ELK HARVEST AND THE ACCESSIBILITY OF HUNT DISTRICTS: DOES ROAD DENSITY INFLUENCE HUNTER HARVEST SUCCESS?

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 2021

ACKNOWLEDGEMENTS

This project would not be possible without the support and professional assistance of the following:

- Sam Carlson, Montana State University Instructor, for his willingness to provide a great deal of GIS assistance and project support.
- My advisor Dr. Scott Powell, for support throughout the program and especially on my project.
- Nick Fox, of Fox Geoscience LLC, for his support as a mentor in GIS. The faculty and staff of MSU, especially my graduate committee which includes Dr. Tracy Sterling, Dr. Robert Peterson, and Dr. Scott Powell.

I would like to thank family and friends who have supported and encouraged me throughout my academic career. I owe a great deal of thanks to my parents for always supporting my dreams, listening to my indecisions, and encouraging me in every way imaginable. They are also responsible for the love and appreciation I have for wildlife and the outdoors. My sisters, Jenna, and Elliott have also been constant sources of support and encouragement in all my endeavors.

Lastly, I would like to thank my husband, Shaun, who has supported me in more ways than I can count. His encouragement, willingness to help me study, ability to sit through long-winded explanations of anything I learn, and constant cookie supply made all of this possible from day one. His love and support have been an invaluable component to my academic success, and I am forever grateful.

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ABSTRACT

Wildlife managers are constantly faced with the difficulty of balancing growing demands for elk hunting opportunities and maintaining elk populations. Presence of roads and associated impacts to elk movements, behaviors, and vulnerability/mortality has been widely studied, with a general consensus of negative impacts to elk where roads are open to motorized use. Road density has also been shown to influence hunter densities and hunter effort which may indirectly effect harvest success. Previous studies analyzing elk harvest were limited to bull harvest only, certain hunting seasons, or lacked spatial replicates. The purpose of my study was to analyze road density and associated, all-inclusive harvest metrics on public land in 13 hunting districts of southwest Montana. Harvest was analyzed in two ways: estimated harvest number and harvest success (percentage successful hunters to total hunters). I obtained harvest reports for 2014 to 2016 data on hunter harvests. I used road data from the Forest Service, Bureau of Land Management, and Montana Department of Transportation, as well as public land GIS data from the state of Montana. GIS methods were conducted using QGIS. I conducted linear regression analyses to determine whether independent variables (road density, hunter density, hunter to elk ratios, hunter effort) were significant predictors on response variables (harvest number or success). Road density and hunter density were not significant predictors of harvest (number or percentage), while hunter effort and hunter to elk ratios were only significant predictors of harvest number. Road density on its own may not significantly predictor of harvest, but traffic on roads might. Hunter density was not directly linked to road density; therefore, it is unclear whether road density influenced hunter density and consequently harvest. One limitation was the lack of data for trails open to motorized use. Motorized route density may have been greater if open trails were included. Hunter effort and hunter to elk ratios may be useful to wildlife managers for predicting elk harvest numbers. If harvest numbers increase when these metrics increase, managers could implement changes to hunting in certain areas to increase hunter interest, therefore increasing hunters and potentially increasing harvest number.

INTRODUCTION

Elk Management

Hunting serves as a useful tool in population management with goals generally aimed at providing ample opportunity for hunters, quality habitat to wildlife, and sustaining healthy populations of wildlife for future generations (Sergeyev et al. 2020). Elk (*Cervus canadensis*) are an icon of the American West and are valued in the ecosystem for various reasons. They play important roles in their landscapes, serve as an umbrella species (conservation allows for protection of other species), and provide an abundance of recreational opportunities that also stimulate local economies (NRCS, 1999; Ranglack et al. 2017; Rowland et al. 2000).

Management practices have traditionally focused on habitat on public land, management of roads, and motorized use (Devoe et al. 2018; Ranglack et al. 2017). Habitat management has generally focused on security cover that would be suitable for male elk survival during hunting seasons, primarily rifle season. Suitable security cover should include adequate vegetative cover, ample foraging opportunities, and some degree of road management (Proffitt et al. 2013). Adequately managed security areas allow for increased potential elk survival during hunting seasons, which in turn allows for greater hunting opportunities (Devoe et al. 2018; Proffitt et al. 2013). In recent years, elk management has shifted from strategies aimed at population growth and habitat management, to strategies that promote regulated harvest of female elk to maintain or reduce population sizes (Proffitt et al. 2013; 2016). Proffitt et al. (2016) suggest that harvest of female elk as an effective tool of management is only effective if female elk are accessible to hunters. Numerous studies have found that elk exhibit increased use of lands restricted to hunter access during hunting seasons, making it difficult for hunters to harvest any animals (Proffitt et el. 2016; Ranglack et al. 2017; Sergeyev et al. 2020). Road management in regard to elk habitat and populations is multifaceted. Managing road access is important for many groups including recreationalists, forest managers, wildfire maintenance, biologists, and hunters. However, it has become increasingly apparent that roads and trails, particularly those open to motorized use, have negative impacts on elk populations, elk movement patterns, and use of habitat in many regions (Wisdom et al. 2018; Rumble et al. 2005; McCorquodale 2013).

Elk Habitat Selection & Movement Patterns

Road effects on elk may fall in two broad categories: indirect effects on elk habitat and direct effects on elk populations and individuals (Rowland et al., 2004; Edge 1982). A primary impact of roads in relation to elk is habitat fragmentation, with heavily roaded areas usually containing fewer patches of forest cover that are large enough to be effective as elk habitat. This is especially true in areas where elk are hunted (Rowland et al., 2004). It has been commonly accepted that security habitat is a critical component of elk survival on public land, while private land tends to heavily restrict hunter access and may act as a refuge to elk during hunting seasons. Generally, elk tend to alter their movement patterns during hunting seasons and select areas further from roads open to motorized use (permanently or temporarily) and areas with reduced hunting pressure or human disturbances (Ranglack et al. 2017; Sergeyev et al. 2020; Unsworth et al. 1998; Wisdom et al. 2018; Millspaugh et al., 2000).

Managing elk populations can be difficult when elk distributions shift from hunter-accessible to non-accessible areas as a result of human disturbances. If elk herds select refuge areas during hunting seasons, this could be problematic for wildlife managers using harvest as a management tool for several reasons including reduced harvest success for hunters, potentially increasing risk of transmissible disease due to larger aggregation of individuals, altered impact to plant communities that also sustain elk populations, and shifts in diet composition and forage quality (Proffitt et al. 2010, Johnson et al. 2004). Devoe et al. (2018) suggest that regardless of hunting risk (high or low) associated with home ranges, elk in their study maintained or increased selection for areas with greater forage quality which suggests that elk did not compromise nutritional resources even in areas where mortality risk was high. Where accessibility and quality forage overlap, elk residing in these areas may be at greater hunting mortality risk.

Habitat selection and movement patterns in elk populations have also been shown to vary depending on the sex of the animal. Female elk (cows) tend to select areas that restrict hunter access, even over security habitat on public land (Proffitt et al. 2013; Ranglack et al. 2017). Unsworth et al. (1998) found that elk shifted from high use of shrub and open timbered habitats to more heavily timbered habitats from spring through fall for both cows and bulls. In that study, cows, and bulls (two years or older), selected habitats with heavy canopy cover in roaded areas during fall and more open timbered areas in unroaded regions. In general, bulls and cows tend to select somewhat steeper areas during fall (Unsworth et al. 1998; Sergeyev et al. 2020); although this also depends on the public/private land matrix of a region and the security habitat available on public land. Where hunting access is restricted (particularly private land), habitat characteristics vary from grasslands to timbered landscapes (Proffitt et al. 2010, 2013; Sergeyev et al. 2020). Ranglack et al. (2017) also found that nutritional resources were an important determining factor in habitat selection by female elk during archery season. In general, studies suggest that density of roads open to motorized use tend to be the strongest predictor of elk distributions and habitat selection (Proffitt et al. 2013; Ranglack et al. 2017).

Road Access & Harvest Success

Studies examining elk vulnerability and harvest mortality generally show increased mortality risk on public land with greater open road density (motorized use), likely due to increased hunter densities (McCorquodale et al. 2003). McCorquodale (2013) summarized the findings of multiple studies that observed elk survival trends/hunter success in relation to open road areas. The likelihood of bull elk survival in one study was nearly double in unroaded areas compared to areas with greater road density (McCorquodale 2013). Other studies summarized in McCorquodale's (2013) synopsis described similar trends including increased probability of mortality with increased road and hunter densities, reduced bull elk survival in highly roaded areas vs less roaded areas, increases in the number of bull elk killed as number of roads increased during a 25-year span, and that locations for living elk were more likely to be farther from roads than elk kill sites (Weber 1991). Cooper et al. (2002) also found that out of a variety of variables that were used to model and predict hunter success in Idaho, road density was one of the most useful predictors.

Gratson and Whitman (2000b) observed slightly different trends in their study looking at road closures, road density, and success of hunters in Idaho. Hunter success was greater in managed access and roadless areas (~25%) compared to roaded areas (~15%). Gratson and Whitman (2000b) suggest that while vulnerability may be greater in areas with high road density, elk may be selecting less roaded areas and surviving better in those areas. Consequently, this may result in more long-term opportunities to harvest an elk in less roaded areas and better-quality hunt experiences for hunters. Millspaugh et al. (2000) described similar trends in their shared space use study of hunters and elk. They found that shared space by elk and hunters was negatively correlated with road use and road density (i.e., hunters and elk were both more likely to select areas with fewer road effects). Managing access to public lands can be a useful tool in big-game management at a local scale, especially game harvest rates (Gratson and Whitman, 2000b). Elk, and other big-game animals, may have substantially higher survival rates in areas with closed roads (or no roads) compared to areas with open roads.

Study Objective

Wildlife managers are constantly faced with both the difficulty of balancing growing demands for elk hunting opportunities (often where demand is greater than elk numbers) and maintaining elk populations. The purpose of this study was to contribute further investigations to the growing repository of management methods that may be successful at finding a balance in hunter regulations that do not limit the number of hunters or season lengths, and also support sustainable elk populations for generations to come. Specifically, this study may contribute to the popularly debated topic of whether road closures are necessary when it comes to elk population and habitat management and how closures might affect hunter harvest.

My primary research question is whether areas (hunting districts) with greater open road density have greater rates of harvest compared to areas with lower open road density in southwest Montana? Southwest Montana is a popular region for elk hunters because of maintained abundances of elk. Because of elk abundance, hunter popularity, and unrestrictive regulations (i.e., no drawing for certain permits), region 3 was the optimal choice for my study area. Other regions of the state, for example eastern Montana, generally have special draw-only permits for harvesting brow tine bulls, which potentially limits hunter densities. Hunter densities may be different in a district if there are limited licenses for brow tine bulls and general licenses that only permit harvest of antlerless elk or spike bulls, compared to districts that do not have these limitations. Hunters targeting brow tine bulls might not consider districts with bull restrictions due to limited licenses. Essentially, hunter representation in districts may be skewed because of harvest limitations and therefore, harvest, road, and hunter relationships may not accurately be portrayed.

I hypothesize that greater open road density will result in increased harvest rates because there may be opportunities to reach more areas of public land than non-motorized areas, therefore increasing the odds of success. Based on previous studies, I expect hunter harvest to be greater in areas (districts) with greater open road density. Harvest will also be considered in relation to hunter density, hunter: elk ratios, and hunter effort, although road density is the primary focus of my study. I considered these additional metrics as possible explanations for harvest simply because the information was available from harvest reports. Harvest is expected to be greater where hunter densities are greater, while harvest is expected to be greater where hunter to elk ratios are lower. Lower hunter to elk ratios (fewer hunters per elk) should theoretically increase chances of success for hunters because there are less hunters for every elk. I also hypothesized that harvest will be greater where there is greater hunter effort.

Harvest was considered as estimated harvest number and harvest success (percentage of total hunters that were successfully harvested an elk on public land). Estimated harvest number provides an estimate of how many elk were taken in a given area regardless of the number of hunters attempting to harvest an animal. Harvest success considers harvest in relation to the number of hunters attempting to harvest an animal in an area. Harvest number gives an idea of how a population might change because of hunting but does not provide specific insight about changes to hunter's outcomes. Without knowing hunter numbers, any amount of harvest might be conceived as "good" when in reality it is not. Harvesting 400 elk, for example, sounds better when 1,000 hunters attempted harvest versus 3,000. Harvest success may be suitable for adjusting hunting regulations or habitat management, specifically motorized routes. For example, if success is relatively low, road closures or restrictions could be applied to a region.

METHODS

Montana Elk Hunting

Montana big-game management is conducted by Montana Fish, Wildlife and Parks (FWP). The state is broken into seven administrative regions, which are further divided into individual hunting districts (also referred to as units or HD(s) from here on). Districts (and regions) have elk abundance objectives and objective ranges. Montana has set laws that are applicable to all regions of the state, in addition to regulations that are specific to individual hunting districts and species of game. Resident and non-resident hunters may obtain one general license for elk, though non-resident hunters have to apply for general licenses through drawings. Additional drawings are available to residents and non-residents for elk "b" licenses, which are valid for an additional antlerless elk. These tags are limited for both resident and non-resident hunters and may follow restrictions specific to hunt districts and season.

Montana has two "general" seasons and "shoulder" seasons for elk. "General" seasons refer to archery and rifle seasons. Archery season begins on the first Saturday of September and lasts until mid-October. A one-week intermission separates the archery-only season from the start of rifle season. Rifle season lasts five weeks usually ending in late-November. Shoulder seasons are conducted before or after the five-week general deer and elk seasons. Specific shoulder season restrictions may apply in certain districts. Recreational accessibility varies across public and private land in Montana. Public land typically provides access through walk-in only trails, gated roads with motorized use restrictions (seasonal/vehicle restrictions), and roads closed entirely to motorized use. Motorized use may include all-terrain vehicles (ATV's), motorcycles (i.e., dirt bikes), side-by-sides, or highway vehicles (i.e., cars or trucks). Where motorized use is prohibited, options for access are typically limited to pack animals (horses, llamas), bicycles, or walking.

Study Areas

The study area is located in southwest Montana and includes 13 hunting districts within region 3. The study area is enclosed by the Montana/Idaho border on the south and western edges, several Montana highways (43, 278, 41, 55) and roadways to the north, and the Tobacco Root Mountains, Madison River, and Highway 87 to the east (Figure 1). A matrix of public and private land ownership covers the extent of the study area, with public land being the focus of this study. Private landownership and associated harvest success were not considered, as private land accessibility is complex, variable, and difficult to determine.

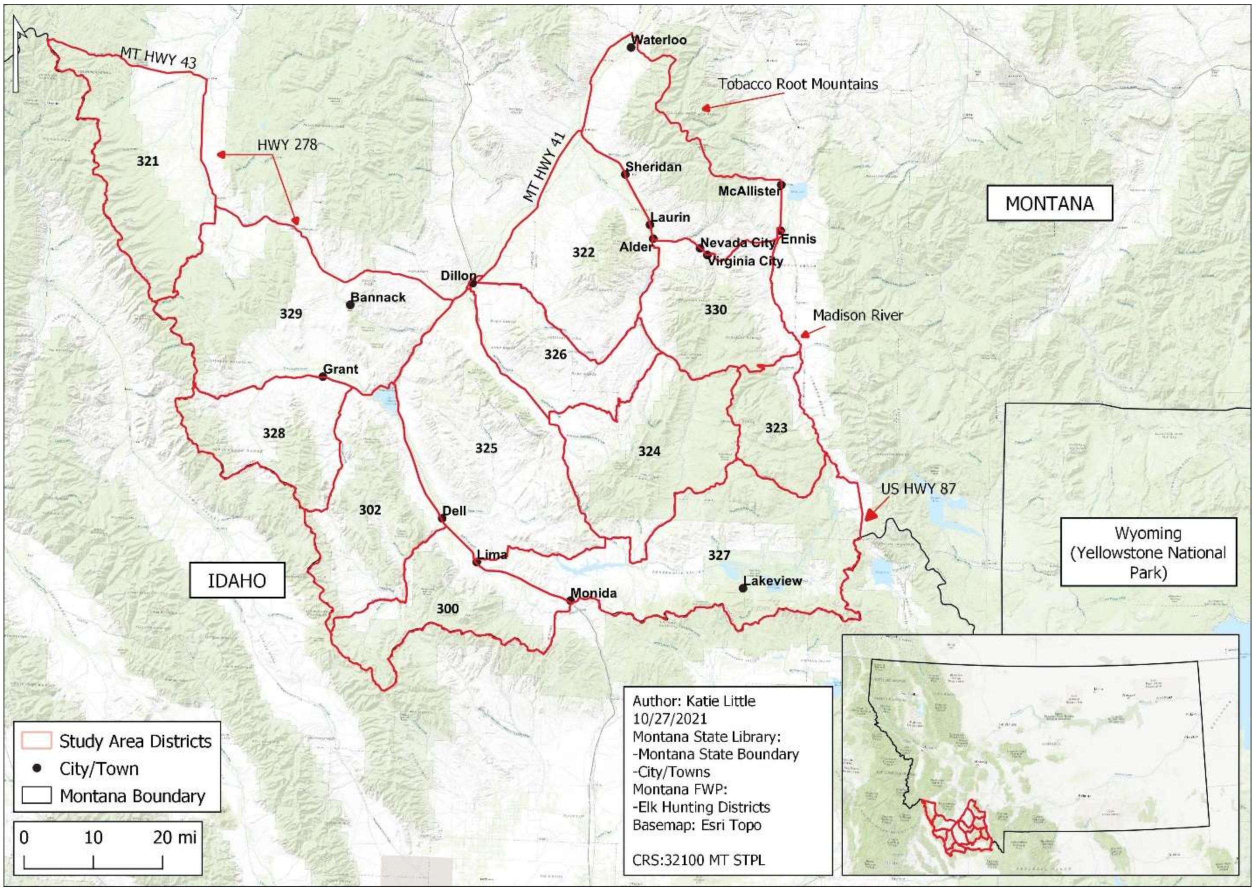

Figure 1: Study area which includes FWP defined hunting districts, labeled here for reference. Highway polylines coincide with hunting district boundaries and are not visible. Highways on the boundaries of the study area have been marked on the map.

Districts were selected based on the following hunting regulations: season dates, animal harvest restrictions, youth hunting, and elk B-licenses. This approach was taken to account for equal harvest opportunity between districts for all hunters. Districts were included if there was a possibility to harvest a brow tine bull or antlerless elk during archery or rifle season, youth hunts (and individuals with a Permit to Hunt from Vehicle, or PTHFV) that allowed harvest of either sex elk for the entirety of both seasons, and elk B-licenses that followed the same restrictions across selected districts and hunting seasons (rifle and archery) (Table 1).

Table 1: Region 3 selected hunting districts summary.

District	Name	Brow-Tined Bull or Antleress Elk	Archery & Rifle Seasons	Youth or PTHFV (Either Sex Elk) with Same Season Dates	*B-License Restrictions	B-License Season Dates	Notes
300	Lima Peaks-Nicholia	Yes	Yes	Yes	B-License 399-00	Same as Generals	
302	Tendoys	Yes	Yes	Yes	B-License 399-00	Same as Generals	
320	South Tobacco Root Mountains	Yes	Yes	Yes	B-License 399-00	Same as Generals	
321	West Big Hole	Yes	Yes	Yes	B-License 321-00	Same as Generals	
322	Lower Ruby	Yes	Yes	Yes	B-License 399-00	Same as Generals	
323	Wall Creek	Yes	Yes	Yes	B-License 399-00	Same as Generals	Brow Tine bull or antlerless elk allowed for full rifle season but with area restrictions (excludes bull elk in Wall Creek WMA). B-license valid on Wall Creek WMA.
324	Snowcrest-Lower Ruby	Yes	Yes	Yes	B-License 399-00	Same as Generals	
325	Blacktail Ridge-Sage Creek	Yes	Yes	Yes	B-License 399-00	Same as Generals	
326	Sweetwater	Yes	Yes	Yes	B-License 399-00	Same as Generals	
327	West Fork Madison-Centennial	Yes	Yes	Yes	B-License 399-00	Same as Generals	
328	Medicine Lodge-Horse Prairie	Yes	Yes	Yes	B-License 399-00	Same as Generals	
329	Horse Prairie-Bannack	Yes	Yes	Yes	B-License 321-00 & B-License 399-00	Same as Generals	Includes both B 321-00 & B 399-00 permits. Both tags include elk that may be harvested from areas within unit 329.
330	Greenhorn Range	Yes	Yes	Yes	B-License 399-00	Same as Generals	

*B-License 321-00: Valid in HD 321 and in North Portion of HD 329 from Big Hole pass along the Big Hole Divide, west of USFS Road
*B-License 399-00 Description: Only valid in HDs 300, 302, 320, 322, 323, 324,325, 326, 327, 328, 329, 330, 331, and 332. Valid on Wall Creek WMA and adjacent land as posted.

Data Collection

Elk harvest data were collected from harvest reports available to the public from FWP. Harvest reports reflect hunting harvest data collected by FWP personnel via telephone surveys following hunting seasons and has been reported as a reliable method of data collection (Gratson and Whitman, 2000b). Reports can be filtered by year, hunting district/region, and species and include the following harvest information: license year, hunting district, residency (non-resident, resident), “hunters” (number of hunters that hunted in district), “days” (number of days spent in a district by hunters), “days per hunter” (days spent per hunter in district), total harvest, animal type (bulls, cows, calves), weapon (bow, rifle), and bull size (spike, < 6 points, ≥ 6 points). Harvest data are available from 2004 to 2020, though not all years have complete information (e.g., missing hunter information). Elk harvest location (i.e., Public, Block Management Area (BMA), Not Family/Friend, Family/Friend, Outfitted, and Access Fee within districts) for each district was provided by FWP personnel for this study. These values were reported as percentages of the total harvest for each land type within a district. The data set included information for seasons between 2013 and 2020 and included all districts within each administrative region. Elk abundance information was collected from FWP and provided elk population objectives (targets) and estimates for each district. Abundance data can be used to determine elk to hunter ratios in districts.

Relevant harvest data for this study included license year, district, total elk harvest, total hunter days, and number of hunters that visited a district. Residency was not distinguished as both residents and non-residents follow the same hunting regulations and district boundaries. Total elk harvest was considered rather than harvest by specific genders because both brow tine bulls, and antlerless elk were permitted during both seasons. Spike bull harvest data was not excluded because spikes can be legally harvested by youth and those with a PTHFV. Antlerless elk may also be harvested using a B-license in the study area (following license specific restrictions). I used data for hunting seasons between 2014 and 2016 as these years had complete datasets. I treated hunting seasons for each year as one long hunting season with no difference between archery and rifle season. Shoulder seasons were not applicable for this study area. Harvest by land ownership, particularly public land ownership, for each district was utilized.

I obtained public land ownership, the Montana state boundary, and city/town locations from the Montana State Library Geographic Information Clearinghouse. Montana FWP regional boundaries, restricted hunting areas, and elk hunting districts were obtained from the Montana FWP GIS data website. Road data were obtained from three sources: Forest Service Geodata Clearinghouse, BLM Geospatial Data, and Montana Department of Transportation (Table 2).

Table 2: GIS data layers included in spatial analysis.

GIS Data Layer	Data Source Name	Type	Link
State Boundary	State of Montana Boundary	Vector	https://ftpgeoinfo.msl.mt.gov/Data/Spatial/MSDI/AdministrativeBoundaries/
City/Town Locations	Montana Incorporated Cities and Towns	Vector	https://ftpgeoinfo.msl.mt.gov/Data/Spatial/MSDI/AdministrativeBoundaries/
FWP Regional Boundaries	Montana State Parks Administratie Regions	Vector	https://fwp-gis.mt.gov/arcgis/rest/directories/arcgisoutput/webResources/metadata/admbnd/REGIONS_PARKS.htm
Hunt Districts	Deer Elk and Mountain Lion Hunting Districts All Past Years	Vector	https://fwp-gis.mt.gov/arcgis/rest/directories/arcgisoutput/webResources/metadata/admbnd/huntDistrictsDeerElkLionAllPastYears.htm
Restricted Hunting Areas	Big Game Hunting District Restricted Areas All Past Years	Vector	https://fwp-gis.mt.gov/arcgis/rest/directories/arcgisoutput/webResources/metadata/admbnd/huntDistrictsRestrictedAreasAllPastYears.htm
Public/Private Land	Montana Public Lands	Vector	http://ftp.geoinfo.msl.mt.gov/Data/Spatial/MSDI/Cadastral/PublicLands/
Roads	(Forest Service) Motor Vehicle Use Maps: Roads	Vector	https://data.fs.usda.gov/geodata/edw/edw_resources/meta/S_USA.Road_MVUM.xml
	BLM National Ground Transportation Linear Feature Public Display Polylines	Vector	https://landscape.blm.gov/geoportal/catalog/search/resource/details.page?uuid=%7BD4B238FD-A2DE-47DD-8C8D-28B45B08ECB9%7D
	Montana Off-System Routes	Vector	https://gis-mdt.opendata.arcgis.com/datasets/mdt::montana-off-system-routes/about

Data Analysis

I conducted spatial analysis using QGIS (Version 3.12.2 with GRASS 7.8.2). The project coordinate reference system (CRS) was set to NAD83/Montana (EPSG: 32100). Layers were set or reprojected to the Montana state plane as necessary. I obtained hunting district area (square kilometers) from the "Deer Elk and Mountain Lion" hunting districts layer. Individual shapefiles for each selected hunting district were also created from this layer. The public land dataset included owner, acreage, and polygon shape area (meters) for all public land polygons. Polygon shape area was converted to square kilometers for each public land polygon using the $area function in QGIS. I clipped public land polygons to individual district shapefiles so total public land area could be calculated for each district. Before clipping public land to district shapefiles, the "Check Validity Tool" was applied to identify errors preventing successful use of the clipping tool with the districts layer. I applied the "Fix Geometries" tool to correct the "Ring Self-Intersection" error reported. No differences in polygon boundaries/areas occurred.

Public land area information was also available from the MT FWP hunt planner for each district. I compared calculated values were against FWP values for accuracy and calculated values were used for further calculations. Public land ownership in the study area consisted primarily of national forest (Beaverhead National Forest), Bureau of Land Management (BLM), and state land (e.g., trusts, FWP) (Figure 2). A small portion of public land consisted of other federal ownership (USDA, Bureau of Reclamation, U.S. Fish and Wildlife Service-USFWS). Few public land polygons existed in the study area that were excluded (e.g., city governments) because hunting is restricted on these lands. There were four "restricted areas" in the study area. These areas did not necessarily restrict hunting activity but did have restrictions on weapons allowed for use. For that reason, I did not exclude these areas from road density or public land area calculations.

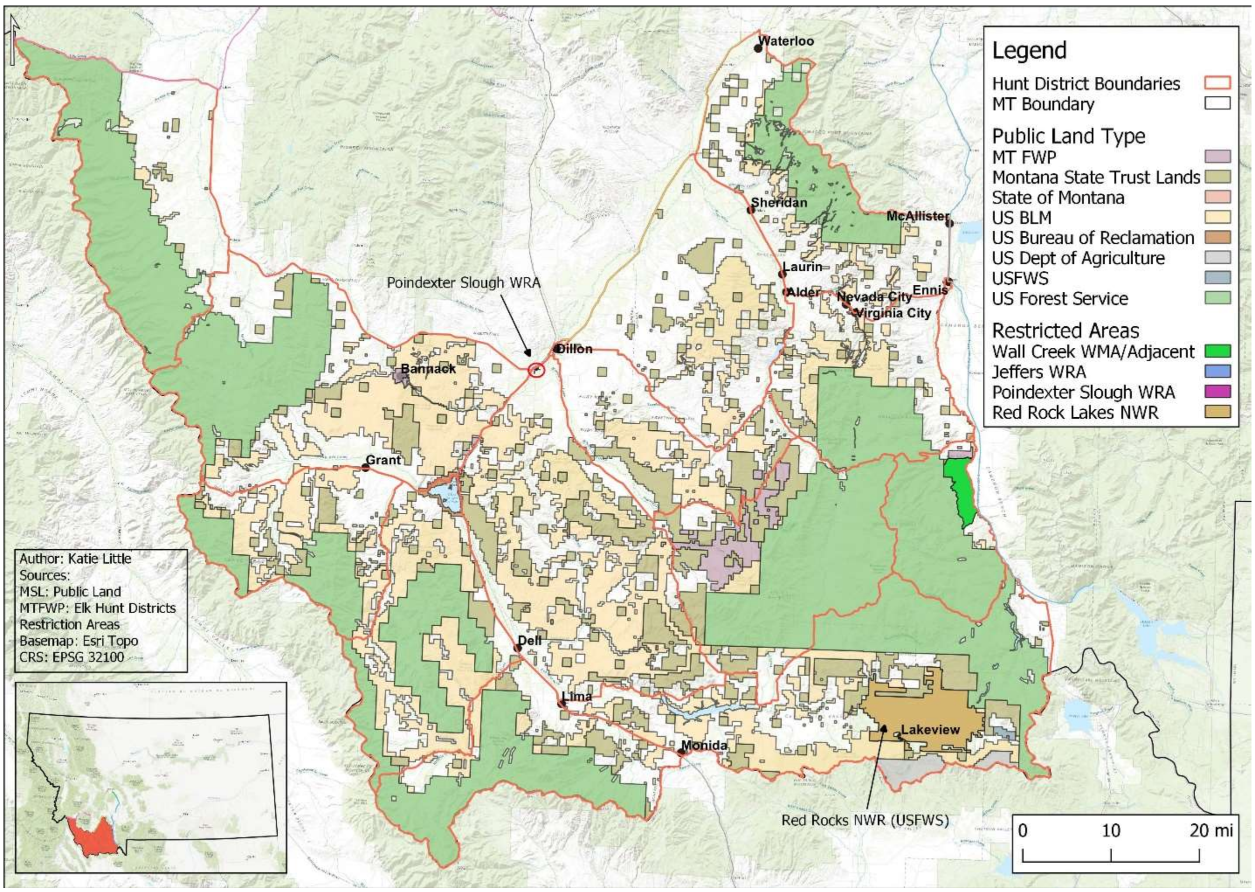

Figure 2: Public land distribution and type. Restricted areas have also been included and are indicated in the legend.

Values for total hunters were averaged across years for each district. Total harvest values and the percentage of elk harvested on public land each year were used to calculate the number of elk harvested in each district. The estimated values were then averaged across years per district. I calculated the percentage of public harvest success using values for estimated public elk harvest and total hunters for each year and then averaged those values for every district. I defined public harvest success as the percentage of total hunters that harvested an elk on public land within each district. I also looked at "harvest number" as a harvest metric and I defined this as the number of elk harvested on public land in a district. This metric did not consider the proportion of elk harvested on public land in relation to total hunters for each district. I calculated hunter density for each year using total hunters in a district and district area and then averaged across years. I used district area for hunter density rather than public land area (within a district) because hunter information is not broken down into land ownership type used by hunters during a season. Hunters have the ability to access public land and potentially private land, but this information is not collected by FWP, so it is not distinguishable here. Hunter density in this study will provide an estimated baseline of how many hunters are visiting any given district.

Hunter to elk ratios were determined using total hunters and elk counts. Seven of the districts in the study area all fell under the same population objective and count (i.e., units 322-327 and 330 had an overall objective of 8,000 elk and count of 10,643 in 2015) during the years selected. In these units, objectives and counts were divided by the number of units to provide an estimate of elk observed in each of those units. In all units, I averaged elk counts across years and averages reported. Counts could then be used to determine hunter to elk ratios. District 321 did not have an objective because a wintering elk herd did not occur in the area; however, a survey from July 2014 provided a count estimate which was used here. I also analyzed the relationship between hunter effort and harvest metrics. Hunter effort was based on the "total hunter days" data from harvest reports. I averaged total hunter days across years for each district, and averages were used for statistical analyses.

Forest Service (FS) road data included roads open to motorized use only. I clipped FS roads to public land polygons within each district to remove roads from non-public land. The original BLM road dataset included road status (open, closed, limited) for roads and trails. I excluded “closed roads” from the study. All trail data were also excluded from the study, as there were no trail data available from the FS on motorized trail routes on national forest in the study area. BLM trail data in the study area included only a small number of trails. Accessible areas that were classified as “Not Assessed” did not distinguish whether the accessible segment was a road or trail. These segments were treated as roads and included because motorized use was permitted on these segments without further specification on limitations. For this reason, they were also treated as “Open” without restrictions. “Limited” access roads could have motorized use restrictions based on vehicle type, season (time of year), or other. When I clipped BLM roads to selected districts only, “limited” access roads in those districts did not include restriction details. A small number of “Unknown” status segments occurred in the study area and I included segments under this category if motorized use permissions were indicated in additional attribute information. The BLM Road dataset was clipped to public land polygons within each district.

The Off-System Routes data included roads on public land, but did not indicate road accessibility (i.e., open or closed). These roads were assumed to be open to motorized use on public land. Off-System routes were clipped to public land polygons within each district. I inspected all road datasets for overlap between datasets to ensure road sections were not counted more than once. Forest Service and BLM datasets had minimal overlap; however, roads in the Off-Systems dataset had substantial overlap with FS and BLM roads. Further inspection of Off-System Road overlap with other datasets showed overlap on primarily FS and BLM land. Roads on state land (e.g., state trust land, FWP owned land) and a small portion of other federal lands (U.S. Fish & Wildlife Service-USFWS, USDA, Bureau of Reclamation) that did not contain FS or BLM roads, were part of the Off-Systems dataset. I created a shapefile containing these land types (state and "other" federal lands) and the Off-Systems dataset was clipped to align with these lands in each district. This removed Off-System roads from FS and BLM land polygons. Any remaining overlap between datasets was removed manually by deleting overlapping road features from one of the three dataset attribute tables. Few overlapping segments required deletion from two road datasets. In some cases, a small portion of a total road segment overlapped with another dataset and could not be removed; therefore, minimal overlap exists between datasets.

Road lengths were reported by respective agencies in miles for FS and Off-System roads and meters for BLM roads. I converted all datasets to kilometers and totaled road data across datasets in each district. I calculated public land road densities (kilometers/square kilometers) for each district using road lengths and calculated public land areas (Figure 3).

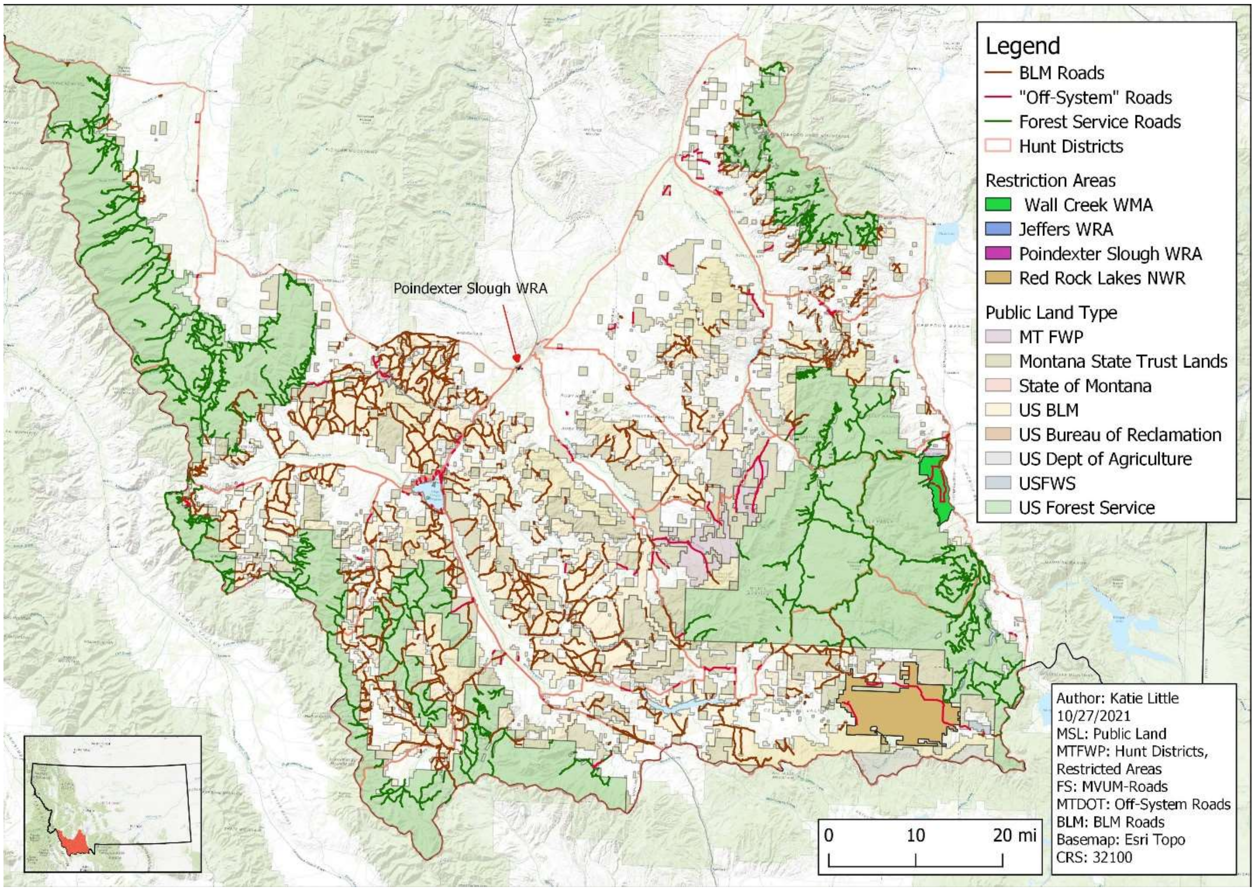

Figure 3: Roads located on public land only in study area. Each road dataset is depicted although roads were summed for calculation purposes.

Statistical Analysis

I used linear regression to examine relationships observed in this study. Relationships included the following: road density and harvest, hunter density and harvest, hunter effort and harvest, and hunter to elk ratio and harvest. Harvest in each scenario refers to both harvest success (percentage of successful hunters) and elk harvest number. The independent variables in each analysis were public road density, hunter density, hunter effort, and hunter to elk ratios, respectively. Response variables were public harvest success (percentage) and elk harvest numbers for all analyses. Statistical analysis was performed using the RStudio software (2021, Version 4.1.2). The standard deviation was calculated for all values that were averaged across years.

RESULTS

Public Land and Road Density

Calculated public land area within districts ranged from 301.1 km^2 to 1,339.9 km^2. All calculated values were less than 0.5% (3 km^2) different than FWP reported values for public land area within districts. Total public land open road lengths ranged from 148 km to 1019.6 km, resulting in road densities on public land from 0.54 km/km^2 to 0.87 km/km^2 throughout the study area (Table 3).

Table 3: Calculated results for harvest, road and hunter density, and district areas.

District	District Area (sq. km)	Public Land Area (km^2)	*Total Hunters	Total Hunter SD	Total Days	Total Days SD	*Public Harvest	Public Harvest SD	Total Public Road Length (km)	Hunter Density (hunters/km^2)	Hunter Density SD	*Public Harvest Success (%)	Public Harvest (%) SD	Public Land Open Road Density (km./sq.km.)
326	845.7	621.6	567	33.9	3061	245	93	25	306.1	1.7	0.2	16.6	5.4	0.49
322	1027.4	819.0	1004	23.7	5590	177	133	30	525.1	0.9	0.1	13.3	3.1	0.64
328	1089.9	494.9	703	89.7	4441	756	165	49	386.5	0.9	0.1	23.3	5.6	0.78
320	1225.6	763.5	1009	69.1	6191	885	94	11	375.2	1.2	0.1	9.4	1.7	0.49
302	1180.0	302.3	957	93.4	6043	444	244	36	162.8	0.9	0.0	25.6	4.0	0.54
327	478.8	440.3	1812	176.1	10872	591	430	189	291.9	3.0	0.3	23.1	8.7	0.66
329	1198.6	1058.8	1858	244.5	11718	2025	373	67	376.1	1.5	0.1	20.1	2.8	0.36
321	1641.4	1020.7	1410	167.7	9257	746	131	60	521.9	1.4	0.1	9.0	3.3	0.51
330	696.7	308.5	1083	68.1	6781	519	149	16	148.0	0.8	0.0	13.7	0.7	0.48
325	1822.0	1332.8	2377	227.3	13183	1603	456	229	556.2	1.0	0.1	19.2	9.2	0.42
324	773.0	542.6	1786	110.4	11270	942	396	159	463.6	0.9	0.1	21.9	7.7	0.85
300	1792.3	1173.0	1453	143.7	8322	1125	283	79	1019.6	1.0	0.1	19.6	5.6	0.87
323	863.5	479.7	1422	123.0	8792	398	238	93	334.1	1.3	0.1	16.5	5.4	0.70

* These values were calculated for individual years (hunting seasons) in respective districts and the reported value is the average of those years. Standard deviation (SD).

Harvest

Average public land elk harvest was calculated two ways for each district: as the calculated number of elk that were harvested from public land and as a ratio (percentage) of elk harvested (from public land) to total hunters in a district. Average harvest numbers ranged from 93 ± 11 elk to 456 ± 229 elk harvested and average public harvest success rates ranged from 9.03 ± 0.71% to 25.59 ± 9.23% (Table 3).

Hunter Density, Hunter Effort and Hunter: Elk Ratios

Hunter density was based on total district area and average total hunters that visited each district. Hunter density ranged from 0.81±0.02 hunters per km^2 to 2.97 ± 0.26 hunters per km^2 (Table 3). Estimated elk population counts ranged from 628 (± 364) individuals to 1,415 (± 154) individuals across districts, resulting in hunter to elk ratios ranging from 0.40 ± 0.4 to 2.14 ± 0.14 (Table 4). Total hunter days ranged from 3,061 (± 245) days to 13,183 (±1,603) days (Table 3). Total hunter days respresent hunter effort in this study.

Table 4: Elk abundance objectives, abundance estimates, hunter: elk ratio results, and total hunter days for districts.

District	Elk Plan Objective	Avg Elk Count	Count SD	Avg Total Hunters	Hunters SD	Hunter:Elk Ratio	Ratio SD	Total Days	Total Days SD
300	800	1024	154	1453	144	1.42	0.18	8322	1125
302	625	1202	298	957	93	0.80	0.20	6043	444
320	1000	1204	85	1009	69	0.84	0.16	6191	885
321	N/A	1269	0	1410	168	1.11	0.11	9257	746
322	1143	1415	154	1004	24	0.71	0.13	5590	177
323	1143	1415	154	1422	123	1.00	0.03	8792	398
324	1143	1415	154	1786	110	1.26	0.07	11270	942
325	1143	1415	154	2377	227	1.68	0.10	13183	1603
326	1143	1415	154	567	34	0.40	0.40	3061	245
327	1143	1415	154	1812	176	1.28	0.01	10872	591
328	625	628	364	703	90	1.12	0.45	4441	756
329	830	868	230	1858	245	2.14	0.14	11718	2025
330	1143	1415	154	1083	68	0.76	0.16	6781	519

[1] Units 322-327 and 330 had the same objective. Counts each year encompassed those 7 units in total. Objectives and counts were divided by number of units to get individual objectives and counts for each unit.

[2] Avg hunter: elk ratios calculated by dividing "Avg Total Hunters" by "Avg Elk Count" for each individual year. Calculated values were then averaged across years for each unit.

[3] Unit 321 does not have a wintering elk population, so surveys are not regularly conducted. One estimate was provided from July 2014 and used for each year.

Road Density and Harvest

Public road density was not a significant predictor of harvest numbers ($F(1, 11) = 1.09$, $p = 0.32$, $R^2 = 0.09$) or harvest success rates ($F(1, 11) = 0.03$, $p = 0.86$, $R^2 = 0.00$) (Figure 4). The intercept coefficients for estimated harvest number ($p = 0.0194$) and harvest success ($p = 0.00929$) were both statistically significant (Table 5).

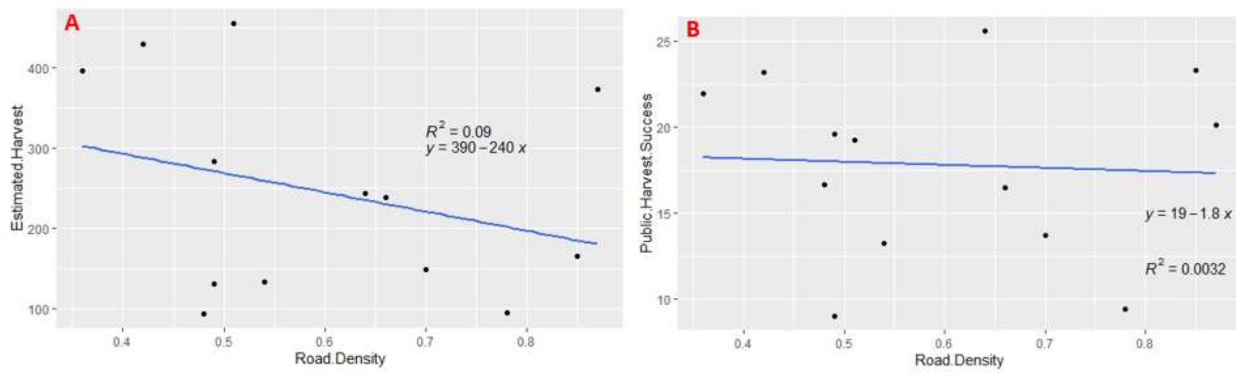

Figure 4: Linear regression plot for road density and harvest relationships. A) Road density and harvest number. B) Road density and harvest success (percentage).

Table 5: Linear regression analysis for road density and harvest (number and %) relationships.

Dependent Variable	**Estimated Harvest**		**Harvest Success (%)**	
Coefficients	Intercept	Road Density	Intercept	Road Density
Estimate	389	-240.2	18.89	-1.81
Std. Error	142.3	229.6	6.00	9.68
t-value	2.73	-1.05	3.15	-0.19
Pr(>|t|)	*0.0194	0.32	*0.00929	0.86
Model				
F -statistic	1.09		0.03	
R^2	0.09		0.00	
Adj. R^2	0.01		-0.09	
p-value	0.32		0.86	

*Indicates significant p-value. Observations for each model=13. df=11 for all models.

Hunter Density and Harvest

Similar to road density and harvest model outcomes, hunter density was not a significant predictor for either harvest success (F (1,11)= 0.00, p = 0.96, R^2=0.00) or harvest number (F (1,11) = 0.60, p= 0.45, R^2= 0.05) (Table 6).

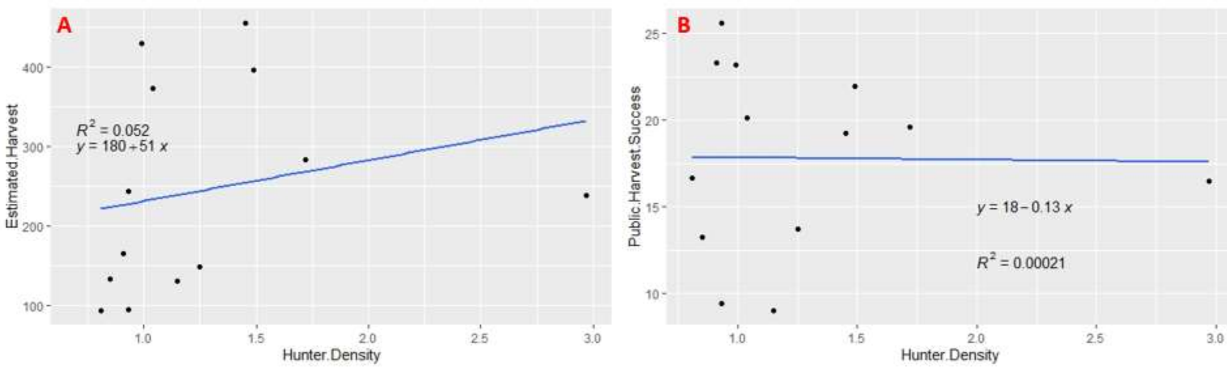

Figure 5: Linear regression plot for hunter density and harvest relationships. A) Hunter density and harvest number. B) Hunter density and harvest success (%).

The intercept coefficient was only significant for the harvest success (percentage) and hunter density model (p = 0.000609). Hunter densities were generally less than 1.7 hunters km^2, with the exception of one unit which had a density near 3 hunters per km^2 (Figure 5a,b). Further analysis of the data indicated this point to be an outlier. I conducted an additional linear regression for hunter density without the outlier, and no significant relationship was found for either harvest metric.

Table 6: Linear regression analysis for hunter density and harvest (number and %) relationships.

Dependent Variable	**Estimated Harvest**		**Harvest Success (%)**	
Coefficients	Intercept	Hunter Density	Intercept	Hunter Density
Estimate	179.96	51.31	17.97	-0.13
Std. Error	91.62	66.09	3.79	2.73
t-value	1.96	0.78	4.74	-0.05
Pr(>|t|)	0.08	0.45	*0.000609	0.96
Model				
F -statistic	0.60		0.00	
R^2	0.05		0.00	
Adj. R^2	-0.03		-0.09	
p-value	0.45		0.96	

*Indicates significant p-value. Observations for each model=13. df=11 for all models.

Hunter to Elk Ratio and Harvest

Hunter to elk ratio was a significant predictor for estimated harvest number ($F(1,11) = 15.01$, $p = 0.00259$, $R^2=0.54$), but not for harvest success rates ($F(1,11) = 1.31$, $p=0.28$, $R^2=0.11$) (Table 7). As hunter to elk ratios increased, estimated harvest numbers also increased (Figure 6a). The independent variable for the estimated harvest model was statistically significant ($p = 0.00259$), while only the intercept in the harvest success model was statistically significant ($p = 0.00558$) (Table 7).

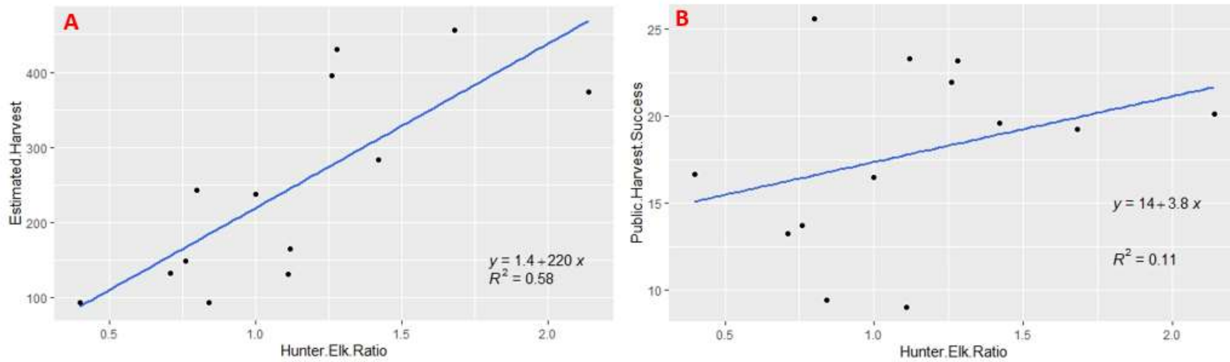

Figure 6: Linear regression plot for hunter to elk ratio and harvest relationships.

Table 7: Linear regression analysis for hunter to elk ratios and harvest (number and percentage) relationships.

Dependent Variable	**Estimated Harvest**		**Harvest Success (%)**	
Coefficients	**Intercept**	**Hunter: Elk Ratio**	**Intercept**	**Hunter: Elk Ratio**
Estimate	1.43	218.11	13.59	3.77
Std. Error	67.56	56.31	3.96	3.30
t-value	0.02	3.87	3.44	1.14
Pr(>|t|)	0.98	*0.00259	*0.00558	0.28
Model				
F-statistic	15.01		1.31	
R^2	0.58		0.11	
Adj. R^2	0.54		0.03	
p-value	*0.00259		0.28	

*Indicates significant p-value. Observations for each model=13. df=11 for all models.

Hunter Effort and Harvest

A significant relationship existed between hunter effort (total days) and estimated harvest number ($F(1,11) = 31.14$, $p = 0.000165$, $R^2=0.74$) (Table 8). Estimated harvest number increased as hunter effort increased (Figure 7a).

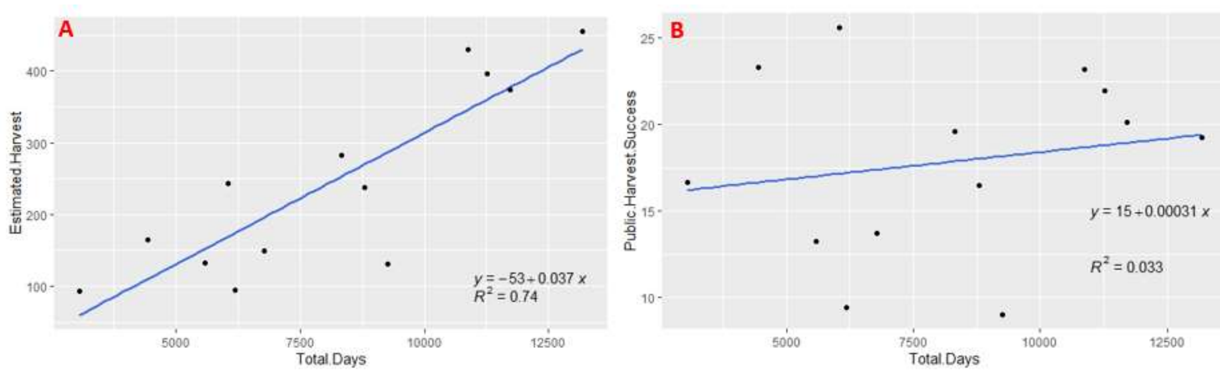

Figure 7: Linear regression plot for hunter effort (total days) and harvest relationships.

Hunter effort was not a significant predictor for harvest success rates ($F(1,11) = 0.38$, $p = 0.55$, $R^2 = 0.03$) (Table 8). The harvest success (%) intercept coefficient was significant ($p = 0.00528$), while the estimated harvest intercept was not. The independent coefficient was significant for the harvest number and hunter effort model ($p = 0.000165$).

Table 8: Linear regression analysis for hunter effort (total hunter days) and harvest (number and %) relationships.

Dependent Variable	**Estimated Harvest**		**Harvest Success (%)**	
Coefficients	**Intercept**	**Hunter Effort**	**Intercept**	**Hunter Effort**
Estimate	-52.70	0.037	15.25	0.000
Std. Error	56.78	0.007	4.40	0.001
t-value	-0.93	5.58	3.47	0.617
Pr(>|t|)	0.37	*0.000165	*0.00528	0.550
Model				
F-statistic	31.14		0.38	
R^2	0.74		0.03	
Adj. R^2	0.72		-0.05	
p-value	*0.000165		0.55	

*Indicates significant value. Observations for each model=13. df=11 for all models.

DISCUSSION

Previous studies have generally found road densities to have negative impacts to elk movement patterns and vulnerability, particularly during hunting seasons (McCorquodale 2013; Gratson and Whitman, 2000b). The variables (primarily road densities) examined in this study aimed to provide insight into whether road density influences hunter harvest success. Road density and hunter density were not significant predictors of harvest metrics in this study, while hunter effort and hunter to elk ratios were only significant predictors of estimated harvest numbers and not harvest success (%). Estimated harvest number was greatest when hunter to elk ratios were greater and when hunter effort increased.

Road Density

Contrary to the findings of most studies, road densities in my study did not predict harvest. Road density values in my study were relatively lower than those of similar studies that found significant impacts of roads on harvest success. For example, Gratson and Whitman (2000b) observed hunter harvest success in three adjacent areas of varying road density: open road access area, managed road access area, and an unroaded area. Road densities reported for their areas were 1.54 km/km^2, 0.56 km/km^2, and 0.23 km/km^2, respectively, while road densities from this study ranged from 0.36 km/km^2 to 0.87 km/km^2. Their study did not include any spatial replicates, but they did report significant differences in harvest success between areas. Harvest success in their study was greatest in managed access and unroaded areas compared to open road areas (Gratson and Whitman, 2000b). Road densities in my study were mostly similar to the managed and unroaded areas of their study. Their study also only accounted for bull elk harvest, as most do when analyzing harvest success, which may have contributed to the significant results they observed.

Other studies summarized by McCorquodale (2013), as previously mentioned, found differing trends of harvest with relation to road and hunter densities. General findings from studies described in that synopsis found that elk mortality from hunting was greater where road and hunter densities were greater and bull survival rates tended to increase as road density decreased. Hayes et al. (2002) studied factors that were expected to influence Idaho bull elk mortality (i.e., hunter density, topography, and vegetation) and reported statistically significant increases of mortality risk as road density increased. According to their model, elk were 1.55 times more likely to be harvested for every 3 km/km^2 increase in overall road density (closed and open) (Hayes et al. 2002). They found that hunts during the rut, and especially those that took place in areas with greater road density, were associated with increased mortality risk. They also note that road density was only important when they combined open and closed road densities, suggesting that road closures in their study area may not reduce elk mortality risk. Sergeyev et al. (2020) reported similar trends in their study of female elk harvest vulnerability. Harvest vulnerability was associated with distance to roads, as well as age of cow elk. Older individuals in their study area were more at risk of being harvested.

Hunter Density

It was hypothesized that hunter density would be greater in districts with greater road density, which would result in greater harvest. Harvest as a function of hunter density was not statistically significant in this study and greatest hunter densities did not always correspond to highest road densities or harvest numbers (or %). Hunter densities in this study did not account for specific season lengths or changes in hunter density throughout seasons. Instead, hunter density in this study was analyzed for districts overall by considering the total number of hunters on public land over all seasons. Hunter density overall in a district, does not necessarily provide a detailed breakdown of how hunters may be utilizing hunting areas or roads. With harvest outcomes not necessarily associated with greatest hunter densities and/or road densities, it is possible that other features of the hunting district (i.e., landscape) may have influenced harvest more than roads, hunter density, or a combination of those two. For example, Basile and Lonner (1979) examined elk harvest associated with road density and hunter density in Idaho. They observed increased hunter densities and elk harvest when road access was restricted and suggest that this was likely because hunters were selecting restricted access areas to hunt. These areas received more hunting pressure which resulted in more elk killed. They also concluded that the differences in hunting pressure were possibly associated with habitat features (i.e., forest cover) in the two study areas.

In contrast, Gratson and Whitman (2000b) found average annual hunter density to be greatest in their roaded control area compared to the managed road and unroaded areas, with harvest success greater in managed and unroaded areas than the roaded control area. Significant differences only occurred for harvest success between roaded and managed areas and roaded and unroaded areas. Managed and unroaded areas were not different in terms of hunter density or harvest success (Gratson and Whitman, 2000b). They also note that there may have been a significant difference in hunter density in the roaded control area compared to other areas because hunters that traditionally chose to hunt the managed area may have selected different hunting areas due to road closures during the study. They reported an increase in the roaded control area from 0.22 hunters/km^2/day (reported from another study) to 0.57 hunters/km^2/day, which possibly supports their assumption of road closures influencing hunter selection of areas of open roads versus areas with closed roads. Lyon et al. (2000) summarized hunter density results from various studies and suspected that hunter distributions in study areas may have been more uniform than what might be expected on larger management areas. They suggest that hunter densities greater than 1.0 hunters/km^2 would result in significant hunter success rates, especially if that density was sustained for at least several days or more. However, their “large” study area was 243 km^2, while my study areas (public land in districts) ranged from 302.3 km^2 to 1,332.8 km^2. Results from my study found hunter densities to be between 0.81 hunters/km^2 and 2.97 hunters/km^2, but no significant harvest outcomes existed for these densities. In general, there is not a clear picture of hunter density influences on elk vulnerability and mortality among previous studies (Lyon et al., 2000), and my study follows suit.

Hunter to Elk Ratios and Hunter Effort

There are few studies that examine the relationship between hunter to elk ratios and harvest. Gratson and Whitman (2000b) observed consistent differences in bull density estimates and hunter success rates between the roaded control and managed areas of their study. Bull density estimates also differed between the managed and unroaded areas, but success rates did not. They note that the inconsistencies of success in study areas could equally be the result of road closures, greater bull densities, or lower hunter to bull ratios. In their study, lower hunter to bull ratios were suggested to be responsible for greater success of hunters in the managed area (Gratson and Whitman, 2000b). Contrasting results were observed in the present study, where hunter to elk ratios were not a significant predictor of harvest success (%). Harvest number outcomes were, however, significant when analyzed against hunter to elk ratios. At lower hunter to elk ratios, harvest number was lower and at greater hunter to elk ratios harvest number was greater. Gratson and Whitman (2000b) sampled hunters two ways: random sampling in the field with follow up after the season and selecting random hunters from a list and following up after the season. Hunters who participated were used to estimate hunter densities. They were also surveyed about harvest success, with success being reported as harvesting a bull elk.

My study included all hunters (e.g., archery or rifle; youth, adult; antlerless or bull) within a district and all hunters that were successful (harvesting any elk), rather than measuring success as harvesting bulls only. Both this study and that conducted by Gratson and Whitman (2000b) estimated total elk abundance for study areas which was used in hunter to elk ratios.

Differences in observed trends between these studies could be associated with what portions of the elk population were considered for hunter to elk ratios and harvest success. These results may also suggest that more hunters to elk may result in better chances of harvest for hunters. This may be true until a certain number of hunters to elk is reached. At that point, harvest may begin to decline until hunter numbers decline or elk populations increase. This relationship between hunter and elk abundances may be viewed as a sort of "carrying capacity", where hunters can only be successful to a certain point in the elk population before success begins to decline.

Gratson and Whitman (2000a) assessed skill level and experience of hunters and how that related to hunting attitudes, behaviors, and possible hunting outcomes. Experience was defined by the number of years that an individual had hunted elk, and skill level was based on the number of bull elk an individual had killed in their lifetime. In that study, hunters in the unroaded areas were generally more skillful than hunters in roaded areas and also tended to have greater success, which was evidenced by greater success rates in managed and unroaded areas. Basile and Lonner (1979) observed similar trends in their study, with hunters who spent more time traveling afoot generally having higher harvest success than those who spent more time in a vehicle traveling along motorized routes. Travel restrictions in one part of their study area prompted hunters to spend more time walking, which increased elk sightings and harvest among those hunters. In this study, hunter effort was associated with the total (average) number of days hunters spent in a district and was only a significant predictor for harvest number. As the total number of days increased harvest number increased, similar to results of previous studies (Gratson and Whitman, 2000b; Basile and Lonner, 1979). These observations point to the assumption that hunters who put forth more effort, at least in the form of time and reduced motorized use, will tend to experience greater harvest success. Although my study shows increased chances of harvest with greater time inputs, it does not distinguish how that time was spent hunting (e.g., motorized use, walking, etc.).

<u>Study Limitations</u>

Several limitations exist that were potentially constraining to the analysis conducted in this paper. Although road data were available for selected districts, motorized trail data were limited. Motorized use trail data exists for BLM managed trails that permit some degree of motorized use within the study area (~ 32 trails). The FS also provides motorized-use trail data for forest service managed trails; however, Beaverhead National Forest does not have a complete/established dataset. Therefore, trail data were excluded. Motorized use on trails is common in much of southwestern Montana's hunting districts. Inclusion of such trail data would have likely provided a better estimate of motorized access on public land, possibly altering the results.

Hunter densities were calculated using the overall district area rather than public land area within a district. Collected hunter information does not reflect what land types (i.e., public or private) hunters visit in a district. Therefore, hunter density in this study is more indicative of a district as a whole, rather than hunter density on public land. This may have had some influence on the models looking at harvest and hunter density, because harvest reflected public land specifically. Hunter distributions across land types may be difficult to estimate, as some hunters may use both public and private land. Therefore, hunter density estimates would be more complex. It may also be useful for hunter densities to be divided based on overall hunting method used by hunters. For example, road hunter densities versus non-road hunter densities and how those densities may be associated with harvest. This may provide a relative idea of hunter densities on roads and potentially how influential road density is on hunter density and consequently harvest for those who do road hunt primarily.

Other studies generally consider habitat/landscape in relation to elk movement patterns and harvest success as part of their analysis. Specific elk harvest locations were not available from harvest reports in this study. For that reason, landscape cover was also not included. Direct inferences about the relationship between landscape cover and elk harvest success could not be determined without more specific information on where elk were harvested within hunting districts. Landscape cover data in the form of cover type percentages (e.g., forest and woodland 10% or grassland 24%) was available from FWP for each district; however, this would be generalized information about a district as a whole without specific harvest location information to narrow the analysis. Including landscape cover with road density and specific harvest location in this study may have produced different results. Specific elk harvest locations would also provide a better understanding of how roads do influence harvest success. Elk proximity to roads could be considered. Actual road traffic/usage is also important and was not determined in this study. A road may exist, but the degree of use is important. If an open road exists on public land but is not frequently used, elk may be more inclined to use those roads or be in closer proximity if there's low potential of being disturbed. As Basile and Lonner (1979) point out, elk avoid human activities that occur on/around roads, rather than roads themselves.

Environmental factors are always a consideration when analyzing wildlife population trends, especially harvest. Environmental factors, specifically weather, can have a variety of impacts on elk movement. For example, snow accumulations may encourage elk shift to winter range or lower elevations. Cooler temperatures early in the fall mating season may prompt elk to begin to rut a few days sooner, potentially increasing the likelihood of archery hunters successfully calling in a bull. Relatively warm temperatures early in fall may push animals to higher elevations or deeper into mountainous habitats, potentially increasing hunter effort for successful harvest. Previous winter/spring conditions can also contribute to the following hunting season's elk population condition. Cooper et al. (2002) point out that there could be difficulty predicting harvest trends when including climate variables and sensitivity of success to those variables because of uncertainty in future weather patterns. They propose using a longer time series of data that accounts for a wide range of climatic conditions that represent long term weather trends. Longer time series trends, for both harvest and weather, may be more reliable for long-term predictions rather than specific short-term instances when climate is not similar to the average.

Finally, other studies observing harvest success in relation to road densities, hunter densities, hunter effort, or elk to hunter/ hunter to elk ratios generally consider bull elk harvest only. All elk harvested in study areas of this study were included. The results of this study may have had similar statistical outcomes as other studies had only bull elk harvest been considered. In general, trends in models followed similar patterns as those of previous studies, though they were not significant. From a population management standpoint, total harvest would likely produce a better biological "picture" of harvest and population dynamics. If specific elk harvest sites could be determined, along with sex of the elk, habitat cover, road density, and hunter density, a more complete model might exist for this particular study area. These factors would be more indicative of an elk's surroundings and provide better insight into an individual's vulnerability risk of being harvested.

CONCLUSIONS

Presence of roads and associated impacts to elk movements, behaviors, and vulnerability/mortality has been widely studied, with a general consensus of negative impacts to elk where roads are open to motorized use. Road density has also been shown to influence hunter densities, and hunter effort which may indirectly effect harvest success. Although the primary variable (road density) of this study did not produce significant model results for harvest, the outcomes and additional analyses on hunter density, hunter effort, and hunter: elk ratios still provided insight about public land elk harvest in these districts. In every relationship, harvest success was not significant. When harvest is associated with the total number of hunters who attempted to harvest an elk in any district, a more realistic perspective of harvest is achieved in regard to independent variables like road density, hunter density, hunter effort, and hunter to elk ratios. This perspective may be more useful than just harvest numbers when determining management needs for districts.

Road density and hunter density on their own were not significant predictors for harvest (number or percentage). It was not possible to determine whether differences in hunter density between districts were associated with road densities in districts in the study. Frequency of hunters using specific roads within districts was not able to be determined; therefore, hunter density reflects overall district use rather than actual road use by hunters. Clear patterns of hunter density effects on elk mortality have not been previously determined, and this study follows suit.

Significant relationships existed between hunter to elk ratios and harvest number and hunter effort and harvest number. Interestingly, as hunter to elk ratios increased harvest number increased, suggesting that more hunters to elk may result in better chances of harvest for hunters, which seems intuitive. More hunters to a large, sustainable population of elk would likely support better chances of harvest. This may be true to a certain "carrying capacity" of hunters. If elk populations are not maintained in an area, an increase in hunters (increased hunter to elk ratio) may eventually result in lower harvest when hunter to elk ratios are high. With increased hunter effort, in this case greater total amount of days spent by hunters, harvest number increased. Hunter effort in this study is more of a reflection of overall hunter effort in a district because total days spent hunting by all hunters was used for the analysis. This does not reflect individual hunters or their methods of hunting (e.g., motorized use, walking, rifle, archery, etc.). Although it could be concluded that greater effort (in this case, time) on a hunter's part will result in better chances of harvest, it cannot be concluded whether certain hunting approaches increase a hunter's chance of harvesting an elk. This is also evidenced by the non-significant influence of road density on harvest and possibly the lack of associated impacts of road density on hunter density. Overall, the results support the idea that hunter effort and number of hunters to elk are better predictors for harvest number rather than road density or hunter density. While roads exist in landscapes, use of the roads by humans, or lack of, is likely a better indicator of harvest risk for elk. If a road is closed or not frequently used, it is essentially just another part of the landscape free of regular disturbance and potentially more likely to be selected/used by elk. Roads may be more responsible for variation in hunter behaviors and therefore success, rather than success directly. Again, potential influences of road density on hunter metrics were not able to be determined in this study and cannot be concluded to be the underlying cause of hunter success.

Management Implications

Managing roads inevitably involves tradeoffs with increased road access. Road restrictions have been a widely suggested method for improving elk distributions across public/private land matrices (Ranglack et al., 2020), improving elk security habitat and use of such habitat (Basile and Lonner, 1979), reducing disturbing hunter pressure (i.e., noisy motorized use) (Lyon et al. 2000), and improving hunter success (Gratson and Whitman, 2000b; Basile and Lonner, 1979). While roads provide the possibility for human activity in landscapes, it's the human activity that's really responsible for elk movement patterns and resource selection. This is true of any human activity, not just activity related to hunting (Wisdom et al. 2018). While road closures may promote elk distributions to shift from restricted access areas to accessible areas, these shifts can benefit hunters in one area while posing a disadvantage for hunters in another area where elk shifted from (Basile and Lonner, 1979; Gratson and Whitman 2000b). Hunter success has also been improved when hunter effort increases. If hunters spend more time hunting on foot, their chances of seeing elk increase as do their chances of harvesting an elk (Gratson and Whitman, 2000b). Inclusion of female harvest can also provide hunters with more opportunities and reduce hunting pressure on males. While road closures can help with these outcomes, enforcement is key to closures and restrictions being effective (Hayes et al. 2002; Rowland et al. 2004). Motorized use on closed roads inhibits the potential for elk to increase use of habitat if there is still lingering human disturbances.

Overall, wildlife managers are faced with the challenges of optimizing elk abundance, age and sex structures, habitat changes, and harvest levels with continually increasing demand for these resources. Mortality rates are a function of hunter pressure, habitat condition, and season structures. Roads are often the underlying source of variability in these factors and may serve as an effective way to manage hunter related variables (i.e., pressure, effort, abundance) and habitat quality (Hayes et al. 2002). Based on results from this study, managers may be able to make assumptions about how many elk might be harvested by considering how much time was spent overall by hunters or how many hunters to elk exist in a district. Actual hunter harvest success relative to overall hunters in a district cannot be assumed based on any of the independent variables here; therefore, the results in this study are likely to be better suited to management of elk population numbers based on hunter effort and hunter to elk ratios. If managers are aiming for a higher number of elk to be harvested, managers could create/alter regulations or other aspects of hunting in those districts that could possibly promote more interest among hunters to visit that area. This would potentially increase the number of hunters to elk and also increase the overall time spent by hunters in a district.

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