Spatial and Temporal Analysis of Rabid Wild Terrestrial Animals along the Colorado Front Range

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Abstract

Rabies is a virus transmitted to humans through the saliva of unvaccinated wild and domestic animals. In 2010, 92% of animals that contracted the virus in the United States were wild animals. Like the majority of the United States, the Colorado Front Range (Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Elbert, El Paso, Jefferson, Larimer, Teller and Weld counties) is not immune to the spread of rabies. The purpose of this study was to explore the spatial and temporal distribution of rabies incidence in the Colorado Front Range.

Rabies data was acquired from the Colorado Department of Public Health and Environment for 2007 to 2014. Geographic Information Systems (GIS) was used to explore the spatial and temporal distribution of rabies incidences and examine the correlation of rabies with land cover.

Eighty-nine percent of terrestrial rabies in the Colorado Front Range occurred in skunks. Incidence was highest in Larimer and Weld County, in particular in the City of Greeley, west and southwest Fort Collins and west Loveland. The majority of cases occurred between April and July in the foot hills of the Front Range and the plains. No cases were reported in the Rocky Mountains. Rabies was predominantly found in areas with land cover types such as open space, grassland, low/medium development, pasture, cropland and shrub. Between 2007 and 2011 the majority of rabies cases occurred in southern counties (El Paso, Elbert, Douglas and Arapahoe), while between 2012 and 2014 there was an increase in cases reported in northern counties (Larimer and Weld).

The findings from this study indicate that skunk rabies incidences occur in clusters along the Front Range. However, these clusters vary spatially and temporally.

Rabies Background

Rabies is a virus transmitted to humans through the saliva of unvaccinated wild and domestic animals (Linscott, 2012). Once the infected saliva has entered a muscle or blood stream, it immediately travels to the brain and spinal cord causing swelling of the brain and death (Figure 1) (Centers of Disease Control and Prevention (CDC), 2011e). The rabies virus is transferred between warm-blooded animals. The typical incubation period for rabies is 1 to 3 months (Linscott, 2012).
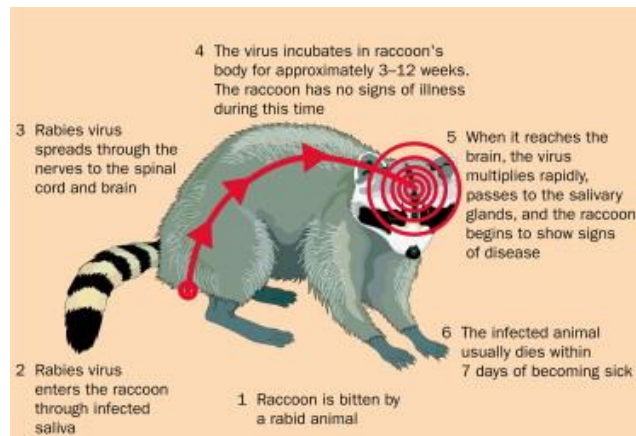

Figure 1: The progression of the rabies virus through an animal. Starting with a bite or scratch from a rabid animal, to the spread of the central nervous system, then to the brain and salivary glands (Rupprecht et al, 2002).

Rabies in humans is incidental where humans only become infected with the virus if scratched or bitten by a rabid animal and through handling of dead infected animals. Once exposed, the bite or scratch area should be washed with soap and water, followed by a meeting with a health care physician. If post- rabies exposure vaccination, prophylaxis, is warranted, then treatment should begin within several days after exposure in order to prevent the onset of symptoms (such as anxiety, confusion, slight or partial paralysis, hallucinations, difficulty swallowing, fear of water and death) (CDC, 2013) (Linscott, 2012). Treatment consists of a series of four rabies vaccines and one immune globulin administered over 14 days. Present day prophylaxis treatments are nearly 100% effective in preventing the onset of rabies (CDC, 2011b). The rabies virus is almost always fatal in humans, unless treated.

From 1995 to 2011, 49 humans, residing in the United States, have become infected with the rabies virus (CDC, 2012). From the 49 cases, 4 cases were transplant participants from the one donor carrying the

rabies virus and 12 contracted the virus outside of the United States (CDC, 2012). The rate of humans becoming infected with the rabies virus in the United States has declined from 100 deaths per year at the turn of the century to 1-2 deaths per year in the 1990's (CDC, 2011c). This decline is due to rabies prevention in the form of human and animal vaccines.

Rabies Prevention

Humans can also become infected with rabies by handling dead infected animals, therefore protective clothing is recommended or to contact animal control. If continually working with rabid animals or travelling for extended periods to countries with a high number of rabies incidences then pre-exposure vaccines are highly encouraged (CDC, 2011b). To combat the spread of rabies to humans both pre- and post- rabies exposure vaccines have been developed.

Domestic animal rabies vaccinations prevent rabies spillover from a wild animal. In the United States most rabid animals are wild, however, most humans are given prophylaxis treatments after coming in contact with a domestic animal (CDC, 2011a). Ensuring domestic animal vaccinations decrease the possibility of a human coming in contact with rabies. In the 1970's and 1980's the first rabies vaccination oral bait trails were started to help combat rabies in wild animals with promising results (Figure 2) (Rupprecht et al, 2002). However, before bait drops are administered epizoological studies are conducted within the target areas.

Figure 2: Raccoon ingesting a rabies oral vaccination (Rupprecht et al, 2002).

Rabies Distribution in the United States

Rabies is found throughout the United States, with the exception of Hawaii (CDC, 2011d). Before 1960 the primary rabies reservoirs were dogs (*Canis familiaris*) and cats (*Felis catus*) (McLean, 1970 from Ramey et al, 2013). Since 1975 more than 80% of the rabies cases reported in the United States were those associated with wild animals (Blanton et al, 2011). Skunks served as a primary rabies reservoir since 1960 but this changed to raccoons in 1989 (Ramey et al, 2013). The key wild species that contract and spread rabies include; raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), bats and foxes (red and gray). Throughout the United States, certain species appear to dominant specific regions. As shown in Figure 3, raccoon's dominate the Eastern coast, while the central states, Rocky Mountain region and California are dominated by skunks.
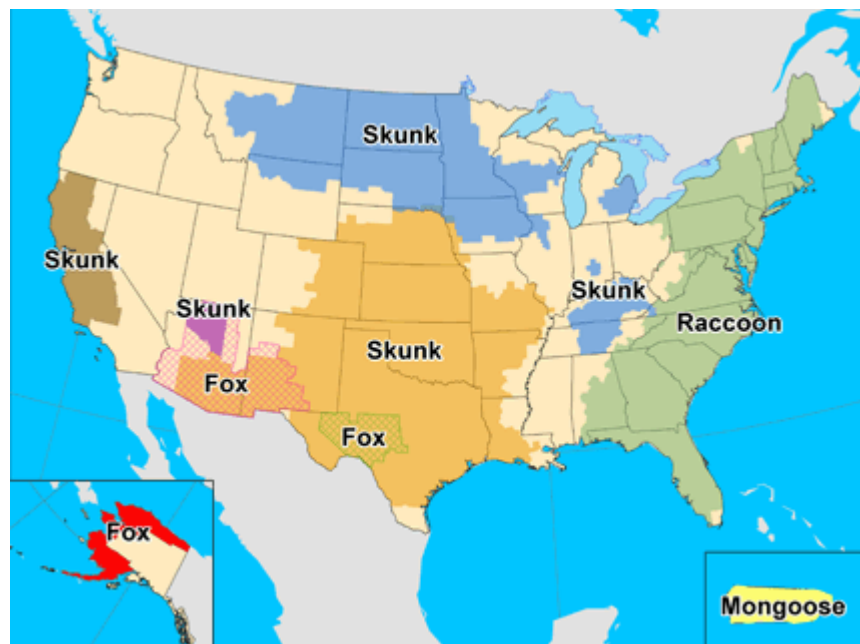

Figure 3: Map displays rabies reservoirs from 2010 in the United States. Skunks dominant the Midwest and California. Rabid Foxes are mainly found in southwestern states and Alaska. The east coast is dominated by Raccoons. In Puerto Rico, the mongoose serves as a rabies reservoir (CDC, 2011f).

More recently, the incidence of rabies in wild animals has increased to 92% (CDC, 2011d).   In 2010, raccoons accounted for most rabid animal cases at 36.5%, followed by skunks (23.5%), bats (23.2%), foxes (7.0%) and other animals, such as cats, dogs and rodents at 1.8% (Blanton et al. 2011). The lesser of the animals that test positive for rabies in the United States are foxes, cats and dogs. Most cases of rabid foxes occur in the eastern U.S., southwestern U.S., and Alaska (Figure 3 and 4d). In 2010, the only rabies positive cases in Alaska were foxes and one dog (Figure 4d and 4e). While the incidences of rabid cats and dogs have

significantly decreased due to vaccination programs, cases do still exist. In 2010, cats accounted for 62.2% of domestic rabid animal cases (Blanton et al. 2011). The majority of these cases occurred in the northeast United States with scattered cases throughout the southern and central region (Figure 4e). Most rabid cat cases occurred in northeastern states where raccoon rabies is enzootic (Blanton et al. 2011). In 2010, only 69 rabid dogs were reported (Blanton et al. 2011). These cases occurred throughout central and eastern U.S., along with 2 cases in California and 1 case in Alaska (Figure 4e). Rabies variants from other species were found in 47 of the 69 rabid dogs, these variants were found in skunks (32 cases), raccoons (14 cases) and foxes (1 case), along with the 9 cases presumed to be infected with canine/mongoose rabies virus variant in Puerto Rico (Blanton et al. 2011).

In addition to terrestrial animals, rabid bats are also prevalent in the USA. In 2010, rabid bats were found in 45 of the 48 contiguous states (Figure 4b) (Blanton et al. 2011). Since 1995, 30 (out of 36) cases of rabies virus found in humans that contracted the virus in the United States were from bats (CDC, 2012). Bats can be found in both urban and rural settings and are known to roost in trees, shrubs, woodpiles and human dwellings (Shankar et al, 2005). Due to the high number of human rabies cases from bats, and bats being found to roost near human activities, the species poses a threat. Bat rabies has also been documented to spill-over into terrestrial animals. This is documented by rabies virus variants only found in bats being seen in both wild and domestic terrestrial animals. However, bat variants only make up a small amount of rabies cases found in animals and do not serve as a significant source of rabies epizootics in the United States (Shankar et al., 2005 & Messenger et al., 2003). Due to the bats high mobility and large ranges it is difficult to combat against the rabies virus carried by bats (Shankar et al, 2005).
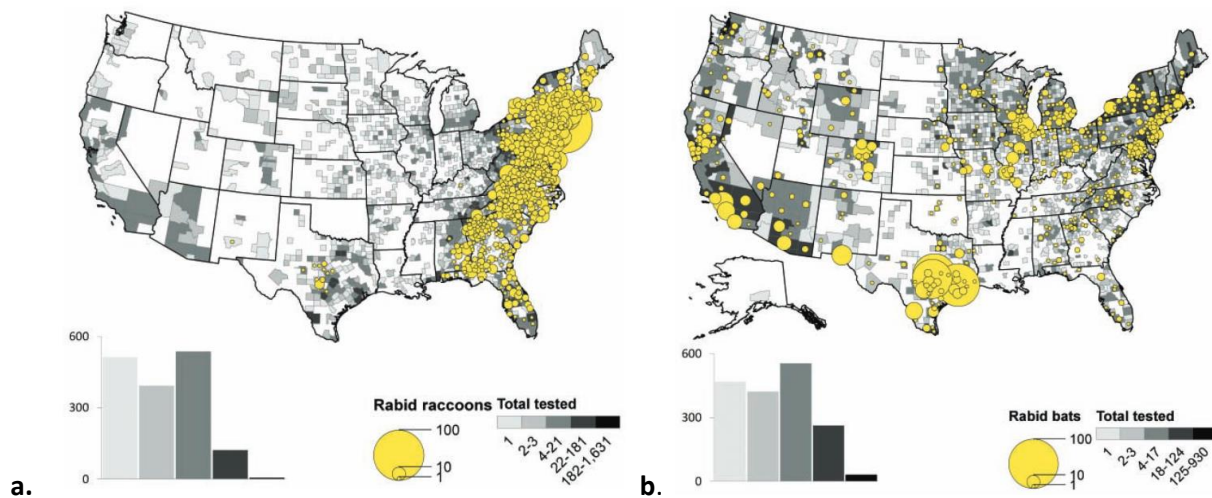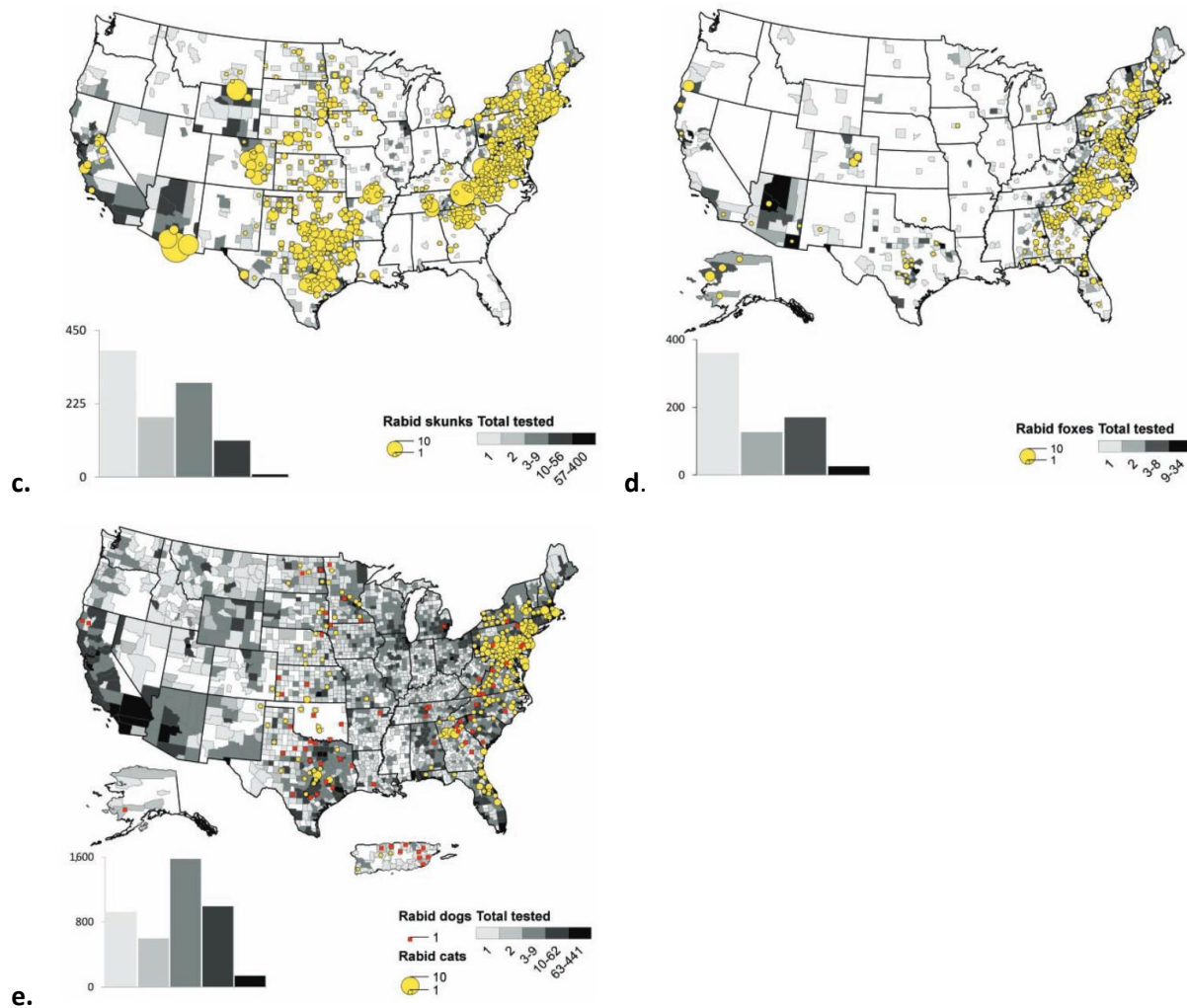
Figure 4: Maps illustrate the location of rabid wild animals within the United States during 2010. Histograms show the amount of animals tested within a county. Map **(a)** shows location of rabid raccoons, **(b)** location of rabid bats, **(c)** location of rabid skunks, **(d)** location of rabid foxes and **(e)** location of rabid dogs and cats (Blanton et al. 2011).

       The state of Colorado is located in the central west portion of the United States where the main wild terrestrial rabies reservoir is the skunk (Figure 3 & 4c). Rabid skunk cases are located along the eastern portion of the state. The eastern side of the state consists of the Great Plains where the land is mainly used or agricultural purposes. Rabid bats are also found in Colorado. The majority of rabid bat cases occurred in the central portion of the state, where most of the human population for the state of Colorado resides. This area serves as the study area to analyze rabies incidences.

Rabies Distribution along the Colorado Front Range

In the state of Colorado, rabies incidence has been recorded in counties along the Front Range which is home to 4.5 million people, and includes the capital, Denver (Figure 5). The area is surrounded by the Rocky Mountains to the West and Great Plains to the East. The goal of this study was to examine the spatial and temporal dynamics of terrestrial rabies, identify areas with rabies and determine how they relate to their preferred habitat in the Colorado Front Range. For the purpose of this study twelve counties along the Colorado Front Range were analyzed. These counties include; El Paso, Teller, Elbert, Douglas, Jefferson, Denver, Arapahoe, Adams, Broomfield, Boulder, Weld, and Larimer.
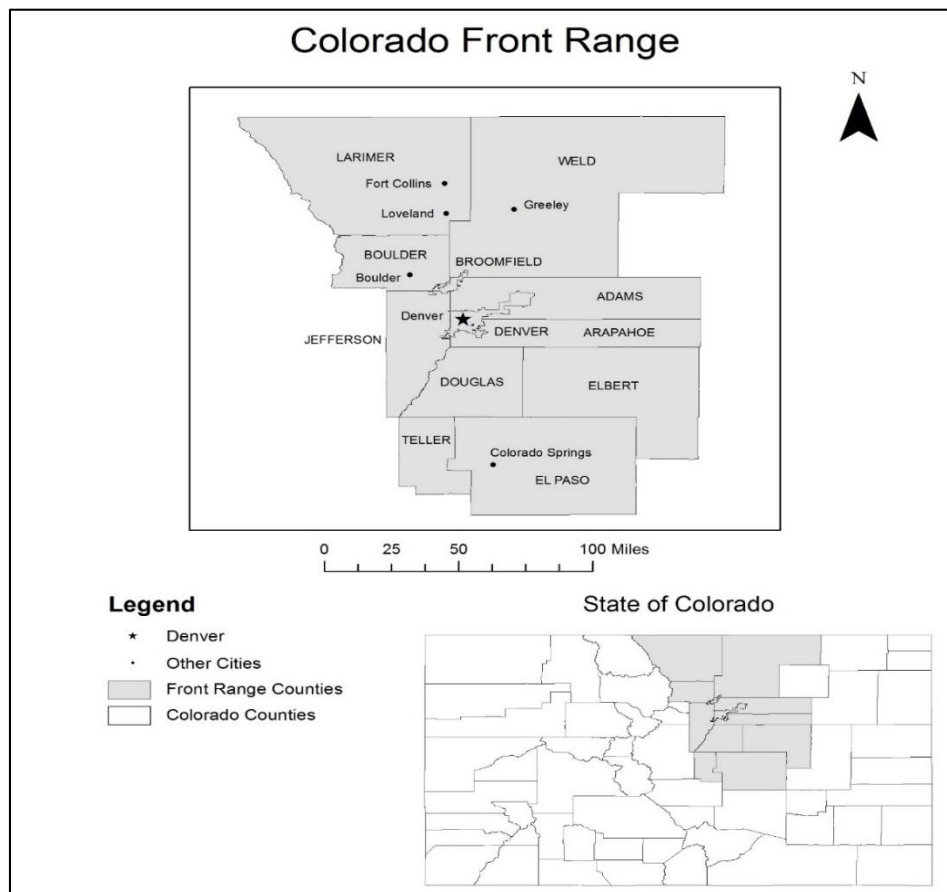

Figure 5: Map displaying Colorado Front Range and the twelve counties comprising the Front Range: El Paso, Teller, Elbert, Douglas, Jefferson, Denver, Arapahoe, Adams, Broomfield, Boulder, Weld, and Larimer.

Methods

Rabies Data

       Rabies data at different scales was acquired from the Colorado Department of Public Health and Environment (CDPHE), Larimer County and Weld County. Each of the data types used in this analysis are described next.

(i)   **Temporal data at the state level:** Temporal incidence of rabies capturing the number of cases per month was available at the state level for 2009 to 2014 (CDPHE 2009 (Appendix C), 2010 (Appendix D), 2011 (Appendix E),
2012 (https://www.colorado.gov/pacific/sites/default/files/DC_CD_Zoo-2012-Data-Table-of-Rabid-Animals-by-County-and-Species.pdf),
2013 (https://www.colorado.gov/pacific/sites/default/files/DC_CD_Zoo-2013-Data-Table-of-Rabid-Animals-by-County-and-Species.pdf),
2014 (https://www.colorado.gov/pacific/sites/default/files/DC_CD_Zoo-Map-of-Rabies-Animal-Monitoring-2007-2014.pdf)).

(ii)   **Temporal data of rabid skunks in Larimer and Weld County:** Data on rabid skunks was obtained for Larimer and Weld County for 2012 to 2014 (Larimer County Rabies Data (2012-2014): http://www.larimer.org/maps/rabies.cfm and Weld County Rabies Data (2012-2014): http://www.co.weld.co.us/Departments/HealthEnvironment/RabiesSurveillance.html). Data included county and date.

(iii)   **Spatial data at the county level:** The number of terrestrial mammal cases was available at the county level for 2009 to 2014 (CDPHE 2009, 2010, 2011, 2012, 2013, 2014).

(iv)   **Point location of rabid skunks:** The distribution of rabid skunk cases from 2007 to 2014 were digitized from maps provided by the Colorado Department of Public Health and Environment (N=214) (Figure 6) (CDPHE, 2014: https://www.colorado.gov/pacific/sites/default/files/DC_CD_Zoo-Map-of-Rabies-Animal-Monitoring-2007-2014.pdf).
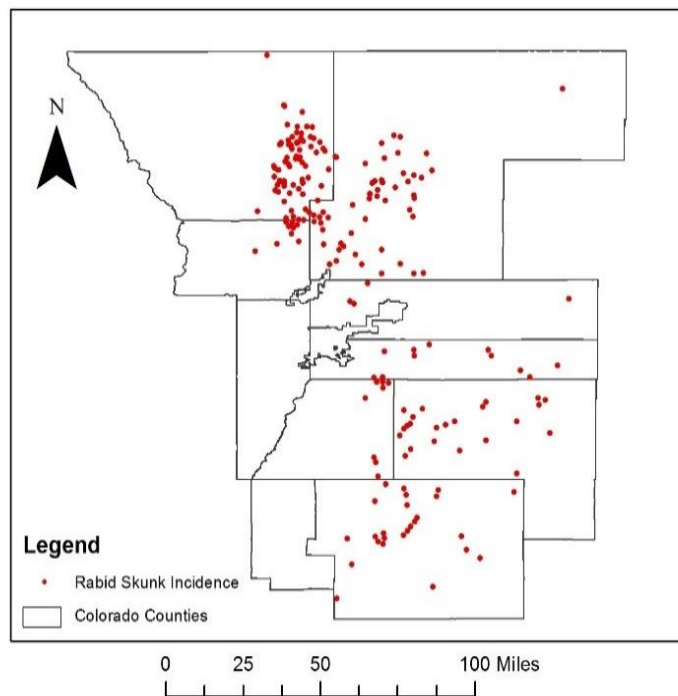
Figure 6: Digitized location of known rabid skunk locations obtained from the Colorado Department of Public Health and Environment for 2007-2012.

Spatial and Temporal Distribution of Rabies

The spatial and temporal dynamics of rabies was analyzed to identify key areas with rabies.

Temporal trends of rabies was investigated to

- determine the time of the year when incidence was highest and
- assess if there was an increasing or decreasing trend over time.

Spatial Trend of Rabies

To assess the spatial trends in rabies several analyses were performed. First, clustering of rabies incidence was examined at the county level (2009-2014) to identify which counties had the highest incidence of rabies. A Global Moran's I analysis was used to assess clustering of rabies cases at the county level. The analysis returned three values of interest; Moran's Index, z-score, and p-value. The Moran's index value indicates if the data has a tendency towards clustering (positive value) or dispersion (negative value). The index value ranges from -1.0 to +1.0. A Moran's index value of 0 indicates that the data is neither clustered nor dispersed. While the z-score and p-value are useful for quantifying the degree of clustering or not by

calculating a test statistic. Thus, if the z-score is positive and the p-value is statistically significant (0.05 or less) then the hypothesis that skunk rabies incidences are random can be rejected. For the purpose of this analysis, the analysis takes incidence into account by comparing the number of cases in each county to that with other counties.

Secondly, analyses were performed using the point data for skunks (2007-2014) (Figure 6). The Average Nearest Neighbor analysis took distance between rabies points into account and calculated the average distance from each rabies case to the nearest neighboring case. The result produces an observed mean distance, expected mean distance, nearest neighbor ratio (observed mean distance/expected mean distance) that was tested at the 5% significance level. In addition, a Multi-Distance Spatial Cluster (Ripley's K Function) analysis was used to assess clustering at different distances by calculating the average number of neighboring rabies cases within a specified distance range, in this case 1km. Five fields were created and include; expected K, observed K, differential K, low confidence envelope and high confidence envelope. Expected K values are the result of a random spatial pattern and the observed K values represent the spatial pattern of the rabies cases. The differential K value is the difference between the observed and expected K values. The low and high confidence envelope values were also determined using 99 permutations, producing a confidence level of 99%. A result of an observed K value greater than the expected K value means the points are more clustered, vice versa, an observed K value less than the expected K value means the points are more dispersed.

A Kernel Density analysis was performed on rabid skunk points from 2007 to 2014 (figure 6) to identify concentrations of rabies incidence. The analysis was accomplished using a kernel size of 1 km^2, representing skunk movement ranges in and around urban environments (see Rosatte et al., 2011 & Weissinger et al., 2009; appendix A).

Lastly, a Directional Distribution analysis (Standard Deviational Ellipse) was used to examine directional trend and central tendency of the known skunk rabies in the study area. Using one standard deviation, this analysis produced an ellipse centered at the mean center of the rabies cases, with the x- and y- axis representing the distribution of the cases. The mean center of the skunk rabies cases was used to determine the directional distribution ellipse and was plotted directly using the mean center analysis tool. All analyses were performed using ESRI ArcGIS 10.2.2.

Spatial Analysis of Skunk Habitat

Skunks account for 89% of wild rabid terrestrial animal cases along the Colorado Front Range. Three different skunk species have been found in Colorado; the most common is the stripped skun*k (Mephitis mephitis)*, western spotted skunk *(Spilogale gracilis)* and hog-nose skunk *(Conepatus leuconotus)*. However, the hog-nose skunk range does not reach the Colorado Front Range and was therefore not considered (Meaney et al., 2006) in this analysis. Skunks preferred habitats include cropland (Larivière and Messier, 1999; Greenwood et al., 1985), grassland (Shirer and Fitch, 1970), scrub land (Neiswenter and Dowler, 2007; Rosatte et al., 2011) and in urban environments (Rosatte et al., 2011 & Weissinger et al., 2009) include open space and low/medium density areas.

Preferred habitats were identified using land cover data from the National Land Cover Database (NLCD) (The National Map, 2011). The NLCD data was clipped for each county and the total amount of preferred habitat per county and the average size of preferred habitat was determined and compared with the total number of rabies cases reported for that county. In addition, the correlation between land cover type and skunk rabies was assessed using Moran's I (see Huo et al., 2012; Walter, 1992). To do so land cover was extracted for each point where skunk rabies was recorded.

The Colorado Front Range is known for having the plains on the East and Rocky Mountains on the West. Using 10 meter Colorado DEM data (Colorado View, 2015) and digitized skunk incidences from 2007 to 2014 (figure 6), analysis was performed to determine if elevation, slope and/or aspect influenced the distribution of skunk rabies. Slope and aspect was created from the elevation model and then extracted for each point where skunk rabies was recorded. The purpose of this analysis was to determine if the Rocky Mountains serve as a barrier in the spread of skunk rabies.

Results

Spatial and Temporal Distribution of Rabies

During 2009 to 2014 a total of 248 rabies cases were reported, the majority of cases were reported in the northern counties with the highest number of cases of terrestrial rabies cases reported in Larimer (32.3%) and Weld (20.6%) County (Figure 7A). Four of the twelve counties did not report a single terrestrial rabies incident (Figure 7A). Skunks were the main terrestrial animal reported with rabies (N=221) representing 89% of the cases (Figure 7B). When county rabies data was analyzed yearly, spatial and temporal variations in the total number of cases were found (Figure 8). During 2009 and 2011 the majority of cases were reported in El

Paso and Elbert Counties, in the South while during 2012 through to 2014 the majority of rabies cases occurred in Boulder, Larimer and Weld Counties to the North (Figure 8).
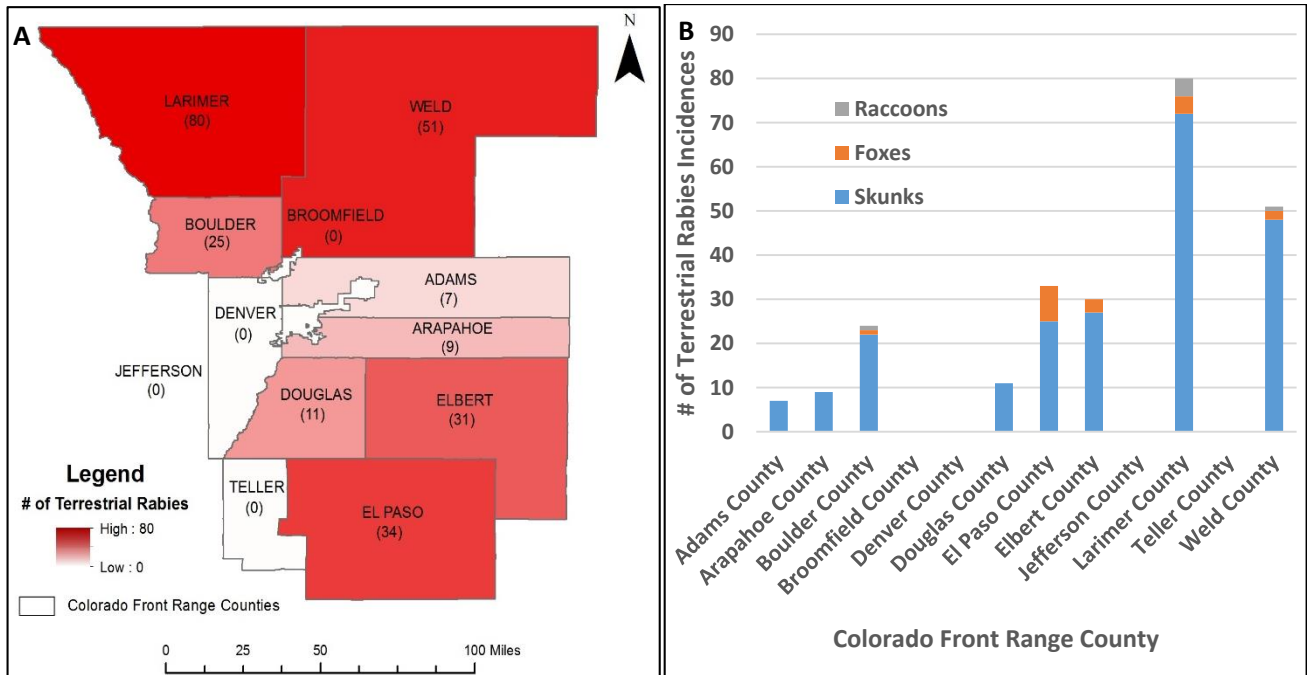

Figure 7: (A) Spatial distribution of the total number of rabies cases reported per Colorado Front Range County from 2009-2014; (B) total number of reported rabies cases (raccoon, fox and skunk) per Colorado Front Range County.
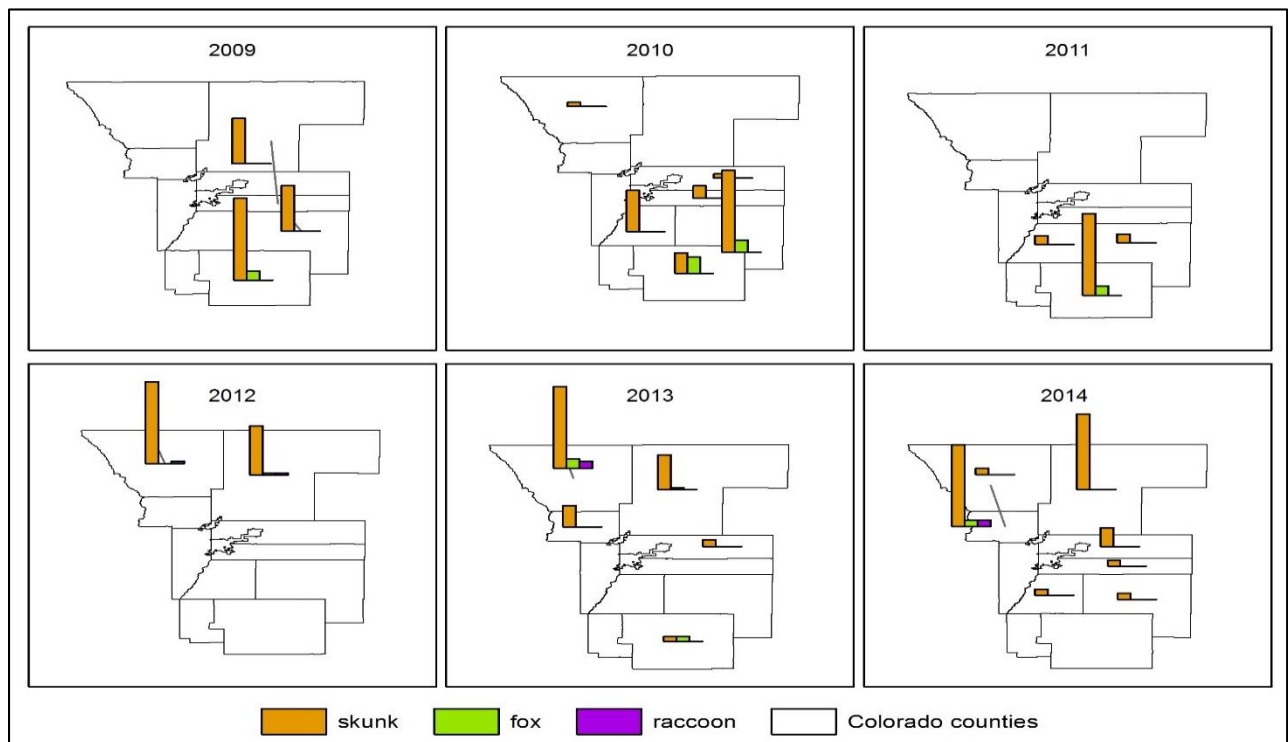

Figure 8: Annual spatial distribution of rabies cases by county (2009 -2014).

Seasonal variation of rabies was also found. The total number of rabid animals reported were highest between April and July (Figure 9), peaking in the spring time throughout the State of Colorado. Since Larimer and Weld County had the highest number of skunk rabies cases between 2012 and 2014, the temporal trends within these counties was further investigated. The majority of cases for these two counties occurred between March and August, peaking during May and June (Figure 10).
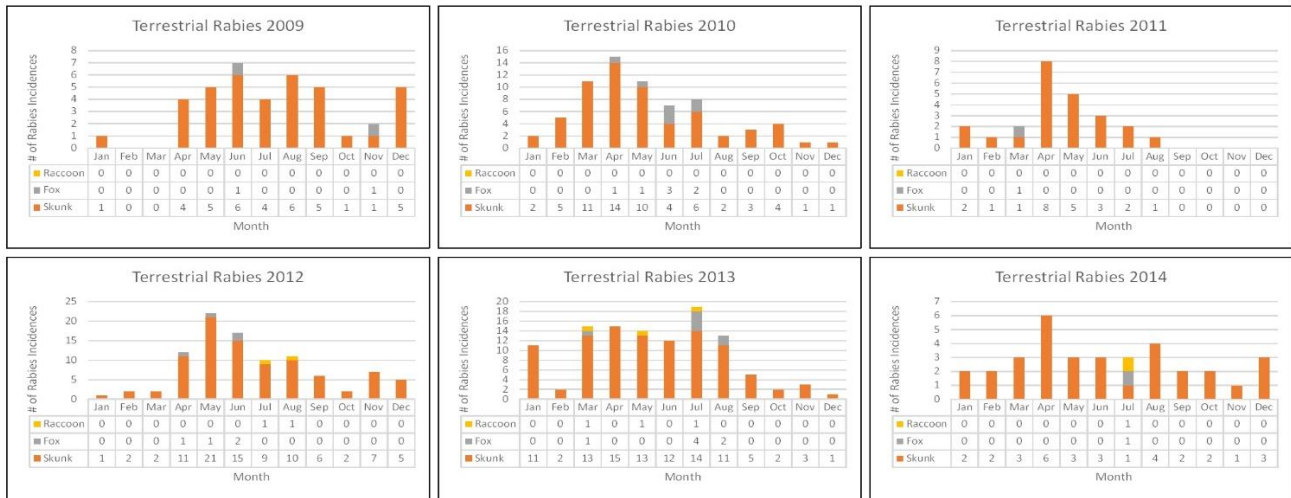
Figure 9: Total number of rabies cases reported for the State of Colorado per month for a given year.
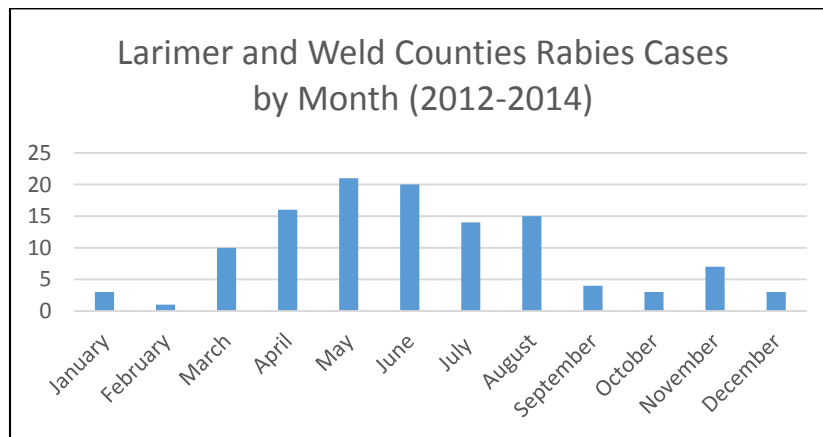
Figure 10: Larimer and Weld Counties seasonal occurrence of skunk rabies from 2012-2014.

Spatial Trend of Rabies

The Global Moran's I analysis of county level rabies data suggest that rabies tends to be clustered (Moran's Index = 0.0326; z- score = 2.2593; p-value = 0.0238). In addition, results of habitats associated with skunk rabies locations found that the occurrence of skunk rabies and the associated habitat was not random (Moran's Index = 0.402; z- score = 11.025; p-value = 0.000000).

The Average Nearest Neighbor analysis also indicated that rabies cases tended to be clustered (NNI = 0.659, Z-score = -9.538; p=0.000) with an observed mean distance of 4,088 meters and expected mean distance of 6,202 meters. The Multi-Distance Spatial Cluster (Ripley's K Function) analysis found an observed K value greater than the expected K value, indicating clustering of rabies points (Figure 12).

Figure 12: Graph displays the results of the Multi-Distance Spatial Cluster (Ripley's K Function) analysis.

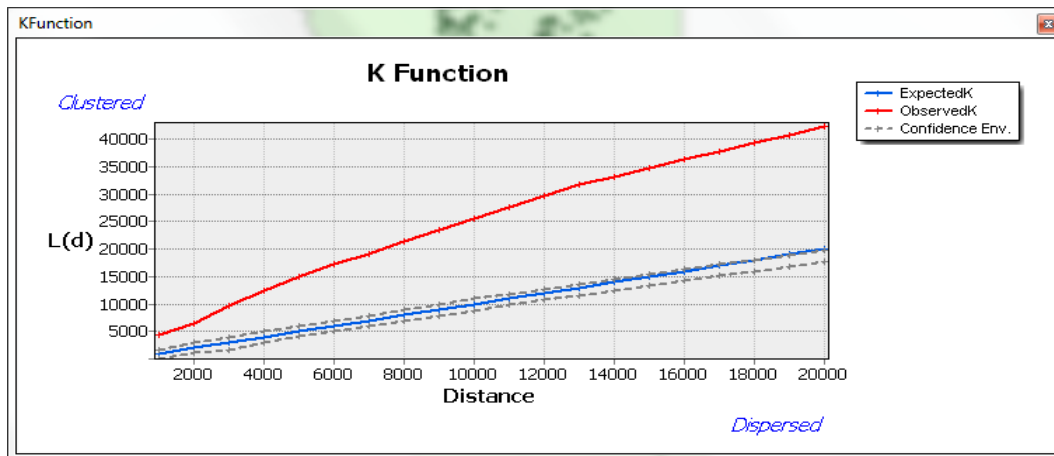Kernel density and directional distribution analysis found that a high density of cases occurred in the surrounding areas of Fort Collins, Loveland and Greeley located in Larimer and Weld Counties with a north-west/ south-east directional trend.

Spatial Analysis of Skunk Habitat

Several land cover types were highlighted as skunk habitat and included; open space, low/medium development, grassland, pasture, cropland and shrub. The amount of rabid skunk cases within each habitat was determined (Figure 13). The amount and average acreage size of preferred skunk habitat found within each county is summarized in Figure 14 A & B. When skunk rabies incidences per county was compared to the percent of preferred habitat (Figure 15) for all counties in the Colorado Front Range study area Larimer and Weld were clearly found to stand out. Larimer although had the highest number of rabid skunk cases (N=72), only contained 10% of the preferred habitat, while Weld contained the next highest number of cases (N=48) contained 34% of the preferred habitat (Figure 15). Rabid skunks within the Front Range study area were found to occur between 4,606ft and 5,250ft with a maximum of 7,703ft, west of Colorado Springs in El Paso County (Figure 16). No rabies was found in the Rocky Mountains.
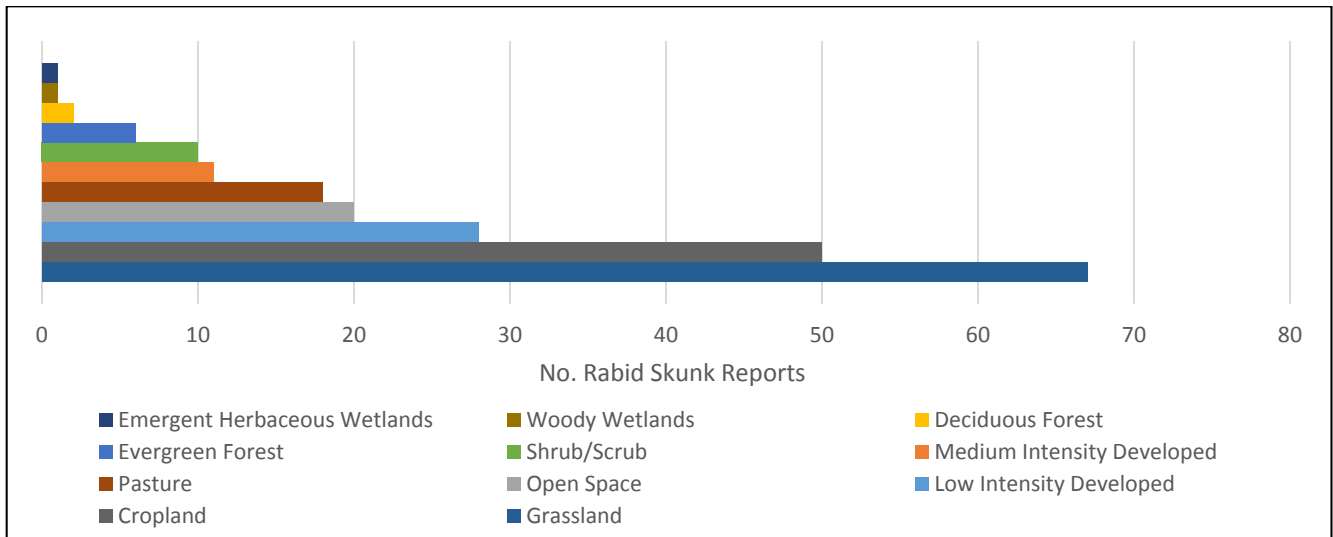
Figure 13: The amount of rabid skunk cases within their respective land cover type. The majority of cases were located in grassland and cropland.
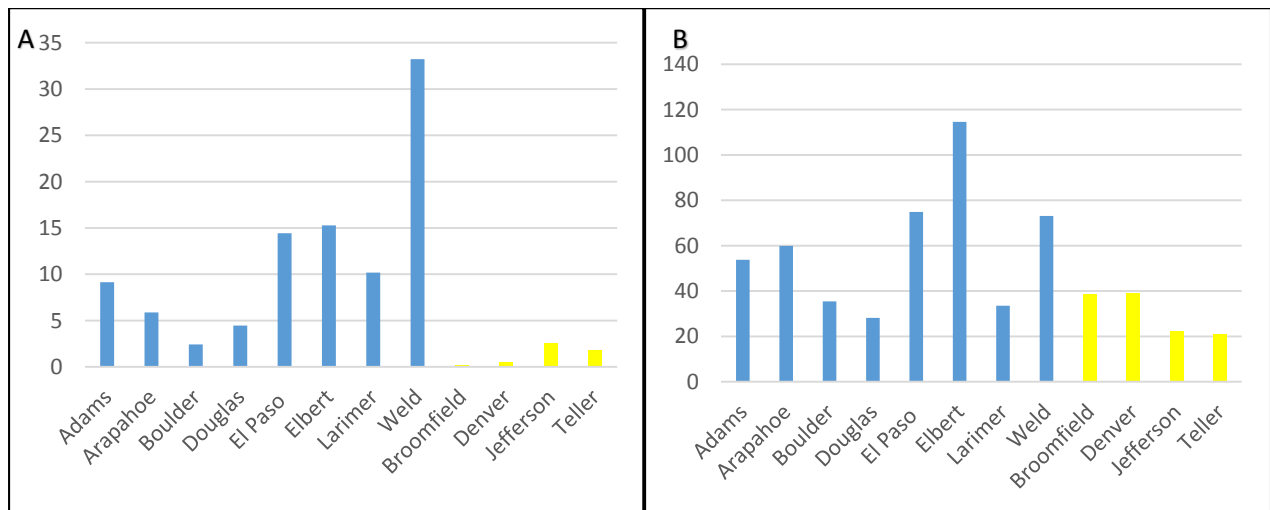
Figure 14: A) Percent of preferred skunk habitat. B) Average acreage size of preferred skunk habitat. In counties with (blue) and without (yellow) skunk rabies cases.
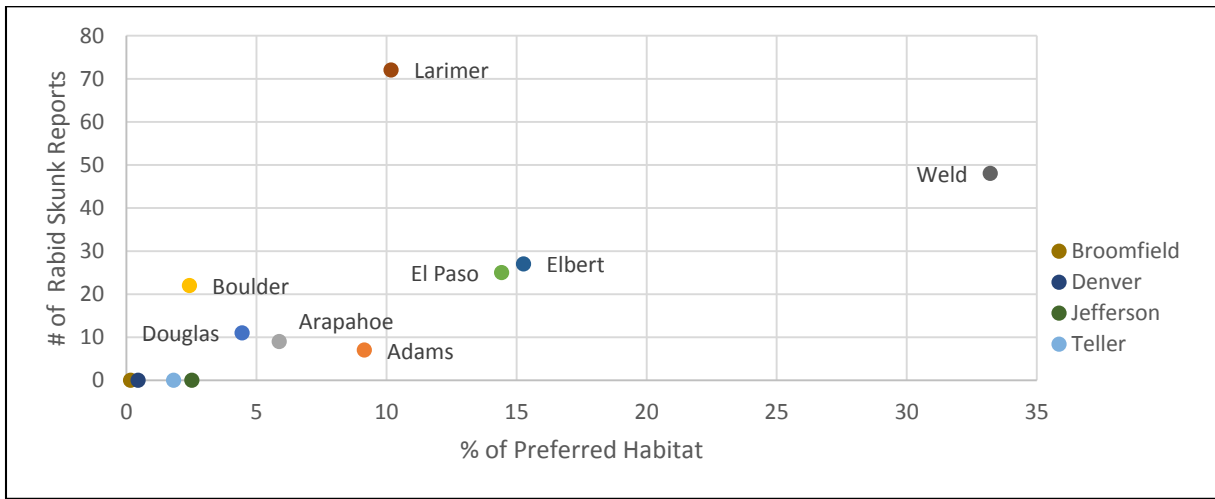
Figure 15: Comparison of the number of rabies skunk incidences to the amount of preferred habitat within each county of the Front Range study area.
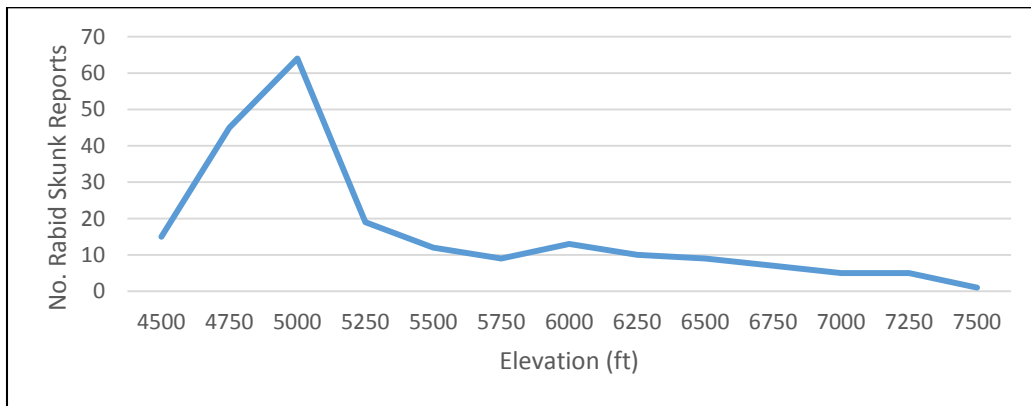
Figure 16: The amount of rabid skunk incidences at their respective elevation (ft).

When the number of skunk cases was compared with slope and aspect. The majority of rabid skunk cases (71%) were found with flat slopes (Figure17) (0 to 4 degrees) that were east facing (Figure 18).
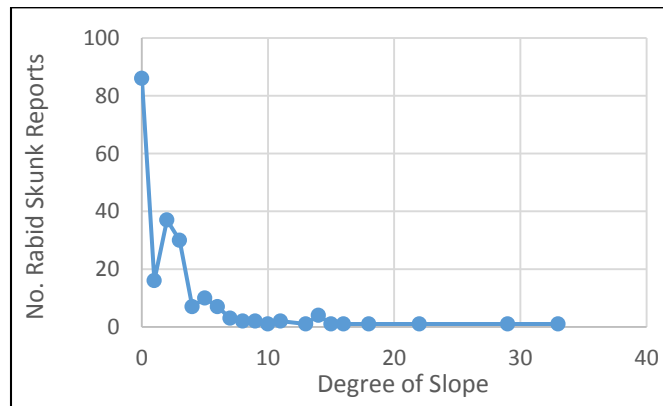
Figure 17: Comparison to the amount of rabid skunk incidences to its respective degree of slope.
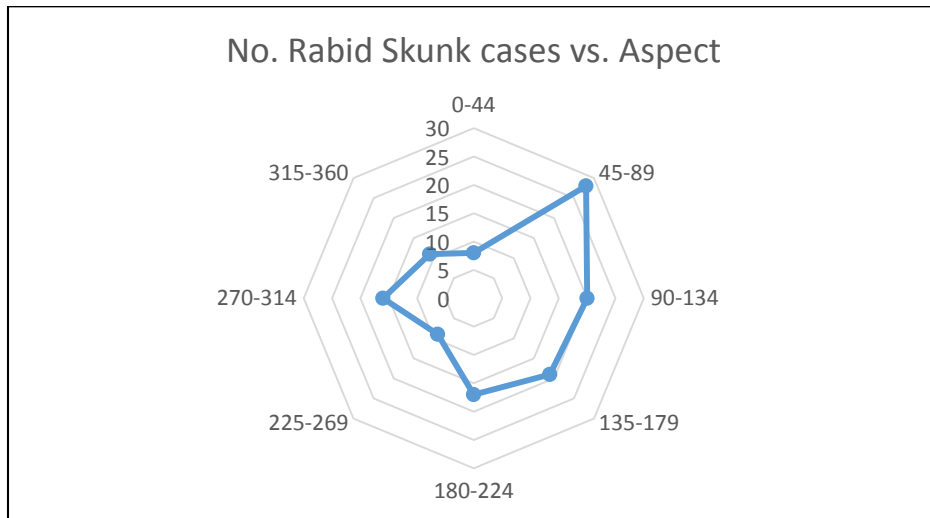
Figure 18: The amount of skunk rabies incidences per aspect.

Discussion and Conclusion

Rabies serves as a potential threat to humans in this study area with ongoing cases reported in wild animals as found in this study when examining rabies cases along the Colorado Front Range between 2007 and 2014. Although, obtaining consistent and detailed data was difficult and the data used to perform these analyses were available at different scales and in different forms, findings from this study clearly showed strong clustering of rabies incidences.

Clear spatial and temporal trends of rabies incidence was found in the Colorado Front Range. The location of rabies incidence varied between years with the highest incidence occurring in the southern portion of the study area for years 2009-2011 and the northern portion of the study area for years 2012, 2013 and 2014. Overall rabies was highest in Larimer and Weld with hotspots in the areas surrounding Fort Collins, Loveland, and Greeley.

Cases peaked in May and June and maybe as a result of seasonal changes that influence movement patterns. On average skunks do not have a large movement range (Appendix A) but these ranges can vary between different seasons. Skunks have larger ranges during spring and summer months than fall and winter months (Bixler and Gittleman, 2000 and Weissinger et al, 2009). During the winter months skunks can be found in communal dens which can aid in the spread of rabies due to the close contact of skunks with one another (Rosatte et al., 2011) and thus communal dens have been linked in previous studies to explain peaks in spring time rabies (Rosatte, 1984).

Knowing when and where rabies cases occur is useful for determining the best locations for vaccine drops in areas where rabies is a problem. Since skunks movement ranges tend to be small in urban environments these serve as an advantage when determining strategies to combat against the spread of rabies (Rosatte et al., 2011). Although, skunks are opportunistic with regards to their habitat and range; they can be found in a variety of habitats (Appendix B) as long as there is a nearby food source. Skunks found in urban environments have smaller ranges, perhaps due to greater food availability (Weissinger et al., 2009). A study conducted by Rosatte et al., 2011, monitored the movement of stripped skunks within Scarborough, Ontario, Canada. For 56% of the observations skunks were found in areas classified as field habitats and 23% found in residential habitats. Due to the skunks small range and communal habits in the winter once rabies had become established remained present for several years (Parker, 1962 and Verts 1965; from Weissinger et al., 2009). A study performed by Storm and Verts (1966), monitored a rabid skunk and determined that its movements where not that different from non-rabid skunks.

Extensive terrestrial rabies studies have been performed to determine the best locations for vaccine drops in areas where rabies is epidemic (Rupprecht et al, 2002). According to Rupprecht et al (2004) oral bait trials performed on raccoons in eastern states, grey foxes in west central Texas and coyotes near the Mexican border have shown promising results. These trials highlighted that rabies virus in terrestrial mammals did not spread outside the study area. The location of vaccine drops can vary between study areas, for example, a study performed by MacInnes et al (2001) determined that the red fox (*Vulpes vulpes*) served as the primary rabies reservoir in Southern Ontario. This study determined a rabies monitoring area and dropped oral vaccine baits annually for 7 years at a density of 20 per square kilometer. The results showed red fox rabies being eliminated from the area. However, a study performed on monitoring rabid raccoons in Ohio did not show promising results with oral vaccines (Henderson et al, 2008). Henderson et al (2008), discuss the possibilities for the poor results, which include; a lack of oral vaccines, the spatial variation of vaccines and lack of rabies surveillance in the area. The amount of surveillance and density of bait drops can vary within each area and by species to ensure elimination of terrestrial rabies. However, there currently in no practical vaccination method for bats and bat rabies can still spill over in to the terrestrial mammal population (Rupprecht et al, 2004).

Analysis of rabid skunks along the Colorado Front Range found that 77% of cases occurred in a field habitat (open space, scrub, grassland, cropland and pasture) and 18% of cases occurred in an urban environment (low and medium development). Similar to the study conducted by Rosatte et al (2011), most cases occurred in field habitats. Although, Larimer and Weld Counties were found to have the highest number of skunk rabies cases, Larimer County did not have a high percentage of preferred habitat (Figure 15). Overall, Larimer County has a high percentage of high elevation evergreen forest (Figure 19), which are not preferred

habitat of skunks. However, in this case the majority of skunk cases that were reported did occur in grassland, scrub and cropland.
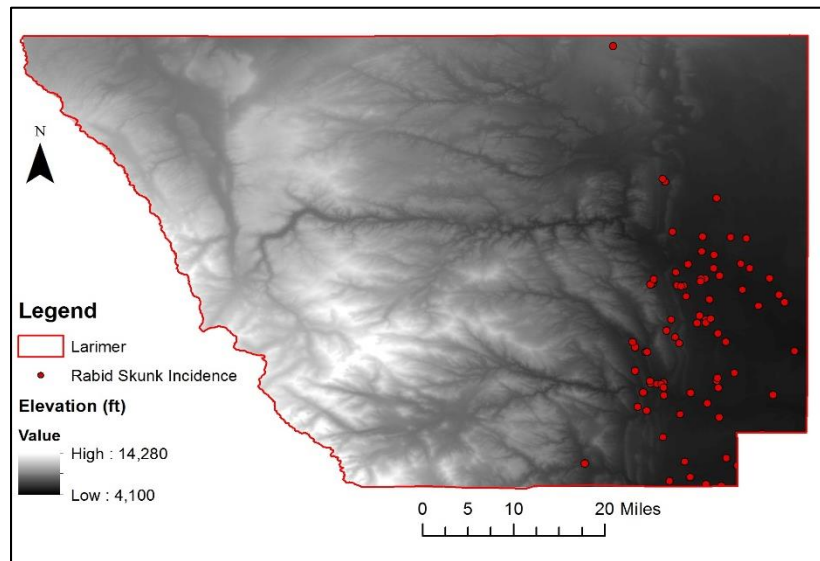
Figure 19: Map shows the location of rabid skunk cases along with a digital elevation model (DEM) of Larimer County. No rabid skunk cases were reported in higher elevation, evergreen forested areas.

Since skunks are opportunistic foragers, the areas surrounding the cities of Fort Collins and Loveland, in Eastern Larimer County, were surrounded by skunk habitat and therefore the majority of cases in Larimer County occurred in this area. Overall, counties with a high amount of skunk habitat also showed a higher amount of known skunk rabies cases (Figure 15).

Although, we were able to identify key areas where skunk rabies is high, there are several limitations of this study.

- The data analyzed in this study are known cases. Unknown cases most likely also occurred throughout the study area but animals were either not found or not reported. Furthermore, testing of wild animals is costly to the county governments and therefore not all known expired wild terrestrial mammals are tested for rabies.
- Data digitized from maps where overlapping points occurred will be missed and although the point dataset is still useful for assessing "hotspots" these may be an underestimation of rabies cases in areas where multiple points overlap.

Due to the patterns found in this study, it is clear that additional analysis should be conducted using more consistent datasets and for longer time frame to better understand what factors are driving these

changing patterns. Future analysis should be performed on known locations of rabid mammals and better surveillance should be performed to fully understand rabies epidemics.

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Appendix A: Skunk Range

Sex &/or Time of Year	Location of Study/ Area Type	Range Size	Source
Annual mean home range size (combined sex)	Scarborough, Ontario, Canada/Urban	0.9 Km^2	Rosatte et al., 2011
Winter (combined sex)	Scarborough, Ontario, Canada/Urban	0.04 Km^2	Rosatte et al., 2011
Spring (combined sex)	Scarborough, Ontario, Canada/Urban	0.25 Km^2	Rosatte et al., 2011
Summer (combined sex)	Scarborough, Ontario, Canada/Urban	0.27 Km^2	Rosatte et al., 2011
Fall (combined sex)	Scarborough, Ontario, Canada/Urban	0.67 Km^2	Rosatte et al., 2011
Spring and Summer (male)	Flagstaff, Arizona/Urban	1.3 Km^2	Weissinger et al., 2009
Spring and Summer (female)	Flagstaff, Arizona/Urban	1.1 Km^2	Weissinger et al., 2009
Fall and Winter (male)	Flagstaff, Arizona/Urban	0.7 Km^2	Weissinger et al., 2009
Fall and Winter (female)	Flagstaff, Arizona/Urban	0.4 Km^2	Weissinger et al., 2009
Males	Carroll County, Illinois/ Rural	5 Km^2	Storm and Verts, 1966
Females	Carroll County, Illinois/ Rural	3.7 Km^2	Storm and Verts, 1966
Males	Southern Alberta, Canada/Rural	2.9 Km^2	Rosatte and Gunson, 1984
Females	Southern Alberta, Canada/Rural	2.5 Km^2	Rosatte and Gunson, 1984
Males	Southern Griggs County, North Dakota/ Rural	3 Km^2	Greenwood et al., 1985
Females	County, North Dakota/ Rural	2.4 Km^2	Greenwood et al., 1985

Appendix B: Skunk Habitat

Habitat Used	Source
Wetlands within a cropland dominated area	Larivière and Messier, 1999
Hardwood Forest and grassy fields	Bixler and Gittleman, 2000
Grassland	Shirer and Fitch, 1970
Marshland	Bailey, 1971
Cropland	Greenwood et al, 1985
Short Grass and Bushy Areas	Rosatte et al., 2011
Scrub/brush	Neiswenter and Dowler, 2007

Rabies in Colorado
January 1 – December 31, 2009
Lab Confirmed Rabies Positive Animals

County	Bat	Skunk	Other	Total
Adams	1			1
Arapahoe	1	5		6
Boulder	32			32
Chaffee	1			1
Denver	12			12
El Paso	2	9	1 horse* 1 mtn lion* 1 fox*	14
Elbert		5		5
Gilpin	1			1
Jefferson	2			2
Kiowa		1		1
Kit Carson		1		1
Larimer	5			5
Lincoln		1		1
Mesa	1			1
Montezuma	1			1
Morgan	1	8		9
Otero		2		2
Prowers		1	1 - fox*	2
Weld	1			1
Yuma	0	5		5
Total	**61**	**38**	**4**	**103**

Year to date known exposures to lab confirmed rabid animals: 23 humans and 107$^\oplus$ domestic animals.
$^\oplus$ Of the 107 domestic animals considered exposed 36 were dogs exposed to one skunk at a private hunt club in Arapahoe County
Number of lab confirmed rabid animals with known exposures to humans: 18
Number of lab confirmed rabid animals with known/suspect exposures to pets/domestic animals: 40
* Testing at CDC of these animals indicated infection with the variant associated with skunks in south central U.S.
** Testing at CDC is pending on these specimens.

Rabies by Month 2009 (by date of report- results from CDPHE or CSU Veterinary Diagnostic Laboratory)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Bat	0	0	0	0	2	8	18	26	6	1	-	-	61
Skunk	1	0	0	4	5	6	4	6	5	1	1	5	38
Fox	0	0	0	0	0	1	0	0	0	0	1	-	2
Other	0	0	0	0	0	0	0	0	2	0	-	-	2
Total	1	0	1	3	8	14	22	32	13	3	2	4	103

Rabies in Colorado
2010
Lab Confirmed Rabies Positive Animals

County	Bat	Skunk	Other	Total	Tested-Bats	Tested-Skunks
Adams	1	1		2	4	4
Arapahoe		3	1 - horse*	4	11	11
Bent		2		2	0	4
Boulder	18			18	113	6
Cheyenne		2		2	0	2
Clear Creek	2			2	4	0
Denver	3			3	21	10
Douglas	1	10		11	9	17
Eagle	1			1	6	0
El Paso	8	5	1 - Fox *, 3 - Fox **	17	34	29
Elbert		20	1-Mule Deer *, 2-Fox*, 1-Fox **	24	5	23
Garfield	1			1	1	0
Jefferson	4			4	42	13
Kiowa		1		1	1	1
La Plata	1			1	8	0
Larimer	7	1		8	38	10
Lincoln		1		1	0	4
Mesa	2			2	13	2
Montezuma			1 - coyote^b	1	1	0
Morgan		4	1- muskrat***	5	0	4
Otero		8		8	1	8
Phillips		1		1	0	1
Prowers			1- cat*	1	1	0
Pueblo	5	4		9	24	16
Saguache	1			1	1	0
Weld	6			6	21	5
Total	61	63	12	136		
Tested	396	180				

Counties not list in table above had no laboratory confirmed rabid animals, but animals may have been tested for rabies from those counties. In 2010, CSU and CDPHE laboratories received 1,280 animals from Colorado for rabies testing. Of those animals submitted, 473 were domestic animals including: 277 dogs, 172 cats, 27 horses, 13 cows, 6 sheep, and 3 goats. For wildlife, other species submitted, excluding bats and skunks, included the following: 57 raccoons, 20 coyotes, 16 mountain lions, 38 foxes, 6 bears, 6 lynx, 3 bobcats, and 3 deer.

Known/strongly suspected exposures to lab confirmed rabid animals: 45 humans and 165 domestic animals.
Number of lab confirmed rabid animals with known/strongly suspected exposures to humans: 15
Number of lab confirmed rabid animals with known/strongly suspect exposures to pets/domestic animals: 76
* Testing at CDC of these animals indicated infection with the variant associated with skunks in south central U.S.
^b Testing at CDC of this coyote indicated infection with a variant associated with *Epitescus fuscus* and *Myotis* species of bats.
** Variant typing was not completed on these animals.
***CDC was not able to perform testing for variant typing, as there was insufficient remaining tissue.
A suspect rabid horse from Franktown, Douglas County, had conflicting rabies DFA results in CO; results from CDC did not support a positive result; therefore, rabies could not be definitively ruled out.

Rabies by Month 2010 (by date of report- results from CDPHE or CSU Veterinary Diagnostic Laboratory)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Bat	0	0	0	0	1	14	15	17	10	3	1	0	
Skunk	2	5	11	14	10	4	6	2	3	4	1	1	
Fox	0	0	0	1	1	3	2	0	0	0	0	0	
Other	1	0	1	1	1	0	0	0	0	0	1	0	
Total	3	5	12	16	13	21	23	19	13	7	3	1	136

Appendix E: 2011 Rabies in Colorado

Rabies in Colorado
January 1 – December 31, 2011
Lab Confirmed Rabies Positive Animals

County	Bat	Skunk	Fox	Other	Total
Adams					
Arapahoe	2				2
Bent		1			1
Boulder	17				17
Broomfield	2				2
Clear Creek					
Denver	10				10
Douglas	3	1			4
Eagle	1				1
Elbert	1	1			2
El Paso	5	9	1		15
Fremont	1				1
Garfield	2				2
Heurfano	1				1
Jefferson	9				9
Larimer	8				8
Las Animas		1			1
Lincoln					
Mesa	1				1
Montezuma					
Otero					
Phillips					
Prowers		1			1
Pueblo	8	9			17
Summit	1				1
Teller	1				1
Weld	7				7
Yuma					
Total	80	23	1	0	104

Year to date known/strongly suspected exposures to lab confirmed rabid animals: 28 human, 67 domestic animals and 12 exotic animals.

Number of lab confirmed rabid animals with known/strongly suspected exposures to humans: 23
Number of lab confirmed rabid animals with known/strongly suspect exposures to pets/domestic animals: 43
Number of lab confirmed rabid animals with known/strongly suspected exposures to exotic animals: 1
* Testing at CDC of these animals indicated infection with the variant associated with skunks in south central U.S. ᴾ Testing at CDC is pending on these specimens.
** Variant typing was not completed on these animals.
***CDC was not able to perform testing for variant typing, as there was insufficient remaining tissue.

Rabies by Month 2011 (by date of report- results from CDPHE or CSU Veterinary Diagnostic Laboratory)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Bat					4	11	19	25	18	3	1		
Skunk	2	1	1	8	5	3	2	1					
Fox			1										
Other													
Total	2	1	2	8	9	14	20	26	18	3	1	0	104