boundaries are used to manage hunters hunting all terrestrial game species except bighorn sheep and mountain goats. CPW updates the boundaries or any changes of region, area, or district yearly during the first week of March (Colorado Parks and Wildlife 2017).

3.2.4. Colorado Post-Hunt Elk Population Estimates

Post-hunt population estimates break down the estimated elk population and bull/cow ratio (per 100) at the DAU level. DAUs represent the range an elk herd utilizes during the year. Population estimates for elk are determined in March after post-hunt aerial surveys and harvest surveys have been completed. These data are then entered into a computer model which calculates elk populations and bull/cow ratios. Because of the statutory requirement to provide population estimates in January, population estimates from the previous year must be used in the legislative report (Post Hunt Elk Population and Sex Ratio Estimates 2016).

3.2.5. Colorado Road Centerlines

This polyline shapefile represents primary and secondary roads throughout Colorado and consists of an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File / Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database. Primary Roads (interstates, highways, etc.) are designated with a S1100 identifier. Secondary Roads (city streets, county roads, etc.) are designated with a S1200 identifier (TIGER 2013).

3.2.6. Elk Overall Range

This polygon shapefile is part of CPW’s Species Activity Mapping (SAM) Dataset, a layer package used for distributing Colorado wildlife GIS data. The elk overall range dataset is a polygon shapefile that represents the area which encompasses all known seasonal activity areas within the observed range of an elk herd (Colorado Parks and Wildlife 2017).

3.2.7. U.S. Federal Land Boundaries

The Federal Land Boundary dataset represents federal- and Indian-owned land areas in the US. This dataset was obtained from The National Map, a portal for obtaining geospatial data created by USGS (The National Map 2017).

3.2.8. USFS Roads

This is a polyline shapefile that represents roads under the jurisdiction of the USFS throughout the state of Colorado. Attributes apply either to the entire road or to some measured distance along the road. According to the USFS (2017), attributes are generated from nationally required descriptive attribute data that is stored within an Oracle database.

3.2.9. 1/3 Arc-second Digital Elevation Models (DEMs)

DEMs provide elevation values in meters of topographic bare-earth land surfaces. This study used 24 1/3 arc-second (10 m) resolution raster tiles from USGS's National Map 3D Elevation Program (3DEP) Downloadable Data Collection (The National Map 2017). LiDAR point clouds were the source data used to create the DEMs.

3.3. Data Aggregation

Before data manipulation or analysis could be performed, an aggregation unit had to be selected. This determined which steps must be taken in order to prepare data for analysis. Since hunter and harvest data were collected at the GMU level and population estimates were obtained at the DAU level, the "modifiable areal unit problem" (MAUP) (Fotheringham and Wong 1991) had to be taken into consideration. The MAUP suggests that the result of an analysis may be influenced by the choice of areal unit.

Because this study analyzed hunter success and GMUs are used to distribute hunters and harvest within DAUs, the GMU was selected as the aggregation unit over the DAU. Choosing to analyze at the GMU level meant that only population estimates had to be calculated at the GMU level. To calculate GMU population estimates, the following equation was used:

$$Avg.\ GMU\ Elk\ Population = \frac{Area\ of\ GMU}{Area\ of\ DAU}\ x\ Avg.\ DAU\ Elk\ Population \qquad (2)$$

This equation allocated the average DAU elk population using the ratio of GMU land area to DAU land area. For example, GMU 3 consists of 30 percent of DAU E-2; therefore, the average population of GMU 3 had 30 percent of the average elk population. GMU elk populations were calculated for each year within the study period. From each year's population estimate, the mean GMU elk population was calculated for each GMU.

3.4. Tabular Data Integration

3.4.1. Harvest Data Integration

The spatial and nonspatial data for this analysis were integrated by creating feature classes of the study area for the GMUs with the OTC rifle hunting seasons. The 93 GMUs in the study area were selected and a feature class was added to a file geodatabase. Since the elk harvest reports were in PDF format, they were converted to Excel spreadsheets using Adobe Acrobat Pro. An Excel workbook was created for each year and the harvest data were separated by season. Figure 8 summarizes the workflow for tabular data integration.

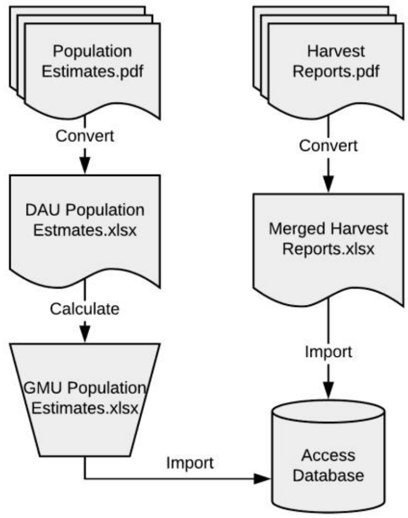

Figure 8. Tabular data integration workflow

3.4.2. Population Estimate Data Integration

Like the elk harvest reports, post-hunt population estimates were in PDF format and they were converted to an Excel spreadsheet using Adobe Acrobat Pro. The population estimates were then merged into one spreadsheet. Because population estimates were calculated at the DAU level, post-hunt population estimates were calculated for each GMU.

After GMU population estimates were calculated, they were imported into an Access database. A query was used to combine all of the desired statistics into one spreadsheet. An Object Linking and Embedding Database (OLE DB) Connection was created in ArcCatalog to join the Access database to the spatial data in ArcMap. After the tabular data in the database were joined to the study area, a new study area feature class was added to the geodatabase.

3.5. Elk Habitat Identification

Not all lands in a GMU are comprised of elk habitat. After the study area feature class was created and tabular data integrated, elk habitat in the study area was identified. Figure 9 summarizes the workflow for this process. Identification of elk habitat helped establish a more accurate mean TRI for each GMU because elk and hunters will not be in areas outside of the overall range or areas that do not offer sufficient forage and cover. Otherwise, the areas not utilized by elk would create a washing effect of the mean TRI.

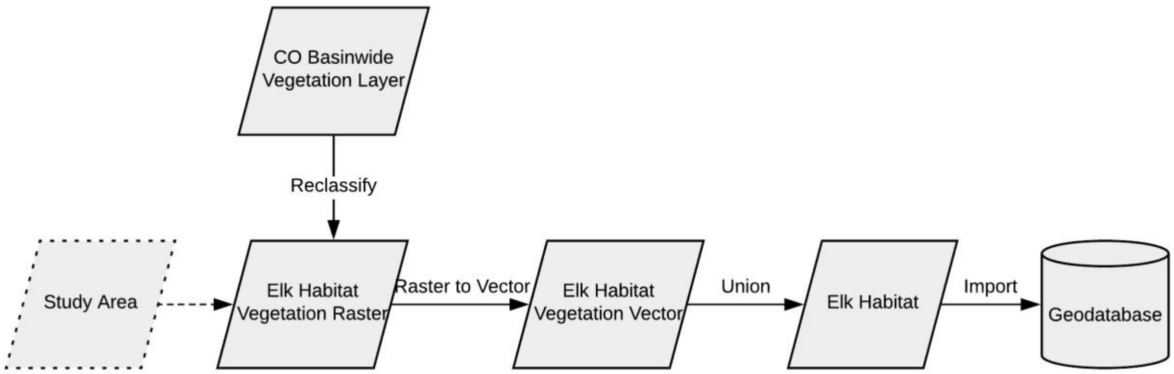

Figure 9. Elk habitat identification workflow

First, the Study Area Overall Range feature class was created by clipping the elk overall range with the study area feature class with the clip tool in ArcMap. The GMU Overall Range feature class was also added to the geodatabase.

Using the Reclassify tool in ArcMap, the Colorado Basinwide Vegetation Layer was reclassified. The GMU Overall Range feature class was used as the processing extent. Non-habitat vegetation types and landcover received a “0” value while habitat vegetation types received a “1” value. Habitat vegetation types include areas dominant in the following vegetation types (Allen 2017):

- Aspen and Aspen-conifer mixes
- Ponderosa and Lodgepole Pines
- Shrublands such as sagebrush, grasses, and forbs
- Mountain Shrubs such as Oak Brush, Maple Brush, Mountain Mahogany, and Serviceberry
- Pinyon-Pine and Juniper woodland
- Interior Douglas Fir and mixed conifers
- Mountain meadows, grassland, and alpine areas

The reclassified vegetation layer was then converted into a polygon feature class with the Raster to Vector tool in ArcMap. The final elk habitat feature class was then added to the geodatabase after selecting all polygons with a value of "1."

3.6. Vector Spatial Data Processing

After elk habitat was identified, vector data were processed within the extent of elk habitat in the study area. The vector data used were either polyline or polygon feature classes. Figure 10 summarizes the vector data processing workflow.

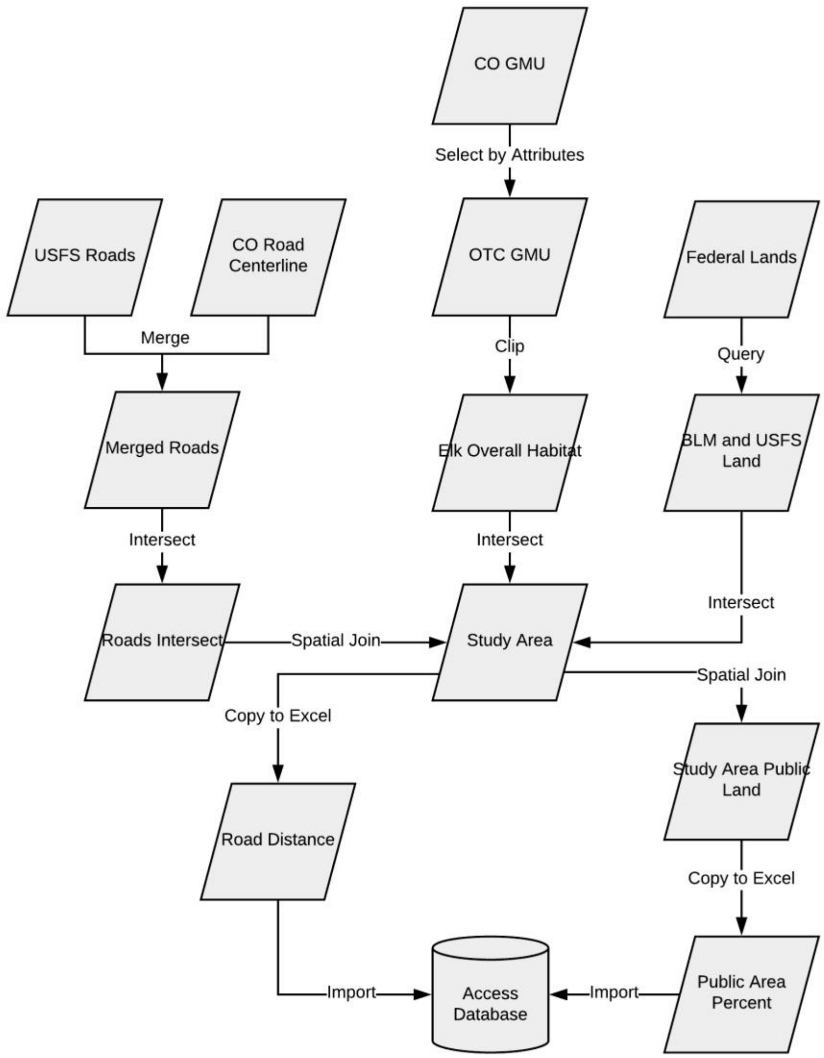

Figure 10. Vector spatial data processing workflow

3.6.1. Public Land Quantity per GMU

The amount of public land was quantified as a percent of the GMU. First, a query was used to extract lands owned by BLM and USFS; these were with the Elk Habitat feature class. State trust lands, land owned by other federal agencies (e.g., Bureau of Indian Affairs, Department of Defense, National Parks), and private land were not considered because hunting is not allowed without permission.

After BLM and USFS lands were selected, they were clipped using the elk habitat as the clip feature to create an Elk Habitat Federal Land feature class. After the Elk Habitat Federal Land feature class has been created, the intersect tool was used to divide the selected Federal Lands between all 93 GMUs in the study area. Next, a polygon-to-polygon spatial join was used to calculate the sum of the Elk Habitat Federal Land area in each of the GMUs. After the attribute table was copied to an excel spreadsheet, the area of Elk Habitat Federal Land was divided by the elk habitat area in each GMU to obtain the public land percentage. After the attribute table was copied to an Excel spreadsheet, the desired fields were imported into the Access database.

3.6.2. Road Quantity per GMU

Roads were quantified as total road distance in meters. First, the Colorado road centerline and USFS roads datasets were merged into a single feature class. Next, the merged feature class was clipped using the elk habitat area as the clipping feature. A polyline-to-polygon spatial join was used to determine the sum of the roads in each of the study area GMUs. After the attribute table was copied to an excel spreadsheet, the desired fields were imported into the Access database.

3.7. Elk Habitat Terrain Quantification

Twenty-four 1/3 Arc-second DEMs were processed to calculate TRI (Riley et al. 1999). TRI is calculated from the square root of the sum of the squared differences between the center cell and all of its 8 neighborhood cells. The equation used to calculate TRI is:

$$\text{TRI} = \text{Y}\left[\sum(X_{ij} - X_{00})^2\right]^{1/2} \quad (3)$$

where X_{ij} represents the elevation of each neighbor cell to cell (0,0) (Riley et al. 1999). Figure 11 summarizes the terrain quantification workflow.

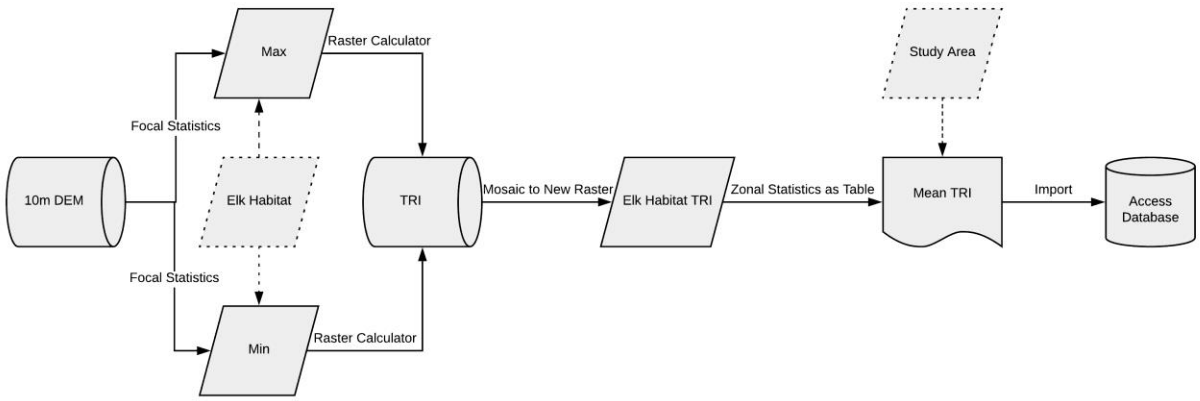

Figure 11. Terrain quantification workflow

A python script was created to automate these phases and the Elk Habitat feature class was used as the processing extent. The first phase of processing calculated the maximum value statistic in a 3x3 window around each input raster cell within the elk habitat area with the Focal Statistics tool in ArcMap. The second phase is similar to the first phase with the exception that the minimum value was calculated. The third stage utilized the Raster Calculator in ArcMap to calculate TRI and create an output raster.

All output rasters were merged with the Mosaic to New Raster tool in ArcMap to create the Elk Habitat TRI raster. Next, the Zonal Statistics as a Table tool in ArcMap was used to calculate Mean TRI statistics for each GMU. The Elk Habitat TRI Raster was used for the input raster and the Study Area GMU feature class was the zone field. The output table was copied to an Excel spreadsheet and the desired fields were imported into the Access database.

3.8. Regression Analysis

Before analysis occurred, all tabular data were merged into one table. A query was used to merge hunter and harvest data, Mean TRI, public land percentage, and sum of road length into one table. This table was joined to the Study Area feature class in ArcMap and the final Study Area feature class was imported into the geodatabase. Figure 12 summarizes the regression analysis processing workflow.

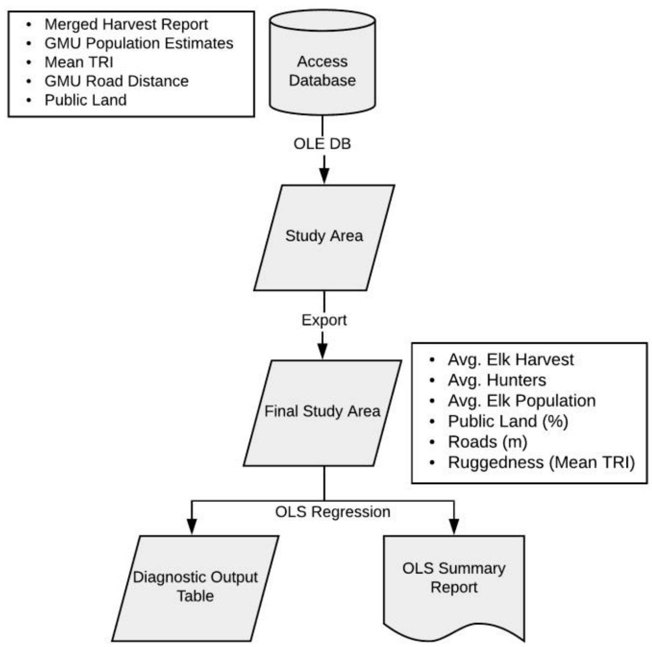

Figure 12. Regression analysis workflow

Directly comparing coefficients is impossible because the units between the different explanatory variables vary. Public land was quantified as a percent, terrain ruggedness was quantified as the average cell value in an area, and roads were quantified as log of kilometers ($\log^{10}$). Average hunter and elk variables were quantified as number of hunters or elk per square kilometer.

After the Final Study Area feature class was created, OLS regression analysis was used to analyze hunter success and explain which variables affect hunter success. The dependent variable for the analysis was mean elk harvest. Mean TRI, average number of hunters, mean elk population, public land percentage, and sum of road length were used as independent variables.

Chapter 4 Results

This chapter presents the results of the analysis. The methods described in the previous chapter were successful in identifying potential elk habitat throughout the study area; nearly 84 percent of the study was identified as potential elk habitat. After the explanatory variables for each GMU were calculated, linear regression found that terrain ruggedness was not a significant variable. Average elk density and public land percentage were the only two significant variables.

4.1. Terrain Quantification

4.1.1. Elk Habitat Identification

Elk habitat within the study area was identified by reclassifying the Colorado Basinwide Vegetation Layer within the boundaries of the Elk Overall Habitat polygon feature class. The vegetation landcover reclassification identified areas dominant with vegetation types used by elk for food and cover such as aspens, conifers, grasses, and forbs. Excluded were developed areas, agricultural areas, such as row crops and orchards, and water bodies. Figure 13 illustrates the identified elk habitat within each GMU.

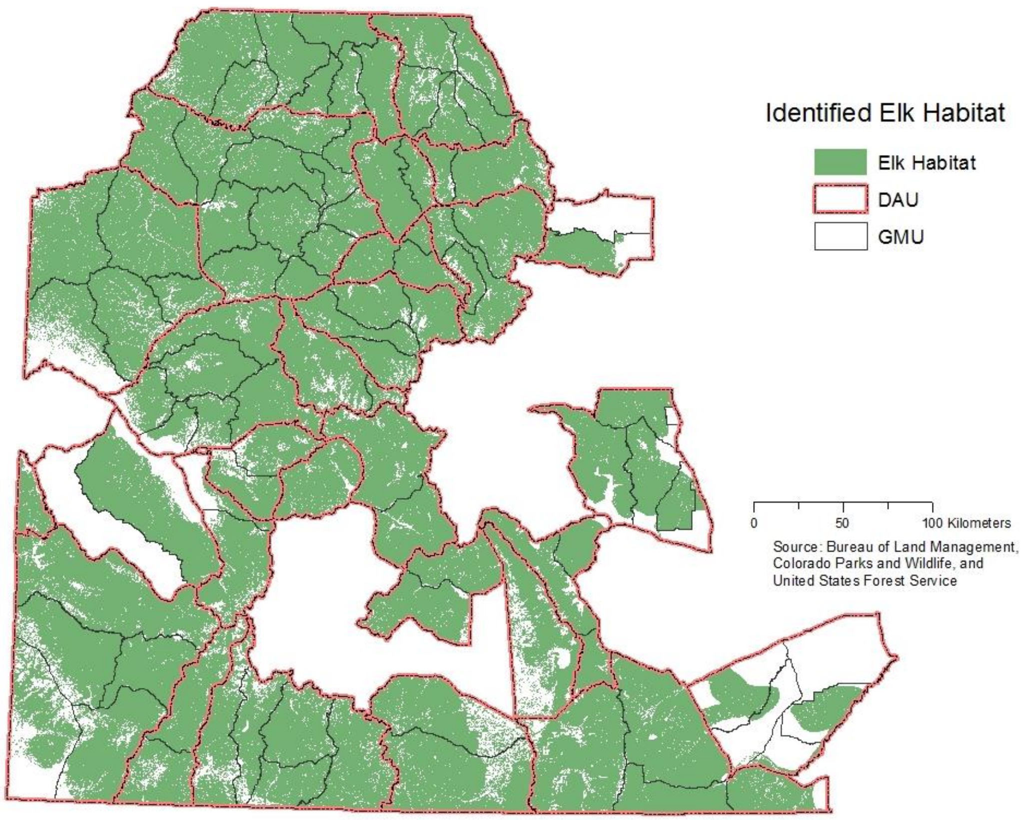

Figure 13. Elk habitat identified within the study area

Approximately 83.75 percent of the study area was identified as potential elk habitat. Only six GMUs (30, 64, 72, 133, 34, and 141) contained less than 50 percent elk habitat. Units 133, 134, and 141 are located in DAU E-53 in the southeastern portion of the study area. Figure 14 specifies elk habitat for each GMU in the study area. The individual numbers for each GMU are itemized in the Appendix.

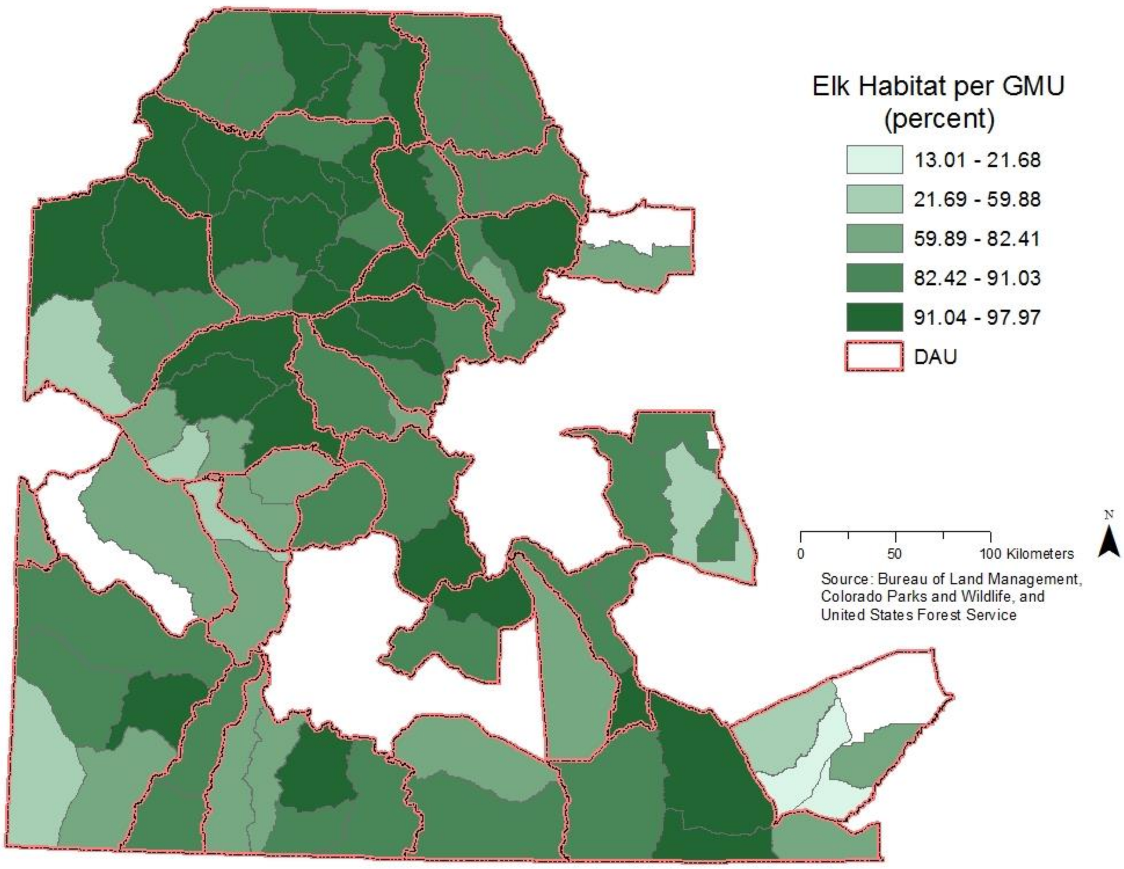

Figure 14: Elk habitat per GMU (percent)

4.1.2. DEM Processing

After the elk habitat was identified, the DEMs were processed in order to calculate Mean TRI for each GMU in the study area. All 24 DEM tiles were processed using a python script with the elk habitat feature class was used as the processing extent. Each tile took several hours to process. After all tiles were processed, the Mosaic to New Raster tool was used to merge all of the tiles to create the Elk Habitat TRI raster. Figure 15 summarizes the ruggedness throughout the elk habitat in the study area and Table 3 lists the TRI classification values (Riley et al. 1999).

Table 3: TRI classification values

Classification	TRI Value (m)
Extremely Rugged	595 – 2,790
Highly Rugged	498 - 958
Moderately Rugged	240 - 497
Intermediately Rugged	162 - 239
Slightly Rugged	117 - 161
Nearly Level	81 - 116
Level	0 - 80

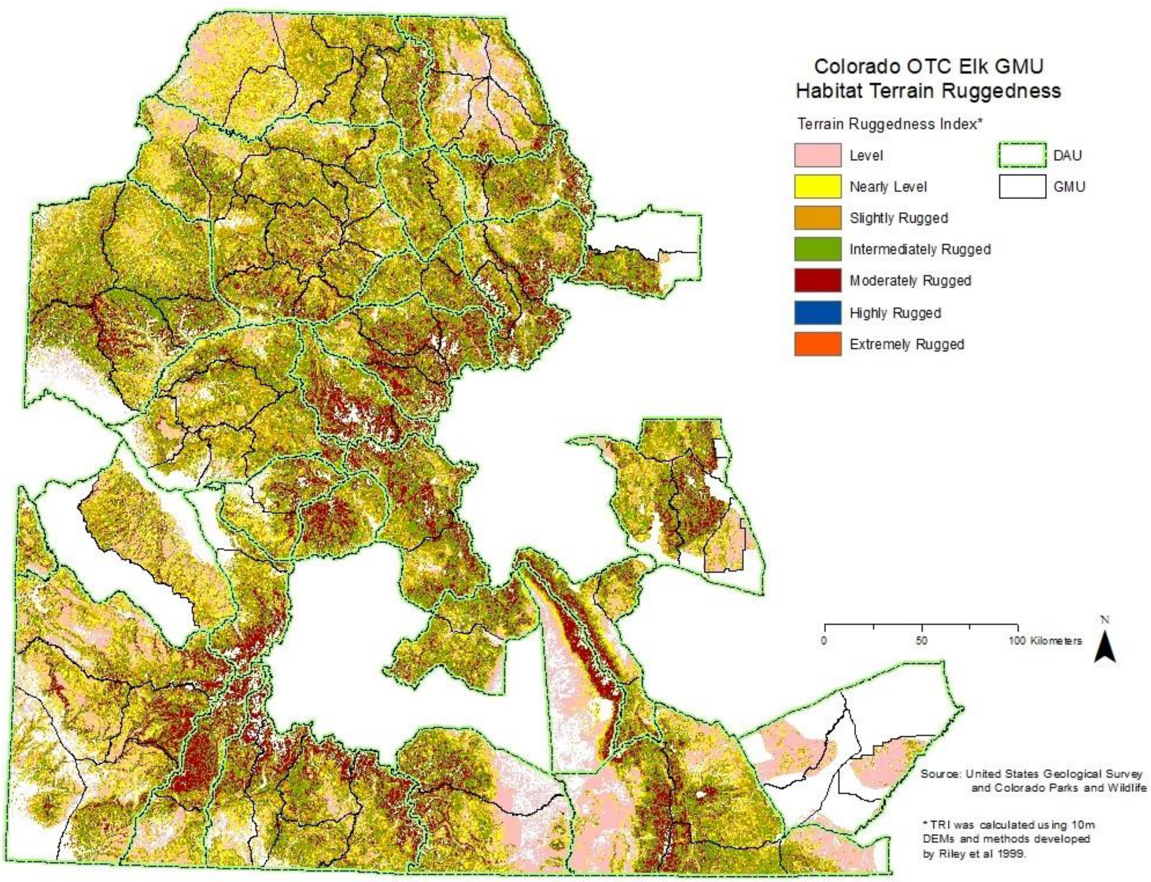

Figure 15. Elk habitat terrain ruggedness throughout the study area

Mean TRI was calculated for each GMU using Zonal Statistics. The Elk Habitat TRI Raster was used for the input raster and the study area GMU feature class was the zone field. Figure 16 summarizes the mean TRI for the elk habitat within each GMU in the study area. The GMUs with the most rugged elk habitat are units are units 43, 45, 47, and 471 in the central portion of the study area and unit 74 in the south central portion of the study area. All of the units in DAU E-53 (GMUs 133, 134, 141, and 142) in addition to GMUs 3, 140, and 591 contain the least rugged elk habitat in the study area. Appendix A lists the Mean TRI for each GMU; Figure 15 shows the Mean TRI for each GMU's elk habitat in the study area.

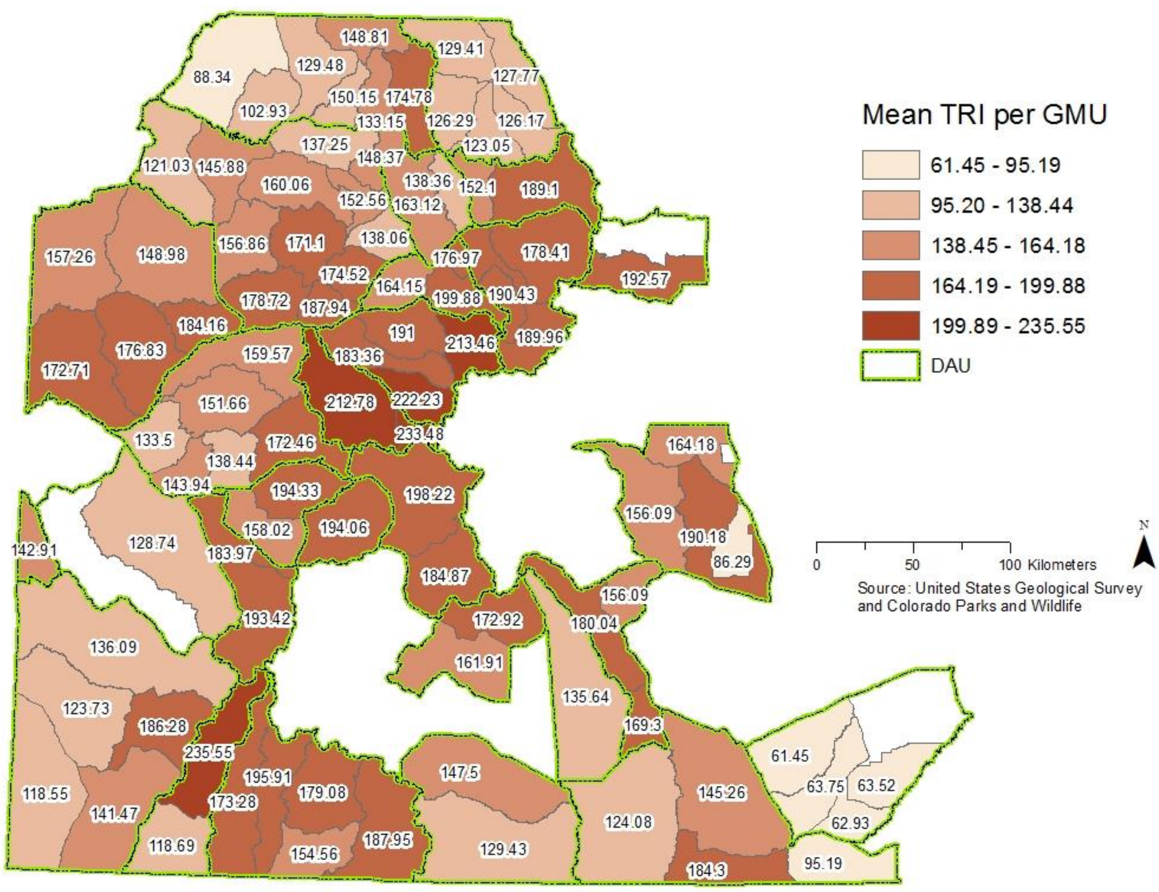

Figure 16. Elk habitat Mean TRI for each GMU

4.2. Regression Results

The final portion of the study used linear regression to attempt to estimate a statistically significant positive relationship between the explanatory variables, average elk and hunter density, terrain ruggedness, public land percentage, and road density, and elk harvest success. The analysis determined that terrain ruggedness, average hunter success, and road density were not significant variables in modeling hunter success. The linear regression model equation was:

$$Avg.Harvest = \ 19.73 + 3.05X_E - 0.13X_{PL} + 1.87 \quad (4)$$

X_E and X_{PL} represent the explanatory variables for average elk density and public land percentage respectively.

Figures 17a and 17b illustrate the model output scatterplot and histogram. The output scatterplot (Figure 17a) is a graph that represents the relationship of residuals in relation to predicted dependent variable values. A properly specified model's scatterplot will have little structure and appear random. While there are some outliers in the histogram (Figure 17b), the histogram appears to follow the bell curve (blue), indicating that the model is not biased. There were two outliers on the histogram that had standard residuals greater than three.

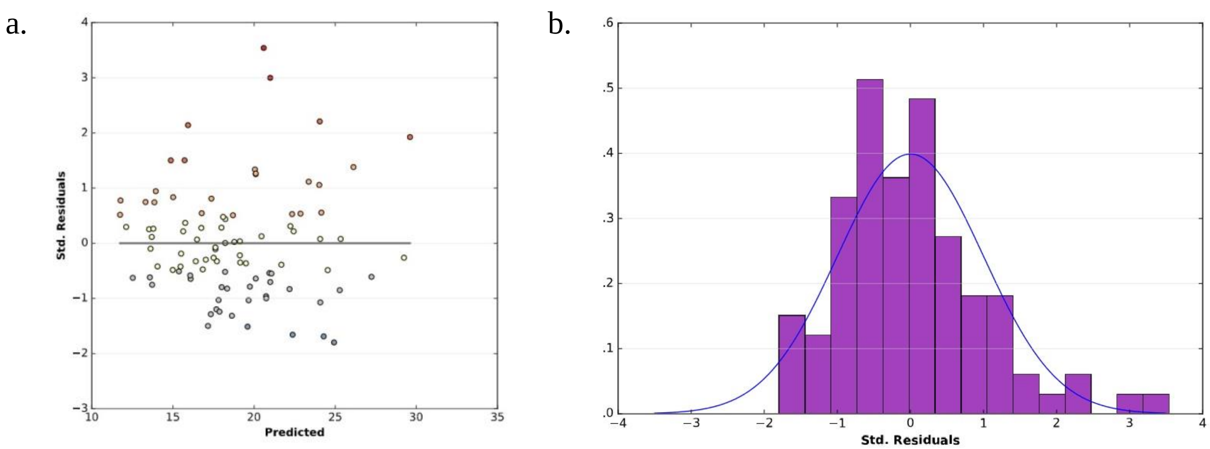

Figure 17. Model output scatterplot and histogram

The Adjusted R^2 value reflects model complexity (i.e., the number of variables) and is a measure of the model's performance. The adjusted R^2 value for the elk harvest model was 0.325933. This indicates that the model describes approximately 33 percent of the variation in the dependent variable, the average elk harvest in the study area. Table 4 summarizes the effects of each explanatory variable.

Table 4. Linear regression model results

Variable	Coefficient	StdError	t-Statistic	Probability	Robust_SE	Robust_t	Robust_Pr	VIF
Intercept	25.659771	8.323266	3.082897	0.002750*	8.155368	3.146366	0.002268*	-------
AVG. HUNTER DENSITY (/km^2)	-0.146431	0.216649	-0.675888	0.500902	0.219476	-0.667182	0.50642	1.864716
AVG. ELK DENSITY (/km^2)	3.308991	0.961947	3.439891	0.000902*	0.884958	3.739149	0.000335*	1.696939
RUGGEDNESS (MEAN TRI)	-0.018771	0.024893	-0.754058	0.452846	0.027412	-0.684758	0.495314	1.753647
ROAD DENSITY (Log^{10})	-1.165267	2.423106	-0.480898	0.631802	2.325109	-0.501167	0.617524	1.187505
PUBLIC LAND (%)	-0.111932	0.034787	-3.217642	0.001821*	0.040153	-2.787678	0.006517*	1.920565

Adjusted R^2 = 0.247868
* = statistically significant p-value ($p < 0.01$)

Terrain ruggedness and average hunter density were the only two explanatory variables that did not have a statistically significant p-value ($p < 0.01$).

Coefficient values represent the mean change in the response given a one-unit increase in the predictor. Average hunter density, public land percentage, and road quantity variables had negative coefficient values. Negative coefficient values indicate these variables had a negative impact on model output. Average elk population, and terrain ruggedness variables had positive coefficient values which indicates a positive impact.

The Variance Inflation Factor (VIF) values for each explanatory variable were below 7.5. A VIF below 7.5 indicates no redundancy among variables. The model's Koenker (BP) Statistic was 7.757241. The Koenker (BP) Statistic is a test that determines whether the model's explanatory variables have a consistent relationship to the dependent variables both spatially and nonspatially. Since this test result was greater than 0.01, the relationships modeled were consistent.

Since the Koenker (BP) Statistic is significant, the Joint Wald Statistic determines the overall significance of the model. The Joint Wald Statistic was 37.674511, indicating that the model is significant. Also, robust probabilities can only be determined if explanatory variables are helping the model.

Another regression analysis was ran without the two insignificant variables. The Adjusted R^2 for this model dropped to 0.0255947. Like the first regression model, the public land percentage and road density variables had negative coefficients while the average elk population coefficient was positive. The only explanatory variable not significant was road density. VIF values for each explanatory variable were below 7.5 meaning there was no redundancy among variables. The Joint Wald Statistic was 35.498409, indicating that the model was also significant. Table 5 summarizes the effects of each explanatory variable.

Table 5. Second regression model results

Variable	Coefficient	StdError	t-Statistic	Probability	Robust_SE	Robust_t	Robust_Pr	VIF
Intercept	23.081652	7.884638	2.927421	0.004340*	8.096324	2.850881	0.005418*	-------
AVG. ELK DENSITY ($/km^2$)	2.941934	0.795327	3.699024	0.000380*	0.793127	3.709283	0.000367*	1.172589
ROAD DENSITY (Log^{10})	-1.033147	2.359187	-0.437925	0.662508	2.392784	-0.431776	0.666955	1.137904
PUBLIC LAND (%)	-0.133422	0.025903	-5.150867	0.000002*	0.026097	-5.112569	0.000002*	1.076403

Adjusted R^2 = 0.255947
* = statistically significant p-value ($p < 0.01$)

A final analysis was ran without the road density variable. The Adjusted R^2 value was slightly better at 0.262629. Coefficients for public land percentage and road density variables remained negative and positive respectively. VIF values for each explanatory variable remained below 7.5. The Joint Wald Statistic was 35.498409, indicating that the model was also significant. Table 6 summarizes the effects of each explanatory variable.

Table 6. Final regression model results

Variable	Coefficient	StdError	t-Statistic	Probability	Robust_SE	Robust_t	Robust_Pr	VIF
Intercept	19.728628	1.874005	10.527519	0.000000*	2.032007	9.708939	0.000000*	-------
AVG. ELK DENSITY (/km^2)	3.047726	0.754341	4.04025	0.000116*	0.820123	3.716181	0.000356*	1.064406
PUBLIC LAND (%)	-0.132224	0.025642	-5.156527	0.000002*	0.025437	-5.198156	0.000002*	1.064406

Adjusted R^2 = 0. 262629
* = statistically significant p-value ($p < 0.01$)

4.3. Key Result

The key result is that the average number of elk and public land percentages were the only significant variables to elk hunter success. Variable significance for both explanatory variables was 100 percent. Average number of elk and public land percentages had 100 percent positive and negative relationships respectively. This indicates a stable relationship between the dependent and explanatory variable. Terrain ruggedness was not significant in explaining elk hunter success.

Chapter 5 discusses the model results further and offers an explanation for the model output, providing explanations for the results and why certain explanatory variables had more of an impact on elk hunter success. Chapter 5 also discusses the successes and limitations of this study in addition to suggestions for future research.

Chapter 5 Discussion and Conclusions

Does terrain ruggedness have a negative impact on elk hunter success? This chapter discusses the results outlined in the previous chapter, providing explanations for the results and suggestions to explain the causes for the outliers in model performance. This chapter concludes with a discussion of the successes and limitations of this study and suggestions for future research.

5.1. Regression Results

This study analyzed the relationship between terrain ruggedness, in addition to other variables, and elk hunting success in Colorado. A total of 24 DEMs plus a GMU and elk habitat feature class were used to quantify elk habitat terrain and create a ruggedness number for the identified elk habitat in each of the 93 GMUs. Linear regression was employed to evaluate the relationship between the average elk harvest and five explanatory variables: average hunter and elk densities, terrain ruggedness, public land percentages, and road densities. The analysis determined average elk and road density were the only two significant explanatory variables. Figure 18 summarizes the standardized residuals (a measure of the strength of the difference between observed and expected values) for each GMU.

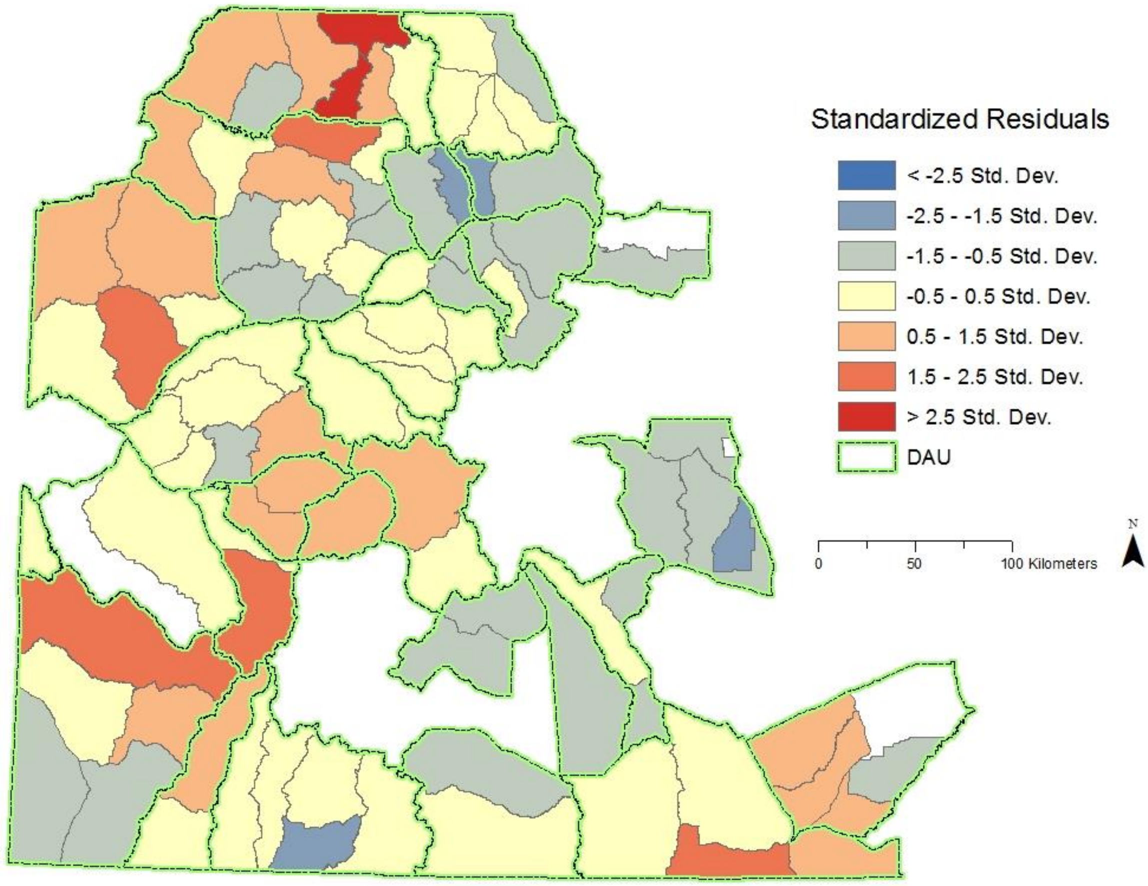

Figure 18. Standardized residuals for each GMU

While the model results followed a normal curve, there were two outliers. GMUs 5 and 441 had a standard residual greater than 3. Both are GMUs in the DAU E-2, the home of the Bear's Ears elk herd, the second largest elk herd in North America. Only one GMU in DAU E-2 had a negative standard residual (GMU 301). According to CPW, the E-2 elk herd is above the population objective of 18,000 elk (Finley and Grigg 2008). CPW has utilized private land only antlerless licenses and late-season antlerless licenses in addition to OTC licenses to reduce the elk population as increased development will lead to more conflicts with elk and humans.

5.2. Analysis Accomplishments

This study was successful in establishing a ruggedness number for the elk habitat in each GMU in the study area. 24 1/3 arc-second DEMs were analyzed to quantify terrain and create a ruggedness number for each GMU's identified elk habitat. Another success was obtaining statistics for the GMUs in the study area from spatial and non-spatial data. Road and public land figures were obtained by processing vector data in ArcMap. Elk habitat was identified from reclassifying a vegetation layer and converting the desired cells into a polygon feature class. Harvest and population estimates were obtained from pdf documents obtained from CPW.

5.3. Analysis Limitations

Limitations in the data included the fact that harvest reports do not disclose whether a hunter harvested an elk on public or private land. While CPW issues landowner hunting licenses to landowners, hunters that hold OTC licenses could hunt private land through an outfitter or permission from landowners. This study analyzed the total harvest for all GMUs in the study area.

Population estimates were a limitation since they are estimated at the DAU level. This analysis aggregated GMU population based of a GMU's percent of DAU land area. CPW estimates elk populations at the DAU level because DAUs represent all of the seasonal ranges for a particular elk herd (Finley and Grigg 2008). These areas are where an elk spends its entire life. No GMU contains the same amount of winter and summer ranges; therefore, an elk herd may move out of one GMU which is in their summer range to another GMU that contains their winter range.

5.4. Conclusions and Suggestions for Future Work

Elk hunting is not an easy endeavor. In 2016, 82 percent of Colorado's elk hunters were unsuccessful. With a terrain ruggedness estimate plus statistics such as percent elk habitat, total road distance, and percent public land, hunters can compare GMUs that offer OTC hunting licenses so they can get away from other hunters, private lands, and roads. A successful hunting trip could mean a return trip in following years; both CPW and the local communities would benefit from the added revenue. Thus added revenue will allow CPW to stay fiscally independent from general fund tax dollars and ensure that all game and fish species exist for future generations to enjoy.

While the linear regression model created in this study was able to tell 26 percent of the Colorado elk harvest story from 2012 to 2016, there are other variables, such as weather, hunter motivation, and the amount of time hunters spend hunting, among others, that may influence elk hunter success. While costly to obtain, this study might have benefited from harvest location data collected by voluntary hunters. Data could be collected with GPS and/or survey data. Another alternative would be to analyze the 2nd and 3rd rifle seasons for the same OTC units from this study and focus solely on the hunters that did not obtain a landowner license.

More accurate GMU population estimates would benefit this study. GMU elk populations are difficult to assess because GMUs were created to manage hunters. Furthermore, each GMU consists of different types of elk habitat range. For example, GMU 5 in DAU E-2 consists of 20.8 percent elk winter range while GMU 301, which is in the same DAU, consists of 99.8 percent winter range (Finley and Grigg 2008). Elk may not be in GMU 301 during the early hunting seasons in a warm year. Analysis could be performed at the DAU level by summing hunter, harvest, and recreational day data for each GMU in a DAU. Ruggedness, road density, and public land percentage could be calculated using different study area data.

Future analyses should analyze each year separately and consider weather variables. Weather can impact hunting success, especially elk hunting. Snow and cold weather forces elk to migrate from their summer range in higher elevations to their winter range in lower elevations. While this study used an average over a five-year period (2012 to 2016) to account for the weather variable, an analysis of the hunting seasons in one year that includes temperature and precipitation in each GMU as exploratory variables could further benefit model performance.

A majority of Colorado’s population lives along the Interstate 25 corridor from Pueblo north to the Wyoming-Colorado border. The GMUs in the western portion of the study area performed better than the GMUs in the eastern portion that are closer to the Interstate 25 corridor. Future studies could analyze the geographic aspect by analyzing proximity to population centers along Interstate 25.

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Appendix: GMU Statistics

GMU ID	Elk DAU	Average Harvest	Average Hunters	Average Recreation Days	GMU Average Elk Population	Ruggedness (Mean TRI)	Roads (km)	Public Land (%)	Elk Habitat (%)	Area (km^2)
3	E-2	3,227	12,258	48,312.2	6,499	88.34	2,016.19	53.3	89.2	2,192.41
4	E-2	4,979	16,292	74,558.0	3,589	129.48	850.12	47.1	93.1	1,210.75
5	E-2	2,330	5,779	23,765.2	2,294	148.81	418.29	59.7	98.0	773.76
6	E-3	2,115	14,403	67,286.6	1,200	127.77	1,019.31	39.7	89.5	916.45
11	E-6	4,668	18,127	75,826.0	5,585	121.03	1,473.80	65.4	93.1	1,581.25
12	E-6	7,335	23,794	104,857.8	4,507	160.06	586.73	50.4	95.0	1,276.02
13	E-6	4,156	9,891	41,252.0	3,313	137.25	973.29	21.8	86.7	937.94
14	E-2	1,756	11,096	63,278.4	3,137	174.78	662.69	85.6	93.9	1,055.94
15	E-7	2,337	17,975	96,240.8	3,385	163.12	879.00	63.5	96.1	1,274.44
16	E-3	1,207	7,133	34,306.0	1,085	126.29	601.75	50.9	84.4	827.71
17	E-3	1,081	7,558	35,605.8	955	123.05	711.33	63.0	90.2	729.16
18	E-8	2,285	22,924	110,366.2	3,478	189.10	1,298.09	87.5	88.7	1,671.28
21	E-10	1,697	10,120	51,018.4	2,660	157.26	1,875.44	86.9	92.1	2,304.01
22	E-10	2,255	11,261	59,877.6	2,957	148.98	2,291.73	70.4	95.5	2,561.25
23	E-6	3,347	16,908	77,542.8	3,866	156.86	693.69	39.5	93.6	1,094.51
24	E-6	2,629	14,404	66,572.8	4,016	171.10	289.68	92.8	95.8	1,137.06
25	E-6	1,265	7,375	37,349.0	2,123	174.52	369.73	83.1	91.8	601.04
26	E-6	929	5,410	27,817.0	2,197	138.06	374.90	49.4	90.3	622.02
27	E-7	835	7,141	32,062.6	1,355	138.36	497.80	55.6	90.6	513.55
28	E-13	2,167	18,173	90,061.8	2,899	178.41	1,825.33	66.7	92.2	1,717.90
30	E-10	697	4,594	19,092.6	2,597	172.71	2,795.91	73.7	47.5	2,249.81
31	E-10	1,657	6,523	31,932.0	2,101	176.83	1,141.85	56.9	88.3	1,819.45
32	E-10	810	3,845	18,072.6	901	184.16	843.63	38.0	86.3	780.29
33	E-6	1,834	12,604	69,264.0	3,808	178.72	1,058.55	73.7	90.8	1,078.22
34	E-6	667	5,109	25,912.8	1,765	187.94	428.56	92.0	96.0	499.79
35	E-12	1,078	6,297	29,819.8	1,622	164.15	875.81	70.8	95.9	694.33
36	E-12	985	8,007	39,970.6	1,664	199.88	735.04	82.3	93.2	712.61
37	E-13	1,194	9,880	45,936.6	2,308	189.96	2,039.70	72.0	86.1	1,367.75
38	E-38	517	5,087	30,436.8	660	192.57	4,076.86	22.0	70.1	1,180.06
41	E-14	1,881	9,720	50,152.6	2,116	133.50	744.54	62.0	69.5	849.81

GMU ID	Elk DAU	Average Harvest	Average Hunters	Average Recreation Days	GMU Average Elk Population	Ruggedness (Mean TRI)	Roads (km)	Public Land (%)	Elk Habitat (%)	Area (km^2)
43	E-15	2,356	12,986	69,023.4	3,547	212.78	1,404.06	71.1	84.5	1,931.31
44	E-16	1,137	8,923	43,827.2	1,939	191.00	1,188.54	78.9	92.1	975.91
45	E-16	842	7,420	41,072.8	1,727	213.46	799.53	89.2	89.7	869.41
47	E-16	713	4,604	24,711.8	1,511	222.23	415.90	91.0	86.4	760.61
52	E-14	1,190	7,223	39,646.2	1,707	138.44	634.54	47.7	76.4	685.37
53	E-52	1,866	9,153	49,598.4	1,836	194.33	510.38	76.9	81.3	1,026.73
54	E-41	2,668	13,151	72,368.0	3,328	194.06	1,074.66	73.4	89.9	1,517.12
55	E-43	2,390	15,866	85,406.6	2,812	198.22	1,596.96	88.7	89.1	2,294.72
59	E-23	441	3,944	21,170.6	1,159	190.18	3,006.49	35.5	59.9	1,674.23
60	E-40	373	1,762	9,852.4	1,870	142.91	563.23	82.3	82.2	616.63
62	E-20	4,180	24,555	142,222.6	5,756	128.74	3,281.89	68.2	77.9	3,568.74
63	E-52	1,173	5,338	28,385.2	1,710	158.02	944.83	56.8	79.1	956.33
64	E-35	1,011	4,172	18,772.2	1,688	183.97	1,001.25	42.9	36.6	697.57
65	E-35	2,901	11,820	62,384.2	927	193.42	1,448.92	49.1	81.8	1,740.17
68	E-26	877	9,140	49,724.4	2,199	161.91	873.14	86.9	90.8	1,561.33
70	E-24	5,355	18,015	93,838.2	6,103	136.09	4,061.82	66.9	90.6	3,914.32
71	E-24	2,388	13,178	71,597.2	2,102	186.28	829.51	84.8	96.6	1,348.46
72	E-24	369	2,575	13,133.6	3,953	118.55	2,079.59	28.3	48.0	2,535.46
73	E-24	739	4,214	23,081.8	3,603	141.47	2,254.42	36.4	82.4	2,310.93
74	E-30	1,668	8,949	53,892.0	2,579	235.55	1,072.93	83.9	88.7	1,541.72
75	E-31	1,684	8,781	49,638.8	4,184	173.28	2,277.43	43.5	78.0	1,673.61
77	E-31	2,222	13,132	68,852.8	3,605	179.08	1,066.41	82.4	92.3	1,442.22
78	E-31	1,977	11,159	59,257.4	4,943	187.95	1,032.09	62.4	91.0	1,977.39
80	E-32	1,634	12,685	71,099.8	4,142	147.50	1,926.30	58.5	77.9	2,296.37
81	E-32	2,135	14,127	78,363.6	5,670	129.43	2,090.09	69.5	87.4	3,143.64
82	E-11	1,460	8,362	39,645.8	4,664	135.64	1,961.74	63.5	64.5	2,818.88
83	E-33	1,455	5,922	30,251.6	4,696	124.08	6,140.71	2.1	87.6	3,240.20
85	E-33	3,088	12,954	73,428.8	4,406	145.26	3,910.35	16.9	94.3	3,040.17
86	E-27	1,249	8,738	53,216.4	1,261	180.04	1,056.45	56.0	84.1	1,278.35
131	E-6	1,704	6,184	31,286.4	1,770	148.37	622.69	14.9	91.8	501.06
133	E-53	81	283	1,342.4	183	61.45	620.54	9.0	49.3	1,490.55
134	E-53	43	151	694.0	126	63.75	594.69	5.4	13.0	1,029.11
140	E-33	463	1,670	8,510.2	1,722	95.19	649.56	3.9	82.2	1,187.93
141	E-53	73	258	1,388.4	76	62.93	602.46	7.8	21.7	617.56

GMU ID	Elk DAU	Average Harvest	Average Hunters	Average Recreation Days	GMU Average Elk Population	Ruggedness (Mean TRI)	Roads (km)	Public Land (%)	Elk Habitat (%)	Area (km^2)
161	E-3	1,198	10,085	53,309.8	1,383	129.41	820.18	70.8	88.9	1,055.97
171	E-3	1,061	7,694	35,673.4	869	126.17	775.15	63.2	88.7	663.56
181	E-8	636	6,442	27,204.4	980	152.10	403.94	60.1	87.9	471.07
211	E-6	2,936	11,362	47,681.6	3,953	145.88	1,321.50	43.2	92.2	1,119.35
214	E-2	2,699	7,705	34,639.0	1,771	150.15	545.66	21.9	89.7	597.38
231	E-6	1,180	7,007	36,213.0	1,631	152.56	249.66	64.0	91.2	461.82
301	E-2	1,561	6,694	24,255.0	2,837	102.93	1,052.73	15.4	87.0	957.19
361	E-12	176	1,777	8,591.6	500	176.97	206.09	67.9	97.5	213.99
371	E-13	803	6,184	28,539.6	750	190.43	353.67	85.1	80.6	444.68
411	E-14	585	3,461	18,481.0	1,482	143.94	432.77	61.8	51.5	595.29
421	E-14	3,108	16,415	89,542.8	3,489	151.66	835.87	64.5	92.0	1,401.27
441	E-2	3,247	7,482	28,063.6	1,491	133.15	378.24	30.0	92.2	503.08
444	E-16	1,329	8,515	47,772.8	1,907	183.36	1,210.93	63.5	91.6	960.01
471	E-15	193	1,338	6,004.8	495	233.48	175.77	88.3	75.3	269.41
511	E-23	831	9,357	54,247.6	649	164.18	2,348.26	61.4	89.5	937.76
521	E-14	3,348	14,822	78,187.8	3,276	172.46	547.61	75.1	93.0	1,315.38
551	E-43	1,107	7,893	43,137.0	1,732	184.87	983.66	86.7	94.6	1,413.44
581	E-23	678	7,490	39,677.2	1,233	156.09	2,424.93	39.1	83.2	1,782.00
591	E-23	198	1,476	7,260.2	835	86.29	1,299.58	0.0	89.9	557.73
681	E-26	503	5,923	31,802.0	1,619	172.92	728.81	87.9	96.0	1,149.91
691	E-27	49	656	3,749.4	643	156.09	843.32	45.5	90.7	652.50
711	E-24	1,744	9,403	49,696.6	3,313	123.73	2,244.57	59.9	85.9	2,124.89
741	E-30	528	2,465	18,639.2	2,097	118.69	1,449.12	5.0	86.5	1,253.85
751	E-31	1,216	6,139	30,646.8	3,000	195.91	835.31	71.3	78.0	1,200.28
771	E-31	360	2,699	12,287.6	2,368	154.56	847.47	18.6	90.0	947.14
851	E-33	1,113	2,907	13,059.0	1,643	184.30	760.88	0.8	96.4	1,133.83
861	E-27	293	1,967	10,077.8	528	169.30	469.24	37.6	94.0	535.59