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Report No. UT-19.27

IDENTIFICATION OF WILDLIFE-VEHICLE CONFLICT HOTSPOTS IN UTAH

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Final Report
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16. Abstract

The Utah Department of Transportation (UDOT) and the Utah Division of Wildlife Resources (UDWR) work together to help reduce wildlife-vehicle collisions and improve the permeability of roads for wildlife. These efforts work largely at the UDOT and UDWR regional levels, yet there is a need to identify locations for top state-wide efforts. This research project began to address top locations for wildlife-vehicle conflict, based on areas of the greatest number of reported wildlife-related crashes, all animal crashes, and domestic animal crashes, carcasses reported along roads, and available data on wildlife movements and habitats near and across Utah roads. From 2008 - 2017, each year there were on average 3,110 crashes reported with animals, 2,756 of these with wild animals, at a societal cost of over $138 million annually. The researchers conducted statewide Geographic Information Systems (GIS) hotspot analyses with Getis-Ord Gi*, of all animals, wildlife, and domestic animal-related crash data, and carcass data to delineate and rank top wildlife-vehicle conflict hotspot areas across Utah and within UDOT Regions. The crash modeling identified the top 25 WVC hotspots for past crashes based on crashes/mile/year with: all animals, wildlife, and domestic animals on highways and local roads. The top five locations for animal and wildlife-vehicle crashes on highways were: 1. US 191 North and South of Monticello; 2. US 89/North State St. in Lindon; 3. US 40 from Heber north to Jordanelle Reservoir; 4. US 189 Deer Creek State Park; and 5. SR 224 Kimball Junction-SR 248 Park City. Recommendations were included in the report detailing past and potential future wildlife mitigation solutions for these five and 20 other top hotspots.

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UNIT CONVERSION FACTORS

All measurements in the text were reported in U.S. Customary system units.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
AVC	Animal-vehicle crashes reported to involve any type of wild or domestic animal
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
GPS	Global Positioning System
MP	Mile Post
OHSA	Optimized Hotspot Analysis
ROW	Right of Way along the side of highways and roads
STIP	Statewide Transportation Improvement Program
UDOT	Utah Department of Transportation
UDWR	Utah Division of Wildlife Resources
UPLAN	UDOT map center interactive mapping platform
VMT	Vehicle Miles Traveled
WVC	Wildlife-vehicle crashes reported to UDOT

EXECUTIVE SUMMARY

Wildlife-vehicle collisions pose a safety threat to Utah motorists, while roads and traffic pose barriers and mortality threats to wildlife. These wildlife and roads challenges are collectively considered wildlife-vehicle conflict. At the time of this study, Utah was best able to address wildlife and transportation conflict by analyzing locations of reported crashes with wild animals, referred to in this report as wildlife-vehicle crashes (WVC), and predict the potential for future crashes with both past crash data and limited habitat data. This study identified top WVC road segments using 2008 – 2017 reported crashes from the Utah Department of Transportation (UDOT). Crash data were modeled with the Geographic Information System (GIS) process, Optimized Hotspot Analysis using the Getis-Ord GI* statistic. This process defined hotspots as statistically significant clusters of crashes in road segments that had far more crashes than in nearby road segments. The hotspots were ranked based on crashes per mile. The study also mapped top-ranked hotspots on Utah roads for all animal crashes (animal-vehicle crashes) which included wildlife and domestic animals, and mapped hotspots of domestic-animal-only crashes.

Each year in Utah there were on average 3,110 animal-vehicle reported crashes; 2,756 with wildlife. Five percent of the total crashes were with wildlife, with an average yearly cost to the Utah public of over $138 million, based on the UDOT 2019 average crash costs. The top five animal-vehicle crash hotspots on highways are presented in Table 1, and Figure 1, the top five WVC hotspots were exactly the same. Utah Division of Wildlife Resources' (UDWR) wildlife habitat and movement data were combined with crash hotspot maps to help pinpoint areas where wildlife and drivers may be at risk for collisions. The results of this research will assist UDOT and UDWR in working together in a strategic manner to identify, plan for, and fund future mitigation in top priority areas.

Table 1. Top Five Animal- and Top Five Wildlife-Vehicle Crash Hotspots in Utah.

	Top Animal-Vehicle Crash Hotspots	UDOT Region	UDWR Region
1.	US 191 North and South of Monticello	Region 4	SOUTHEASTERN
2.	US 89/North State St. Lindon	Region 3	CENTRAL
3.	US 40 Heber to Jordanelle Reservoir	Region 3	CENTRAL
4.	US 189 Deer Creek State Park	Region 3	CENTRAL
5.	SR 224 Kimball Junction-SR 248 to Park City	Region 2	CENTRAL

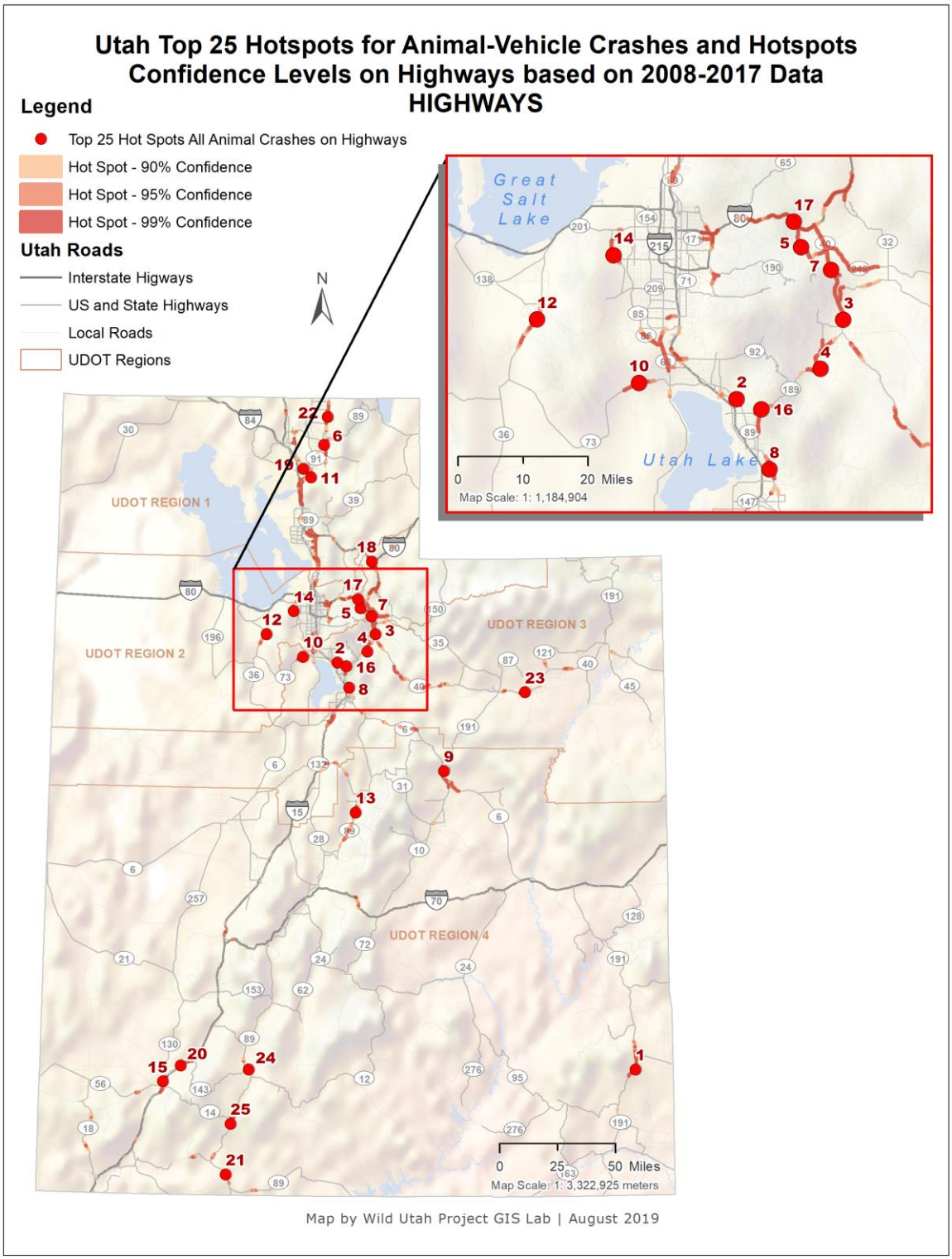


Figure 1. Master Map of Top 25 Animal-Vehicle Reported Crash Hotspots on Utah Highways, Based on 2008 - 2017 Utah Department of Transportation Crash Data.

1.0 INTRODUCTION

1.1 Problem Statement

The Utah Department of Transportation (UDOT) and Utah Division of Wildlife Resources (UDWR) work together to help reduce wildlife-vehicle collisions and improve the permeability of roads for wildlife. These efforts work largely at the UDOT and UDWR regional levels. Utah could best address the potential for mitigating crashes with wildlife, and the effects of transportation on wildlife, which are collectively considered wildlife-vehicle conflict, across the state if there was a standardized prioritization process to identify the areas in greatest need of wildlife mitigation. This research project began to address top-ranked locations of wildlife-vehicle crashes (WVC), based on areas of the greatest number of reported wildlife-related crashes, carcasses reported along roads, and available data on wildlife movements and use of habitat near and across Utah roads. This combined approach is an early step in the inclusion of wildlife needs to move in a detailed analysis, which is more appropriate to address the potential for conflict with wildlife and transportation rather than only addressing past reported crashes with wildlife. The original term, wildlife-vehicle collision, was used to address the overall phenomena of crashes with wildlife, both reported and unreported. The new approach to change the term to wildlife-vehicle conflict helps to combine crash and safety concerns with the wildlife and ecological concerns with respect to transportation. In this report we will consistently refer to reported crashes with wildlife as WVC.

1.2 Objectives

The primary objective of this study was to conduct a repeatable, thorough statewide Geographic Information Systems (GIS) analysis of wildlife and overall animal-related crash data, carcass data, and large wildlife species' occurrence and movement data to help UDWR and UDOT delineate and prioritize WVC hotspot areas on Utah roads. In this study hotspots were defined as statistically significant clusters of crashes in road segments that had far more crashes than in nearby road segments. The study also offered recommendations for future actions to address the top 25 animal-vehicle crash hotspots in Utah. The results will assist UDOT and

UDWR in reducing WVC and help make Utah roads safer, and in promoting wildlife connectivity across roads with wildlife mitigation. The study addresses all animal-, wildlife-, and domestic animal-vehicle crashes.

1.3 Scope

The research completed the following seven tasks:

Task 1. Create statewide and UDOT Region Maps of top WVC hotspot areas that utilize 10 years of wild and domestic animal crash data.

Task 2. Identify hotspots for WVC at state and UDOT regional level based on crash and carcass data, and available UDWR wildlife location and habitat data.

Task 3. Identify species of wild and domestic animals involved in the top 25 crash hotspots and mitigation solution recommendations for each hotspot.

Task 4. Conduct a cost analysis of average annual crashes with wildlife and livestock.

Task 5. Produce recommendations to UDOT and UDWR for future collaboration.

Task 6. Conduct a workshop with UDOT and UDWR based on the research.

Task 7. Deliver Final Report, GIS instruction manual, GIS products and GIS shape files that result from the project.

1.4 Outline of Report

This report is presented in the following format:

Executive Summary

1. Introduction
2. Research Methods and Data Collection
3. Data Evaluation - Results
4. Conclusions

5. Recommendations and Implementation
6. References
7. Appendix A Model Factor Selection Notes
8. Appendix B Maps of Species of Wild and Domestic Animals' Carcass Locations Merged with Crash Data from Narratives
9. Appendix C Maps of the Top 25 Wildlife-Vehicle Crash Hotspots on Utah Highways and Top 25 Hotspots on Local Roads Merged with UDWR Wildlife Species' Habitat Maps
10. Appendix D Maps of the Top 25 Wild Ungulate Carcass Hotspots on Highways and Top 25 Hotspots on Local Roads Based on 2008-2019 Data Merged with UDWR Species' Habitat Maps
11. Appendix E Guide to Delivered GIS Files: ArcGIS Map Documents, Geodatabases, Layers, and Figures for UPLAN.

2.0 DATA COLLECTION AND RESEARCH METHODS

2.1 Overview

This chapter describes the data sources used in this research and the methods of analyses created and used to process the data and present the overall picture of the challenge of all animal, wildlife, and domestic animal-vehicle crashes. The results of these methods are presented in Chapter 3.

The prime data sources for this research included: UDOT crash data, UDOT-UDWR carcass data, UDOT LRD routes (roads dataset), and Average Annual Daily Traffic (AADT) data layers, UDWR large mammal species' habitat maps, and jurisdictional boundary maps of UDOT regions, UDWR regions, and Utah counties. These data sources informed data analyses and modeling of hotspots in a repeatable, transparent manner that UDOT can replicate in future years.

The data used were tens of thousands of crash records, carcass records, and maps commonly available to UDOT personnel. Due to the large number of records, they were not included in this report, but can be accessed at UDOT and UDWR websites. The map layers and resulting maps created in this research were made available on the UDOT UPLAN website of GIS information.

The research methods are presented as four steps in this chapter:

1. Meetings with Technical Advisory Committee Members
2. Data Gathering
3. Data Preparation, Analyses, and Mapping, and
4. Data Modeling.

2.2 Meetings with Technical Advisory Committee Members

The research team met with the Technical Advisory Committee on the following dates:

August 7, 2018 – Scoping meeting with research team and Technical Advisory Committee (TAC) at UDOT headquarters.
December 11, 2018 – Update meeting at UDOT headquarters.
July 17, 2019 – Met with members of UDOT Environmental and Planning divisions to review first draft final report (June 2019), results, and potential edits.
September 12, 2019 – The research team met with the full panel at UDOT headquarters to review results of the final report, and plan for workshop.
November 26, 2019 – Workshop with panel and UDOT and UDWR participants.

2.3 Data Gathering

In the fall of 2018, Dr. Cramer and Wild Utah Project Senior GIS Analyst, Emanuel Vásquez, obtained the following datasets from Utah agencies, Table 2.

Table 2. Data and Geo-Referenced GIS Layers Obtained.

Type of database/Geo-Referenced Data	Formal Name of Data Layer
UDOT all crashes database 2008 - 2017	crash_data_2008_2017
Utah carcass data 2000-2018	carcass_wvc_reports_RevJan2019
UDOT Region GIS Layer	udot_regions
UDOT Roads GIS Layer	udot_lrs_routes
UDOT Annual Average Daily Traffic Volume GIS Layer	udot_annual_average_daily_traffic
2016 UDOT cost estimates for crashes of various severities	Received from Mr. Clancy Black, consultant to UDOT
Utah Counties GIS Layer	agrc_counties
UDWR Regions GIS Layer	udwr_regions
UDWR Mule deer population estimates 1992-2017 Excel worksheet	wildlife_management_units_wmus_deerpop
UDWR Wildlife Management Units GIS Layer	wildlife_management_units_wmus
UDWR species' habitat maps for mule deer, elk, moose, bison, three sub-species of bighorn sheep, and black bear	bison20141030 blbe20060701 CA_BHS dbhs20131031 moose20180305 mude20150806 PRHO20181108 rmbhs20060701 rmelk20130408

Type of database/Geo-Referenced Data	Formal Name of Data Layer
UDWR Brownian Bridge Model of Paunsaugunt GPS Deer Movements in Southern Utah	paunsaugunt_bbmm

These data sets and geo-referenced data were used to analyze the crashes, carcasses, and wildlife locations in Utah in the proceeding steps. The research team worked with UDOT and UDWR personnel to assemble and organize the above data and assure its accuracy. The UDOT crash data were supplied by UDOT's Traffic & Safety Division. All reported crashes from 2010 - 2017 were extracted from the UDOT database and delivered to the research team in November, 2018, then in December, 2018, the 2008-2009 crash data were delivered.

2.4 Data Preparation, Analyses, and Mapping

2.4.1 Crash Data Preparation

The research team prepared the 2008 - 2017 crash data for mapping. Original data acquired from UDOT consisted of Excel spreadsheets, one spreadsheet per year. As a first step, the datasets were assessed in order to determine location information fields and other relevant fields for the purpose of this study (i.e., crash severity, animal type involved, etc.). Second, we proceeded to address any data inconsistencies such as location information recorded in different coordinate systems (Universal Transverse Mercator - UTM vs. Latitude/Longitude- Lat/Long) and determined the total number of records that lacked location information. This process was repeated for each of the crash datasets, 2008 - 2017. The pre-2010 crash data were not as accurate as later years, in part because UDOT's milepost system was re-calibrated in 2010 and the earlier records were not as accurate for geo-referenced modeling as the later years of data. As a third step, the data were transformed from tabular to GIS data format using ArcGIS Desktop software. After this transformation, the resultant datasets were combined by using the Merge Tool in ArcGIS Desktop and produced a multi-year crash dataset. Figure 2 presents the number of entries that did not have location information (coordinates or UTMs) for each year. The graph

reflects how UDOT effectively updated the entries that did not have correct geo-referenced information from 2010 onward.

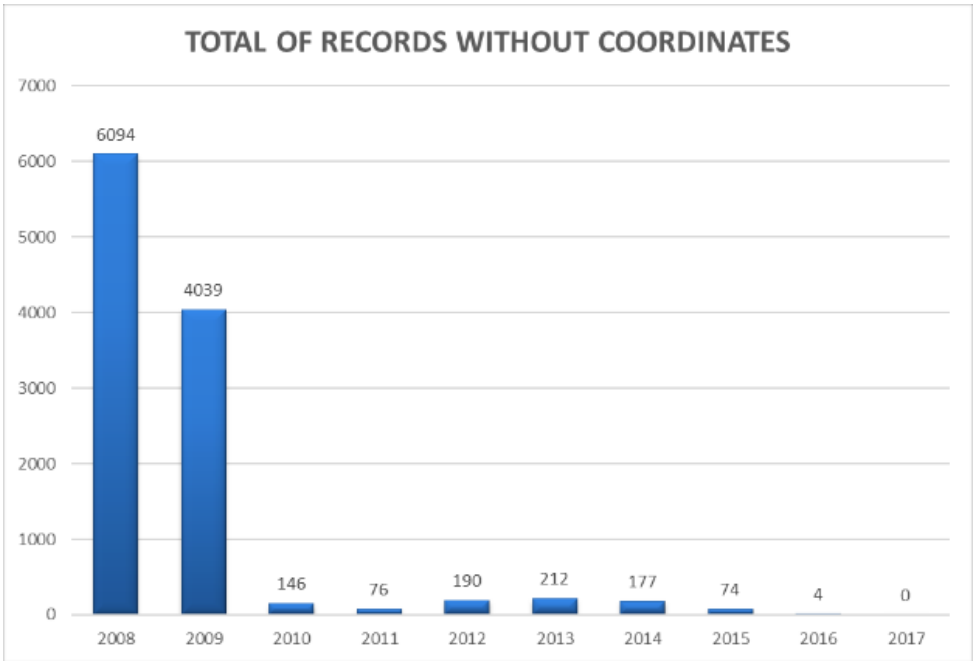


Figure 2. Number of Wildlife and Domestic Animal-Vehicle Reported Crashes Each Year That Lacked Location Information (Coordinates or UTMs).

2.4.2 Parsing Out Wildlife and Domestic Animal Crashes and Costs (Task 4)

The total number of crashes for each year of data was parsed out, along with all accidents reported to involve wild animals, and those that involved domestic animals. The number of WVC and total animal crashes were calculated for each Utah county and UDOT region. The number of wildlife crashes and domestic animal crashes of the five crash severity types, Property Damage Only (PDO), possible injury, minor injury, serious injury, and human fatality were parsed out for each of the 10 years of data. An annual average for each crash type was calculated and multiplied by the 2019 UDOT average crash costs for the five crash types. These calculations were used to estimate the average annual cost of WVC, and all animal-vehicle crashes. The data were also used to make a map of all serious and fatal crashes with wildlife. A Colorado Department of Transportation benefit-cost approach (Kintsch et al., 2019) was used to give a valuation of the worth of a mule deer. That individual animal value was then multiplied by

the average annual number of WVC to estimate a value of the animals killed in these crashes annually.

2.4.3 Extracting Crashes with Animal Names in the Narratives

Clancy Black, consultant to UDOT, performed UDOT SQL code queries to search for animal names in the narratives (Table 3). The narrative of each crash data entry was where the reporting officer provided a description of the event. The extracted records were then used to identify the potential species of animals involved in various crashes. These query results were created through an iterative process of searching for the listing of words in the narrative, and looking for the various species and common animal names. For example, mule was a term used to help find crashes with mule deer. Cow, cattle, and bull were all used for locating crashes with cows. When the bighorn sheep word pairing resulted in one crash, the word sheep was used to determine if perhaps the query could locate additional bighorn crashes.

Table 3. Animal Names Used in the UDOT Query of 2008 - 2017 Crashes with Wildlife and Domestic Animals.

Species	**Species**
Antelope (*Antilocapra americana*)	Cougar (*Puma concolor*)
Bear (*Ursus americanus*)	Coyote (*Canis latrans*)
Bighorn sheep (*Ovis canadensis, canadensis* and *nelson*)	Deer (*Odocoilues hemionus*, and *virgianus*)
Bull (*Bos taurus*)	Dog (*Canis lupus familiaris*)
Burro *(Equus asinus*)	Elk (*Cervus canadensis*)
Cattle (*Bos taurus*)	Horse (*Equus caballus*)
Cow (*Bos taurus*)	Mule (for mule deer, *Odocoilues hemionus)*
	Sheep (for bighorn sheep, *Ovis canadensis)*

2.4.4 Mapping Crash Locations Where Animals Were Mentioned in Narratives

A preliminary heat map based on the density of the crashes with all animal species in the crash report narratives was created. This data visualization of the narratives was created in ArcGIS Pro using the heat map symbology under layer properties. Density values behind the heat map were estimated based on the Kernel Density which breaks the map into pixels or raster cells, and calculates a density of occurrences, in this case, crashes, based on neighboring cells. This method provides a quick view of areas with dense and sparse animal-related crashes. However, it is not as accurate as the methods used later in this research because linear features such as roads have higher densities of occurrence at areas where roads bisect within a raster cell rather than areas where a single road occurs in a raster cell.

2.4.5 Extracting and Mapping Carcass Data

The research team downloaded all carcass data reported from 2010 - 2018 on the Utah Wildlife-Vehicle Collision Carcass website, which is open only to registered users: https://mapserv.utah.gov/wvc/desktop/index.php. After acquiring these data, we conducted a data quality check and addressed some inconsistencies in the data. For instance, the spelling for elk had different variations (i.e., elk, ELK, Rocky Mountain Elk) that could potentially affect the data analysis process.

2.4.6 The Creation of Species Maps Based on Crash Narratives and Carcass Reports

Narrative query crash maps were created for each species used in the narrative search, and were combined with the carcass locations for those species from the 2010 - 2018 carcass database. These maps represented the best approach available in early 2019, to determine the top hotspots for both crashes and carcasses for each species of interest.

2.4.7 Mule Deer Densities and Annual Average Daily Traffic Analysis

The Technical Advisory Committee was interested in any potential relationship between the deer numbers across regions of the state, and the Average Annual Daily Traffic (AADT) of the roads that bisected those areas. The researchers obtained a data worksheet in Excel of the

historic deer population estimates from 2000 - 2017, and an ESRI Map Package of the UDWR Wildlife Management Units, both provided by Bill James of UDWR. These were used to map the mule deer densities of the dozens of wildlife management units in Utah. The UDOT AADT data for Utah's major roads were also mapped, and the two maps were brought together for viewing of the potential interplay of mule deer densities and traffic volumes.

2.4.8 Deer Densities Over Time

The researchers obtained UDWR estimates for mule deer numbers overall in Utah, and plotted the annual number to better understand the trends in risks of vehicle collisions with mule deer.

2.5 Data Modeling: The Optimized Hotspot Analyses (Tasks 1 and 2)

The objective of this research was to take existing data available to UDOT, and scientifically determine the top 25 hotspots for all animal, wildlife, and domestic animal-vehicle crashes, and wildlife carcasses, and bring that data together with UDWR data on wildlife locations and habitat to further identify areas of potential wildlife-vehicle conflict. These steps were accomplished by modeling the data with ArcGIS tools and bringing the model results together with other information to best inform both UDOT and UDWR in identifying the top conflict areas for large wild ungulates (hooved wildlife) and transportation. A detailed guidebook for recreating this process was provided to UDOT as a deliverable to the project. (See Vásquez 2019.)

The data modeling process began by obtaining the UDOT GIS layer, UDOT LRD Routes data set of interstates, U.S. and state highways, and local roads, and transforming the roads to reduce complexity for analyses. The crash data were then mapped on the roads layer in preparation for the hotspot mapping.

Hotspot modeling using ArcGIS is a convenient and accurate method to identify past events where WVC have occurred. Earlier state prioritization maps of wildlife-vehicle conflict relied on

creating hotspots based on raster data (Cramer et al., 2014; Cramer et al., 2016), where the pixels with the greatest number of crash records are considered hotspots. As the state of the science developed, the ArcGIS Getis-Ord Gi* tool became a standard to evaluate aggregations of occurrence data that identify hotspots along linear infrastructure such as roads (Garrah et al., 2015; Kociolek et al., 2016; McClure and Ament, 2014; Shilling and Waetjent, 2015; Visinti et al., 2016). A recent statewide hotspot analysis for prioritization of wildlife-vehicle conflict was completed for Nevada in 2018 using this Getis-Ord Gi* method, and conducted by the PI of this project (Cramer and McGinty, 2018). These hotspots analyses can be considered statistically sound because the Getis Ord Gi* tool is accepted as the best statistically sound predictor of clusters of data points (Getis and Ord, 1992).

The researchers applied the Optimized Hotspots Analysis (OHSA) tool that uses the Getis-Ord Gi* statistic tool in ArcGIS Desktop. The crash data were selected as the only database to use in the true hotspot analyses because they were the most consistently collected data. In this modeling, the occurrence data were crash locations for all animal-vehicle crashes, wildlife-vehicle crashes, and domestic animal-vehicle crashes from 2008 - 2017. Wild animal carcass data, 2010 - 2019, were used for later hotspot analyses for comparisons with crash data. Multiple runs of the Getis- Ord Gi* tool found that inclusion of local or Federal Aid roads complicated results. In some cases, local neighborhood roads become statewide hotspots because of their proximity to interstates and U.S. highways with WVC problem areas, and other times interstates with obvious WVC problem areas were "watered down" and not included as statewide hotspots because of inclusion of local roads in the model distance band (search distance). As a result, hotspot modeling was done separately for the two types of roads: highways and local roads.

The OHSA Getis-Ord modeling was run in multiple iterations over months of time through different model settings. Appendix A presents one aspect of those settings and is an example of how the process is described in the guidebook (Vásquez, 2019). The modeling was tested for best parameters for this research through experimenting with several different lengths of road segments of all UDOT-administered roads, and distance band to find the best match for the data, concentrations of roads in the Wasatch Front, and the size of the state. The optimum

selections for model settings became a half-mile segment for all UDOT highways and local roads, and a 2,000-meters distance band, which was the size of the neighborhood search distance in the OHSA. The Getis-Ord Gi* model runs output results of hotspot areas based on crash data that were within 90, 95 and 99 percent confidence intervals of statistical significance. The 99 percent confidence interval segments were then prioritized for the state based on the number of crashes per mile per year within each hotspot segment.

The top 25 animal-vehicle crash hotspots were identified and mapped for Utah highways. This was also conducted for animal-vehicle crashes on Utah local roads. The same prioritization and mapping occurred for WVC hotspots on highways and then local roads, and domestic animal-vehicle crash hotspots on highways and local roads. Top hotspots less than two miles were parsed out for all sets of hotspots. This was done because in transportation planning, money sources for projects are typically available for lengths of road in these longer stretches. It was also done because the longer hotspots were as long as 28 miles in length and it was deemed by several Technical Advisory Committee (TAC) panel members that this was an unfair bias of potential project comparisons that were greatly different in lengths. Thus, it was decided through meeting with select TAC panel members, that lengths of two miles and longer were more representative of the scale of business UDOT works. The two-mile threshold was also used in the Nevada hotspot prioritization study (Cramer and McGinty, 2018). The animal-vehicle crash top 25 hotspots map for highways became the master map for the study. Hotspots less than two miles with the same rate of crashes per mile per year as the top 25 longer hotspots were presented in a table in a fashion similar to the top 25 hotspots of the state.

These animal, wildlife, and domestic animal-vehicle crash hotspot maps were then merged with other data to create maps of interest based on UDOT regions, UDWR regions, and various wild animal habitat maps (see Figure 3).

The carcass data for all wild animals and for wild ungulates were also mapped and prioritized for Utah highways and local roads. These hotspots were mapped over three wild ungulate habitat maps, mule deer, elk, and pronghorn, and then over seven different species of large wild mammal UDWR habitat maps (Figure 4).

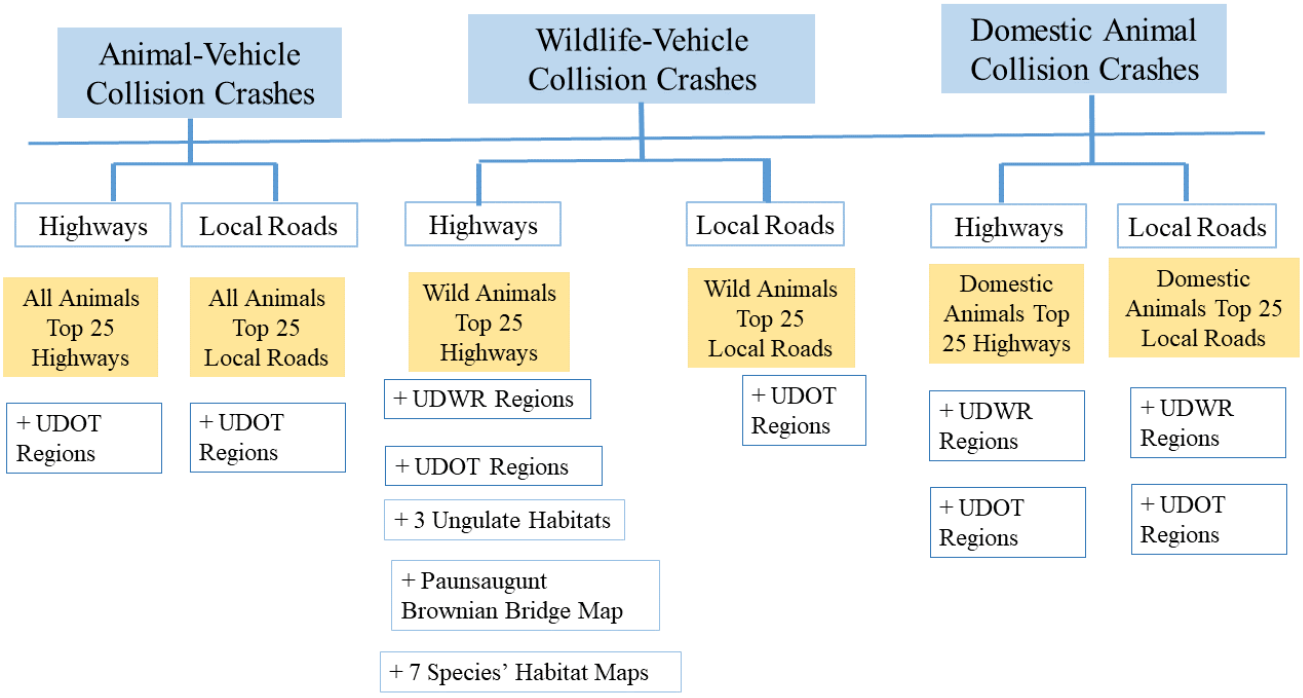


Figure 3. Flow Diagram of Crash Hotspot Modeling Maps.

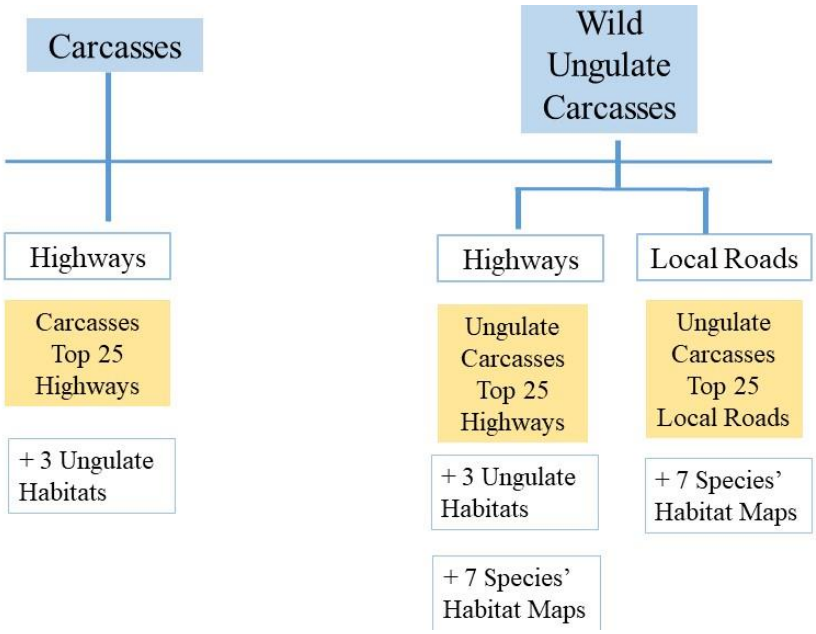


Figure 4. Flow Diagram of Carcass Hotspot Modeling Maps.

All maps were made available in the UPLAN web portal in ArcGIS projects, and in JPG and PDF formats.

2.5.1 Top 25 Wildlife-Vehicle Crash Hotspots and Wildlife Data (Task 2)

The researchers reached out to TAC member, Dr. Daniel Olson of UDWR, for available maps of ungulate locational data from Global Positioning System (GPS) collars. These data are typically gathered and modeled through a Brownian Bridge modeling technique that helps identify the core and peripheral areas the collared animals were believed to use. The goal of this task was to place the top 25 crash hotspots of WVC over these maps to see how the data lined up and to begin to see how following phases of research could predict areas of wildlife-vehicle conflict, not just past reported crashes. The only available map was that of Brownian Bridge predictions of Paunsaugunt mule deer movements in the southwestern portion of Utah, near Kanab. Researchers on this project placed a local map of the state top 25 crash hotspots with wildlife over this UDWR-generated map.

2.5.2 Descriptions of Past Actions and Future Mitigation Solutions for Top 25 Wildlife-Vehicle Crash Hotspots (Task 3)

The top WVC hotspots were identified with respect to UDOT and UDWR regions. The TAC members were asked for input as to the causes and potential solutions to these areas. The researchers then reached out to UDWR Habitat Managers and Biologists in the UDWR Regions where these crashes occurred, to ask for similar input. UDWR personnel then helped describe these areas and working solutions. Their information was incorporated into the Task 3 table of top 25 hotspot solutions.

2.6 Summary

The data and methods used in this research were based on maps and data available to state agency personnel who can repeat these methods to deliver similar results in future years. The 2008 - 2017 domestic animal- and wildlife-vehicle crash data were analyzed with respect to annual averages, crash severity, crash costs, and occurrence in Utah counties and UDOT regions.

The domestic animal- and wildlife-vehicle crash data were then combined to map all animal crashes, wildlife-only crashes, and domestic animal crashes, with Utah road data in an OHSA Getis-Ord GI* hotspot analysis of every half-mile of every highway and every local road in Utah. The resulting maps then allowed for multiple ways to view the information to inform UDOT and UDWR where the most urgent crash locations were in the state with respect to all animals, only wildlife, and only domestic animals. The crash data and carcass data were combined with UDWR species' maps to view the potential for wildlife-vehicle conflict. Finally, the top 25 WVC hotspots were analyzed for past actions and potential future actions to mitigate wildlife-vehicle conflict. The results of this research can be used as a base to further model and explore Utah's top areas of wildlife-vehicle conflict.

3.0 DATA EVALUATION - RESULTS

3.1 Overview

This chapter presents the results of crash and carcass data analyses, and the Optimized Hotspot Analysis (OHSA) modeling results for animal and wildlife-vehicle crash data and wild animal carcass data. Maps were created that combined species listed in crash narratives with the same species carcass records (Appendix B). The results of modeling are also combined with UDWR habitat maps of seven large wild mammal species to assist UDOT and UDWR in further identifying the extent of wildlife-vehicle conflict areas (Appendices C and D). Finally, the TAC members and representative UDWR personnel gave input on potential solutions to the top 25 WVC hotspots.

The research team worked with UDOT and UDWR personnel to assemble and organize the data and wildlife habitat maps, and to assure their accuracy. The files created in these analyses were delivered in the geo-referenced materials delivered to UDOT. Appendix E details the folder naming system and describes files in each folder.

3.2 Crash Data Analyses and Mapping (Task 1)

3.2.1 Overall Crash Numbers for Utah

The crash data were analyzed to gain a better understanding of the significance of reported crashes with all animals, wildlife, and domestic animals. The data were parsed according to Utah counties, UDOT regions, and the severity of crashes and annual averages of each type and their costs. The carcass data were analyzed with respect to species of animal. As trends emerged, additional UDWR data on mule deer management units and state annual population estimates were obtained, mapped, and graphed.

For every year of crash data analyzed (2008 - 2017), the total number of crashes in Utah and the number of crashes with wildlife, and with domestic animals were parsed, and the

percentage of total crashes in Utah that were wildlife related and domestic animal related were calculated for each year and for an overall average, see Table 4 and Figure 5. WVC represent, on average, five percent of all reported crashes in Utah.

Table 4. Utah Reported Crashes 2008 - 2017: All Crashes, Crashes with Wildlife, and Crashes with Domestic Animals. Source: Utah Department of Transportation, December 2018.

Year	Total Reported Crashes	Total Reported Crashes Involving Wildlife	Total Reported Crashes Involving Domestic Animals	Percentage of All Crashes Involving Wildlife	Percentage of All Crashes Involving Domestic Animals
2008	56,360	2,457	420	4.36	0.75
2009	51,180	2,527	382	4.94	0.75
2010	47,757	2,541	327	5.32	0.67
2011	46,392	2,458	310	5.66	0.67
2012	49,254	2,626	357	5.33	0.72
2013	55,463	2,746	352	4.95	0.63
2014	52,090	2,781	315	5.26	0.60
2015	57,526	3,229	319	5.61	0.55
2016	62,363	3,198	397	5.13	0.64
2017	62,855	2,993	360	4.76	0.51
Total	542,054	27,556	3,539	5.09	0.65
Averages	54,205	2,756	354	n/a	n/a

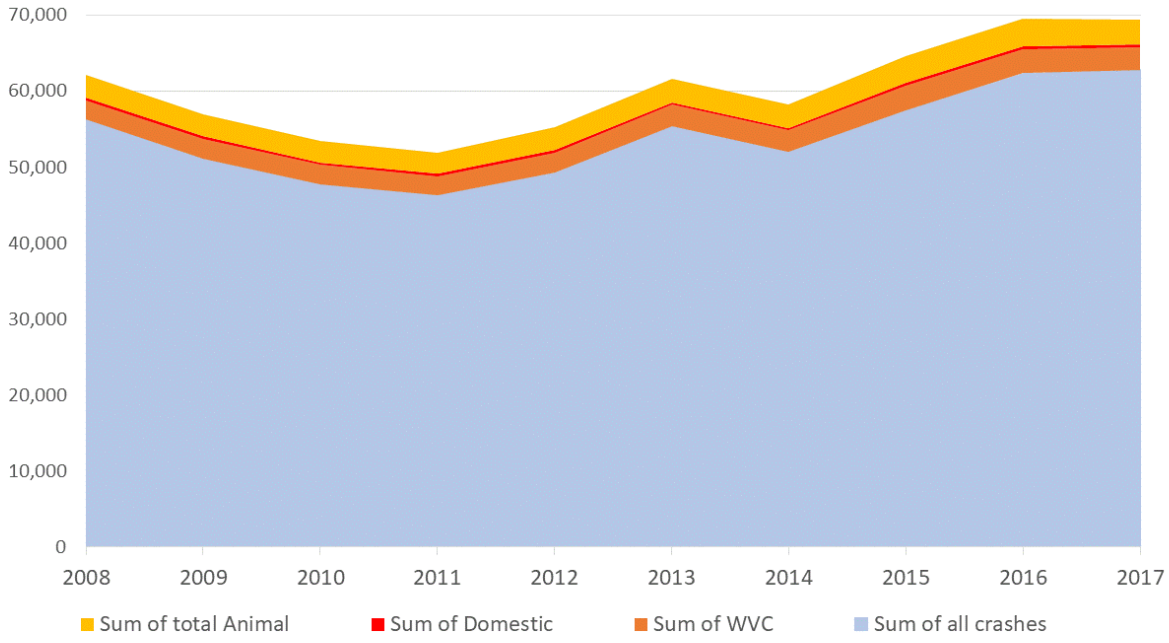


Figure 5. All Reported Crashes, Wildlife Related Crashes, Domestic Animal Related Crashes, and Total Animal-Related Crashes in Utah, 2008 - 2017.

Wildlife-vehicle crashes averaged 5.1 percent of the total reported crashes annually.

In Utah each year there are on average 2,756 reported wildlife-vehicle crashes.

In Utah each year there are on average 354 reported domestic animal-vehicle crashes.

In Utah each year there are on average 3,110 reported animal-vehicle crashes.

3.2.2 Crash Numbers by County

The number of crashes from 2008 - 2017 with wildlife plus the crashes with domestic animals, which are the total animal-vehicle crashes, were presented for each Utah County (Figures 6 and 7, Table 5). The total number of crashes with animals was highest in counties in the urban-suburban wildland interface of the greater Salt Lake City area. The greatest percentages of total crashes that were animal related per county occurred in counties the greatest distances away from Salt Lake City.

The top five counties for total numbers of animal-vehicle crashes were in order:

1. Utah
2. Salt Lake
3. Summit
4. Box Elder, and
5. Wasatch.

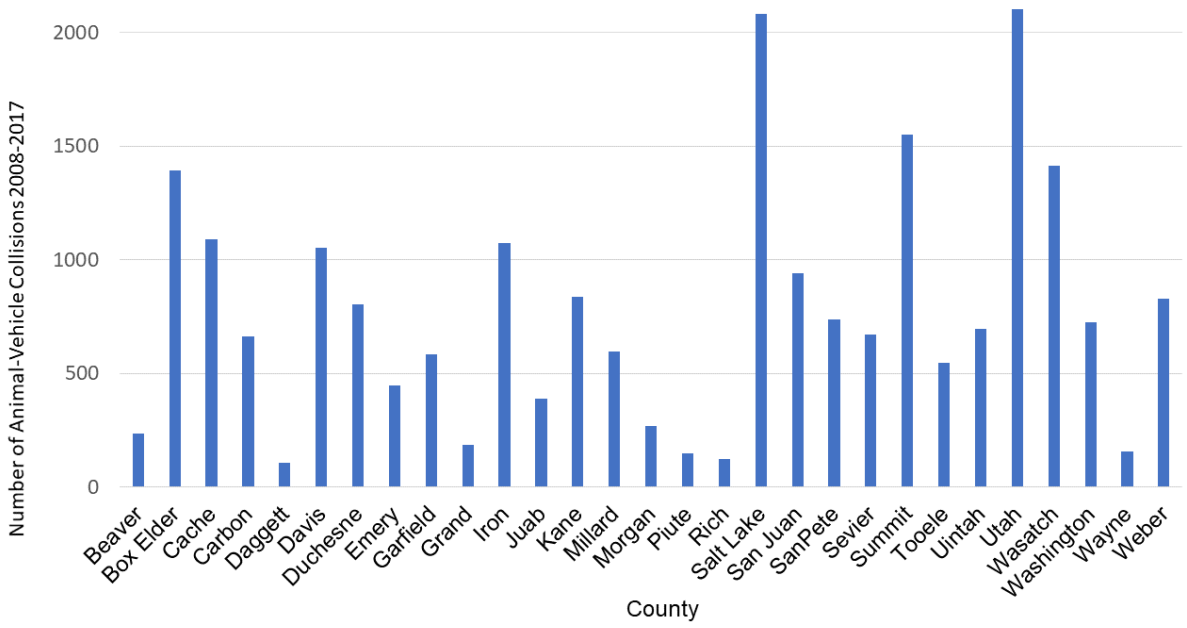


Figure 6. Number of Reported Animal-Vehicle Crashes for Each County in Utah, 2008 - 2017.

The top five counties for percentage of crashes that were animal related were, in order:

1. Piute, 51.8%
2. Kane, 46.1%
3. San Juan, 42.9%
4. Dagget, 42.3%
5. Garfield, 41.4%

These counties were displayed on a statewide county map (Figure 7).

Table 5. Number of Total Crashes, Animal-Vehicle Crashes, and Percentage of Crashes That Were Animal Related for Utah Counties, 2008 - 2017.

County	Total Crashes	Wildlife & Domestic Animal Crashes	Percentage of All Crashes That Are Animal Related
Beaver	2,437	332	13.6
Box Elder	11,371	1,838	16.2
Cache	18,705	1,369	7.3
Carbon	4,091	873	21.3
Daggett	352	149	42.3
Davis	47,558	1,245	2.6
Duchesne	4,431	1,122	25.3
Emery	2,631	563	21.4
Garfield	1,764	731	41.4
Grand	2,433	226	9.3
Iron	8,501	1,301	15.3
Juab	3,259	507	15.6
Kane	2,206	1,018	46.1
Millard	3,818	803	21.0
Morgan	1,782	321	18.0
Piute	328	170	51.8
Rich	770	179	23.2
Salt Lake	236,631	2,561	1.1
San Juan	2,716	1,166	42.9
Sanpete	3,039	877	28.9
Sevier	4,014	881	21.9
Summit	10,869	1,889	17.4
Tooele	9,766	705	7.2
Uintah	5,865	880	15.0
Utah	83,692	2,832	3.4
Wasatch	6,446	1,739	27.0
Washington	20,994	885	4.2
Wayne	665	216	32.5
Weber	40,103	979	2.4
Total	541,237	28,357*	5.2

** This number does not necessarily agree with total numbers in other tables due to inaccuracies in reporting crashes with wild and domestic animals. These numbers were derived from selecting the fields checked for wild and domestic animals in each year's crash database.*

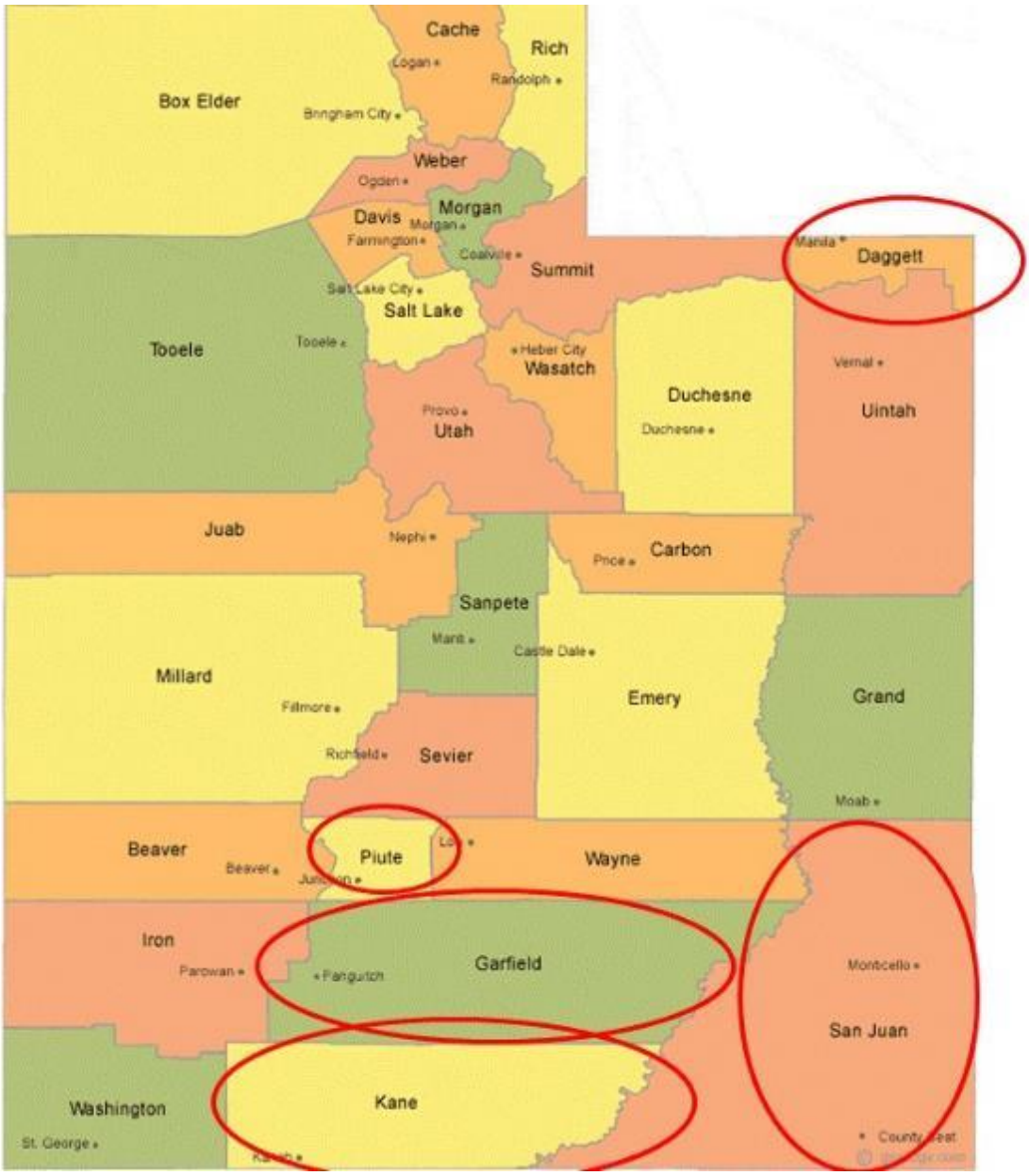


Figure 7. Top Five Utah Counties with the Greatest Percentage of All Crashes That Were Reported to Involve Wildlife or Domestic Animals, 2008 - 2017.

Each county's annual average number of animal-vehicle crashes was classified into a ranked class and mapped (Figure 8).

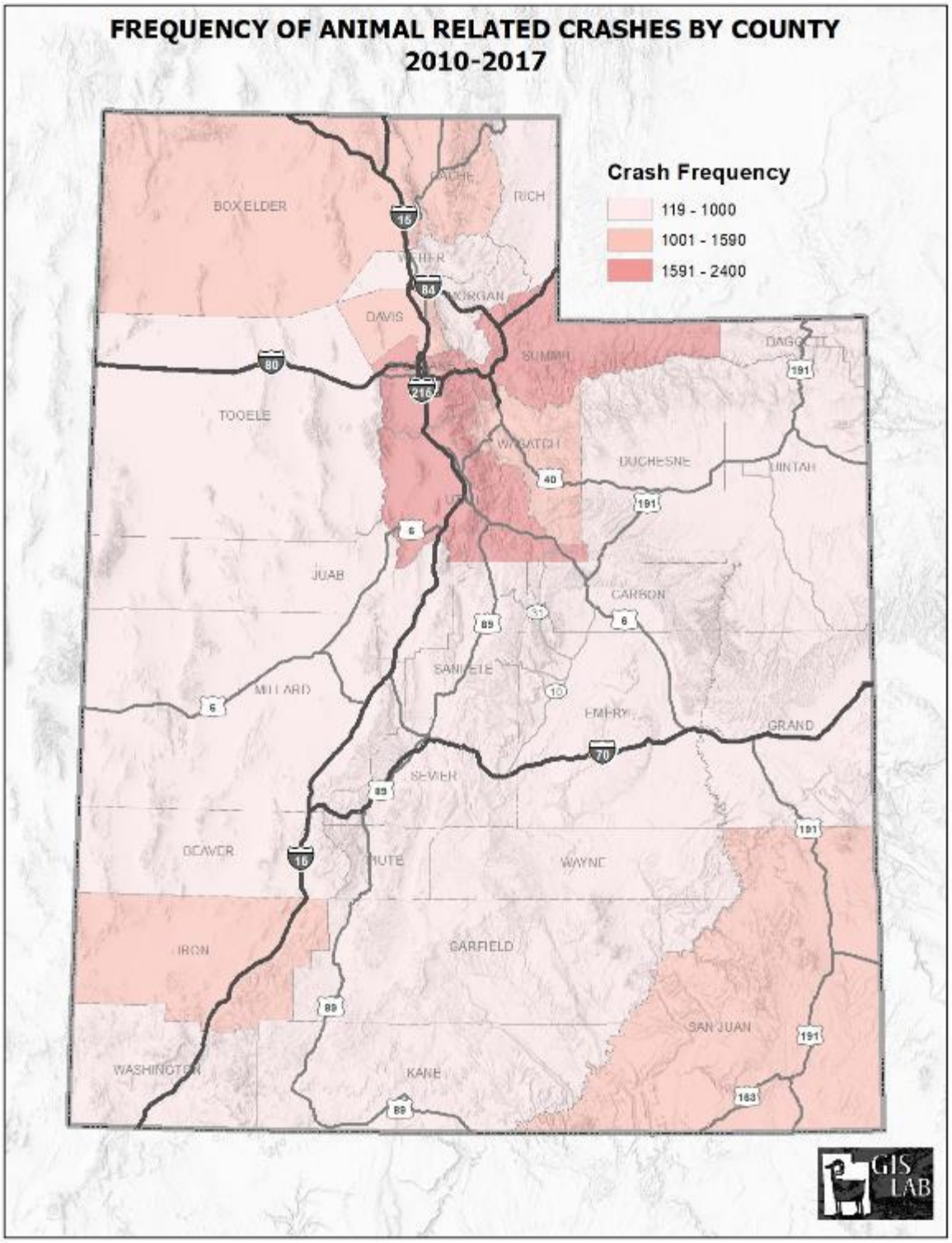


Figure 8. Frequency of Wildlife- and Domestic Animal-Vehicle Crashes (AVC) per County in Utah, Based on 2008 - 2017 Data.

3.2.3 Crash Numbers Per UDOT Region

For each UDOT Region, the total number of crashes, total animal-related crashes, the total percentage of crashes that were reported to involve an animal, and that region's percentage of the total number of animal-related crashes are reported for the period 2008 - 2017 in Table 6. Each UDOT region's number and share of all animal-vehicle crashes for the state of Utah were mapped and presented as a pie chart (Figure 9).

Table 6. Total Crashes and Animal-Vehicle Crashes by UDOT Region, and Percentage of Crashes That Are Animal Related for Each Region 2008 - 2017.

Utah Department of Transportation Region	Total Number of All Crashes from 2008 - 2017	Number of Animal-Related Crashes 2008 - 2017	Percentage of Region's Crashes That Were Animal Related	Region's Percentage Share of All Animal-Related Crashes for the State
Region 1 Ogden	120,289	5,931	4.9	21
Region 2 Salt Lake	257,266	5,155	2.0	18
Region 3 Orem	104,045	7,229	7.0	26
Region 4 Richfield	59,640	10,042	16.8	35
Totals	541,240	28,357	5.2	Not applicable

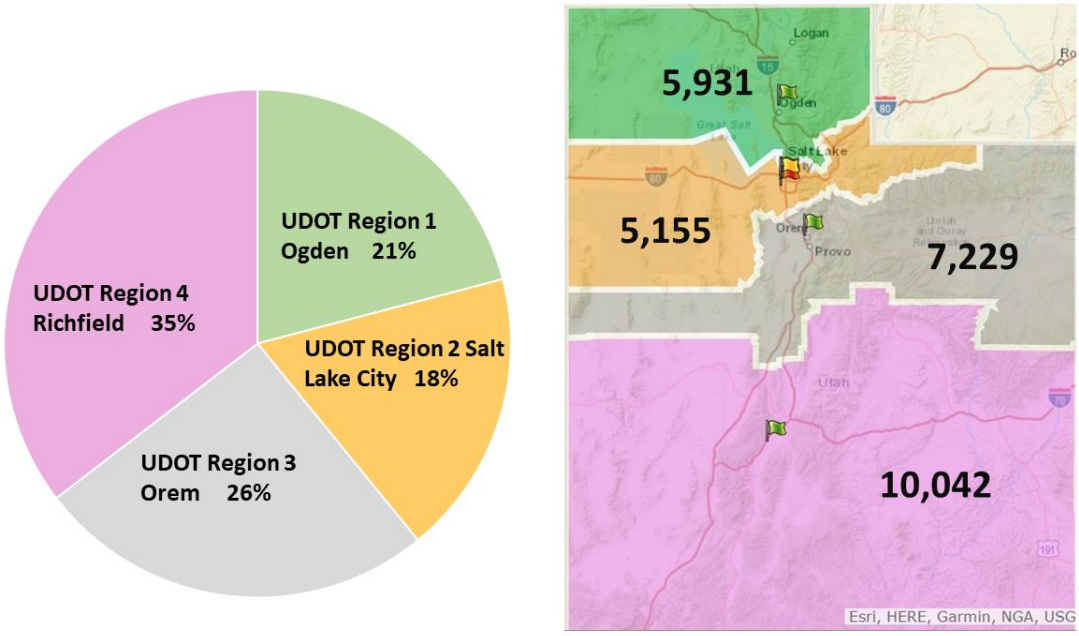


Figure 9. Each UDOT Region's Share of State's Total Animal-Vehicle Crashes (left) and Number of Animal-Vehicle Crashes per Region, 2008 - 2017 (right).

3.2.4 Crash Severity and Costs

For each year from 2008 - 2017, the number of reported crashes with wildlife and domestic animals were reported and tallied for each type of crash severity: Property Damage Only, Possible Injury, Minor Injury, Potential Serious Injury, and Human Fatality (Table 7). In Utah each year, on average, there were 2,851 Property-Damage-Only crashes with animals, 255 crashes where there were injuries and potential injuries, and 2.9 human fatality crashes.

Table 7. Number of Reported Wildlife and Domestic Animal-Vehicle Crashes of Each Crash Severity Type, Each Year in Utah from 2008 - 2017. PDO=Property Damage Only. Possible, Minor, and Serious Refer to Type of Injury.

	Types of Crashes					
Animal Type/Year	**Property Damage Only**	**Possible**	**Minor**	**Serious**	**Fatal**	**Totals**
Wildlife 2008	2,292	87	67	9	2	2,457
Domestic 2008	358	36	23	2	1	420
Totals 2008	2,650	123	90	11	3	2,877
Wildlife 2009	2343	104	63	13	4	2,527
Domestic 2009	320	33	26	3	0	382
Totals 2009	2,663	137	89	16	4	2,909
Wildlife 2010	2,329	110	82	15	5	2,541
Domestic 2010	272	26	23	5	1	327
Totals 2010	2,601	136	105	20	6	2,868
Wildlife 2011	2,250	100	88	19	1	2,458
Domestic 2011	261	24	22	2	1	310
Totals 2011	2,511	124	110	21	2	2,768
Wildlife 2012	2,414	109	84	18	1	2,626
Domestic 2012	311	15	25	6	0	357
Totals 2012	2,725	124	109	24	1	2,983
Wildlife 2013	2,580	90	66	8	2	2,746
Domestic 2013	298	22	26	6	0	352
Totals 2013	2,878	112	92	14	2	3,098
Wildlife 2014	2,584	103	81	11	2	2,781
Domestic 2014	267	27	16	5	0	315
Totals 2014	2,851	130	97	16	2	3,096
Wildlife 2015	3,001	127	81	19	1	3,229
Domestic 2015	273	21	17	6	2	319
Totals 2015	3,274	148	98	25	3	3,548
Wildlife 2016	2,951	150	85	12	0	3,198
Domestic 2016	330	36	28	1	2	397
Totals 2016	3,281	186	113	13	2	3,595
Wildlife 2017	2,762	123	88	18	2	2,993
Domestic 2017	317	25	13	3	2	360
Totals 2017	3,079	148	101	21	4	3,353
Total Wildlife	25,506	1,103	785	142	20	27,556
Total Domestic	3,007	265	219	39	9	3,539
10 year Total for All Animals	28,513	1,368	1,004	181	29	31,095
Annual Wildlife Average	2,551	110	79	14	2.0	2,756
Annual Domestic Average	301	27	22	4	0.9	355
Annual Average All Animals	2,851	137	100	18	2.9	3,110

Each year in Utah there are on average 18 serious injury crashes and 3 fatal crashes with animals.

The WVC serious injury and fatal crashes were selected for each year of 2008 – 2017. These 162 crash locations (of which 20 were fatalities) were mapped (Figure 10).

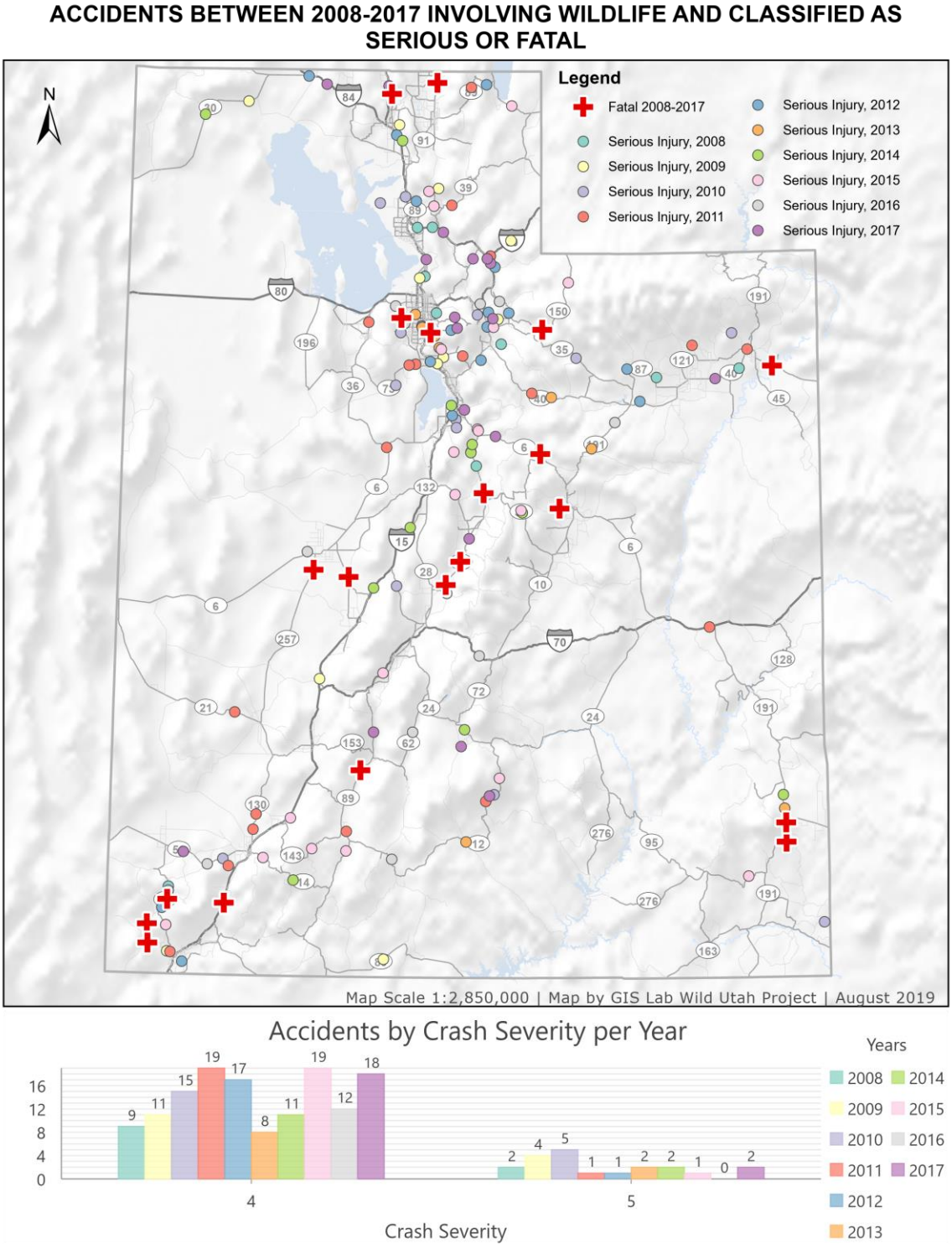


Figure 10. All Reported Wildlife-Vehicle Collision Reported Crashes That Involved a Serious Human Injury or Fatality, 2008 - 2017.

Crash severity of 4 = Serious Injury Crashes, Crash Severity of 5 = Fatal Crashes.

The 2019 UDOT average estimated cost for Property-Damage-Only Crashes (PDO), Possible Injury Crashes, Minor Injury Crashes, Potential-Serious-Injury Crashes, and Fatal Crashes were applied to the annual average value for each of these crash types for wildlife crashes, domestic animal crashes, and animal crashes in total (Table 8).

Table 8. UDOT Average Annual Cost of Wildlife-Vehicle Crashes, Domestic Animal-Vehicle Crashes, and All Animal-Vehicle Crashes in Utah, from 2008 – 2017, Based on 2019 Crash Values.

Type of Crash and Costs	Property Damage Only	Possible Injury	Minor Injury	Serious Injury	Fatality	Total Average
Average Annual Number of Wildlife Crashes	2,551	110	79	14	2	2,756
Average Annual Number of Domestic Animal Crashes	301	27	22	4	0.9	355
UDOT 2019 Cost per Crash	$12,300	$131,700	$233,500	$2,707,000	$2,707,000	
Wildlife Crash Costs	$31,377,300	$14,487,000	$18,446,500	$37,898,000	$5,414,000	$107,622,800
Domestic Animal Crash Costs	$3,702,300	$3,555,900	$5,137,000	$10,828,000	$2,436,300	$25,659,500
Average Annual Cost All Animal Crashes Total						$133,282,300

When UDOT 2019 crash values are applied to wildlife-vehicle crashes (2008 – 2017), the cost to the Utah public is over $107 million annually. When domestic animal-related crashes are added, the total cost of animal-vehicle crashes to the Utah public is over $133 million annually.

The Federal Highway Administration (FHWA) published national crash values for the five crash types in 2018 (Harmon et al., 2018). These were meant to establish national standards to allow for comparisons among states and nationally. These values were applied to the Utah wild and domestic animal reported crashes, Table 9.

Table 9. FHWA Average Annual Cost of Wildlife-Vehicle Crashes Based on Harmon et al., 2018, Domestic Animal-Vehicle Crashes, and All Animal-Vehicle Crashes in Utah, from 2008 - 2017.

Type of Crash and Costs	Property Damage Only	Possible Injury	Minor Injury	Serious Injury	Fatality	Total Average	
Average Annual Number of Wildlife Crashes	2,551	110	79	14	2	2,756	
Average Annual Number of Domestic Crashes	301	27	22	4	0.9	355	
FHWA 2018 Cost per Crash	$11,900	$125,600	$198,500	$ 655,000	$11,295,400		
Wildlife Crash Costs	$30,356,900	$13,816,000	$ 15,681,500	$ 9,170,000	$ 22,590,800	$91,615,200	
Domestic Animal Crash Costs	$3,581,900	$ 3,391,200	$ 4,367,000	$ 2,620,000	$ 10,165,860	$24,125,960	
Average Annual Cost All Animal Crashes Total						**$115,741,160**	

When FHWA 2018 crash values are applied to wildlife-vehicle crashes (2008 – 2017), the cost to the Utah public is over $91 million annually. When domestic animal-related crashes are added, the total cost of animal-vehicle crashes to the Utah public is over $115 million annually.

During the development of this research project, the PI, Dr. Cramer, compiled western states' wildlife-vehicle crash costs for an FHWA Pooled fund study led by the Nevada Department of Transportation. The preliminary results of that study are presented here to compare Utah's cost of crashes with wildlife with other western states. Dr. Cramer contacted department of transportation traffic safety engineers and environmental staff to ask for the following from each of the 15 states: From 2013 – 2017, the annual crashes for each year, the total wildlife-related crashes for each of those years, the number of wildlife-related crashes for each of the five different crash types (Property Damage Only to Fatal) for the five years, and the cost each transportation agency places on those five types of crashes. The data, percentages, and costs are presented below (Table 10), using the FHWA 2018 costs for each crash type (Harmon et al., 2018). The data were collected and tabulated using the same methods used in the Utah FHWA calculations.

In the 15 western states where crash data were analyzed, Utah had the sixth largest number of reported crashes with wild animals, ranked seventh in the percentage of crashes that were wildlife related, and seventh for total cost of wildlife crashes.

Table 10. The Average Annual Number of, Percentage of Total, and Cost of Wildlife-Vehicle Crashes in 15 Western States Based on 2013 - 2017 Crash Data.

State	Annual Average Number of Total Crashes	Annual Average Number of Wildlife-Vehicle Crashes	Percentage of Crashes That Are Wildlife Related	Annual Average Cost of Wildlife-Related Crashes Based on FHWA Costs
Alaska	11,458	696	6.1	$47,238,680
Arizona	117,909	2,761	1.7	$125,190,140
California	171,663	1,568	0.7	$135,458,960
Colorado	116,616	2,672	3.2	$129,887,660
Idaho	24,105	1,055	8.6	$77,598,800
Montana	22,241	2,989	12.4	$107,880,760
Nevada	47,406	4,495	1.0	$53,034,020
New Mexico	42,352	3,782	2.5	$32,656,680
North Dakota	16,229	2,068	12.7	$68,898,880
Oregon	23,321	789	3.4	$46,852,460
South Dakota	17,549	1,190	25.6	$84,208,460
Texas	561,031	463	0.7	$342,547,260
Utah	58,222	2,989*	5.1	$82,720,480*
Washington	51,446	4,018	3.0	$45,939,360
Wyoming	14,151	3,038	18.9	$64,000,540

** Utah value in this table based on 2013 - 2017 crash data, not the 2008 - 2017 data used in previous tables.*

3.2.5 Utah Crash Values with the Value of Wildlife Included

The crash values in the above sections do not include the value of the animals lost to these crashes. The Colorado Department of Transportation (CDOT), in conjunction with the CDOT economist, developed a benefit-cost analysis for evaluating the cost of crashes with wildlife and potential mitigation solutions (Kintsch et al., 2019). The research placed a monetized value of a single deer killed at $2,061, and the cost of an elk killed at $2,392. The Utah annual average number of reported crashes with wild animals is 2,756. If this is multiplied by the value of one mule deer per crash, $2,061, the value of all the mule deer killed annually

was on average $5,680,116. When these values are added to the crash costs, the total value of WVC and mule deer lost in those crashes is $113,302,916. This value does not include values for other wildlife species such as elk, moose, pronghorn antelope, or bighorn sheep. It also does not take into account the 5.26 more wild animal carcasses found on the side of Utah highways than are reported in the crash data (Olson, 2013). The unaccounted-for animals that were not included in the crash analysis would increase the total of wildlife value by 5.26, or $29,877,410.

When UDOT 2019 crash values are applied to wildlife-vehicle crashes (2008 – 2017), and the value of the mule deer killed in those crashes are taken into account, the cost to the Utah public is over $113 million annually. When domestic animal-related crashes are added, the total cost of animal-vehicle crashes to the Utah public is over $138 million annually.

3.2.6 Crashes with Wildlife Species as Derived from Narratives

The query of the narratives of the crash records from 2010 - 2017 for the 15 words used to describe wildlife and domestic animals resulted in data points for 21,395 crashes out of a total of 524,054 crashes (4.1 percent). These crashes were mapped, Figure 11.

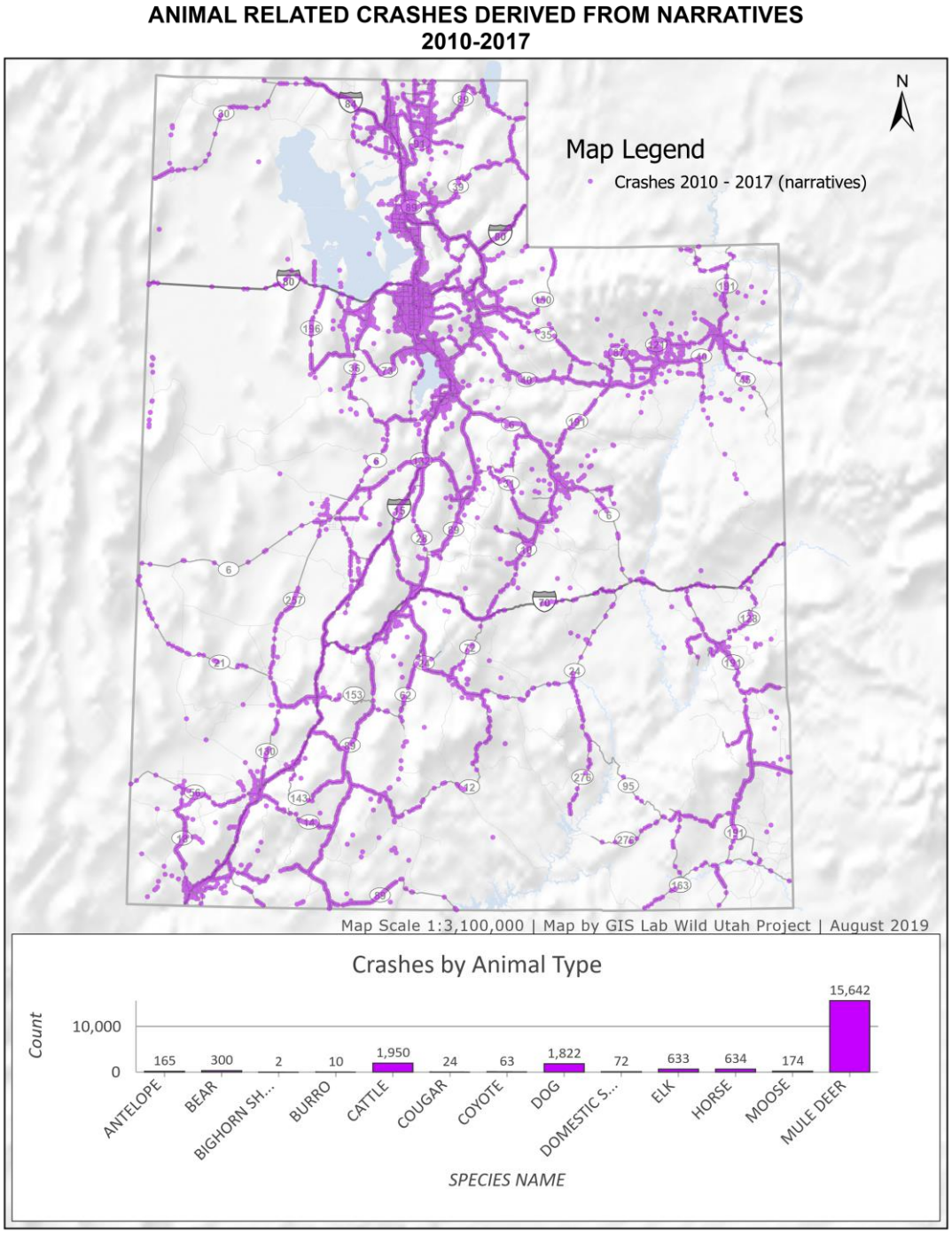


Figure 11. Crashes Where Queries of Narratives Found One of the 15 Animal Names Used, UDOT Crash Data 2010 - 2017.

The resultant map layer allowed the research team to visualize the resulting hotspots from narrative queries. Urban areas' crash hotspots most likely have a greater portion of crashes with

animal words other than deer that actually defined names of human-created entities, such as roads and businesses that were near the crash location, than the more rural areas. The greatest number of crashes reported with species' names were with deer, which may reflect true hotspots in the urban-wildland interface. However, when the species' narrative maps were created, (Appendix B), the rarer species such as black bear also had heavy representation in areas where bear would have a difficult time surviving, such as the Wasatch Front interface.

After these steps were completed and maps were compiled, UDOT updated its database so users could add an additional filter that queried the database for "animal related" to significantly reduce the number of street names and businesses included in narrative queries of animal names. In future database queries, this added filter can be used to narrow down the number of false positives of animal names that involved names of places and streets in addition to actual animals involved. The update came after the task was completed for this research.

The preliminary heat map of crashes with animal names in the narratives is presented in Figure 12. The map provides a quick view of areas with dense and sparse animal-related crashes.

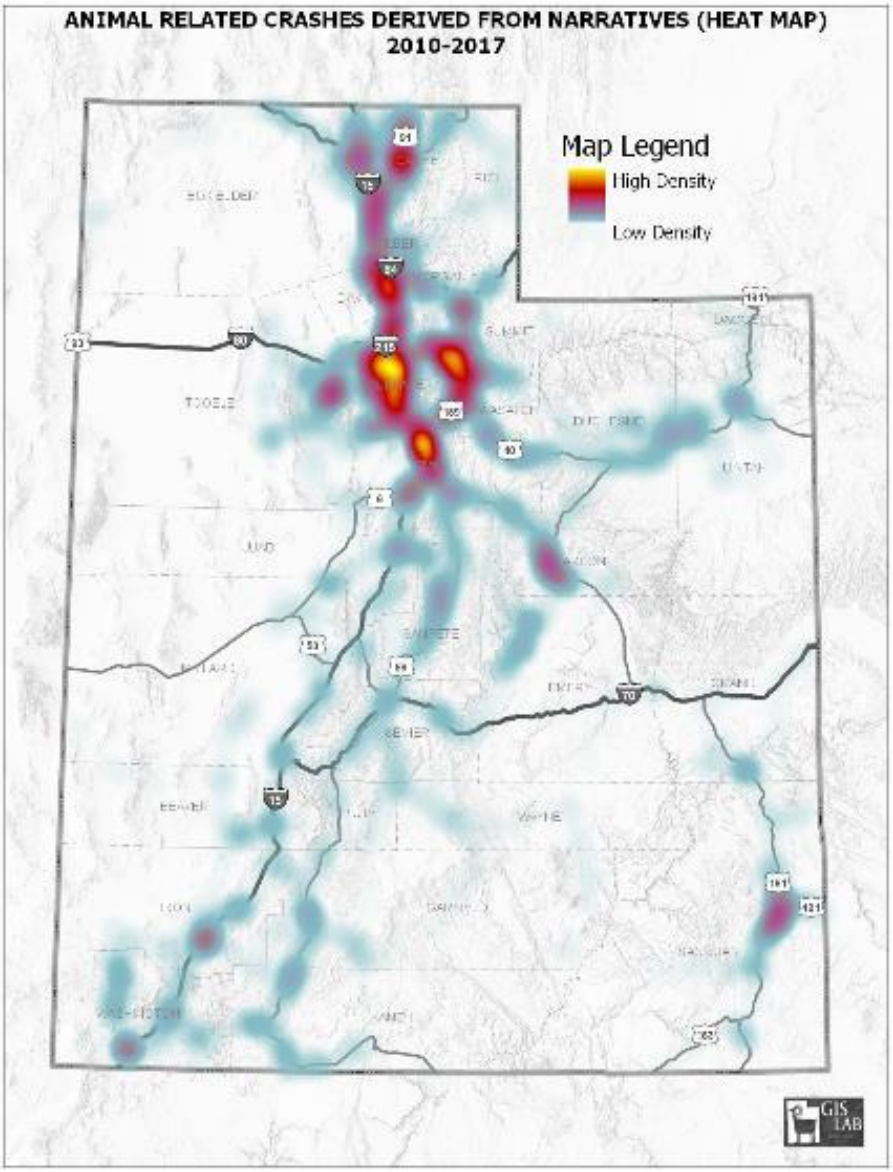


Figure 12. Heat Map of the Density of Crashes with Animal Names Mentioned in the Narratives Describing the Crash, 2010 - 2017.

3.2.7 Carcass Data

The number of carcasses of the most-often-collected mammal and bird species are presented below (Figure 13) for an early iteration of carcass analysis, when a limited number of carcass records was available.

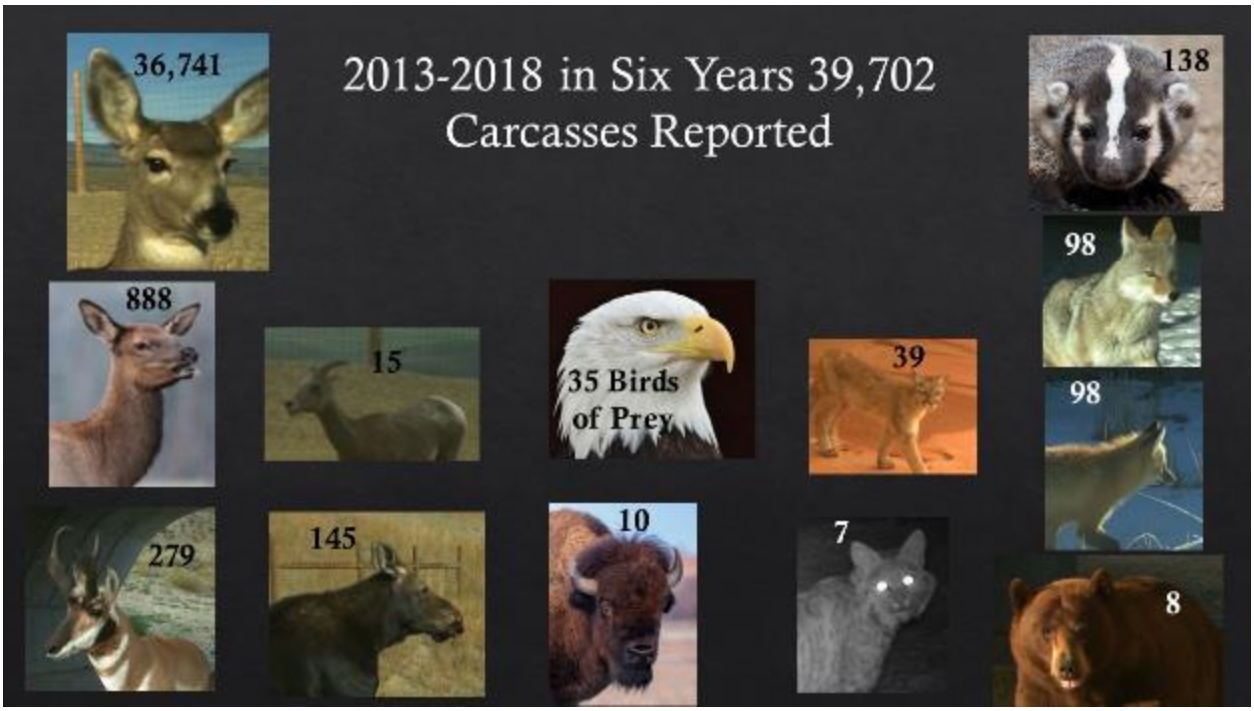


Figure 13. Utah Species of Wildlife Most Recorded in the Utah Wildlife-Vehicle Collision Carcass Database, 2013 - 2018.

Maps resulting from the crash narrative query were created for each species, and were combined with the carcass locations for those species from the 2010 - 2018 carcass database. (See Appendix B for these species' maps.)

3.2.8 Mule Deer Densities and Annual Average Daily Traffic Analysis

The mule deer densities of the dozens of wildlife management units in Utah were mapped by the researchers (Figure 14). The UDOT AADT data for Utah's major roads were also mapped in this project, and the two maps were brought together for viewing of the potential interplay of mule deer densities and traffic volumes (Figure 15). The areas in the state with higher traffic volumes (highways are depicted in darker shades of red), that also coincide with higher mule deer numbers (polygons of darker colors), can be compared in later maps in this report that demonstrate that the same areas have many of the top WVC hotspots.

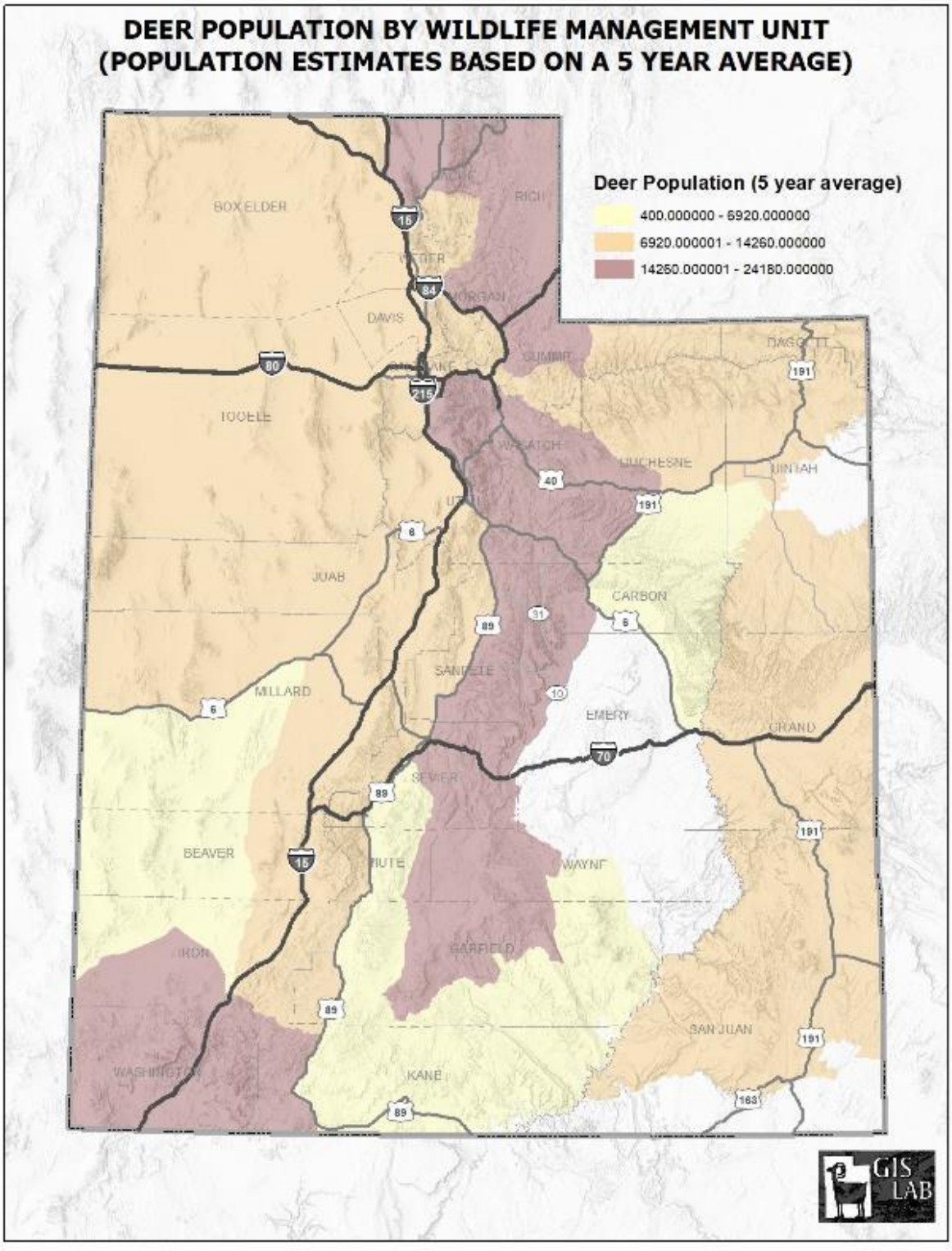


Figure 14. Mule Deer Estimated Densities in UDWR Mule Deer Management Units, 2017.

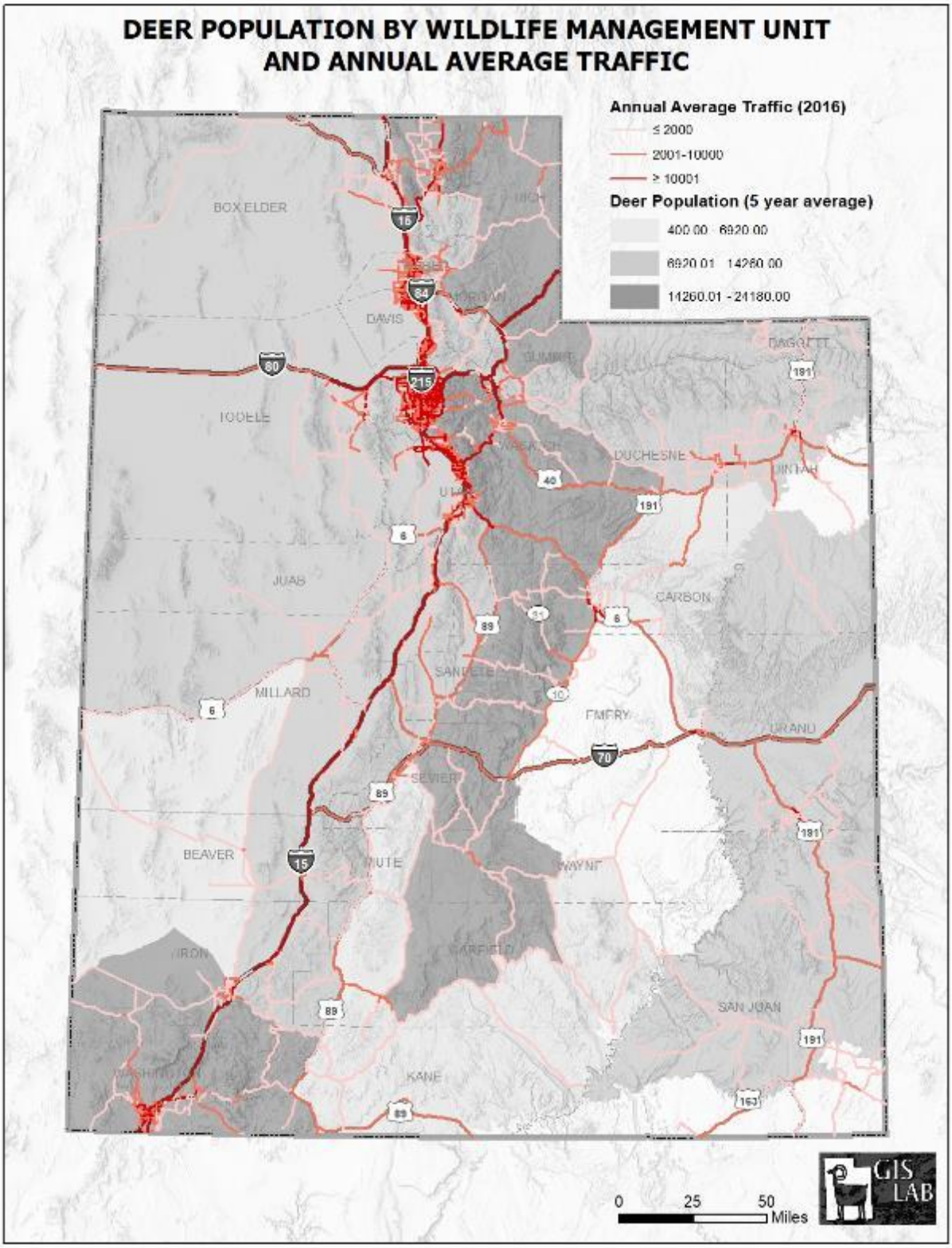


Figure 15. Mule Deer Densities, Classes of UDWR Mule Deer Management Units, and Average Annual Daily Traffic Classes for UDOT-Administered Roads.

3.2.9 Deer Densities Over Time

The researchers obtained UDWR estimates for mule deer numbers overall in Utah, and plotted the annual number (Figure 16). Mule deer numbers across Utah began increasing about 2011. The increase from 2011 to 2017 was approximately 33 percent. This could help explain why the road-wildlife mitigation projects Utah built have not decreased the statewide wildlife-vehicle crashes over the past six years.

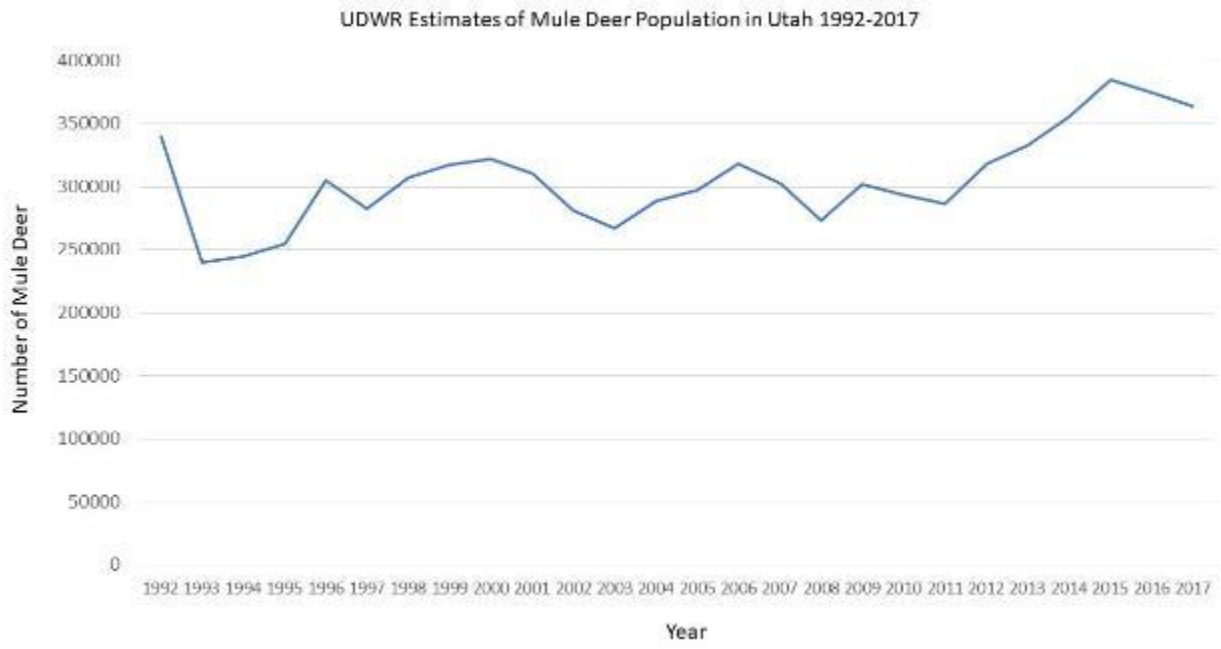


Figure 16. Mule Deer Estimated Numbers Across Utah, 1992-2017, as Estimated by UDWR.

The increase in WVC could also be influenced by the growing human population. From 2008 to 2017, the Utah population of humans increased by 13.9 percent, adding 378,000 people (U.S. Census Bureau, 2019). This is also related to vehicle miles traveled (VMT). From 2008 to 2017, UDOT estimated VMT increased from 25,883,627,040 to 31,510,020,465, an increase of 21.7 percent (Utah Department of Transportation, 2019). The sheer numbers of animals increased as the number of humans and vehicle miles increased, thus placing drivers and mule deer in greater risk of conflict.

3.3 Modeling Data - the Optimized Hotspot Analyses (Task 2)

The OHSA was calculated for different types of crashes, carcasses, and roads in Utah. The list below summarizes the presentation of these analyses in this section.

- Animal-vehicle crash hotspots on Utah highways for 90, 95 and 99 percent confidence intervals.
- The 90 to 99 percent confidence intervals crash hotspots and top 25 animal-vehicle crash hotspots on highways - the Master Map.
- The top 25 animal-vehicle crash hotspots on Utah highways.
- The 90 to 99 Percent confidence intervals hotspots and top 25 Animal-vehicle crash hotspots on Utah local roads.
- The top 25 animal-vehicle crash hotspots for Utah highways and top 25 crash hotspots on local roads.
- The top 25 WVC hotspots on Utah highways.
- The Top 25 WVC hotspots on Utah local roads.
- The state's top 25 animal-vehicle crash hotspots on highways in each of UDOT's regions.
- The top 25 WVC hotspots on highways in UDWR regions.
- The top 25 WVC hotspots on highways mapped over UDWR habitat maps for mule deer, elk, and pronghorn.
- The top 25 domestic animal-vehicle crash hotspots on highways and UDOT regions.
- The top 25 domestic animal-vehicle crash hotspots on local roads and UDOT regions.
- The top 25 domestic animal-vehicle crash hotspots on highways and UDWR regions.
- The top 25 domestic animal-vehicle crash hotspots on local roads and UDWR regions.
- The top 25 wild animal carcass hotspots on highways mapped over UDWR habitat maps for mule deer, elk, and pronghorn.
- The top 25 ungulate carcass hotspots on Utah highways mapped over UDWR mule deer, elk, and pronghorn habitat maps.
- The top 25 WVC hotspots map was laid over the UDWR Brownian Bridge Model of the mule deer collared in the Paunsaugunt herd map.
- The top 25 WVC hotspots on highways laid over the UDWR habitat maps for multiple species.
- The top 25 wild ungulate carcass hotspots on highways in relation to UDWR habitat maps for various wild animal species.

3.3.1 Animal-Vehicle Crash Hotspots on Utah Highways for the 90, 95, and 99 Confidence Intervals

The hotspot analysis examined Utah highways for clusters of animal-related crashes. The OHSA Getis-Ord Gi* modeling produced segments of highway with clusters of hotspots with 90, 95, and 99 percent confidence intervals. The higher the confidence interval, the more certain we are that the model results identified actual hotspots. These three confidence level hotspot segments were mapped, Figure 17.

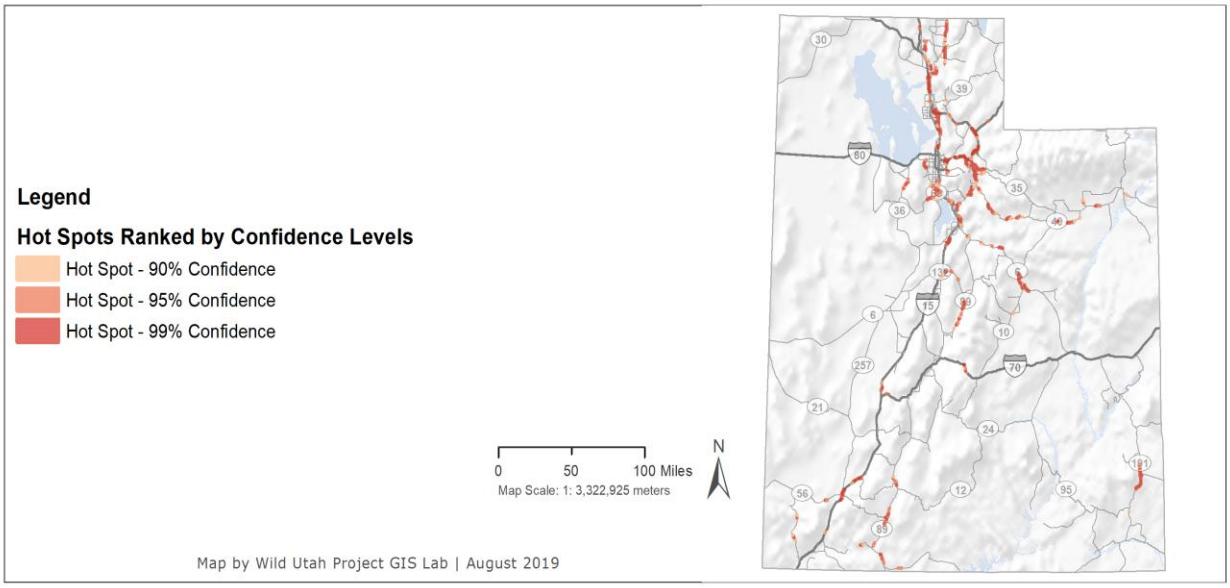


Figure 17. Utah Animal-Vehicle Crash Hotspots on Highways within the 90, 95, and 99 Percent Confidence Intervals, Based on 2008 - 2017 Crash Data.

3.3.2 The 90 to 99 Percent Confidence Interval Crash Hotspots and Top 25 Animal-Vehicle Crash Hotspots on Utah Highways

The hotspots modeling identified the top 25 highest ranked hotspots on highways based on the number of animal-vehicle crashes per mile per year on Utah highways. These top 25 hotspots were ranked, and the information was mapped over the 90 to 99 percent confidence interval hotspots map, Figure 18. This became the master map for the research.

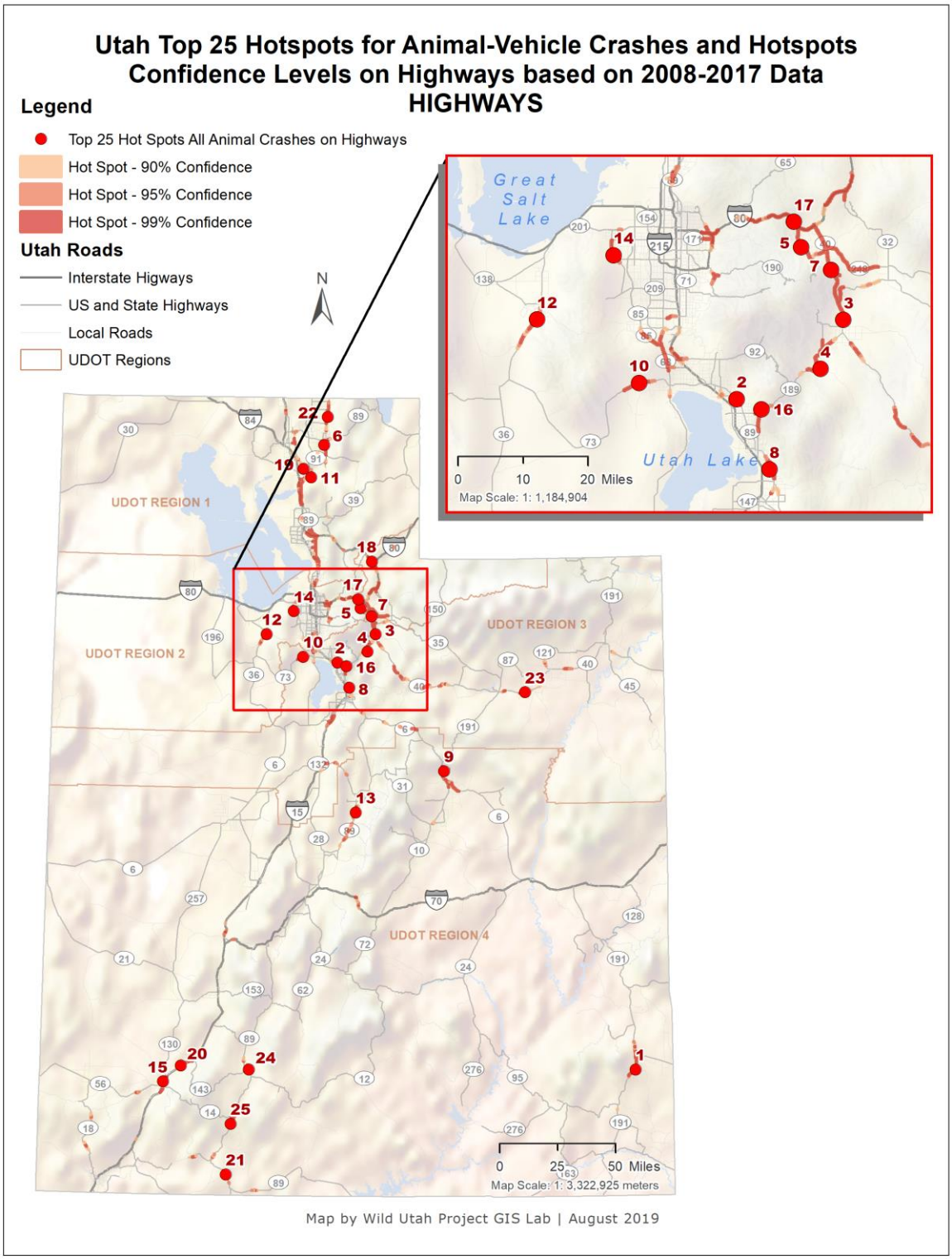


Figure 18. Top 25 Animal-Vehicle Crash Hotspots and all 90 to 99 Percent Confidence Interval Hotspots on Utah Highways Based on 2008 - 2017 Crash Data.

The top 25 animal-vehicle crash hotspots on highways are described in Table 11, along with the UDOT and UDWR region where they occurred. The top seven hotspots on highways that were less than two miles in length and still had at least 2.40 reported animal-vehicle crashes per mile per year, and which were originally in the top 25 hotspots prior to the two-mile minimum requirement, are presented in Table 12, below. Names of hotspots in Table 11 are hyperlinked to Table 15 where the potential species involved in crashes and recommended solutions are described.

Table 11. Utah's Top 25 Animal-Vehicle Crash Hotspots on Highways, Based on 2008 - 2017 Data, Length, and Crashes per Mile per Year, and UDOT and UDWR Region.

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
1	US 191 North and South of Monticello	15.00	3.50	Region 4	SOUTHEASTERN
2	US 89/North State St. Lindon	2.08	3.12	Region 3	CENTRAL
3	US 40 Heber North to Jordanelle Reservoir	2.50	3.08	Region 3	CENTRAL
4	US 189 Deer Creek State Park	10.00	2.99	Region 3	CENTRAL
5	SR 224 Kimball Jct.-SR 248 to Park City	6.00	2.97	Region 2	CENTRAL
6	SR 165-US 91 Hyrum and Wellsville to Logan	7.73	2.96	Region 1	NORTHERN
7	US 40 - SR 248 Jordanelle Reservoir	28.70	2.92	Region 2	CENTRAL
8	US 89 -West 1400 North Springville to 1140 South Street Provo	5.53	2.89	Region 3	CENTRAL
9	US 6 Helper	8.92	2.88	Region 4	SOUTHEASTERN
10	SR 73 Eagle Mountain	5.00	2.80	Region 3	CENTRAL
11	US 91 Brigham City to Sardine Summit	6.50	2.75	Region 1	NORTHERN
12	SR 36 Old Lincoln Highway South Main St. - Tooele	4.50	2.69	Region 2	CENTRAL
13	US 89 North of Ephraim Sanpete Valley	7.20	2.67	Region 4	CENTRAL
14	SR 111- West Valley Highway Magna South to West 5400 South-SR 173	4.50	2.62	Region 2	CENTRAL
15	I-15 – SR 130 Cedar City North to 3600 North	8.50	2.54	Region 4	SOUTHERN
16	US 189 North University Ave through E Provo-Canyon Road Orem	4.61	2.47	Region 3	CENTRAL
17	I-80 Parley’s Summit to US 40	11.10	2.36	Region 2	NORTHERN

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
18	I-80 and I-84 Echo Junction	6.93	2.32	Region 2	NORTHERN
19	SR 38 North Brigham City Kotter Canyon to Dry Canyon	2.50	2.32	Region 1	NORTHERN
20	I-15 at Summit	2.50	2.32	Region 4	SOUTHERN
21	US 89 North Kanab – Three Lakes Canyon	2.50	2.32	Region 4	SOUTHERN
22	US 91 Smithfield-Richfield-High Creek	10.32	2.32	Region 1	NORTHERN
23	US 40 Bridgeland – Antelope Creek	4.50	2.31	Region 3	NORTHEASTERN
24	US 89 Panguitch - Casto Canyon Road to Roller Mill Hill Drive	3.00	2.17	Region 4	SOUTHERN
25	US 89 North Glendale – Dixie National Forest	2.50	2.16	Region 4	SOUTHERN

Table 12. Top Seven Animal-Vehicle Crash Hotspots on Segments of Utah Highways Less Than Two Miles in Length, Based on 2008 - 2017 Crash Data.

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
1	Jordan River and W 12300 South	1.5	3.4	Region 2	CENTRAL
2	I-15 Malad Valley-Little Canyon	1.5	2.7	Region 1	NORTHERN
3	US 191 and East Canyon Road North of Monticello	0.5	2.6	Region 4	SOUTHEASTERN
4	SR 9 East of Zion Buffalo Ranch	1.5	2.6	Region 4	SOUTHERN
5	I-84 Morgan at E 400 North	0.5	2.6	Region 1	NORTHERN
6	County Road 135 Pleasant Grove Blvd, Lindon	0.3	2.5	Region 3	CENTRAL
7	US 91 Hyde Park	0.5	2.4	Region 1	NORTHERN

3.3.3 Top 25 Animal-Vehicle Crash Hotspots on Utah Highways

The top 25 animal-vehicle crash hotspots on Utah highways were placed on a map without the lower ranked hotspot segments for ease of viewing, Figure 19.

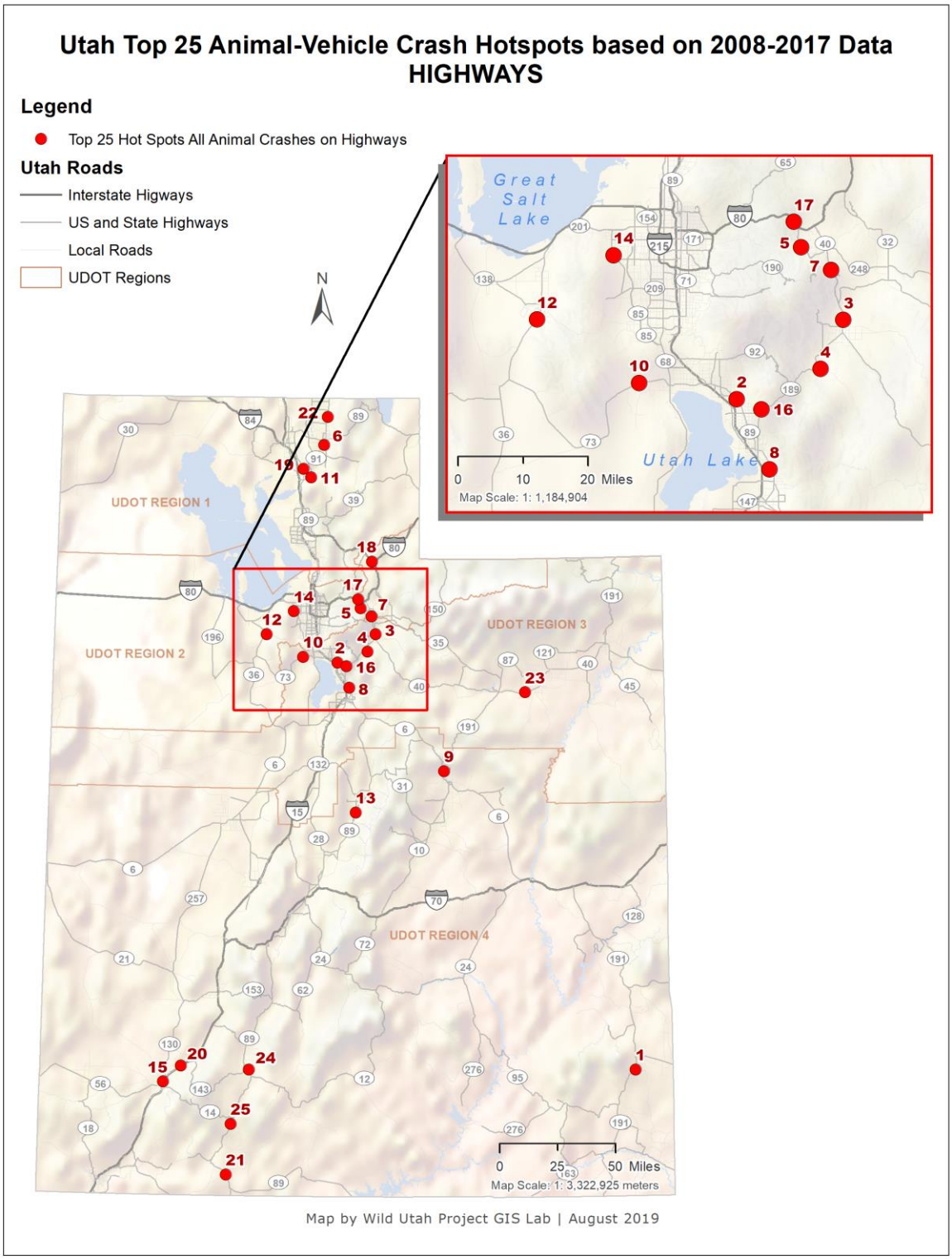


Figure 19. The Top 25 Animal-Vehicle Crash Hotspots on Utah Highways Based on 2008 - 2017 Crash Data.

3.3.4 The 90 to 99 Percent Confidence Interval Hotspots and Top 25 Animal-Vehicle Crash Hotspots on Utah Local Roads

The 90 to 99 percent confidence interval crash hotspots on the local (Federal Aid) roads were calculated for animal-vehicle crash hotspots. These were mapped along with the top 25 crash hotspots on these roads, Figure 20. Table 13 presents all top 25 hotspots with official names, roads, lengths, crashes per mile per year, and UDOT and UDWR regions where they are located.

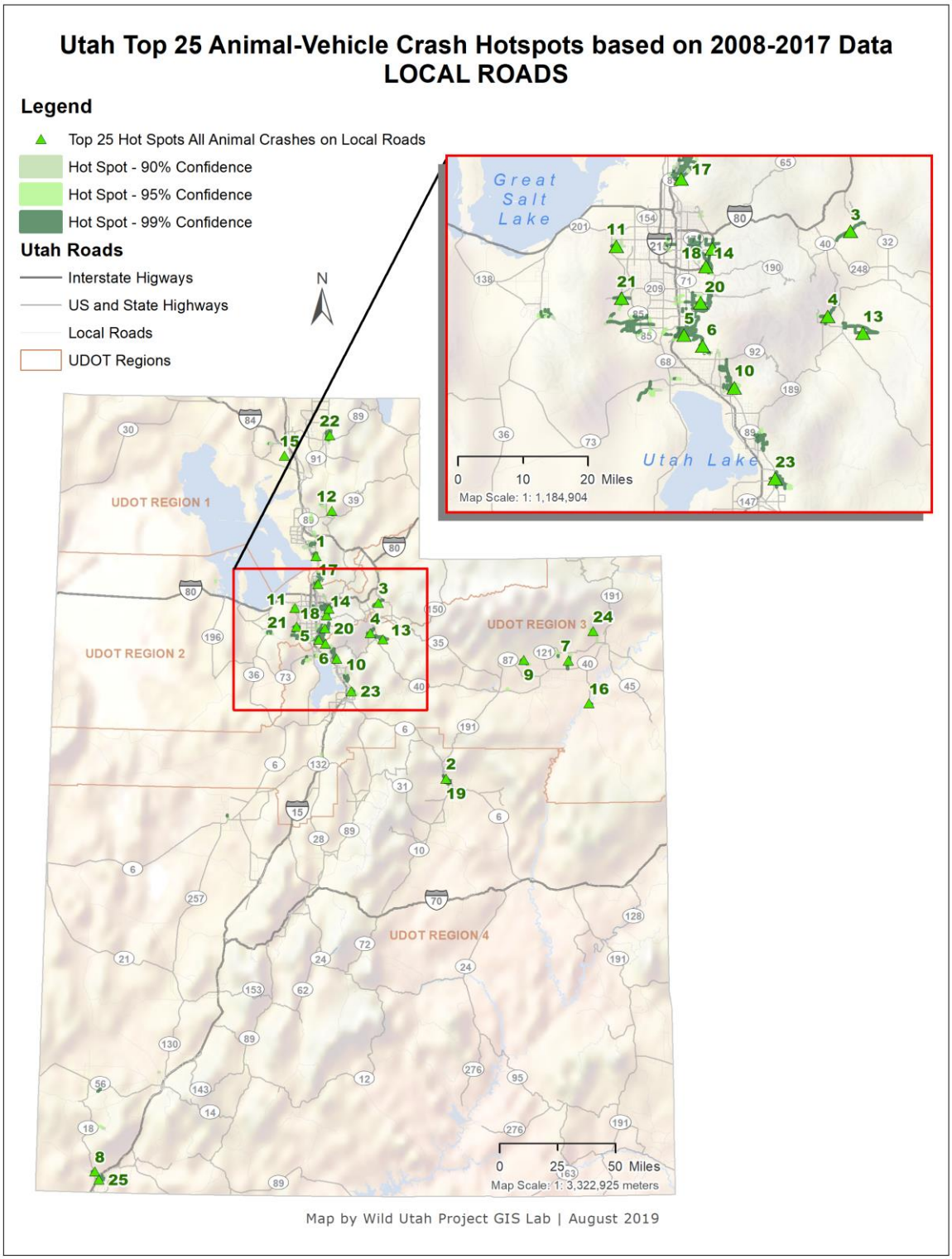


Figure 20. The 90 to 99 Percent Confidence Interval Hotspots and Top 25 Animal-Vehicle Crash Hotspots on Utah Local Roads Based on 2008 - 2017 Data.

Table 13. The Top 25 Animal-Vehicle Crash Hotspots on Local Utah Roads Based on 2008 - 2017 Data, Length and Crashes per Mile, and UDOT and UDWR Regions.

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
1	North Main Street & South Mountain Road - Farmington	2.43	1.19	Region 1	NORTHERN
2	North Carbonville Road - Carbonville	3.46	1.04	Region 4	SOUTHEASTERN
3	Browns Canyon Road - Kamas	5.44	0.86	Region 1	NORTHERN
4	River Road - Midway	5.50	0.80	Region 3	CENTRAL
5	East Traverse Ridge Road - Draper	33.31	0.67	Region 2	CENTRAL
6	Suncrest Drive - Draper	3.51	0.66	Region 2	CENTRAL
7	North Lapoint Highway - North Duchesne	7.00	0.64	Region 3	NORTHEASTERN
8	Red Hills Parkway – St. George	2.50	0.60	Region 4	SOUTHERN
9	CR 142-Bluebell Road, - NW of Roosevelt	4.04	0.59	Region 3	NORTHEASTERN
10	Grove Creek Drive - Pleasant Grove	10.34	0.58	Region 3	CENTRAL
11	W 4100 South -Magna	2.50	0.56	Region 2	CENTRAL
12	N 7100 - Huntsville-Pineview Reservoir	2.50	0.52	Region 1	NORTHERN
13	E 1200 South - Heber City	10.06	0.52	Region 3	CENTRAL
14	Big Cottonwood Road & Holladay Blvd. - Holladay-Cottonwood	2.20	0.50	Region 2	CENTRAL
15	Iowa String Road 6400 N to 8000 N - Honeyville	2.01	0.50	Region 1	NORTHERN
16	West Chipeta Grove Road & South Seep Ridge Road – Uinta Basin	2.84	0.49	Region 3	NORTHEASTERN
17	North Salt Lake – Eaglewood Golf Course	6.70	0.48	Region 1	NORTHERN
18	Oak View Drive - Holladay	9.63	0.44	Region 2	CENTRAL
19	N Keller Lane - Carbonville	4.01	0.42	Region 4	SOUTHEASTERN
20	East Dimple Dell Road - Sandy	8.07	0.42	Region 2	CENTRAL
21	111 Bacchus Highway and Bingham Creek - South Jordan	5.00	0.42	Region 2	CENTRAL
22	Northeast Logan – 1200 E to 1600 East and E 1400 North to E 2500 North	18.81	0.42	Region 1	NORTHERN
23	Center Street - Springville	9.72	0.40	Region 3	CENTRAL
24	North Dry Fork Canyon Road - Vernal	3.50	0.40	Region 3	NORTHEASTERN
25	E. 1450 South and S. River Road – St. George	3.00	0.40	Region 4	SOUTHERN

3.3.5 Top 25 Animal-Vehicle Crash Hotspots for Utah Highways and Local Roads

The map of the top 25 animal-vehicle crash hotspots on highways was combined with the top 25 animal-vehicle crash hotspots on local roads, Figure 21. There was a large clustering of hotspot locations in the Salt Lake City-Wasatch Front and back area. The greater Salt Lake City area tended to have crash hotspots on local roads, and the Wasatch Back area from Provo Canyon through Heber and north to Park City had a tendency for a higher concentration of highway crash hotspots.

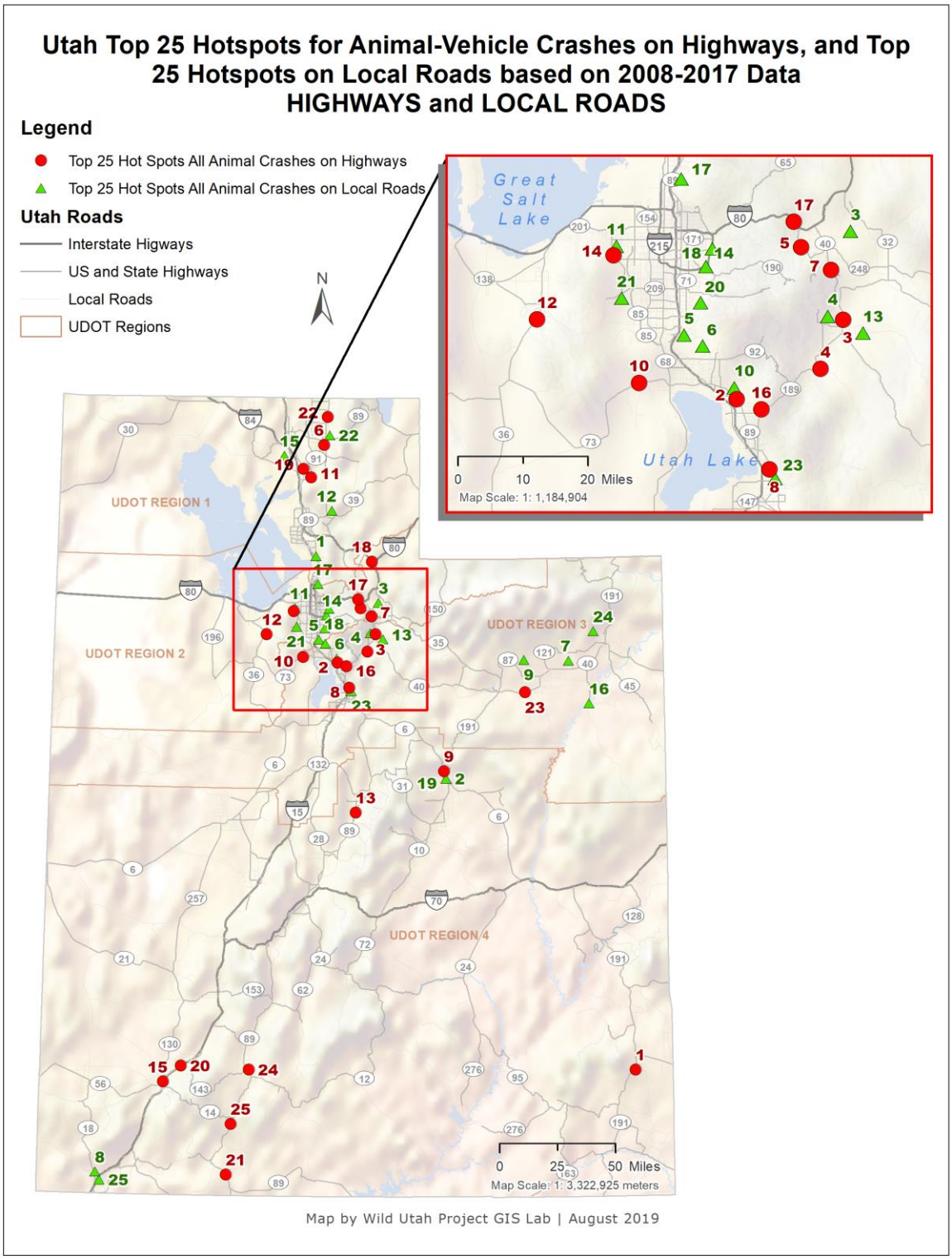


Figure 21. Top 25 Animal-Vehicle Crash Hotspots on Utah Highways and Top 25 Crash Hotspots on Local Roads, Based on 2008 - 2017 Crash Data.

3.3.6 Top 25 Wildlife-Vehicle Crash Hotspots on Utah Highways

The WVC were modeled for hotspots on Utah highways, Figure 22. Twenty-four of these hotspots were identical to the all animal-vehicle crash hotspots. Since the WVC hotspot map was so similar to the animal-vehicle crash hotspots on highways map, the 90 to 99 confidence interval segments were not included in Figure 22. Table 14 presents all top 25 WVC hotspots with official names, roads, lengths, crashes per mile per year, and UDOT and UDWR regions they are located in. Within the name column, the hotspot is compared with the identical hotspot for animal-vehicle crash hotspots for highways. The top five hotspots for wildlife were identical to the top five animal hotspots on highways. Every one of the top 25 hotspots for wildlife had an identical hotspot in the top 25 animal crash hotspots on highways, with the exception of number 24, I-80 at Jeremy Ranch, which had no equivalent hotspot with the overall animal analyses.

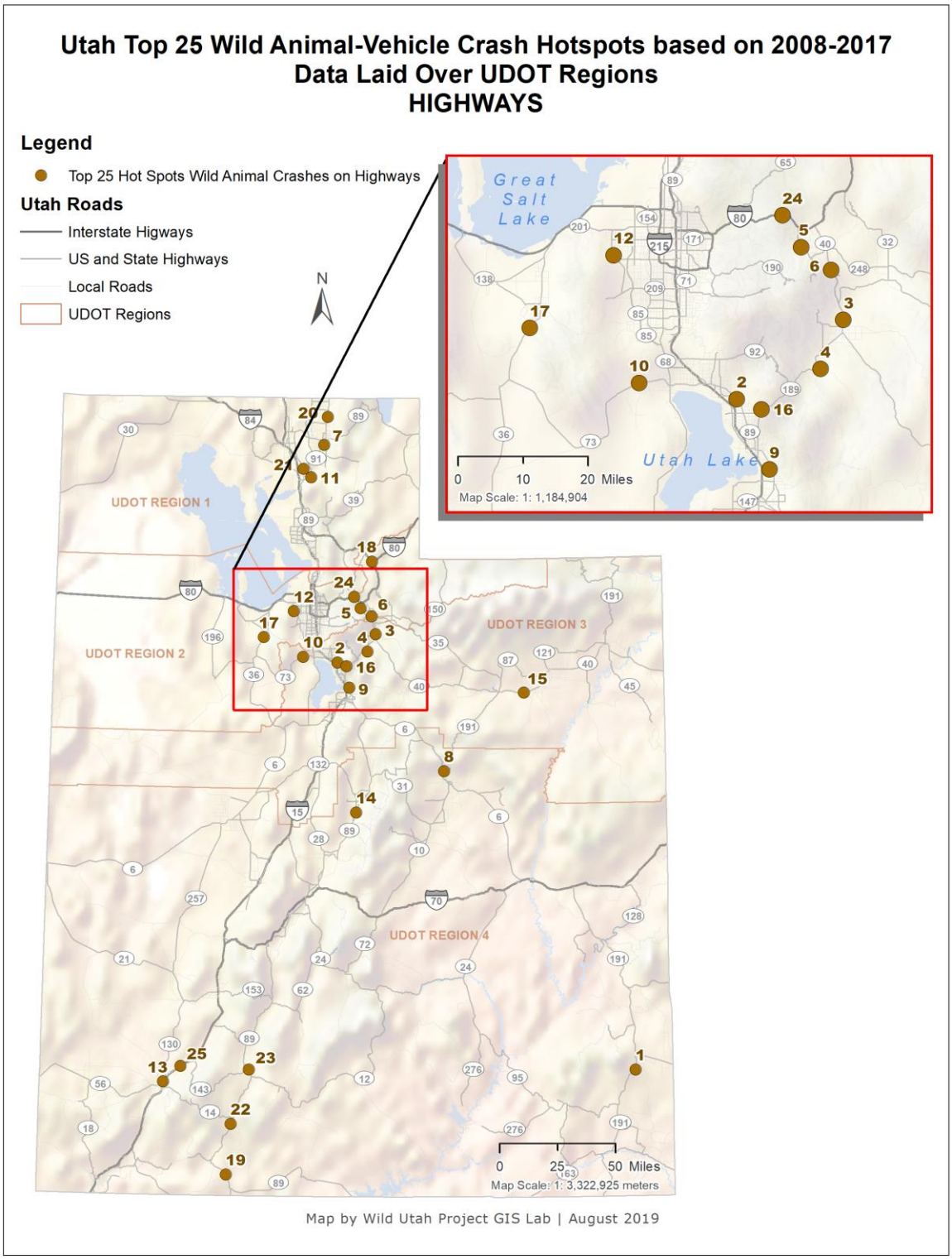


Figure 22. The Top 25 Wildlife-Vehicle Crash Hotspots on Utah Highways, Based on 2008 - 2017 Crash Data.

Table 14. The Top 25 Wildlife-Vehicle Crash Hotpots on Utah Highways, Based on 2008 - 2017 Data. The Hotspot's Rank in the Animal-Vehicle Crash (AVC) Hotspots on Highways is Provided for Comparison.

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
1	US 191 North and South of Monticello (AVC#1)	16.00	3.29	Region 4	SOUTHEASTERN
2	US 89/North State St. Lindon (AVC#2)	2.08	3.12	Region 3	CENTRAL
3	US 40 Heber to Jordanelle Reservoir (AVC#3)	2.50	2.96	Region 3	CENTRAL
4	US 189 Deer Creek State Park (AVC#4)	10.00	2.96	Region 3	CENTRAL
5	SR 224 Kimball Junction-Park City-to US 40 (AVC#5)	6.00	2.93	Region 2	CENTRAL
6	US 40- SR 248 Jordanelle Reservoir (AVC#7)	28.70	2.91	Region 2	CENTRAL
7	SR 165-US 91 Hyrum and Wellsville to Logan (AVC#6)	7.73	2.83	Region 1	NORTHERN
8	US 6 Helper (AVC#9)	8.92	2.83	Region 4	SOUTHEASTERN
9	US 89 -West 1400 North Springville to 1140 South Street Provo (AVC#8)	5.53	2.82	Region 3	CENTRAL
10	SR 73 Eagle Mountain (AVC#10)	5.00	2.76	Region 3	CENTRAL
11	US 91 Brigham City to Sardine Summit (AVC#11)	6.50	2.74	Region 1	NORTHERN
12	SR 111- West Valley Highway Magna South to West 5400 South-SR 173 (AVC#14)	4.50	2.56	Region 2	CENTRAL
13	I-15 – SR 130 Cedar City North to 3600 North (AVC#15)	8.50	2.52	Region 4	SOUTHERN
14	US 89 North of Ephraim Sanpete Valley (AVC#13)	7.70	2.49	Region 4	CENTRAL
15	US 40 Bridgeland – Antelope Creek (AVC#23)	3.50	2.43	Region 3	NORTHEASTERN
16	US 189 North University Ave through E Provo-Canyon Road Orem (AVC#16)	4.62	2.43	Region 3	CENTRAL
17	SR 36 Old Lincoln Highway-South Main St. – Tooele (AVC#12)	6.50	2.40	Region 2	CENTRAL
18	I-80 and I-84 Echo Junction (AVC#18)	6.93	2.32	Region 2	NORTHERN
19	US 89 North Kanab – Three Lakes Canyon (AVC#21)	2.50	2.28	Region 4	SOUTHERN

Rank	Name	Length in Miles	Crashes/ Mile/ Year	UDOT Region	UDWR Region
20	US 89 Smithfield Richfield High Creek (AVC#22)	10.32	2.16	Region 1	NORTHERN
21	SR 38 North Brigham City Kotter Canyon to Dry Canyon (AVC#19)	2.50	2.16	Region 1	NORTHERN
22	US 89 North Glendale – Dixie National Forest (AVC#25)	2.50	2.16	Region 4	SOUTHERN
23	US 89 Panguitch - Casto Canyon Road to Roller Mill Hill Drive (AVC#24)	3.00	2.13	Region 4	SOUTHERN
24	I-80 – Jeremy Ranch – (no AVC equivalent)	15.60	2.05	Region 3	NORTHERN
25	I-15 at Summit (AVC#20)	3.00	2.03	Region 4	SOUTHERN

3.3.7 Top 25 Wildlife-Vehicle Crash Hotspots on Utah Local Roads

The top 25 WVC hotspots were mapped for local Utah roads, Figure 23. Seventeen of the 25 hotspots were in the Greater Salt Lake City-Wasatch Front and back. There was no table compiled for these hotspots because the WVC hotspots on highways were so similar to animal-vehicle crash hotspots on highways, thus readers can refer to those animal-vehicle crash local roads hotspots for a comparative evaluation of wildlife-related crash hotspots on local roads.

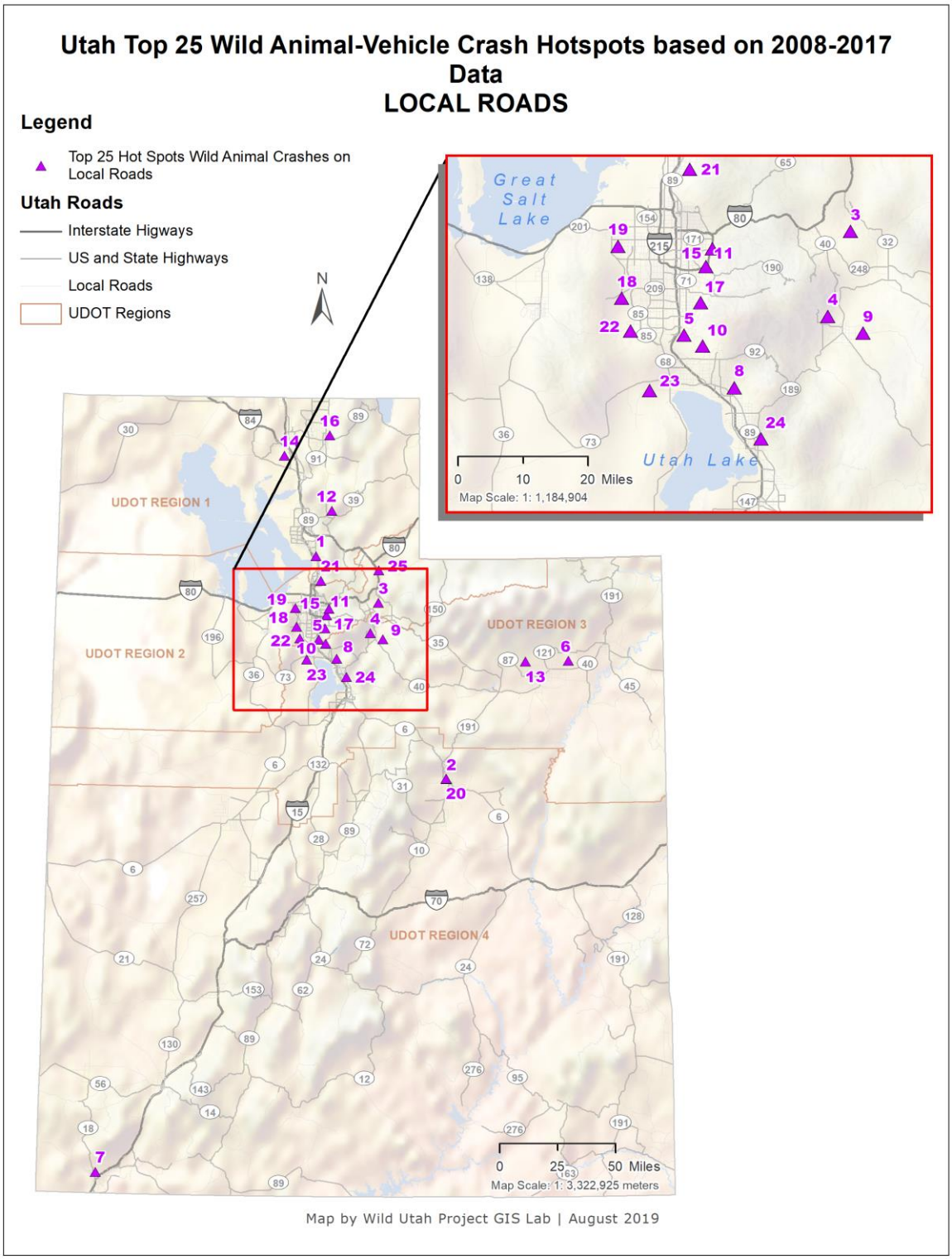
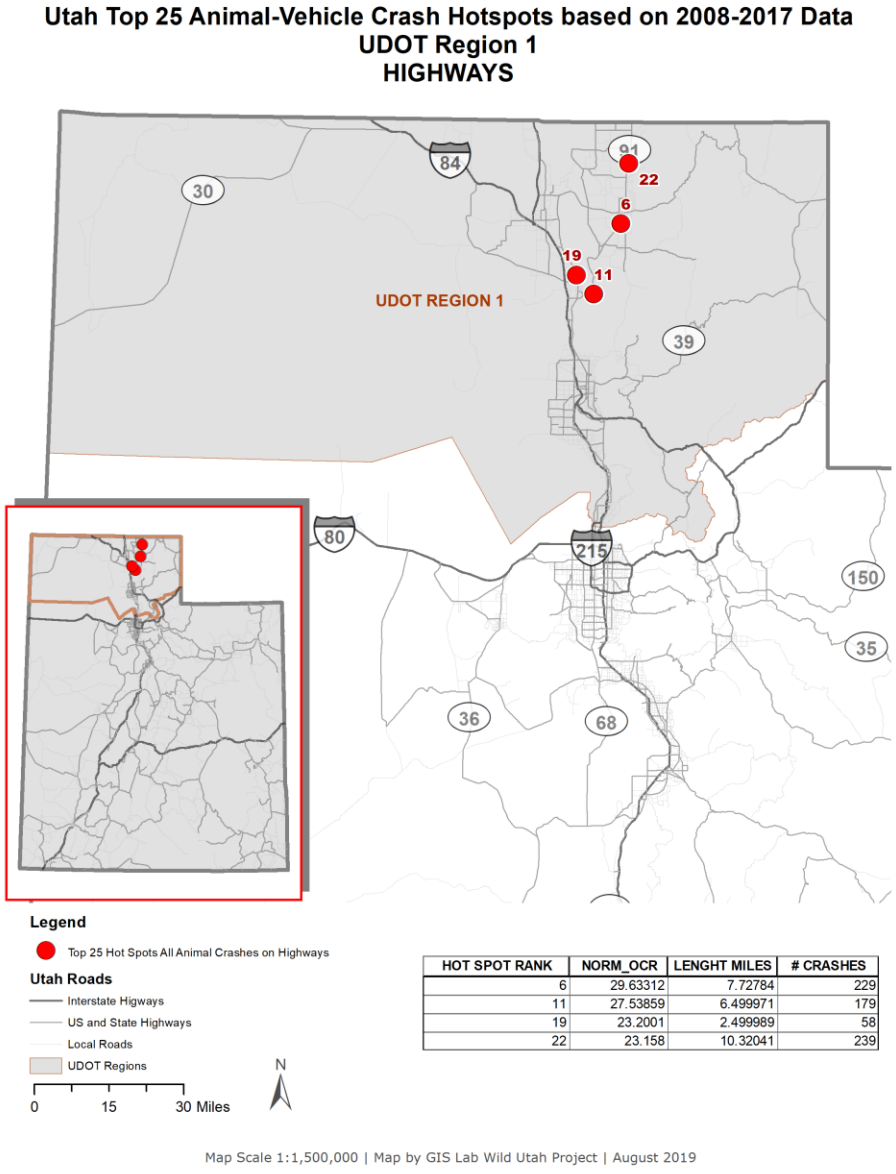


Figure 23. The Top 25 Wildlife-Vehicle Crash Hotspots on Utah Local Roads, Based on 2008 - 2017 Crash Data.

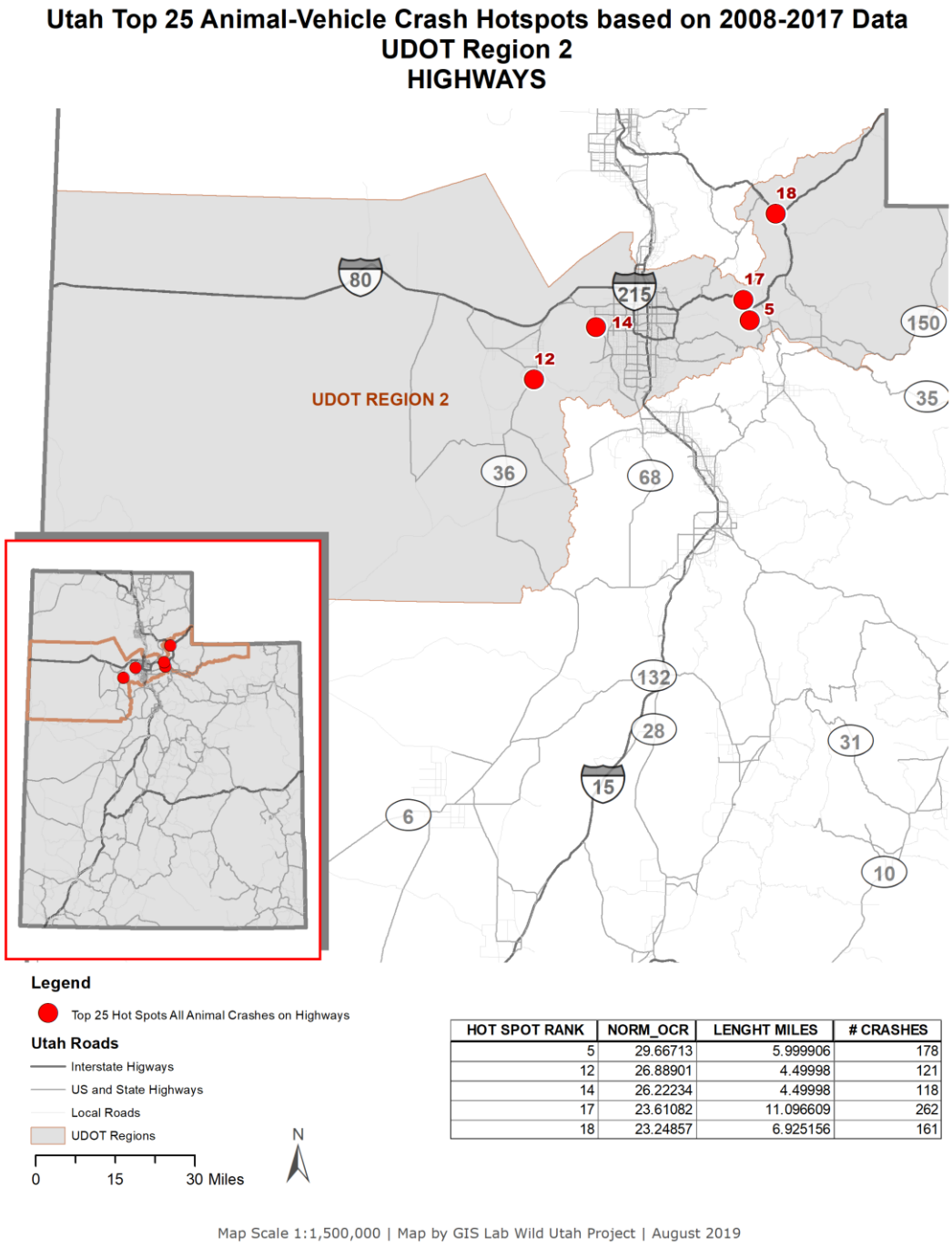
3.3.8 The Top 25 Animal-Vehicle Crash Hotspots on Highways in Each UDOT Region

The state's top 25 animal-vehicle crash hotspots on highways were mapped for each UDOT region, Figures 24-27.



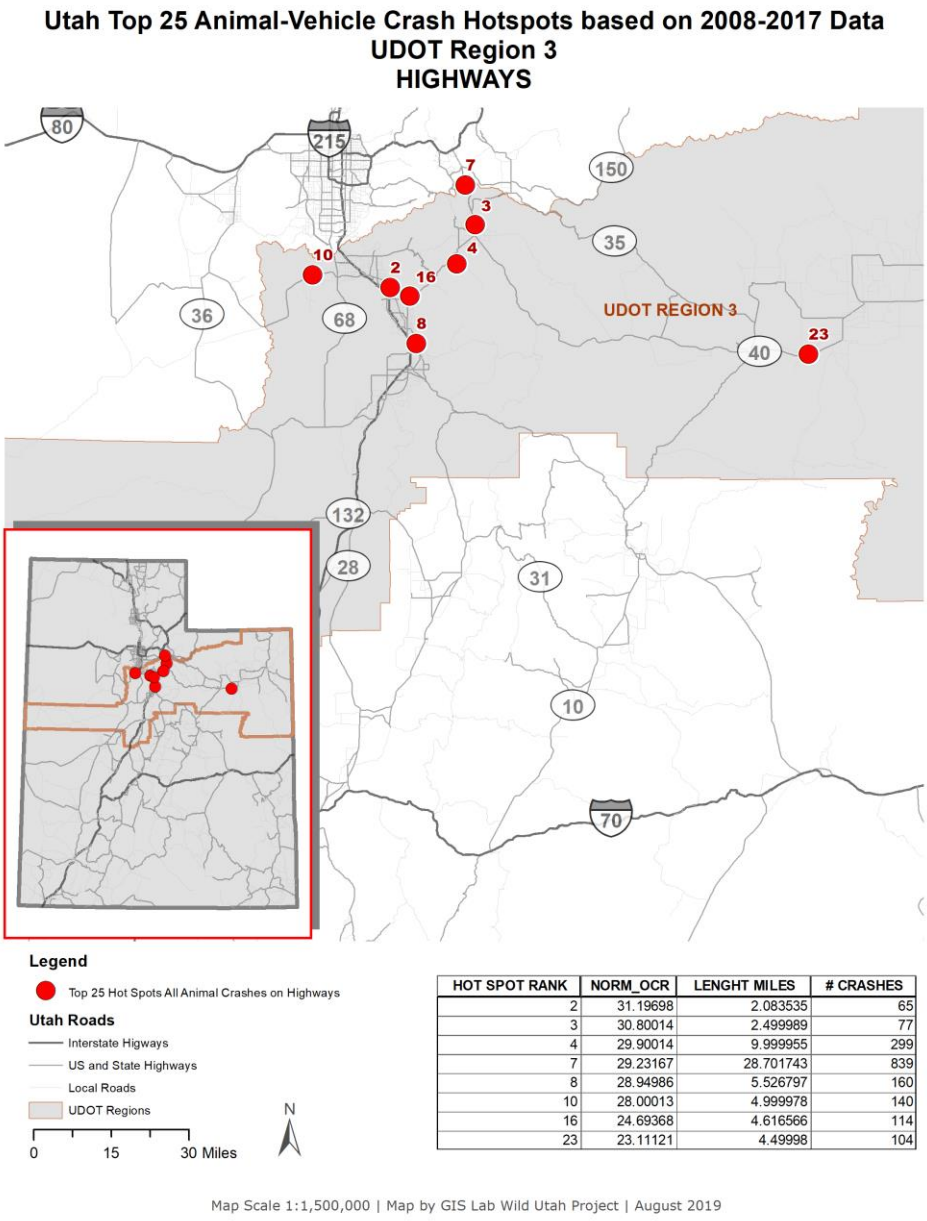
HOT SPOT RANK	NORM_OCR	LENGHT MILES	# CRASHES
6	29.63312	7.72784	229
11	27.53859	6.499971	179
19	23.2001	2.499989	58
22	23.158	10.32041	239

Figure 24. Top 25 Statewide Animal-Vehicle Crash Hotspots located in UDOT Region 1, Based on 2008 - 2017 Crash Data.



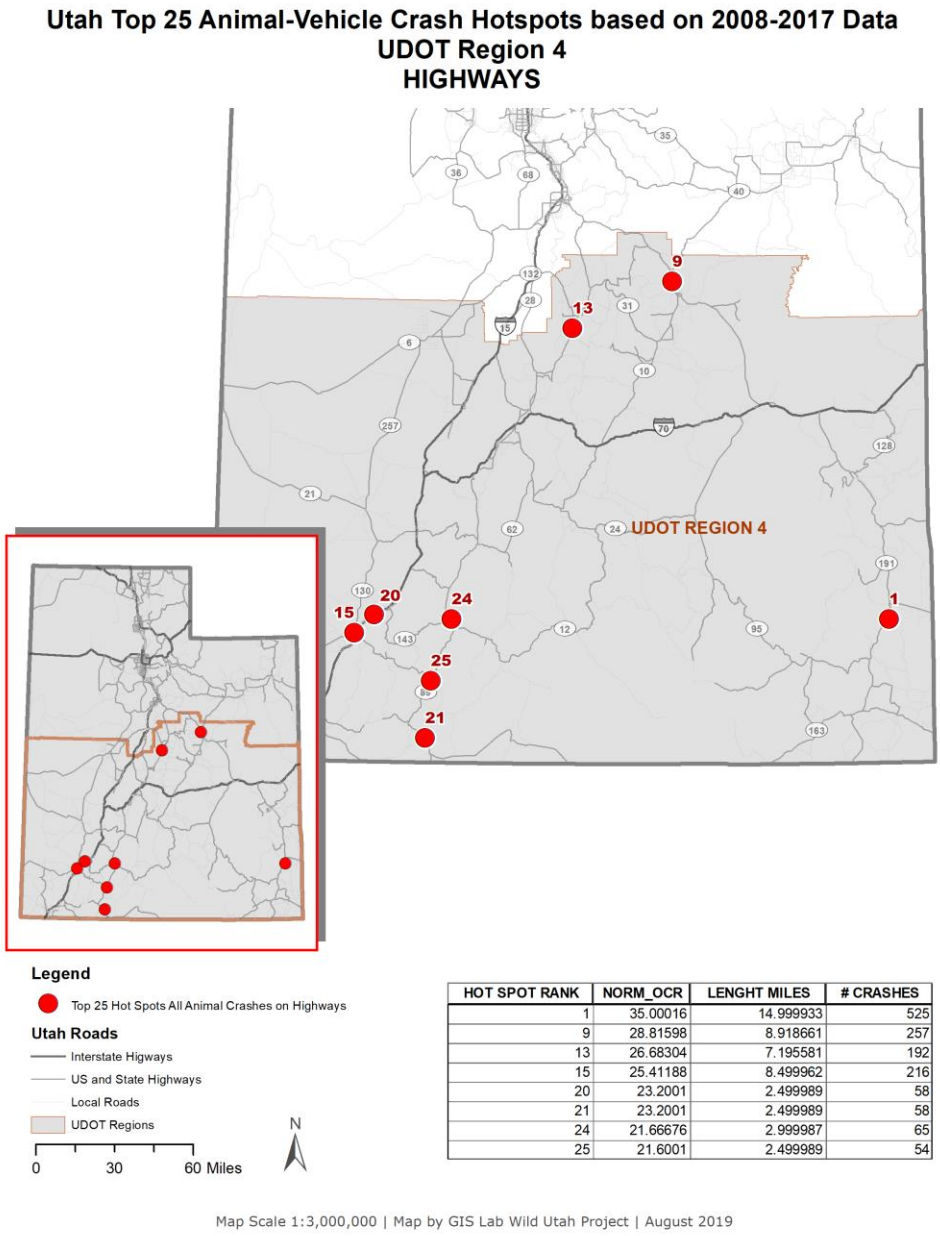
HOT SPOT RANK	NORM_OCR	LENGHT MILES	# CRASHES
5	29.66713	5.999906	178
12	26.88901	4.49998	121
14	26.22234	4.49998	118
17	23.61082	11.096609	262
18	23.24857	6.925156	161

Figure 25. Top 25 Statewide Animal-Vehicle Crash Hotspots on Highways Located in UDOT Region 2, Based on 2008 - 2017 Crash Data.



HOT SPOT RANK	NORM_OCR	LENGHT MILES	# CRASHES
2	31.19698	2.083535	65
3	30.80014	2.499989	77
4	29.90014	9.999955	299
7	29.23167	28.701743	839
8	28.94986	5.526797	160
10	28.00013	4.999978	140
16	24.69368	4.616566	114
23	23.11121	4.49998	104

Figure 26. Top 25 Statewide Animal-Vehicle Crash Hotspots on Highways located in UDOT Region 3, Based on 2008 - 2017 Crash Data.



HOT SPOT RANK	NORM_OCR	LENGHT MILES	# CRASHES
1	35.00016	14.999933	525
9	28.81598	8.918661	257
13	26.68304	7.195581	192
15	25.41188	8.499962	216
20	23.2001	2.499989	58
21	23.2001	2.499989	58
24	21.66676	2.999987	65
25	21.6001	2.499989	54

Figure 27. Top 25 Statewide Animal-Vehicle Crash Hotspots on Highways Located in UDOT Region 4, Based on 2008 - 2017 Crash Data.

3.3.9 Utah Top 25 Wildlife-Vehicle Crash Hotspots on Highways with Respect to UDWR Regions

Wildlife-related crashes are a greater concern for UDWR than overall animal-vehicle crashes. Thus, the top 25 WVC hotspots on highways were mapped over the UDWR regions rather than overall animal-vehicle crash hotspots, Figure 28.

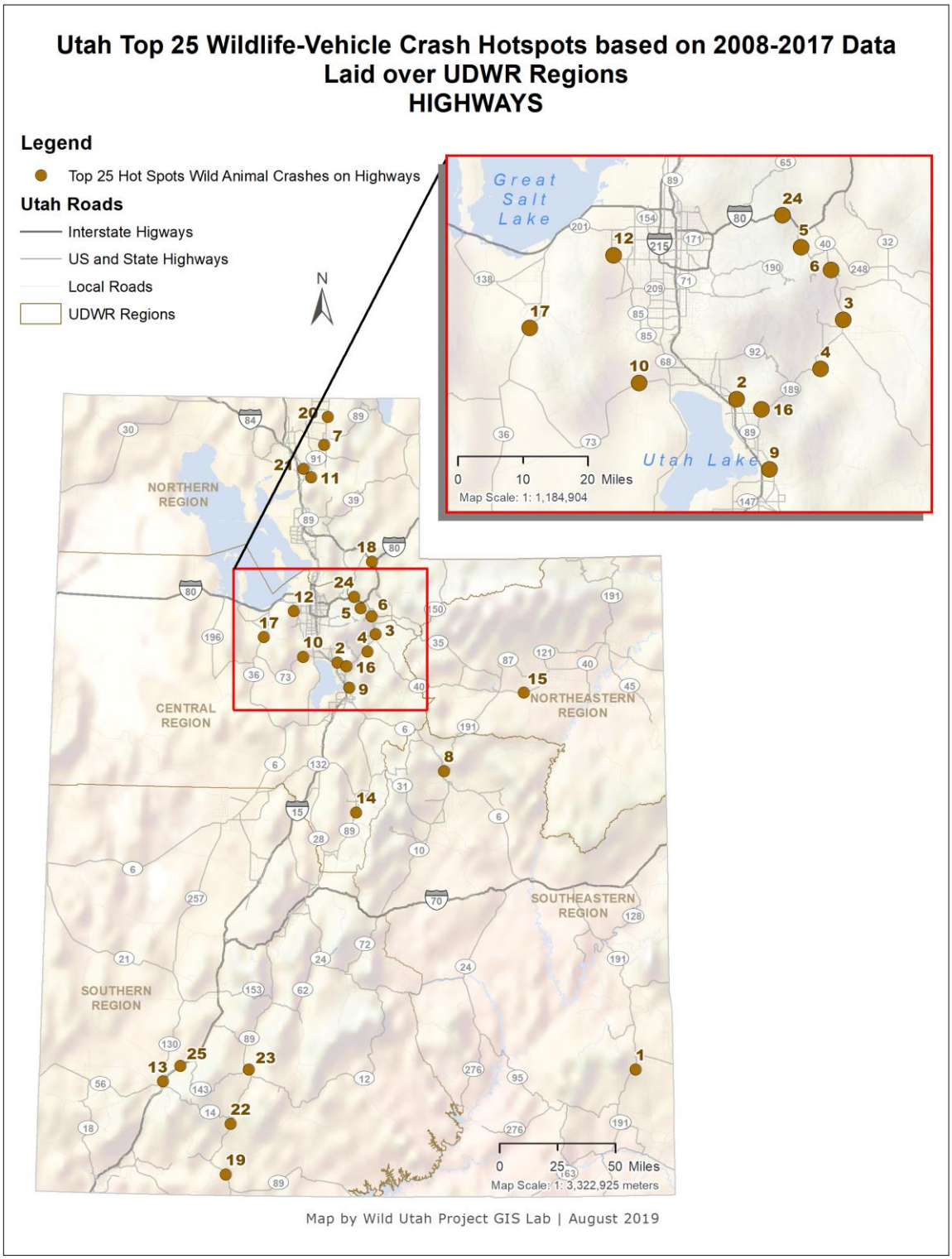


Figure 28. Top 25 Wildlife-Vehicle Crash Hotspots on Highways and UDWR Regions, Based on 2008 - 2017 Data.

3.3.10 The Top 25 Wildlife-Vehicle Crash Hotspots on Highways Mapped Over UDWR Habitat Maps for Mule Deer, Elk, and Pronghorn

The top 25 WVC hotspots on highways map was laid over the UDWR habitat maps for the top three ungulates most involved in wildlife-vehicle crashes: mule deer, elk, and pronghorn antelope (Figure 29). This allows for an initial viewing of the potential for wildlife-vehicle conflict with these three species as well as past reported crashes.

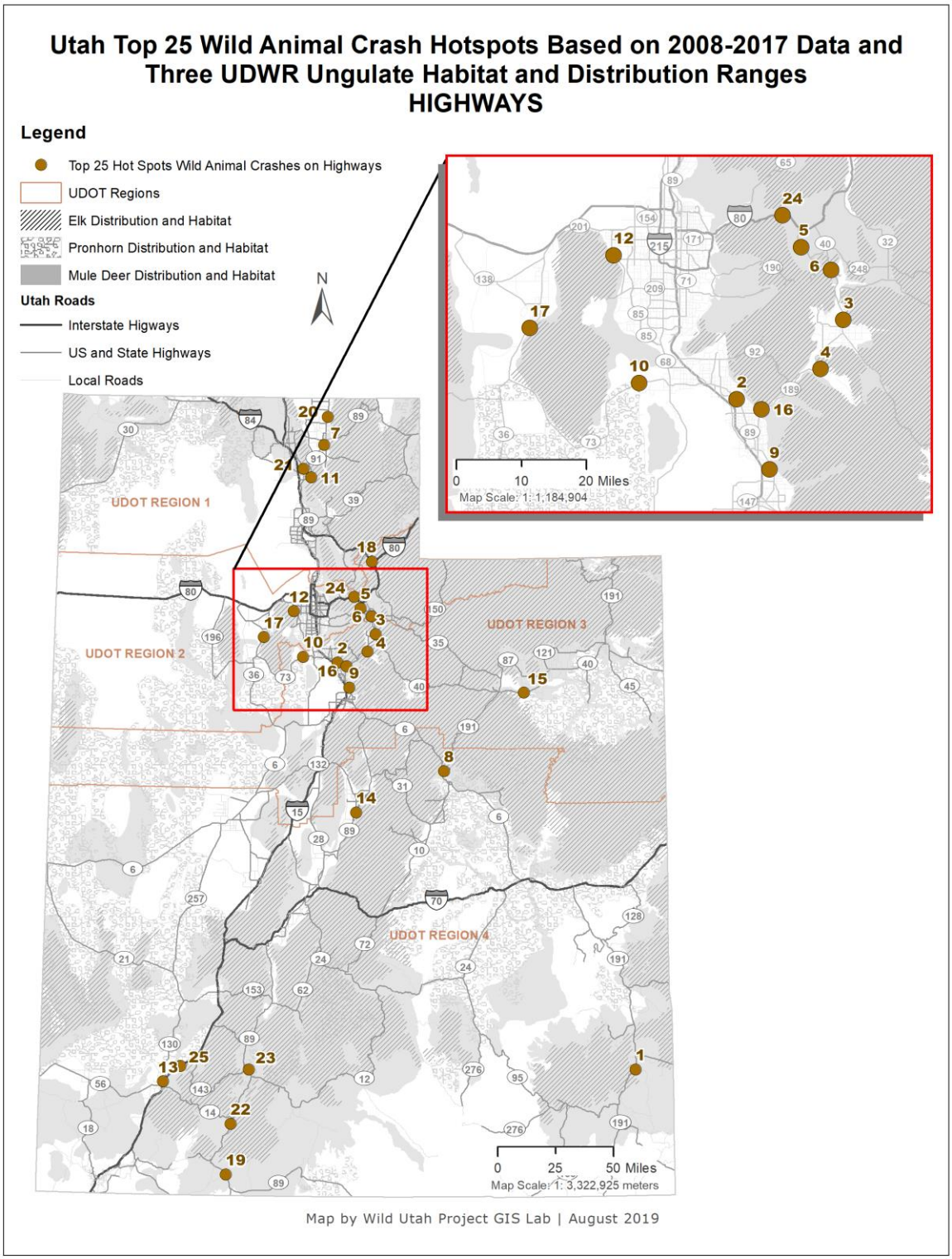


Figure 29. Top 25 Wildlife-Vehicle Crash Hotspots on Utah Highways Based on 2008 - 2017 Crash Data, and UDWR Habitat Maps for Mule Deer, Elk, and Pronghorn.

3.3.11 The Top 25 Domestic Animal-Vehicle Crash Hotspots on Highways, Local Roads, and UDOT and UDWR Regions

The top 25 domestic animal-vehicle crashes were mapped for highways, and for local roads, and placed over UDOT and UDWR regions (Figures 30 - 33).

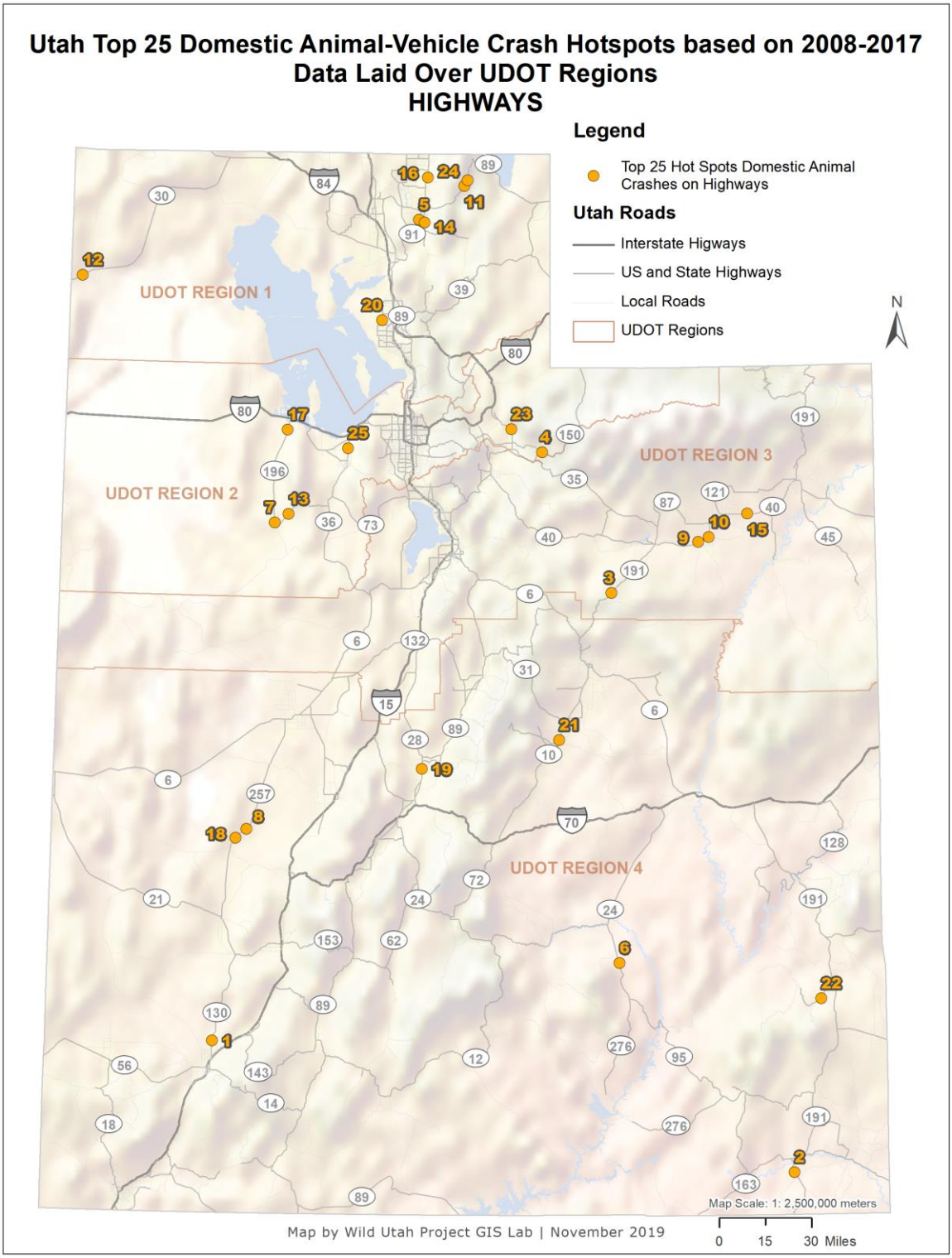


Figure 30. Top 25 Domestic Animal-Vehicle Crash Hotspots on Utah Highways Based on 2008 - 2017 Crash Data and UDOT Regions.

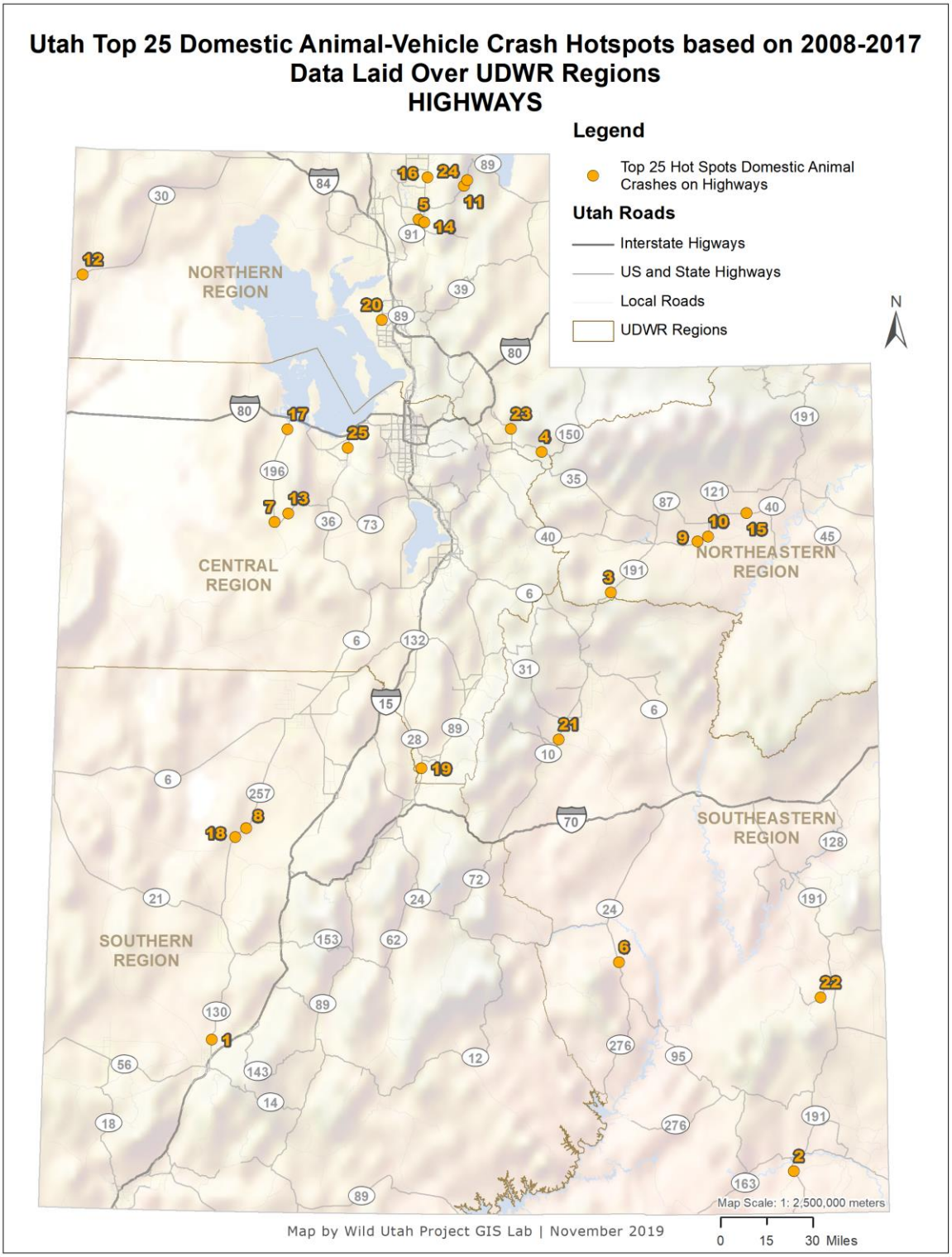


Figure 31. Top 25 Domestic Animal-Vehicle Crash Hotspots on Highways Based on 2008 - 2017 Crash Data, and UDWR Regions.

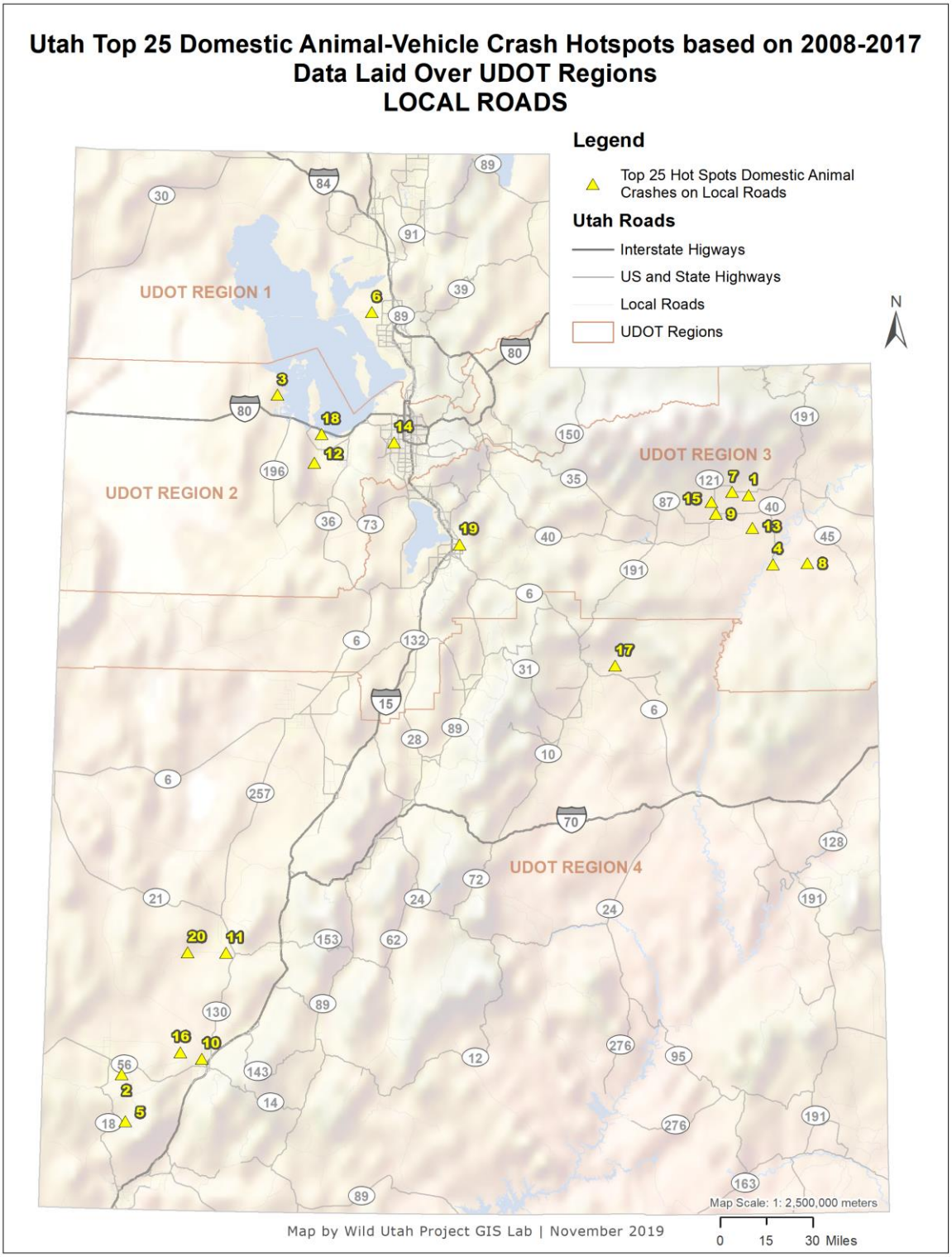


Figure 32. Top 25 Domestic Animal-Vehicle Crash Hotspots on Local Roads Based on 2008 - 2017 Crash Data, and UDOT Regions.

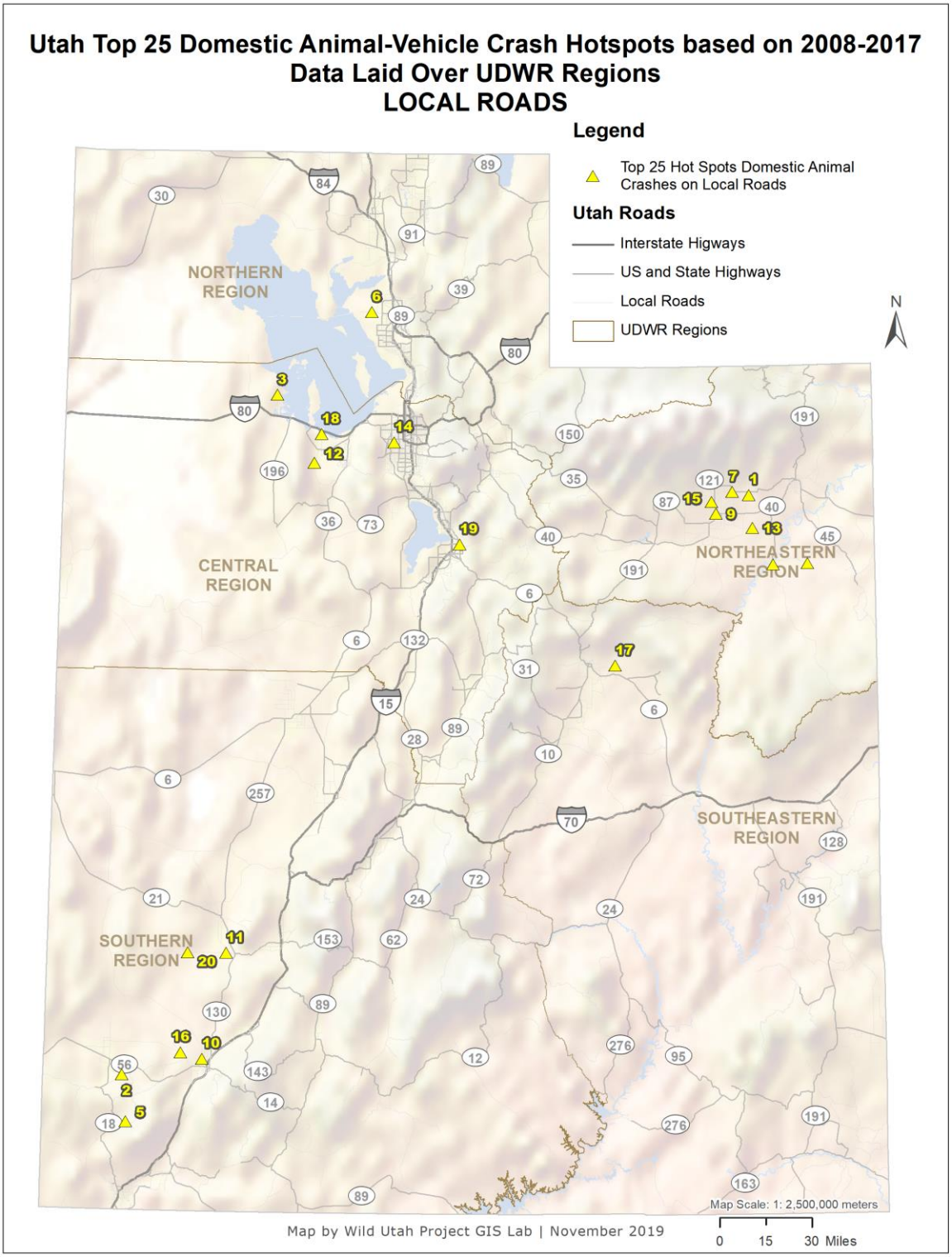


Figure 33. 25 Domestic Animal-Vehicle Crash Hotspots on Local Roads Based on 2008 - 2017 Crash Data, and UDWR Regions.

3.3.12 The Top 25 Wild Animal Carcass Hotspots on Highways Mapped Over UDWR Habitat Maps for Mule Deer, Elk, and Pronghorn

The researchers took the carcass data from 2009 to 2018, applied the OHSA model for hotspot analysis, and mapped the top 25 all wild animal carcasses hotspots on highways and laid this map over the habitat maps for mule deer, elk, and pronghorn combined, Figure 34. Note the lack of carcass hotspots in the southern half of the state when compared to the crash data maps, with the exception of the Monticello area.

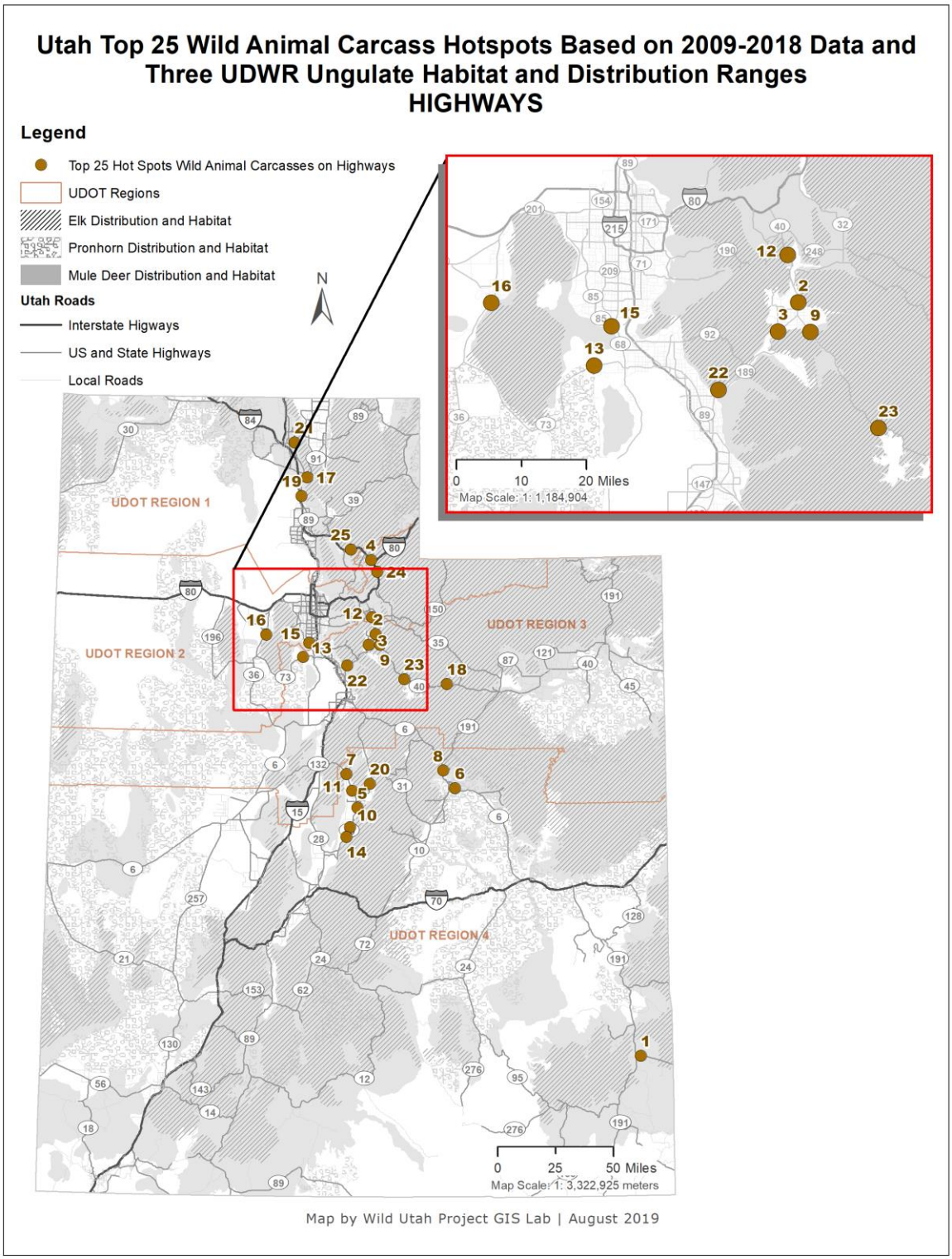


Figure 34. Top 25 Wild Animal Carcass Hotspots on Utah Highways and UDWR Habitat Maps for Mule Deer, Elk, and Pronghorn, Based on 2009 - 2018 Carcass Data.

3.3.13 The Top 25 Ungulate Carcass Hotspots on Utah Highways Mapped Over UDWR Mule Deer, Elk, and Pronghorn Habitat Maps

The 2009 - 2018 carcass data were parsed to limit the data to only wild ungulate species. These ungulate carcass locations were modeled for the top 25 ungulate carcass locations on highways. These in turn were merged with the habitat maps for mule deer, elk, and pronghorn, Figure 35.

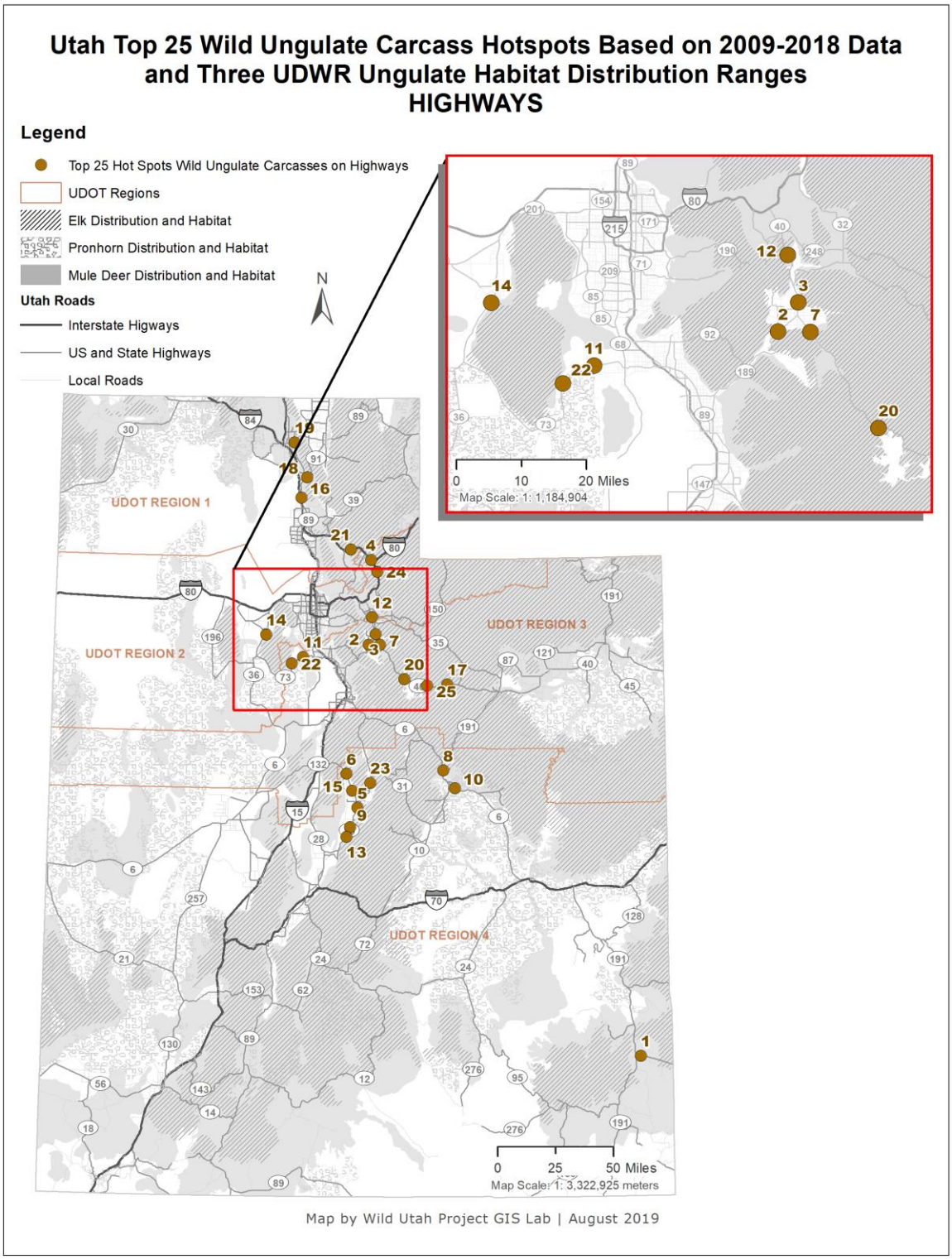


Figure 35. The Top 25 Wild Ungulate Carcass Hotspots on Utah Highways Based on 2009 - 2018 Data, and UDWR Habitat Maps for Mule Deer, Elk, and Pronghorn.

3.3.14 Utah Top 25 Wildlife-Vehicle Crash Hotspots Laid Over Kanab Area Brownian Bridge Mule Deer Movement Maps

The 95 and 99 percent confidence intervals of WVC hotspots on highways statewide were overlaid on the UDWR Brownian Bridge Movement Model map of collared mule deer in the Paunsaugunt herd, just outside of Kanab, Utah in the southwest-central corner of the state (Figure 36). This was the only map of its kind available to the researchers. It demonstrates potential for how future mule deer movement maps, when combined with crash hotspot data, show congruency in identifying areas of mule deer-vehicle conflict.

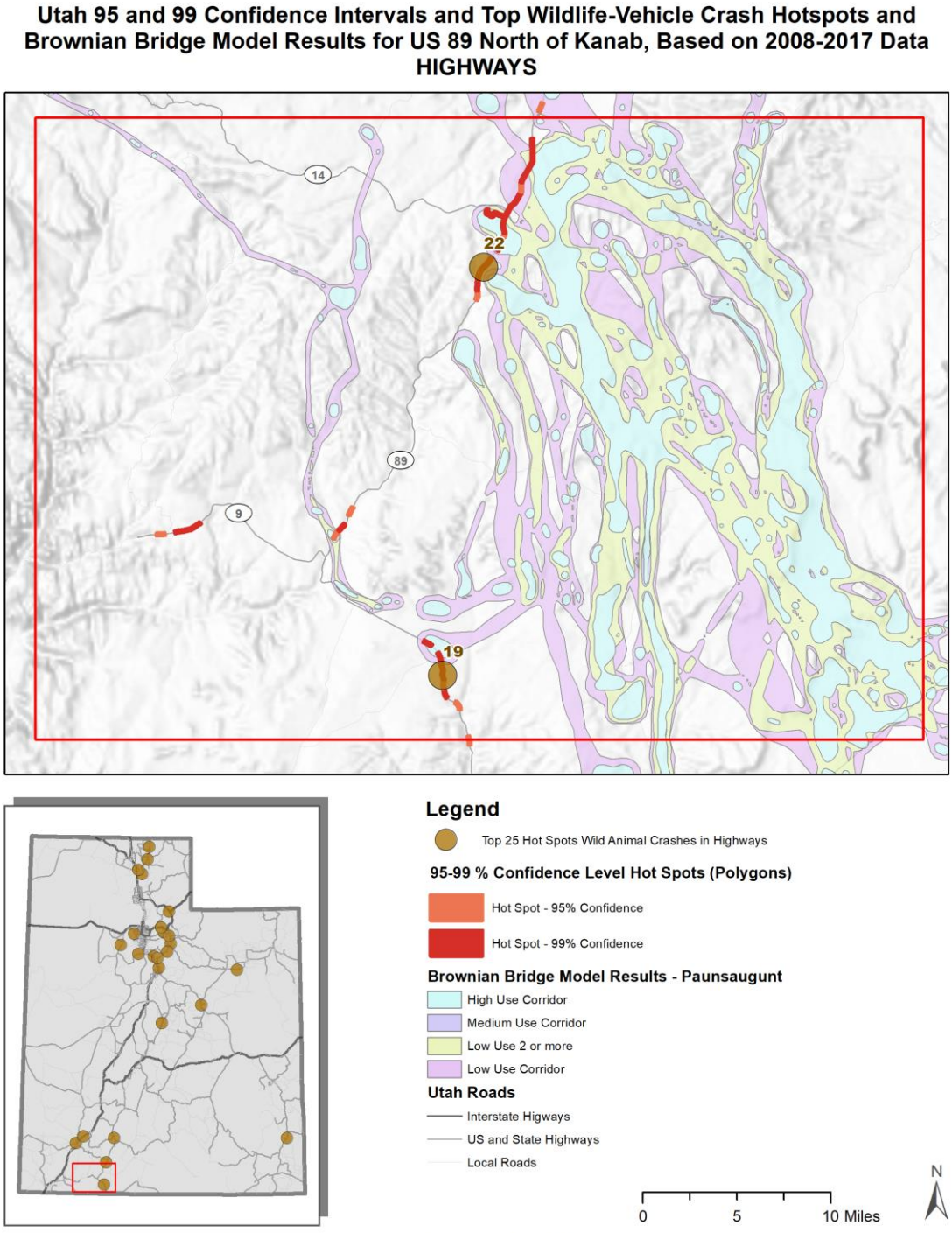


Figure 36. Brownian Bridge Movement Model of Paunsaugunt Mule Deer GPS Collar Movements and the Nearby Top 25 Wildlife-Vehicle Crash Hotspots on Highways in Utah.

3.3.15 The Top 25 Wildlife-Vehicle Crash Hotspots on Highways Laid Over the UDWR Habitat Maps for Multiple Species

The top 25 WVC hotspots on highways were mapped over each of the habitat maps of seven species of wild mammals, including maps of the three subspecies of bighorn sheep. The resulting map for mule deer was included below (Figure 37), while the other species' maps are presented in Appendix C.

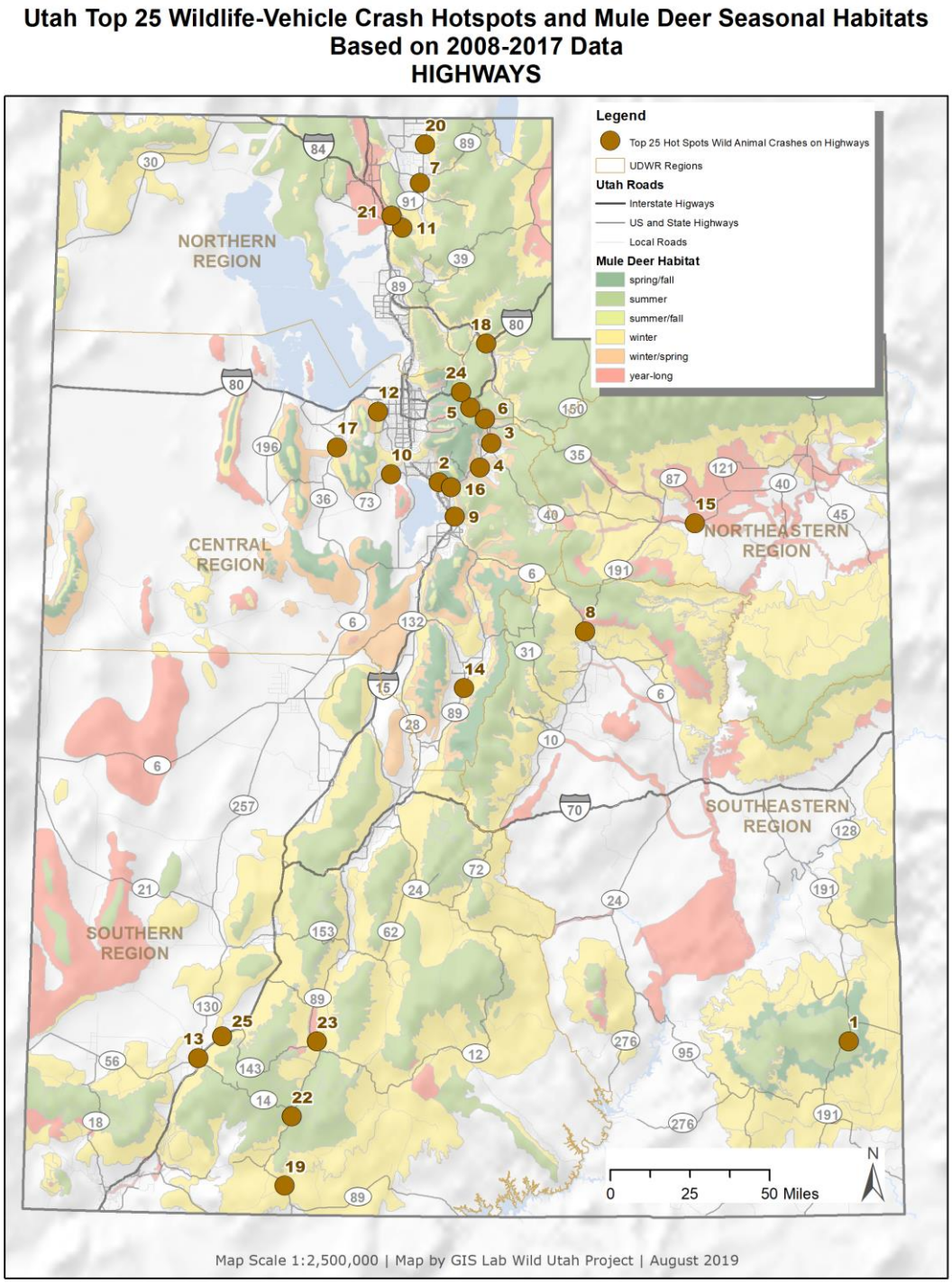


Figure 37. The Top 25 Wildlife-Vehicle Crash Hotspots on Utah Highways Based on 2008 - 2017 Data and UDWR Mule Deer Seasonal Habitat Maps and UDWR Regions.

3.3.16 Utah Top 25 Wild Ungulate Carcass Highway Hotspots Laid Over Seven Wildlife Species' UDWR Habitat Maps

The top 25 wild ungulate carcass highway hotspots were mapped over each of the habitat maps of seven species of wild mammals, including maps of the three subspecies of bighorn sheep. The resulting map for mule deer is included below (Figure 38), while the other species' maps are presented in Appendix D.

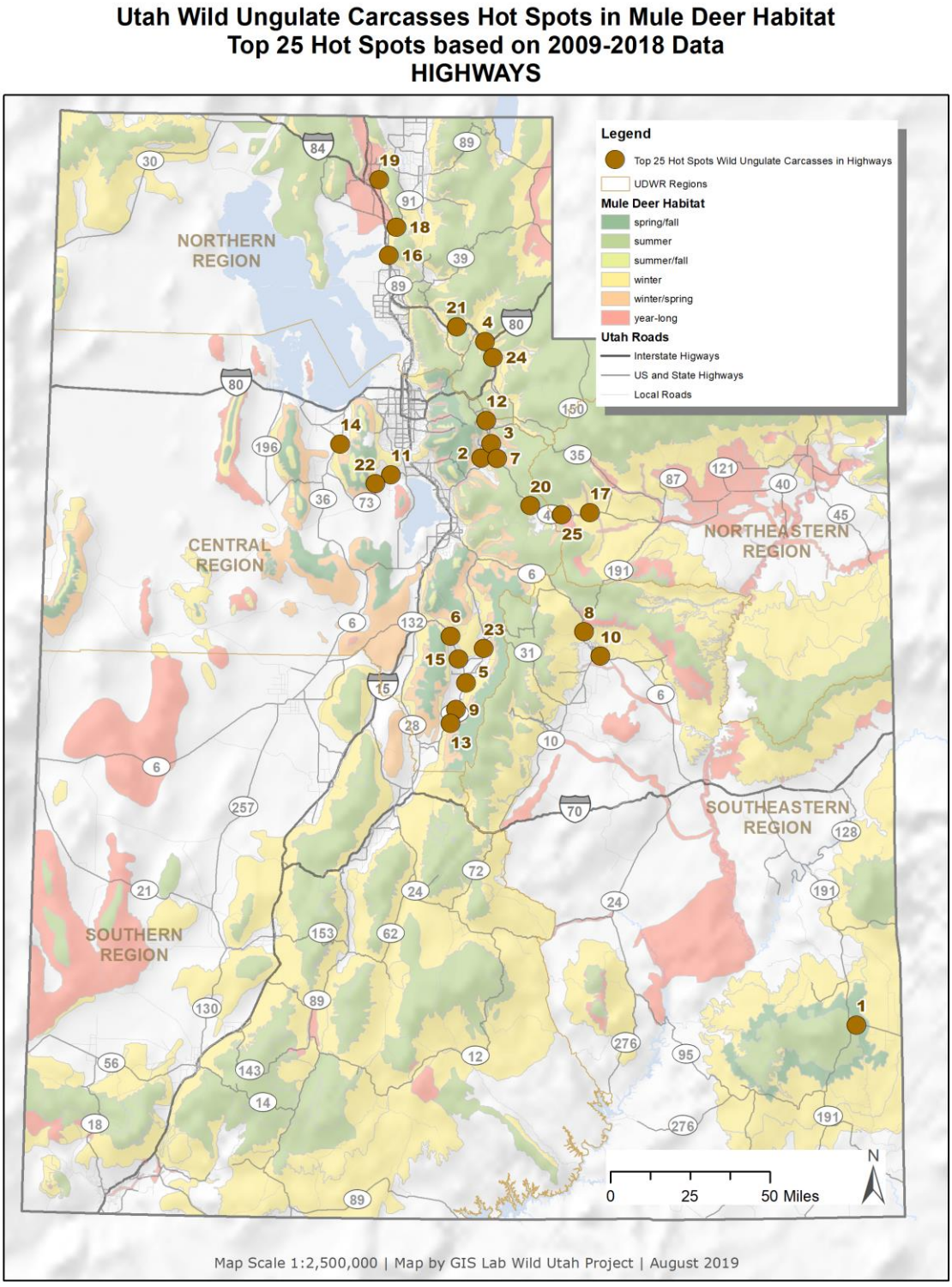


Figure 38. The Top 25 Wild Ungulate Carcass Hotspots on Utah Highways Based on 2008-2019 Data and UDWR Mule Deer Seasonal Habitat Maps and UDWR Regions.

3.4 Identification of Mitigation Solution Recommendations for Each Hotspot (Task 3)

The top 25 WVC hotspots are in areas where UDOT and UDWR are aware of the problem. The researchers reached out to UDWR personnel, and the UDOT-UDWR TAC members for this project to learn of problems and their recommendations for potential solutions for all 25 animal-vehicle crash hotspots on highways. The ongoing issues, past mitigation efforts, future and potential efforts are summarized for each location, Table 15.

Table 15. Species of Wildlife, UDOT and UDWR Efforts and Potential Recommendations for Mitigating Utah's Top 25 All Animal-Vehicle Crash Hotspots.

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
1	US 191 North and South of Monticello	UDOT 4 UDWR SOUTHEASTERN
	This area has mainly mule deer killed but elk and other wildlife also migrate across US 191 with mule deer to access winter habitat to the east, and summer habitat to the west. There are also resident herds that remain in the area most of the warmer and dryer months of the year. Black bear and puma have also been recorded killed and photographed using structures here. Multiple wildlife crossing structures are needed along this 15-16 mile stretch. UDOT built two dedicated wildlife crossing structures in this segment in 2005 (MP 60.1, and 61.9) with 3 miles of fence (MP 59.5-62.3); added an additional wildlife crossing structure in 2016 (MP 68.2), along with 3.5 miles of fence placed to an existing culvert (MP 66.7); and in 2019-2020, erected wildlife exclusion fence and constructed three wildlife crossing structures (MP 66.7 in the north for deer, MP 65.1 for deer, and MP 63.6 for elk to the south). See Cramer and Hamlin, 2019a for report on monitoring 2016 structures, and see Cramer, 2014 for the 2005 structures monitoring results. Additional efforts will be needed closer to the north and south ends of Monticello.	
2	US 89/North State St. Lindon	UDOT 3 UDWR CENTRAL
	There is a suburban-urban mule deer population in this highly developed area. Recommended mitigation solutions are different for this largely urban site, and tend toward pedestrian safety solutions. Perhaps underpass structures for human residents could be shared with wildlife using them at night to cross US 89. Additional pedestrian solutions, such as added lighting could help avoid deer-vehicle crashes.	
3	US 40 Heber North to Jordanelle Reservoir	UDOT 3 UDWR CENTRAL
	This area has largely mule deer movements east and west across the highway. The area has high potential for wildlife crossing structures with the rolling topography and lack of human development along the highway. Both underpass structures and overpass structures with the existing wildlife fence are recommended. There is potential for human development on both sides of the highway. If this occurs, perhaps possible pedestrian underpasses or an overpass could be shared with wildlife, such as the pedestrian underpass just north on US 40.	
4	US 189 Deer Creek State Park	UDOT 3 UDWR CENTRAL

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	Mule deer, with some elk and moose, are crossing the road to access south-facing slopes to the north side of US 189 along with water resources in the state park. UDOT and UDWR worked together in 2010 and in 2016 to provide 2 wildlife crossing underpasses along this stretch, MP 19.4 in 2010, and MP 21.4 in 2016. Fence and escape ramps were also placed for approximately 3.7 miles along the road at Deer Creek State Park. Cramer and Hamlin (2019b) monitored both crossing structures, which were highly used. If future crash data show there is not a significant reduction (over 50 percent) of wildlife-vehicle crashes, additional structures may be necessary. The elk and moose were documented to use the MP 19.4 structure approximately one animal in 8 years of monitoring, and no use of the MP 21.4 structure in 3 years. Their movements should be accommodated in future crossing structures, with bridges or overpasses.	
5	SR 224 Kimball Junction-Park City-to US 40	UDOT 2 UDWR CENTRAL
	Mule deer, elk, and moose have been killed here repeatedly for years as the Park City area has become more developed and visited. Local non-profit groups have placed signs and tried to educate the residents and visitors to slow down in these areas. The local residents may be open to installation of a wildlife crossing structure or several along this road if the lands on both sides can be protected. Existing recreational underpass(es) may be adapted for wildlife use at night if fence is placed along highway. In 2019 the county was working with citizens to identify potential locations for an underpass for wildlife near MP 8. There is an existing pedestrian path underpass near this location on US 40 at MP 2 where elk have been photographed using the structure.	
6	SR 165-US 91 Hyrum and Wellsville North to Logan	UDOT 1 UDWR NORTHERN
	This area within Cache Valley is rapidly developing, and does not have protected land on both sides of these highways, so it will be difficult to install crossing structures. If human underpass structures could be developed, perhaps local suburban mule deer may use them. With the agriculture lands in these areas turning into subdivisions, migratory mule deer populations may die out. Solutions are difficult. As of 2019 the mule deer appear to more heavily cross the road during seasonal migration periods. Potential driver warning systems, that place electronic variable message boards (permanent or trailer-mounted) notifying drivers of animals on the roadway, may have the best success at reducing wildlife-vehicle crashes. General dates are October 15 - December 1 and March 1 - April 30. Another alternative would be to install several flashing static "wildlife on roadway" signs in each direction of travel. Development and topography limit the possible use of crossing structures and fencing. In areas of denser development, installation of street lights may better illuminate animals on the roadway.	
7	US 40 and SR 248 on West and North Sides of Jordanelle Reservoir	UDOT 2 UDWR CENTRAL
	Mule deer is the main species in this area. This hotspot is just north of Hotspot 3 from Jordanelle south to Heber. Similar to Hotspot 3, wildlife overpass and underpass structures, along with wildlife exclusion fencing, are a possibility because the landscape is not yet developed and topography is favorable to an overpass. In addition, state lands are located to the east and west of US 40. Land protection immediately adjacent to US 40 should be undertaken if crossing structures are considered appropriate.	

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	SR-248. Despite this section of highway having wildlife exclusion fencing installed many years ago, the area continues to have high numbers of wildlife mortality. This is due to the numerous openings created in the fence for subdivisions, roads, and individual homes. These openings, most of which do not have wildlife guards or double cattle guards, have made the fence ineffective with animals easily gaining access to the ROW. The area is rapidly developing and solutions are difficult. UDOT and UDWR have met to discuss not permitting any additional road or driveway breaches in the fence without the installation of wildlife guards or double cattle guards. There are a few areas where wildlife crossing structures could be placed, but lands on both sides of the highway should be targeted for protection to facilitate wildlife use. One possible location for a joint non-motorized human and wildlife underpass is near the Rail Trail on the western section of this area. Another possible location for a crossing structure is near the eastern portion of this area. All existing openings in the fence should have wildlife guards / double cattle guards installed. Existing wildlife exclusion fence needs to be maintained, with new fencing added where it has been removed. Wildlife escape ramps also need to be installed.	
8	US 89 -West 1400 North Springville to 1140 South Street Provo	UDOT 3 UDWR CENTRAL
	Mule deer in this highly human-dominated area are staying near the foothills of the mountains, which provide prime winter habitat and water features. Wildlife crossing structures would be difficult to build if the lands on both sides of US 89 are not protected from development. Traffic volumes are too high and the road too wide for driver warning systems. Also, pedestrian solutions, such as added lighting could help avoid deer-vehicle crashes. Driver warning signs through variable message boards could be placed seasonally.	
9	US 6 Helper	UDOT 4 UDWR SOUTHEASTERN
	Mule deer graze on agricultural lands on mainly the south and west side of US 6. Private lands in the area probably preclude underpass solutions. Wildlife exclusion fence may be the only option, guiding animals to existing bridged and culvert structures to pass beneath US 6. Traffic volume and the width of US 6 at this point preclude driver warning systems.	
10	SR 73 Eagle Mountain	UDOT 3 UDWR CENTRAL
	Mule deer move through this area. Recent human development in this area has caused spikes in deer-vehicle crashes. UDOT in 2019 experimented with a primitive driver warning system. UDWR has identified this area as an important migration area to remedy WVC. Wildlife underpass structures may prove to be an elusive solution due to private lands. The protected lands in Camp Williams will provide a source of mule deer from the north in future years, and the Lake Mountains to the south will also be a deer source and refuge, so the problem will persist until accommodations for wildlife are made. UDWR is exploring possibilities with UDOT and working with Eagle Mountain to preserve a corridor from the Lake Mountains to Camp Williams which will include fencing and crossing structures as needed. The deer move through a second corridor to the west side of Eagle Mountain near Five Mile Pass. The animals are moving between the Oquirrh Mountains, and the Lake Mountains and Tintic Mountains. The UDWR Central Region is involved in helping Eagle Mountain design its new city in this area.	
11	US 91 Brigham City to Sardine Summit	UDOT 1 UDWR NORTHERN

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	Mule deer is the main species that needs to cross the highway in this area, but moose and elk have been photographed moving along here and have been involved in crashes. This area has two wildlife crossing culvert underpasses built in 1995 (MP 5.2 and MP 8.3) and miles of wildlife exclusion fence (MP 5-15). The MP 8 underpass has the highest mule deer repel rate in the state of all monitored wildlife crossing structures, and the MP 5 underpass is small for a mule deer underpass, and does not appear to be heavily used, except by humans. Since 2013 UDWR and UDOT have tried various solutions to prevent mule deer access into the ROW and to provide connectivity. These efforts have only had minimal success. Additional wildlife crossing structures, including an overpass just north of Mantua (MP 7.2) may be the best solution because mule deer need access to water and winter habitat on both sides of the highway.	
12	SR 36 Old Lincoln Highway South Main St. - Tooele	UDOT 2 UDWR CENTRAL
	Mule deer move within Tooele and to and from the Stansbury Mountains to the southeast and the Tooele Army Depot to the west. There should be some potential for wildlife crossing structures south of town to provide connectivity between these two areas.	
13	US 89 North of Ephraim & SR 132 in Sanpete Valley	UDOT 4 UDWR CENTRAL
	Mule deer and elk are the species of concern. This area has a consistent high number of deer crashes, and in some years, elk crashes. Although human development is low in this area, agricultural fields can be found on both sides of the highway through this stretch making it attractive for wildlife. Topography is very flat and finding locations for crossing structures is challenging. Use of crossings within this hotspot should be analyzed carefully as to avoid congregating large numbers of big game animals into agricultural areas which would create depredation problems. Exclusionary fencing should not be used in the absence of an adequate number of crossings as wildlife would stack up along the fence causing potential starvation, disease and other issues. Other mitigation options that could be explored include at-grade crossings, radar detection warning systems, reduced speed limits during winter months and/or at night, and other options.	
14	SR 111- West Valley Highway Magna South to West 5400 South-SR 173	UDOT 2 UDWR CENTRAL
	Mule deer and limited numbers of elk are of concern. This area is adjacent to heavily urbanized communities to the east and large tracts of open space on the west including Kennecott Copper property. Long-term development plans should be understood when determining potential mitigation options to ensure mitigation actions would provide the long-term benefits intended following construction.	
15	I-15 – SR 130 Cedar City North to 3600 North	UDOT 4 UDWR SOUTHERN
	The problem is with urban mule deer herds and potentially winter migrants in the area that was traditional winter habitat. This is the north half of Cedar City Main Street, which has a speed limit of 45 mph. There has been a steady rise in traffic and WVC here. The problem is primarily in the winter when the herd comes down the hill to the sliver of winter range they have left. Fawns are often hit. UDWR is not sure why the mule deer are so motivated to cross here. They may be resident deer on the golf course that get pushed west by the migrant deer	

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	coming off Cedar Mountain. Alternatively, before the I-15 wildlife fence was installed the deer may have been accustomed to getting further west than I-15. The deer have few options to cross I-15 with the wildlife fence in place (there are underpasses with urban traffic). This area is difficult for drivers and deer when there is a snowstorm in the valley. Driver warning flashing signs are installed but have little impact on drivers as locals have acclimated to them. Fencing is not a feasible option here as it is all urbanized. There is very limited sustainable mule deer habitat west of I-15 in Cedar City and deer that do get west of I-15 become depredation problems in the agricultural areas. A typical problem of urbanization of winter habitat for mule deer and little left for them to move to.	
16	US 189 North University Ave through E Provo-Canyon Road Orem	UDOT 3 UDWR CENTRAL
	Mule deer normally migrated down into these hills for winter habitat. This area is already heavily urbanized and continues to be developed. Mitigation options are limited as areas of intact habitat are nonexistent within the hotspot. A higher proportion of wildlife-vehicle crashes in this area occur with urban deer rather than migratory populations. A goal of any mitigation action employed should not be to build urban deer populations as UDWR is working closely with municipalities, including Provo City, on deer removal efforts to curb urban deer populations. Safety solutions include lighting this area for drivers and deer to better see one another, and other pedestrian type solutions.	
17	I-80 Parley's Summit to US 40	UDOT 2 UDWR NORTHERN
	Mule deer, elk, and moose are all hit in this area and need to migrate seasonally, as well as resident herds that stay year long. This area has been heavily developed with homes on both sides of I-80. There are several existing culverts and interchanges under the highway that may be retrofitted for wildlife, but the high traffic volumes and human use of these structures would probably preclude most wildlife use, and the surrounding human development may also deter use. UDOT built a wildlife overpass over I-80 at Parley's Summit (2018). Initial camera monitoring documented a wide diversity of wildlife species using the overpass, although camera monitoring with scientific analysis of photos for animal use per day, and success and repel rates is not yet underway. UDOT also constructed a joint human and wildlife culvert underpass on US 40 (MP 2), south of the junction with I-80. Cameras placed on this culvert have documented the passage of elk. There are still high wildlife needs for moose, mule deer, elk, and other wildlife to move across I-80. Additional infrastructure needed in this stretch includes: wildlife fence, escape ramps and wildlife underpass crossing structures in protected areas.	
18	I-80 and I-84 Echo Junction	UDOT 2 UDWR NORTHERN
	Mule deer, elk, and moose are here, and hundreds of animals have been killed in this area in the prior several years. The natural topography is a "bowl" which includes: the interchanges and ramps for both I-84 and I-80; an active railroad line and a railroad spur; two frontage roads; a non-motorized trail; Echo Reservoir Dam; the Weber River; and Echo Creek. Around 2012 UDOT replaced the Weber River Bridge on I-80, which was also enlarged to allow terrestrial passage for wildlife to move east and west at this junction. Cramer (2014) monitored this new structure and found some mule deer use. The wildlife exclusion fence only extends out several hundred feet in each direction and does not adequately guide animals to the structure. The frontage road on the west side of the "bowl" has a bridge underpass under I-84, which provides for wildlife movements, although there is no wildlife exclusion	

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	fencing to guide animals to the underpass. The north end of the "bowl" supports an abandoned railroad bridge over I-80. This bridge has chain-link fencing blocking access, but deer and elk tracks observed during the winter months indicate these animals continually approach the crossing. Initial conversations have been undertaken with multiple stakeholders (UDOT, Union Pacific RR, Utah State Parks and Recreation, Summit County, and a Rails to Trails group) on opening up and modifying this bridge for wildlife access. The UDWR owns Henefer-Echo Wildlife Management Area which lies north and northeast of the bowl and provides crucial mule deer and elk winter habitats. This RR bridge should be opened for wildlife crossing, and wildlife exclusion fences, and ramps need to be extended beyond the bowl in each of the three directions to guide animals to these 3 crossing structures.	
19	SR 38 North Brigham City Kotter Canyon to Dry Canyon	UDOT 1 UDWR NORTHERN
	Solutions are difficult to mitigate for mule deer. Electronic variable message boards that warn drivers during migration seasons is the top option. These could be done with existing signs, and with the placement of new electronic variable message boards (permanent or trailer-mounted) notifying drivers of animals on the roadway. General dates for message board placements are October 15 - December 1 and March 1 - April 30. Another alternative would be to install several flashing static "wildlife on roadway" signs in each direction of travel. Human development and topography limit the possible use of crossing structures and fencing. In areas of denser development, installation of street lights may better illuminate animals on the roadway.	
20	I-15 at Summit	UDOT 4 UDWR SOUTHERN
	Mule deer accessed the highway here mainly from the east. In past years, the I-15 wildlife exclusion fence was only on the east side of the highway and was not fully 8 feet tall. The double cattle guards at the interchange were very old and ineffective. Cramer and Flower (2017) studied these guards and found mule deer were accessing the highway at these points from the east. The double cattle guards were replaced in 2017 (approximately) and UDOT placed wildlife fence on the west side of this stretch of I-15, along with two additional double cattle guards on the entrance and exit ramps. Mule deer may need to migrate across the highway at this point and there is evidence of animals moving back and forth over the highway in the past, and they may need a future wildlife crossing structure. UDWR will not likely support a wildlife crossing in this area as everything west of I-15 is agriculture. This section of I-15 is not a major migratory blockage but it does impede gene flow to resident herds in the Southwest Desert unit. The priority for this area is for UDWR to focus on improving seasonal transitional habitat on Cedar Mountain east of I-15 to expand useable habitat for deer going into winter and to protect the minimal existing winter habitat. UDWR has current treatments to address these issues in this area. UDWR and BLM have treated all available winter range on the Parowan front and are now slowly moving up the hills to the east, trying to carve out habitat. Hard winters with high snow are devastating for this herd. Keeping the mule deer alive in the winter on the east side of the highway is the UDWR priority.	
21	US 89 North Kanab – Three Lakes Canyon	UDOT 4 UDWR SOUTHERN
	This stretch of US 89 is the area where deer from the Paunsaugunt area cross US 89 into the Zion Unit. The extent of the mule deer numbers is not known. There is both summer, transitional, and winter habitat on either side of this stretch of highway. Many treatments have	

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	improved habitat west of 89 in this area so the problem may escalate. This stretch is very busy in the summer months for tourist season to Lake Powell, the Grand Canyon, and areas north and south. Also, motorists drive very fast in this area even though the speed limit is 55 miles per hour. More flashing signs may be useful as the traffic is often tourists. Fencing is not a feasible solution unless it was a very focused and well researched stretch of floating fence. That said, a fence will likely just push the problem to the end of the fences. There is no easy solution for this area and a wildlife crossing is likely not realistic unless a crucial stretch to place an underpass is located.	
22	US 91 Smithfield-Richmond-High Creek	UDOT 1 UDWR NORTHERN
	Mule deer is the species of concern. US 91 in this area of Cache Valley is located along the foothills in a rapidly developing area between Logan, Utah and Preston, Idaho. Mule deer move to the west side of the road to access winter habitat, much of which is becoming subdivisions and agricultural fields. Few if any lands are protected across the highway in this valley, thus mitigation remedies would not stay effective unless land was protected on both sides of the highway. The UDWR-owned Richmond Wildlife Management Area is located east of Richmond and provides crucial mule deer winter range. Solutions are difficult. Just as hotspot 19 north of Brigham City poses the same situation of development in mule deer habitat, the solutions are similar: the seasonal use (during migration periods) of existing, or the placement of new electronic variable message boards (permanent or trailer-mounted) notifying drivers of animals on the roadway may have the best success at reducing wildlife-vehicle crashes. General dates are October 15 - December 1 and March 1 - April 30. Another alternative would be to install several flashing static "wildlife on roadway" signs in each direction of travel. Development and topography limit the possible use of crossing structures and fencing. In areas of denser development, installation of street lights may better illuminate animals on the roadway.	
23	US 40 Bridgeland – Antelope Creek	UDOT 3 UDWR NORTHEASTERN
	Mule deer are the main species in this UDWR Northeastern Region's most critical location for wildlife-vehicle crashes. There are large mining trucks and regular vehicles that travel this road and collide with deer. There are agricultural lands on the north side, Uintah and Ouray tribal lands with brush cover to the south, and water resources both north and south. There is a herd of resident deer that is moving back and forth over US 40 to access those resources. There are conflicts with agriculture land resource owners and deer eating crops. Potential solutions include replacement of the Antelope Creek Bridge that would be high enough and wide enough to allow for mule deer and other species to pass beneath on terrestrial pathways beneath the bridge. Fencing of the highway in this area would extend to the east even though there would be little opportunity for wildlife to use existing structures to move beneath the road, they appear to have necessary resources on both sides of the road. Fencing to the west, there are additional opportunities within this hilly area to install wildlife crossing structures. There are two top 10 hotspots for domestic animal crashes to the east of this spot that could be mitigated for with wildlife mitigation.	
24	US 89 Panguitch - Casto Canyon Road to Roller Mill Hill Drive	UDOT 4 UDWR SOUTHERN
	This stretch of road bisects winter, summer, and transitional range between the east Dutton and West Panguitch Lake Wildlife Management Units. This area has thousands of tourist motorists each year going to Bryce Canyon. Flashing signs and other public outreach may help. This area has a mix of all types of habitats and sees migrant deer and resident deer. A	

Rank	Name	UDOT Region UDWR Region
	Potential Species and Mitigation Solutions	
	clear migratory pattern is not known at this time but with mule deer GPS collar data UDWR may learn of a few crucial crossing stretches. Fencing would fragment habitat and may not be economically feasible. No clear mule deer migratory path is apparent so a wildlife crossing structure is not likely to be effective. A million acres of treatments have been completed on the Panguitch side (south and west) of this stretch and may be pulling in animals from the east. There are no easy or inexpensive solutions in this location.	
25	US 89 North of Glendale – Johnson Canyon CR 10, SR 136 north	UDOT 4 UDWR SOUTHERN
	This area is the crossroads of the Panguitch, Zion, and Paunsaugunt mule deer herd units. This area seems to be an active east-west migration route for mule deer between the Paunsaugunt and Panguitch units based on mule deer GPS collar data. This is the stretch from the junction of Highways 14 and 89 south to Glendale. This is essentially all deer summer range but also a high elk-use area. Many mule deer fawns get hit here and people drive very fast on this stretch. There is heavy tourist traffic during summer, which is when most of the deer are around this area. More flashing signs may help motorists to slow down or be cautious, or a reduction in the speed limit to < 50 miles per hour. This is also the stretch of road that sees consistent coal truck traffic from the Alton Coal mine. Fencing and wildlife crossings are likely not feasible and would come at the cost of fragmented habitat. There are no easy answers in this location. A Banff style overpass would be the best solution if costs were not an issue.	

3.5 Summary

The data presented on all animals, wildlife, and domestic animal-vehicle crashes illuminate the extent of the challenge: Five percent on average of all crashes each year are with wildlife, and the cost to the Utah public is over $133 million annually when UDOT 2019 crash costs are used to calculate the value. The mapping of these reported crashes and reported carcasses revealed the extent of the animal-vehicle crash problems across the state and within each UDOT and UDWR region. When wild animal habitat maps are added to the top 25 hotspots maps of animal and WVC on highways, the resulting map assists the reader in starting to identify potential wildlife-vehicle conflict areas. The results of this research will assist UDOT and UDWR in working together in a strategic manner to identify, plan for, and fund future mitigation in top priority areas.

4.0 CONCLUSIONS

4.1 Summary

This research identified the overall state of wildlife-vehicle conflict in Utah based on crash and carcass data analysis and modeling of crash and carcass locations. The cost of WVC and domestic animal-vehicle crashes, based on UDOT 2019 crash values was established; over $133 million annually. The top 25 hotspot areas across Utah for animal, wildlife, and domestic animal-vehicle conflict were identified. Recommendations were made for future actions on the top 25 animal-vehicle crash hotspots on highways.

4.2 Findings

The primary objective of this study was to conduct a repeatable, thorough statewide GIS analysis of wildlife-related crash data, carcass data, and large wildlife species' occurrence and movement data to help UDWR and UDOT delineate and prioritize WVC hotspot areas on Utah roads. This objective was met with the results of the research presented here, and a companion guidebook that will assist UDOT and UDWR in future analyses of potential wildlife-vehicle conflict hotspots. With this information Utah can prioritize wildlife mitigation actions, and potentially avoid further transportation development in certain areas, knowing that all roads were analyzed in a standardized repeatable process. The report results can help the two agencies have a concerted front in presenting the scientifically determined top-ranked WVC locations to the public and other stakeholders.

Major findings are presented below, with blue hyperlinks embedded in the sentences that the reader can click on and the document will present the section where the information is first introduced.

4.2.1 Animal-Vehicle Crashes Can Be Serious and Deadly

From 2008 - 2017 there were 142 serious reported crashes, and 20 deadly crashes for motorists involved in accidents with wildlife. There may have been even more deadly crashes when motorists swerved to avoid an animal and died without the reporting officer knowing why the motorist crashed. These serious and fatal crashes were dispersed throughout the state, north to south and east to west. The serious crashes ranged from eight to 19 per year, and the fatalities ranged from zero to five per year, with an average of 2.0 fatalities from wildlife crashes, and 2.9 fatalities from overall animal crashes annually. Perhaps as these numbers come to light, agencies and the public will start to understand the potential severity of accidents with wildlife in the state.

4.2.2 Wildlife-Vehicle Crashes Are Lower Than True Number of Collisions

Wildlife-vehicle crashes are 5.1 percent of all reported crashes. This is a large underestimate of the total number of wild animals killed on Utah roads. Olson (2013) collected large mammal carcasses along the road and in the right-of-way (ROW) of interstates, U.S., and state highways in Utah, and found there were 5.26 times more large animals collected than reported in the crash database. If this "Olson Factor" is applied to the annual average of 2,775 wild animal reported crashes, there are an estimated 14,597 large wild animals killed on Utah interstates, U.S. Highways, and State Highways each year. This number does not include roads administered by other entities such as counties and municipalities, and roads on public lands such as U.S. Forest Service and Bureau of Land Management Roads, or the animals that leave the ROW and die away from the road area. The reported crash values are used in this research because they are the most consistently collected collision data in Utah, and other U.S. states. The crash numbers and values per mile per year allow for comparisons among places in Utah so top-ranked locations can be identified using the same standards statewide. As carcass data collection is improved in Utah over time, there will be more accurate estimates of the number of large mammals killed on Utah highways, and thus, potential solutions can be identified knowing the extent of those collisions and the species involved.

4.2.3 Wildlife and Domestic Animal-Vehicle Crashes Cost Utah Over $138 Million Annually

The researchers used the UDOT 2019 crash cost values to evaluate the extent of the wildlife and domestic animal-vehicle crashes for each year of the 10 years between 2008 – 2017. Annual average societal costs of WVC are over $107 million, and domestic animal-vehicle crashes are over $25 million, for a total societal cost of $133,282,300 annually. The value to Utah citizens of the animals killed is not included in this average number. When CDOT values (Kintsch et al., 2019) are used for the individual deer potentially killed in each crash reported with wildlife, the value of the mule deer killed to society was on average $5,680,116 annually. When these values were added to the crash costs, the total value of WVC and mule deer lost in those crashes is $113,302,916, and $138,962,416 for all animal crashes annually. This value does not include values for other wildlife species such as elk, moose, pronghorn antelope, or bighorn sheep. It also does not take into account the 5.26 more large wild animal carcasses found on the side of Utah highways than are reported in the crash data (Olson, 2013). The unaccounted-for animals that were not included in the crash analysis would increase the total of wildlife value by 5.26, or $29,877,410.

These costs are an important part of the collaborative evaluation of the problem of WVC and conflict and could be used in benefit-cost analyses of the animal-vehicle crash problems.

4.2.4 Wildlife-Vehicle Crashes in Utah Are Among the Highest in the West

Utah has the sixth highest number of reported WVC of the 15 states surveyed in the west, and ranks seventh for total cost of crashes (see Table 10 for comparisons among 15 states). More populated states of Texas, California, Arizona, and Colorado have lower numbers of crashes, but the crash costs are higher than Utah's. This is probably because the types of crashes are more severe than those reported in Utah. On another note, Montana has just one million people, which is one-third of Utah's human population, and a very comparable number of wildlife-vehicle crashes. However, their costs are far higher than Utah's: Utah's cost is approximately $83 million per year (using the data presented in Table 10), and Montana's is over $107 million. It appears other states' reported crashes with wildlife can cost more than Utah's for reasons varying from crash severity reporting, to the presence of moose and elk, which can cause far greater

damage to vehicles and human occupants in those vehicles involved in crashes than collisions with deer. In the end, the trends and data comparisons among states do not follow clear trajectories in numbers and costs and in relation to the human population. It can be said, however, that wherever there are large numbers of humans living and traveling near wildlife and especially mule deer habitat and winter range, there are higher probabilities of wildlife-vehicle crashes.

4.2.5 The Wasatch Front and Back Counties Have the Greatest Density of Animal-Vehicle Crashes Yet Lower Percentages of the Total Reported Crashes

Analyses of the counties with the greatest number of wildlife and domestic animal-vehicle crashes demonstrated that areas where large numbers of motorists drive in areas with wildlife, largely in the mountainous regions near Salt Lake City, there is the greatest problem of wildlife, domestic animal, and vehicle crashes (Table 5, Figure 8). Another way to look at the crash data is to examine what percentage of a county's total crashes were due to wildlife and domestic animals (Table 5). The map in Figure 7 is very instructive in demonstrating the high percentages of crashes that occur with animals in the southern counties, in UDOT Region 4.

4.2.6 The UDOT and UDWR Regions with the Greatest Number of Hotspots

The top 25 hotspots for animal-vehicle crashes and WVC on highways fall most predominantly within UDOT Region 4 (eight animal-related crash hotspots, eight wildlife hotspots), and UDOT Region 3 (seven animal related and 10 wildlife-related crash hotspots). The UDWR regions with the highest number of hotspots are the Central Region (11 animal-related crash hotspots, and 10 wildlife crash hotspots), and the Northern Region (six animal related hotspots and six wildlife hotspots). UDOT Region 3 and UDWR Central Region are where the Wasatch Front and Back areas have increasing human populations settling and driving in wildlife's winter and summer habitat.

4.2.7 UDOT Regions Vary in Wildlife Crash Numbers and Percentages of Regional Total Crashes

While the Wasatch Front and Back counties have the greatest numbers of wildlife- and domestic animal-related crashes, the UDOT regions in that area have significantly different portions of their total crashes that are related to wildlife as compared to southern and northern UDOT Regions. In UDOT Regions 2 and 3 (the Salt Lake City-Wasatch Front area), just two to seven percent of total crashes are with animals. Alternatively, UDOT's Region 4, based in Richfield, has both the greatest total number of animal-related crashes and 16.8 percent of its total crashes involving animals. It also has over one-half of the state's land area and would be expected to have higher numbers of crashes for the additional miles of roads in Region 4. These values can help UDOT visualize where the greatest efforts to mitigate wildlife and domestic animal-vehicle crashes should take place.

4.2.8 Local Road Hotspots Did Not Have as High Rates of Crashes as Highways

If the top 25 animal and wildlife vehicle crash hotspots on local roads are examined, it becomes quickly evident that human development in the foothills of the mountains brought large numbers of vehicles to mule deer, elk, and other wildlife winter range (Figure 20, Table 13). It is also important to note that the rate of reported crashes with animals is far lower for local roads than for highways. The lowest rate of crashes per mile per year on highways for animals or wildlife crash top 25 hotspots was 2.16. The highest rate of crashes per mile per year on local roads for animals or wildlife hotspots was 1.19.

4.2.9 Crash Reporting Forms Will Need to Include a Menu with Species' Pull-Down Lists

The crash reporting system in Utah only allows officers and deputies reporting the crash to indicate an animal was wild or domestic. The query of the narratives helped provide some species-specific data, but it was less than accurate in areas where the human population was more dense and had businesses, roads, neighborhoods, and other entities with names of animals that were indicated by the reporting officers in the narratives. To best address a problem with animals near and on roads, UDOT, UDWR and researchers will need to know the animals

involved. The solutions to keeping cows off roads are very different than keeping wild elk off roads. Mitigation solutions are very specific to the species of animal, and UDOT can save precious time and taxpayer dollars if they apply the correct solution to the problem area. UDOT will need to work with Utah's Department of Public Safety to add a minimum of 10 species to a drop-down list of potential animals involved, as Nevada has for their reporting officers. If the reporting officer is not sure of the animal, there could be a section where a photo of the animal's carcass could be photographed and uploaded; in fact, this could be a requirement, which would allow researchers to query and review all reported crash records for the species' identification, gender, and size.

4.2.10 Mule Deer Densities and Traffic Volumes Are Somewhat Predictive of Problem Areas

The researchers mapped the several dozen UDWR mule deer management units (Figure 14) and rated the units in relation to the deer numbers. TAC team members were interested to see if there appeared to be a correlation with the mule deer unit deer numbers and the AADT of the roads that bisected them. These two data sets were brought together (Figure 15). The one area where there were higher concentrations of deer and higher AADT roads was the area where Utah and Wasatch counties come together, east of I-15, west of US 40, south of I-80. These areas also agree with the maps of animal and wildlife-vehicle crashes on highways and local roads. Crash data confirmed there was a relationship between mule deer numbers and AADT as the panel members correctly predicted. The researchers just did not have a way to quantify and test the spatial accuracy of these theories in the areas of interest.

4.2.11 Carcass Maps Demonstrate the Lack of Reporting in the Southern Half of the State

The carcass data maps on highways and local roads underscore the importance of carcass data collection in the absence of crash reporting with a species pull-down menu for reporting officers. The crash data can only be generally applied when examining the problem locations for wildlife-vehicle conflict. The lack of carcass hotspots in the southern half of the state, except for the Monticello area, indicate that the contractors there are not reporting carcasses as often as the carcasses are occurring. In the one exception, the Monticello area, the contractor collecting carcasses on US 191 and reporting carcass data provides information to such an accurate degree

that the carcass numbers and hotspot ranking within the state closely match the crash data hotspots. If carcass collecting contractors are not held accountable for their lack of reporting, the state cannot accurately determine the problem animal species, and thus mitigation solutions, in all hotspots.

4.3 Limitations and Challenges

The research results are only as good as the data they are dependent on, the modeling parameters used, and a wide understanding of the wildlife-vehicle conflict areas across Utah. Numbers, rates, and percentages do not tell the whole story. The ten years of crash data used in the analyses span periods of time when wildlife crossing structures were created along with wildlife exclusion fence and escape ramps in some of the top 25 crash hotspot areas, such as US 189 Deer Creek State Park. Thus, to truly understand each hotspot, a detailed crash analysis pre- and post-construction of wildlife mitigation is necessary, along with looking at mule deer population trends, traffic volumes, vehicle miles traveled, and other factors.

This research was meant to compare areas across the state to prioritize where UDOT and UDWR will need to concentrate future analyses and actions. The reader is advised to look into many more specific details of areas of concern before making conclusions about specific sites and the efforts to mitigate roads for wildlife in Utah. The hotspot modeling identified general areas of hotspots within the parameters coded in the models. These facts, combined with the coarseness of the scale for the entire state, precluded the results from being specific enough to dictate exact locations for potential mitigation. In fact, the mile posts of the hotspots were intentionally not given in this report so agency personnel are more encouraged to look at the problem hotspot areas more holistically rather than focusing on the statistically highest accident road segments of an overall area.

5.0 RECOMMENDATIONS AND IMPLEMENTATION

5.1 Recommendations

The researchers present recommendations for future research and actions, on the part of UDOT and UDWR. These fulfill the Task 5 deliverable. The researchers, in conjunction with UDOT and UDWR, held a workshop on the research results and next steps, on November 26, 2019. This fulfilled Task 6. Several recommendations from the participants were included in this chapter, as noted.

5.1.1 Continue Work on the Identification of Wildlife-Vehicle Conflict Hotspots

This work in ranking of hotspots for wildlife and domestic animal-vehicle crashes is a first step, but is not the final step in bringing together the full spectrum of ecological and safety data to identifying top areas to mitigate roads for wildlife in Utah. UDWR can now bring in habitat maps and GPS locational data on mule deer and other species of wildlife movements to inform where and what mitigation strategies might help reduce conflict, which includes the potential for wildlife to be blocked from necessary movements across habitats, as well as the risk of crashes with wild animals. This can be done in a quantifiable manner as was done for Nevada (Cramer and McGinty, 2018) and Idaho (Cramer et al., 2014).

5.1.2 UDOT and UDWR Shall Develop GIS Story Layers for Planning and Operational Groups within UDOT

The Planning Division and the Operations Group (including Traffic and Safety Division staff) are the key positions within UDOT to help determine the scope of future projects and are the early decision makers for allocating funds for projects. The advisory panel for this project suggested these are the best people for reviewing the problem of wildlife-vehicle conflict in potential future projects, and are in positions to help allocate funds for wildlife mitigation in those projects. These decision makers will need story maps in a GIS platform, available in the online UDOT ArcGIS website, UPLAN. UDWR and UDOT will need to work together to take

the GPS collar data from mule deer herds and other species, and place animal movement data in a GIS layer along with other information into UPLAN. From this information, stories could be gleaned, and planning and operational group personnel could understand and plan for those animal movements across roads. This approach would help to proactively mitigate for wildlife in areas where they are crossing. It will help the transportation planning process move from a reactive position from looking at past crash data, and evolve into a more proactive position to look at where and when wildlife will possibly be a threat to motorists, and make informed decisions on solutions to the potential for wildlife-vehicle conflict.

5.1.3 UDWR Personnel in Specific UDOT Regions Reach Out to Program Managers

The UDOT and UDWR personnel who participated in the final workshop of this project set a course to have members of the newly developed Wildlife Conflict Prevention Steering Committee and others meet individually with their respective UDOT Region Program Managers. The objective of these and future meetings would be to inform Program Managers of the overall problem of wildlife-vehicle conflict, describe wildlife monitoring efforts and stories of animals moving across that UDOT region, and identify top locations for terrestrial and aquatic wildlife mitigation. Program Managers have greater ability to include the consideration of wildlife and aquatic wildlife in transportation planning long before the development of specific projects. This early consideration will help allocate funds for these mitigation efforts. This approach will help efforts for ecological considerations far greater than approaching project managers after a project has already been scoped and funded.

5.1.4 Include Analyses of Animal-Vehicle Crashes and Carcasses in Traffic Safety Crash Analyses Statewide and on a Project-by-Project Basis

Traffic and Safety personnel are key leaders in analyzing crash and carcass data but they are not the only ones. Project Managers, Planners, and Environmental staff could all be looking at the maps created in this project and overall crash and carcass data to identify areas of past problems with wildlife. These data analyses should become steps in these UDOT positions' descriptions and even their manuals.

An example of how this approach has been codified can be taken from Texas. The Texas Department of Transportation (TxDOT) commissioned a study to develop recommendations for changes to TxDOT manuals for multiple divisions. This quote is taken from that study's abstract: "*This work recommends specific language modifications to 18 TxDOT manuals and provides a new manual on wildlife crossing structures. The project findings demonstrate that data-driven, carefully planned, and well-designed wildlife crossing structures can enhance traffic safety significantly, are cost-effective across much of the TxDOT network, and help ensure that TxDOT can play a meaningful role in preserving human and animal lives and property for the benefit of current and future Texans.*" (Loftus-Otway et al., 2019).

5.1.5 UDOT Will Continue to Work with Counties and Other Entities to Find Solutions and Partnerships

UDOT works with UDWR, counties, the Bureau of Land Management (BLM), the U.S. Forest Service (USFS), across state lines with Arizona Game and Fish, sportspeople's organizations, and public citizen nonprofit groups to plan for, fund, and maintain wildlife mitigation across the state. This will increasingly become the norm for wildlife mitigation projects. With the results of this study, UDOT and UDWR can raise additional support for future mitigation projects, as other entities learn of the extent of the wildlife-vehicle conflict problem in their jurisdictions.

5.1.6 Include Species Pull-Down List on Crash Reporting Forms

UDOT and UDWR should work with Utah Department of Public Safety to include species pull-down menus on crash reporting forms. In Nevada, the following species list is included in reporting officers' forms (from Cramer and McGinty, 2018):

- Dog/Coyote
- Burro
- Cattle
- Deer
- Horse
- Bear

- Antelope
- Bighorn Sheep
- Elk
- Other Animal

In Utah, this list would also need to include moose.

5.1.7 Terminate Non-Compliant Carcass Collector Contractors

The carcass mapping demonstrated the mismatch of crash data hotspots with carcass data hotspots for the majority of the southern half of Utah, with the exception of the Monticello area. For years the carcass contractor(s) in southern Utah have not reliably reported accurate carcass data information. The identification of species collected along the road is crucial to mitigation solutions. It may also be crucial to funding for future wildlife mitigation projects. The carcass information is too important to be lost by non-compliant contractors.

5.1.8 Adapt UDOT's Website for Click and Fix to Upload Wildlife Data and Push to Specific Personnel Positions in UDOT and UDWR

UDOT has a user-friendly public phone and computer application for members of the public to report problems in UDOT's transportation system. This can include things as varied as crashes, potholes, and dead animals. Participants in the workshop noted that if this system could be adapted for reporting live as well as dead animals, the data could be immediately sent to UDOT and UDWR personnel for "fixing." Utah would have a way for citizens and visitors to participate in reporting when and where animals were crossing or near the road, alive, and where their carcasses were. See: https://www.udot.utah.gov/main/f?p=100:pg:0:::T,V:376.

5.1.9 UDWR Create Additional Wildlife Movement Maps

As UDWR continues to collect GPS collar data from wildlife species, it is important that habitat and movement maps be shared with UDOT to help to proactively deploy both short-term and long-term solutions to potential wildlife-vehicle conflict in areas where wildlife are known

to move across roads. These maps could be loaded to UPLAN in a specific wildlife and safety portion of the site.

5.1.10 Use GPS Collars on Mule Deer and Other Ungulates that Can Alert Driver Warning Systems

UDWR GPS collars on wildlife could communicate to UDOT and UDWR in real time when and where animals are moving in their seasonal migrations near roads. In turn, the collar data could inform warning devices along the roads to alert drivers in the area that wild animals are about to cross the road. UDOT and UDWR could use technology that generates real-time notifications for when herds of deer and elk are crossing the road, and that in turn would signal a tracker beacon that would turn the driver warning system on. This would be a very specific mitigation timed to meet seasonal movements of animals.

5.1.11 Inform UDOT and UDWR Regional Staff of These Research Results

This research was conducted at a statewide level with results also presented for regional UDOT and UDWR staff to see the hotspots that lie in their regions. The researchers encourage wide dissemination of this report and links to the future UPLAN page where personnel can download the geo-referenced data layers.

5.1.12 Memorandum of Agreement or Understanding Between UDOT and UDWR

The collaborative work that UDOT and UDWR have performed over the decades of creating wildlife mitigation will continue in the future. An efficient approach to the multiple efforts across the state would be to create a mechanism for personnel from both agencies to meet regularly and exchange ideas and updates with one another. In 2019, UDOT and UDWR personnel worked together to create the Interagency Wildlife Conflict Prevention Team, a collaborative steering committee between UDWR and UDOT. A Memorandum of Agreement or Understanding between the two agencies on how they will work together, share data, and assign responsibilities would codify the collaboration for future personnel in the agencies. Idaho's Transportation Department and Fish and Game Department created a similar MOU after the

results of that state's prioritization of wildlife-vehicle conflict hotspots was published (URL: https://islandparkus20.com/wp-content/uploads/2017/01/IDFG-ITD-MOU-7-15-15.pdf, Cramer et al., 2014).

5.2 Implementation Plan

This implementation plan identifies entities responsible for conducting the 12 recommendations for implementation in section 5.1.

5.2.1 UDOT Responsibilities and Actions

- It is recommended that UDOT work with the Department of Public Safety for immediate inclusion of species pull-down menus in crash reporting software, and work with Public Safety to provide the opportunity to include photos of animals killed in reported crashes.
- UDOT should terminate the carcass collection contracts of contractors who are not reporting carcasses in areas where the crash data indicate there are problem hotspots in numbers at least close to equivalent to crash reports in those areas. All future carcass collector contracts should contain clauses that if spatially and temporally accurate data are not collected, contracts will be terminated.
- UDOT Traffic and Safety should include the type of analysis that was conducted for this research in their safety data analysis each year, and potentially include UDOT GIS Services personnel in regular mapping as was done with this research.
- UDOT Planning should include steps to consider these data and work with the future GIS layers uploaded in UPLAN as part of planning every transportation project.
- UDOT Planning and UDOT regional staff should use the results of this research to include all top 25 animal and wildlife-vehicle crash hotspots on both highways and local roads in future transportation plans and projects.

5.2.2UDWR Responsibilities and Actions

- It is recommended UDWR create additional wildlife movement maps, for example Brownian Bridge models created by the Migration Initiative's GPS collar data for various areas of the state, that can be combined with this research's crash maps to identify potential areas where wildlife-vehicle conflict can be mitigated in either standalone projects or as part of UDOT projects in the long-range plan and STIP. These maps should

be made available to UDOT in a timely manner so UDOT staff can plan best for mitigating potential wildlife-vehicle conflict at the state and regional level.
- The UDWR wildlife maps can be combined with these research results to further identify top wildlife-vehicle conflict areas based on not only past crash data but also wildlife occurrence information.

5.2.3 UDOT and UDWR Collaborative Actions

- Both UDOT and UDWR should take the results of this research to their headquarters and regional staff to inform them of important areas of wildlife-vehicle conflict and to strategize on potential actions in the short and long term.
- UDOT and UDWR should develop or further develop an existing Memorandum of Understanding to create this type of analysis every year or every five years, and to meet quarterly every year to discuss opportunities to include wildlife considerations in the transportation processes and upcoming projects.

In summary, this research assists Utah agencies in becoming more proactive in mitigating wildlife-vehicle conflict. It is a phase along a continuum of work that Utah has conducted for decades and will continue to bring to fruition in the future as the many partners work together to make Utah roads safer for motorists and wildlife.

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APPENDIX A. MODEL FACTOR SELECTION NOTES

This appendix provides details on the selection of specific quantitative values for the OHSA.

By Emanuel Vásquez and P. Cramer

Methods for Selecting the Distance Band and Road Segment Length for the Optimized Hotspot Analyses (Getis-Ord Gi*)

The distance band is an important parameter that defines the scale of analysis in the OHSA tools in ArcGIS. When predicting clustering of events such as animal-vehicle crashes, the OHSA tools takes a distance unit as input parameter that gets translated into the cell size that will act as capture area to determine the density of events or clustering. The appropriate distance band can be chosen in conjunction with the following tests.

We used the Spatial Autocorrelation tool to calculate z-scores for the animal-vehicle crash (AVC) data. A z-score is a statistical evaluation of the data to determine if the features within a set range are significantly clustered or dispersed. We recursively ran the tool for the AVC dataset (Figure 39) and the subset of AVC that intersect with minor roads (Figure 40). Figures 39 and 40, below are plots of z-score values for each of the datasets.

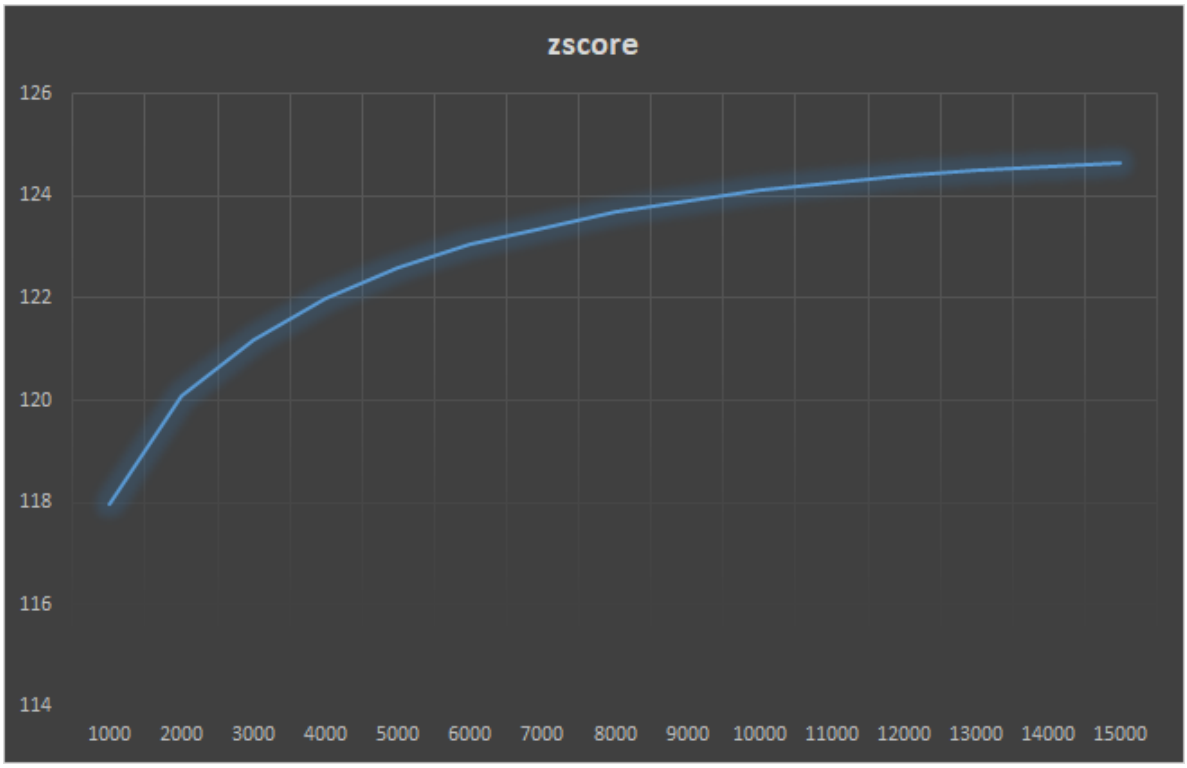

Figure 39. Z-Scores for AVC Dataset.

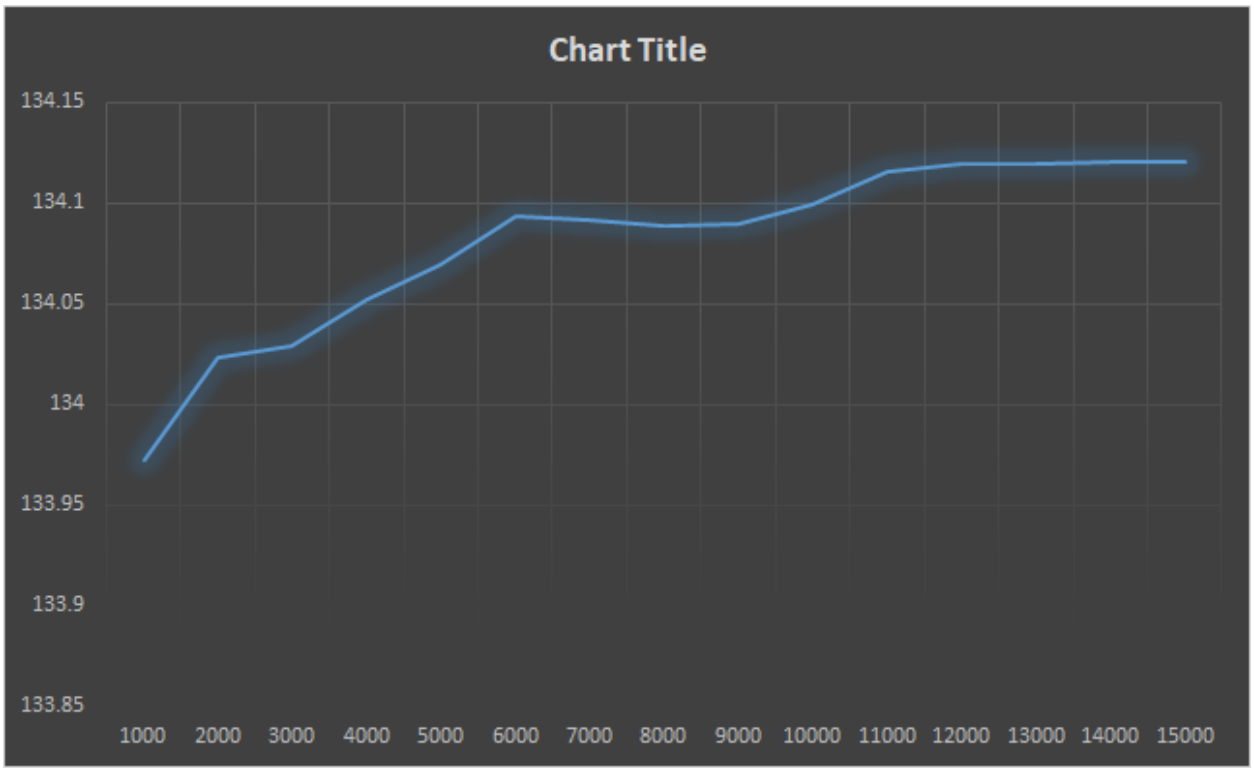

Figure 40. Z-Scores for AVC Subset (AVC that intersect with minor roads).

According to the consulted documentation, (https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/spatial-autocorrelation.htm and https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/what-is-a-z-score-what-is-a-p-value.htm)
we concluded that 2,000 meters is an adequate value to be used as the DISTANCE BAND in the OHSA tool in ArcGIS. As displayed, in both graphs, z-core values at 2,000 meters are located at the breakpoint where z-core values tend to increase. Our understanding is that positive values and the tendency for increased z-score values confirms that clustering of the data exists.

Based on the results of our spatial autocorrelation test, we did some adjustments to the OHSA tool and incorporated the new value of 2,000 meters in the DISTANCE BAND parameter. We also ran three different iterations using the 0.1, 0.25, and 0.5-mile aggregation polygons. Overall results obtained after running the OHSA tool showed that the prediction of hotspots tended to over-estimate some areas. However, we did some further exploration of the attributes table in the resultant hotspots layers and found that the OHSA tool conducts a count of incidents inside each aggregation polygon, hence it is possible to further refine the results of the OHSA. See figure 41 below, which shows a BEFORE-AND-AFTER data refinement.

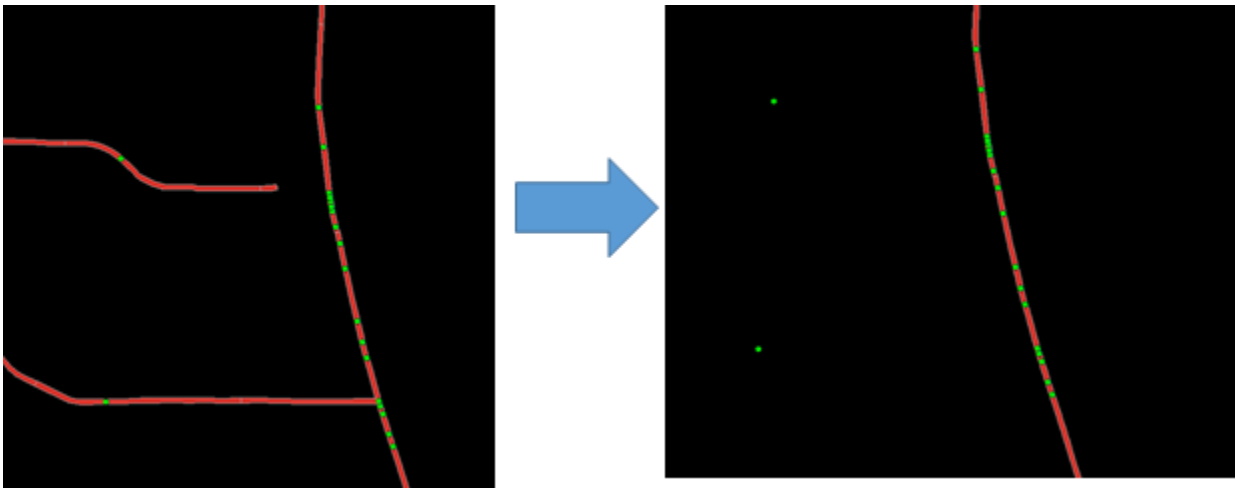

Figure 41. Results of OHSA Model with a 2,000-meter distance band (left) and refinement of results after filtering hotspot by incident count (right).

We also compared the OHSA results for each of the aggregation polygons (0.10, 0.25, and 0.50-mile) and concluded that the 0.5-mile buffer as aggregation polygons yielded the best results. The main reason is that when using a smaller size aggregation polygon (i.e., 0.10 and 0.25 mile) when applying a refinement of the OHSA results, we observed that some hotspots tend to disappear. This is due in part to breaking the roads into smaller and smaller polygons which then have less crashes in each polygon to the point there are many polygons with zero crashes in them, thus they tend to overwhelm the prediction of hotspots resulting in less accurate results.

The figures below show how the size of the aggregation polygons has an effect on the results.

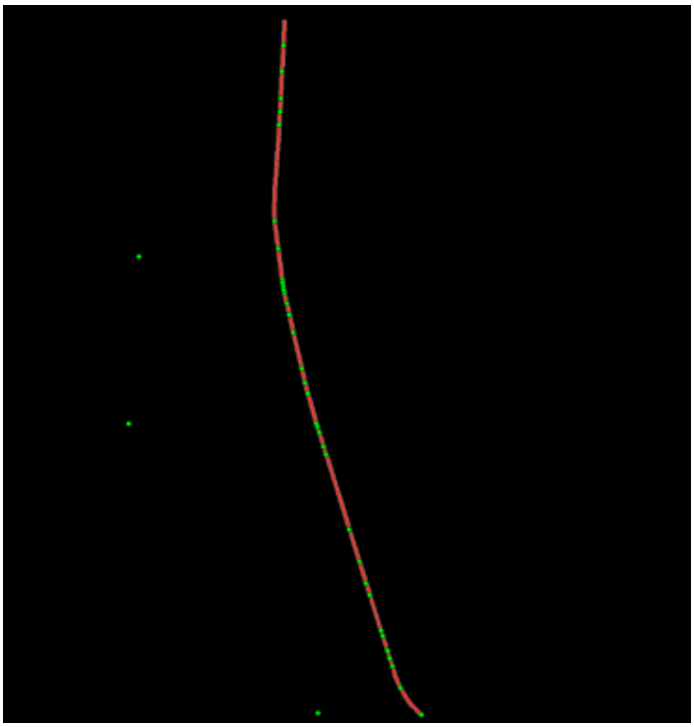

Figure 42. OHSA 0.5-mile aggregation polygons: Filtered results show a total of 5 polygons ranked as a hotspot with an incident count >= 5.

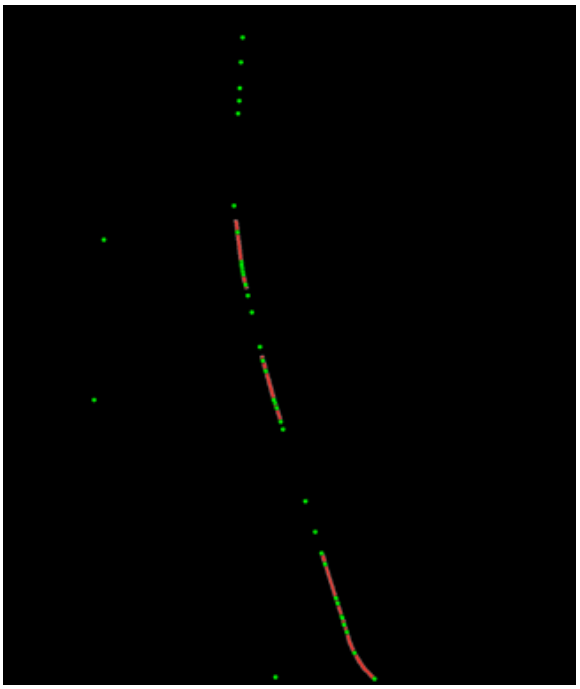

Figure 43. OHSA 0.25-mile aggregation polygons: Filtered results show a total of 3 polygons ranked as a hotspot with an incident count >= 5.

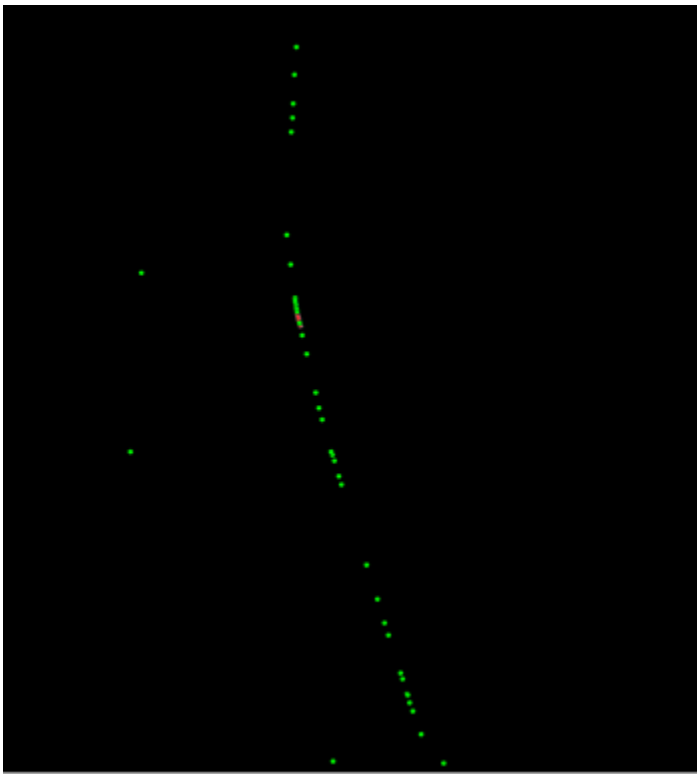

Figure 44. OHSA 0.1-mile aggregation polygons: Filtered results show a total of 1 polygon ranked as a hotspot with an incident count >= 5.

APPENDIX B. MAPS OF SPECIES OF WILD AND DOMESTIC ANIMALS' CARCASS LOCATIONS MERGED WITH CRASH DATA FROM NARRATIVES

Crash Narrative Animal Locations and Carcass Locations Maps for Each Species

The crash data narratives were queried for animal names that may have been involved in the crashes. The resulting data points for those crashes with specific species were plotted for each species along with the carcass data points (2009 - 2018) for that species. The resulting maps are presented below.

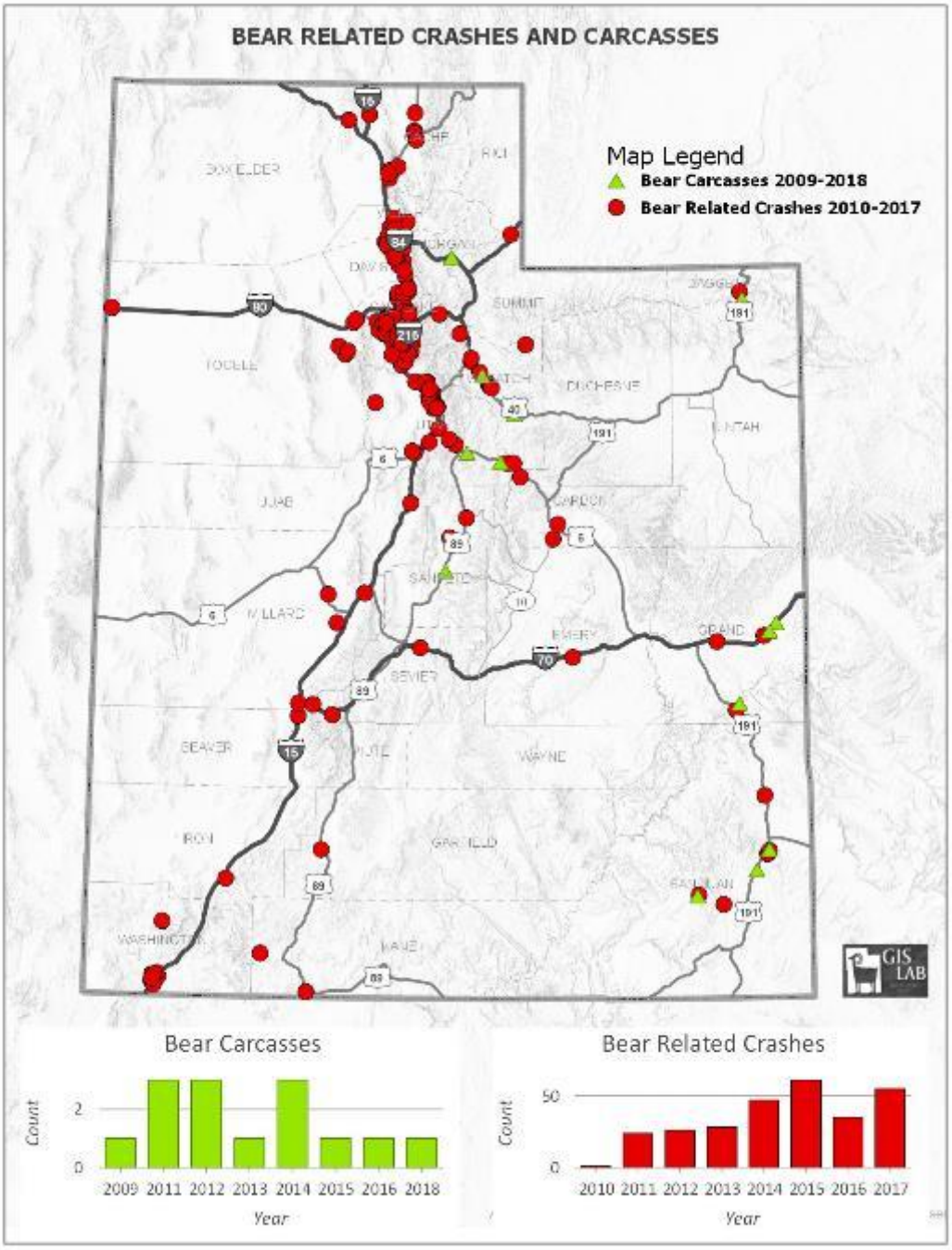

Figure 45. Bear Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Bear in the Narrative 2010 - 2017.

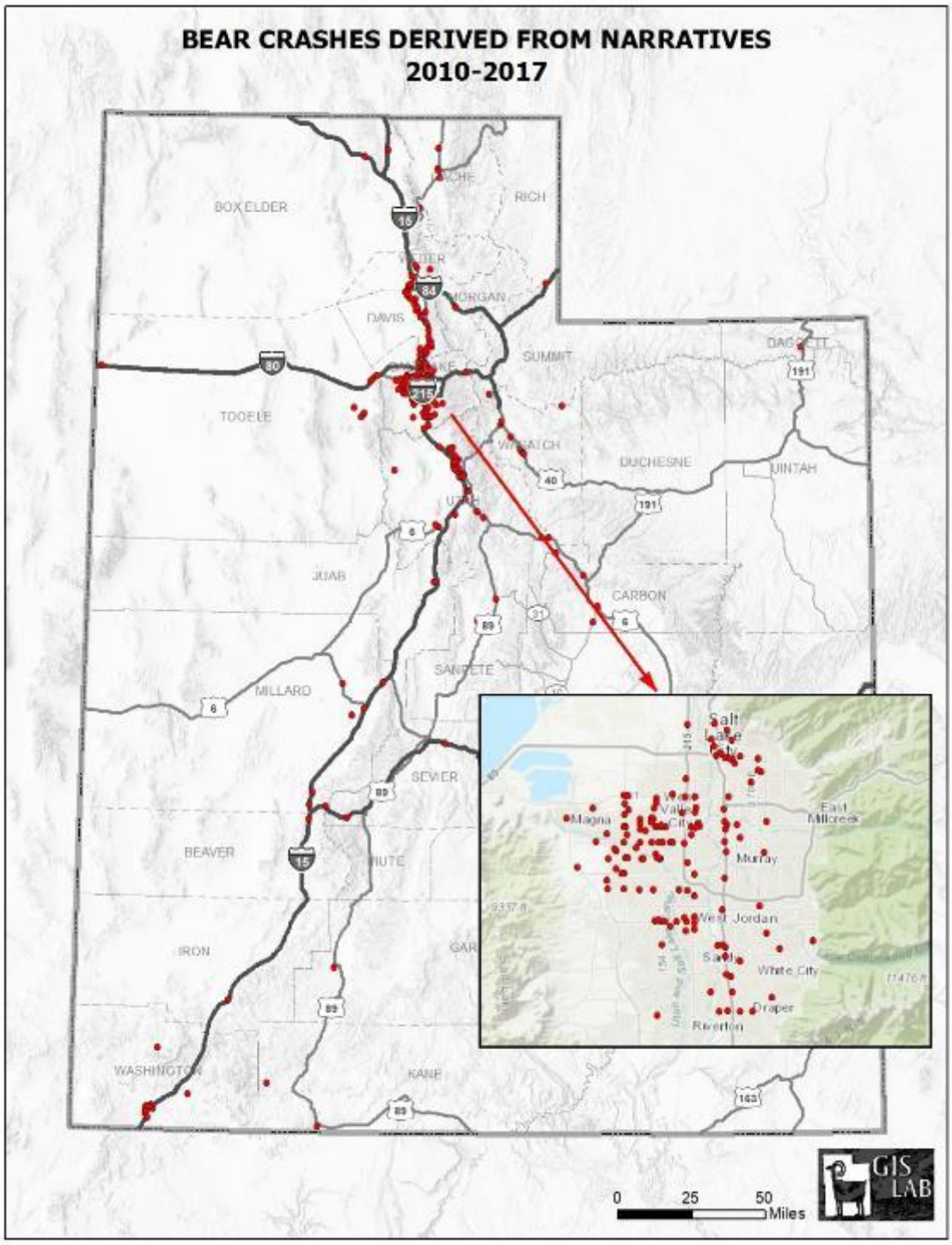

Figure 46. Map of Crashes from 2010 - 2017 Where the Word Bear was Used in the Narrative, With Inset of Crash Locations in Salt Lake City Area.

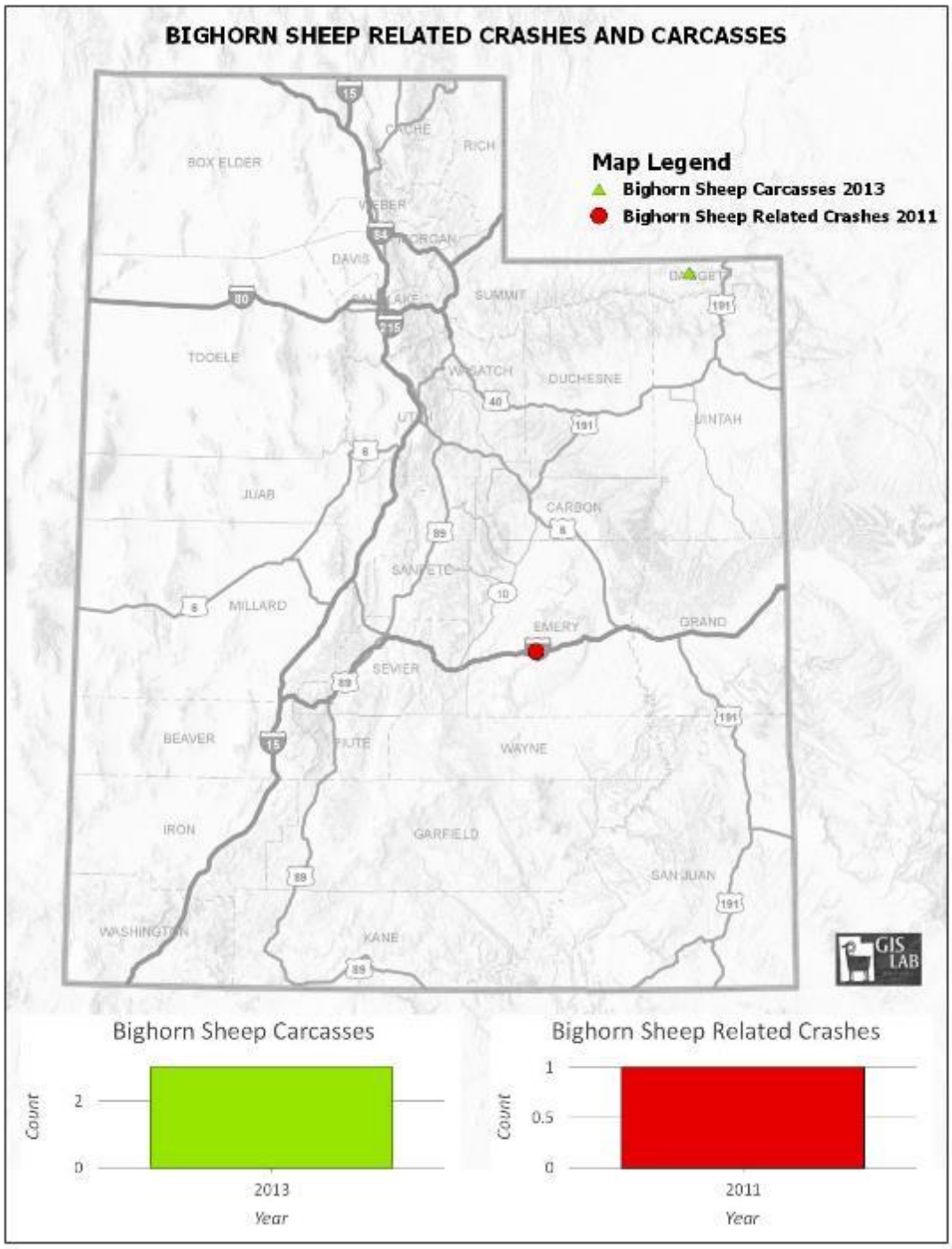

Figure 47. Bighorn Sheep Carcasses Reported from 2009 - 2018 and Reported Crashes with the Words Bighorn Sheep in the Narrative 2010 - 2017.

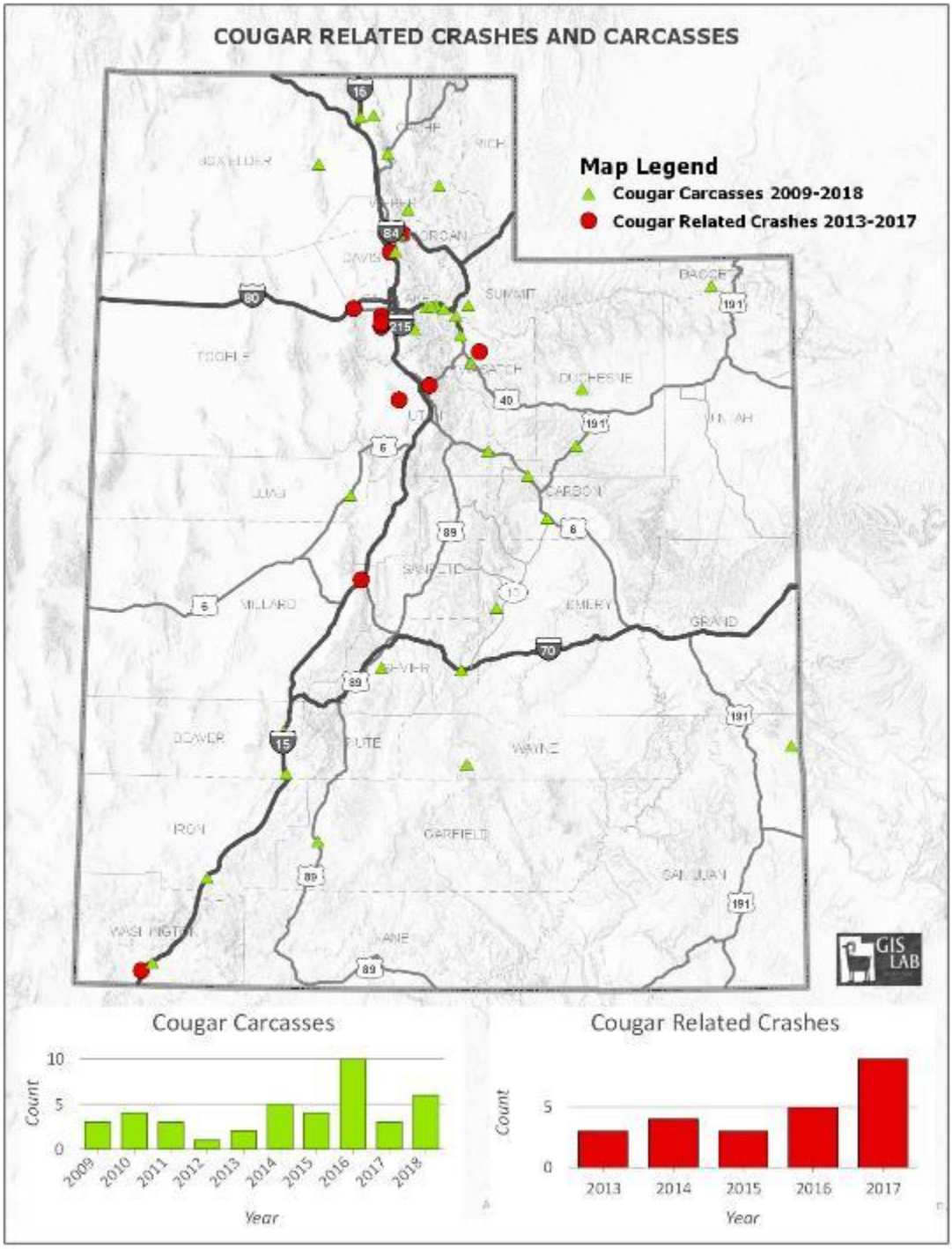

Figure 48. Cougar (Mountain Lion) Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Cougar in the Narrative 2010 - 2017.

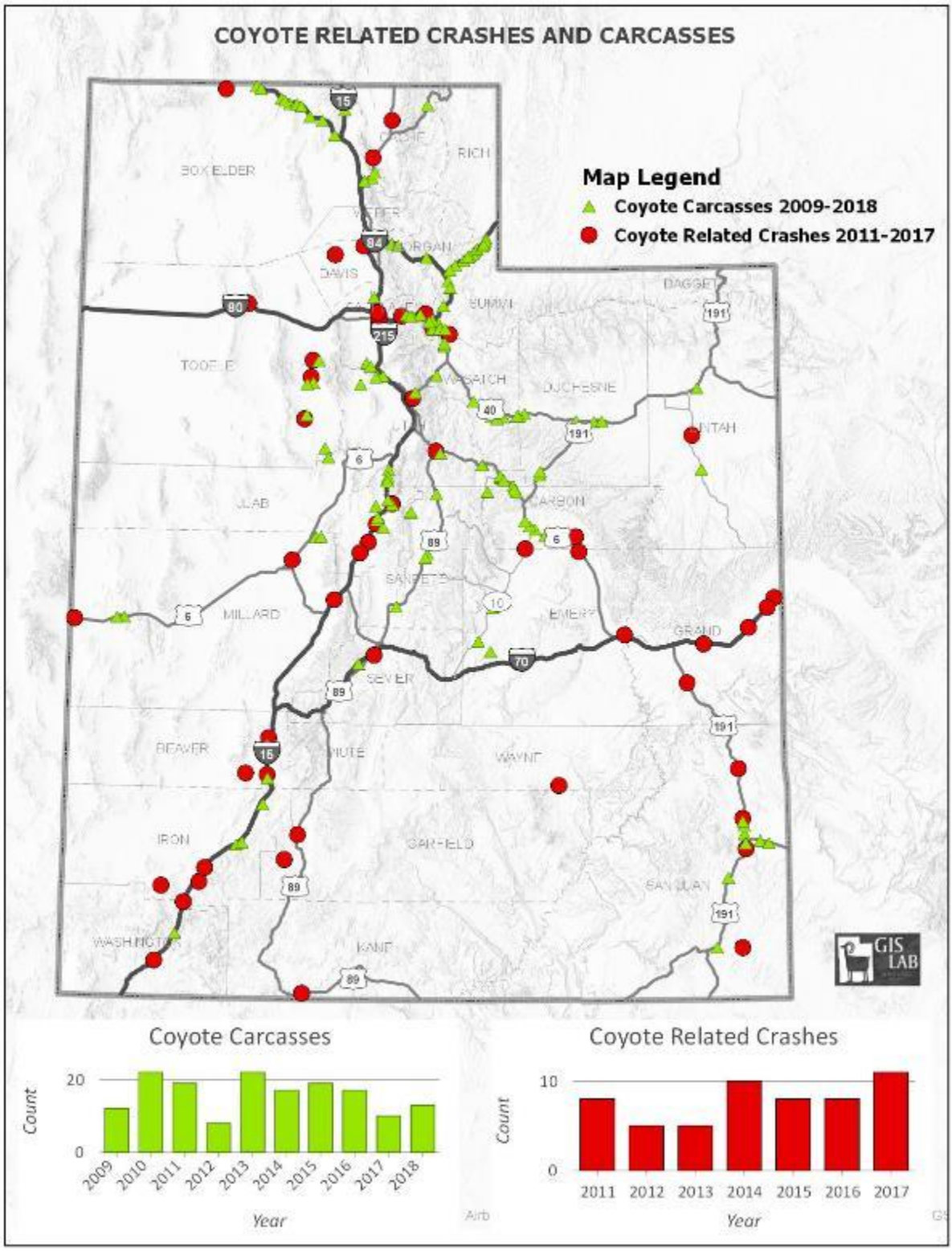

Figure 49. Coyote Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Coyote in the Narrative 2010 - 2017.

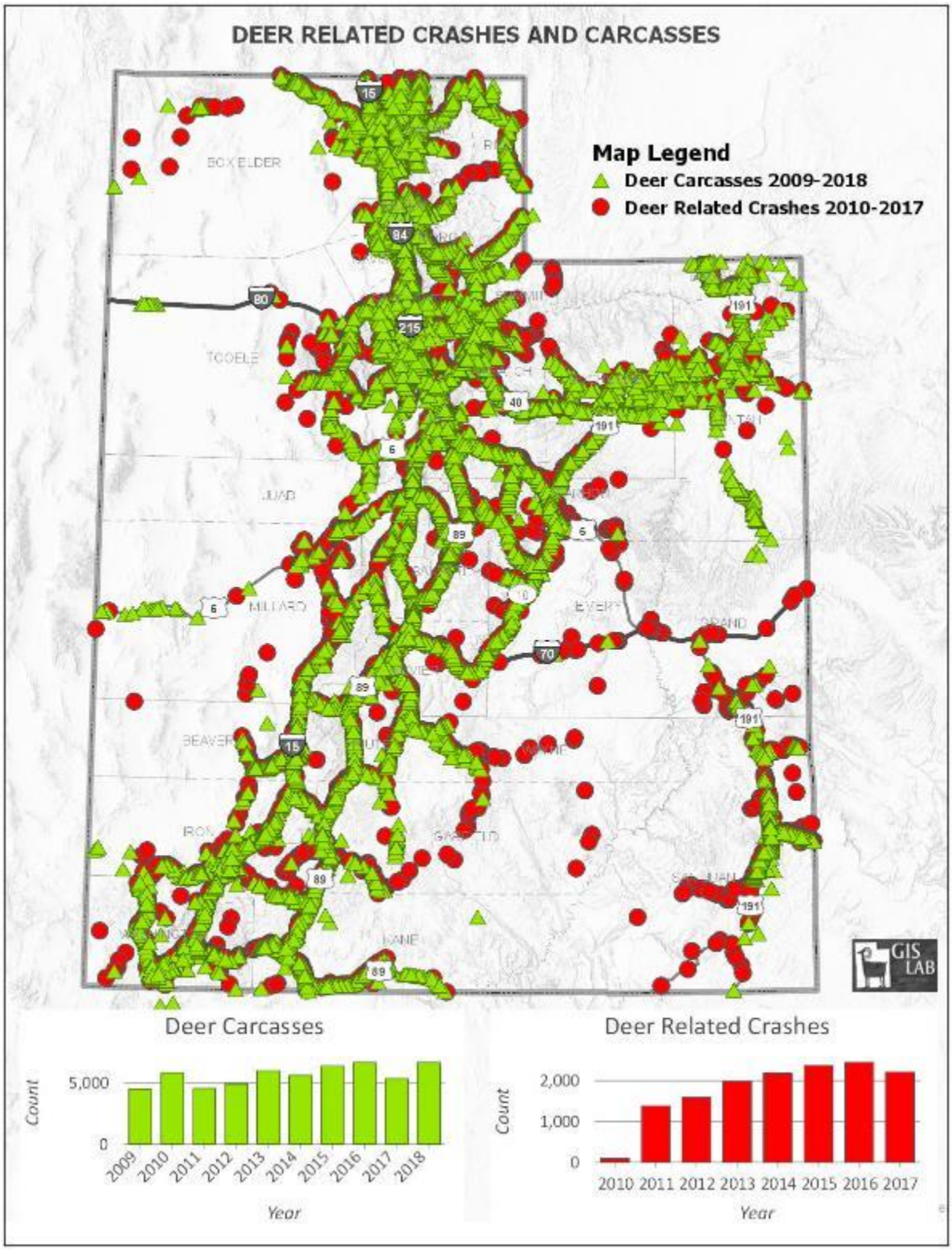

Figure 50. Deer Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Deer in the Narrative 2010 - 2017.

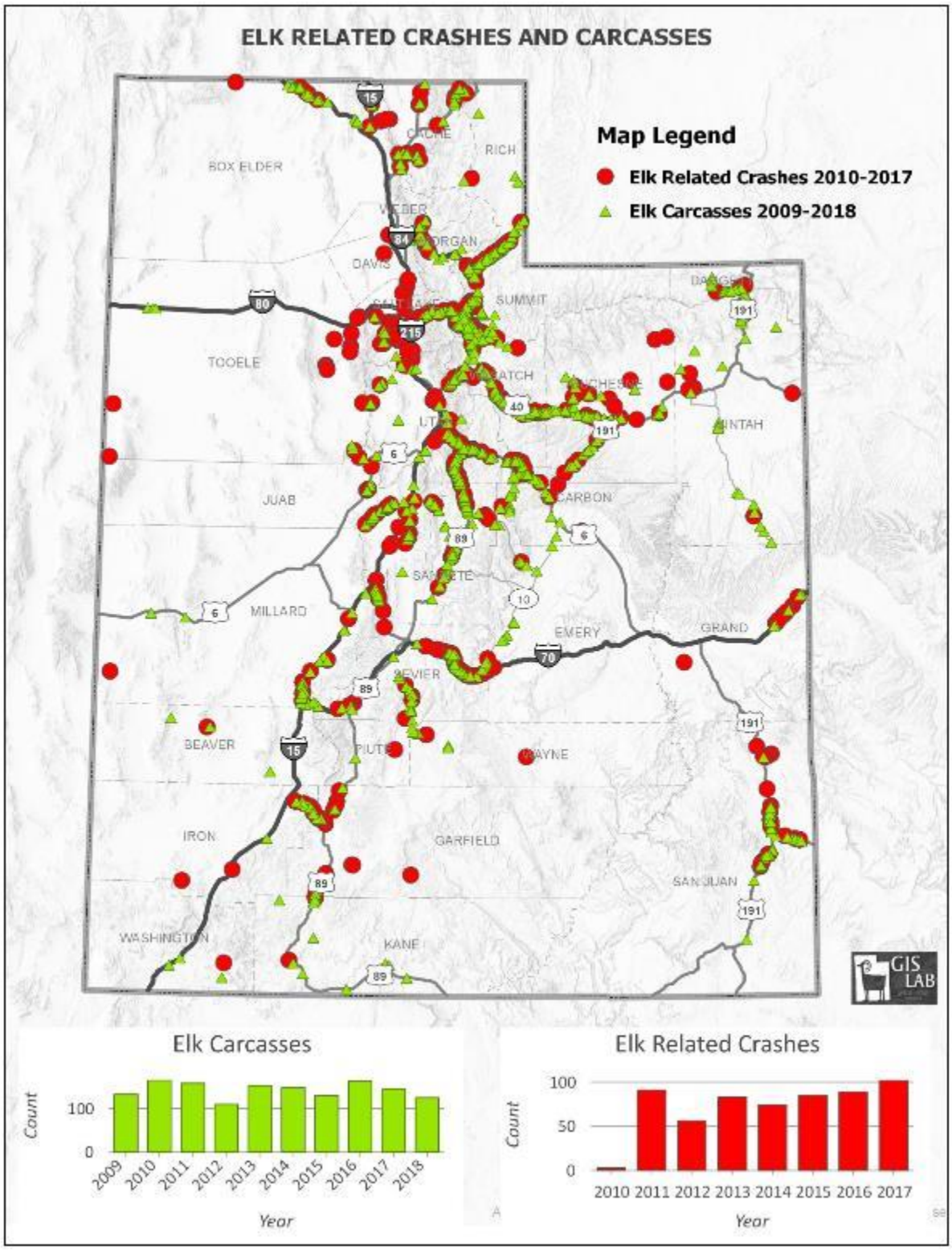

Figure 51. Elk Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Elk in the Narrative 2010 - 2017.

The elk carcasses and crashes were compared on a section of US 40 near Strawberry Reservoir. This section of US 40 was studied by the PI, Dr. Cramer for a UDOT project, and the crashes and carcasses in that section were known prior to this mapping. The following map of elk crashes and carcasses with an inset of the US 40 Strawberry Reservoir area demonstrates a congruence between the two data sets.

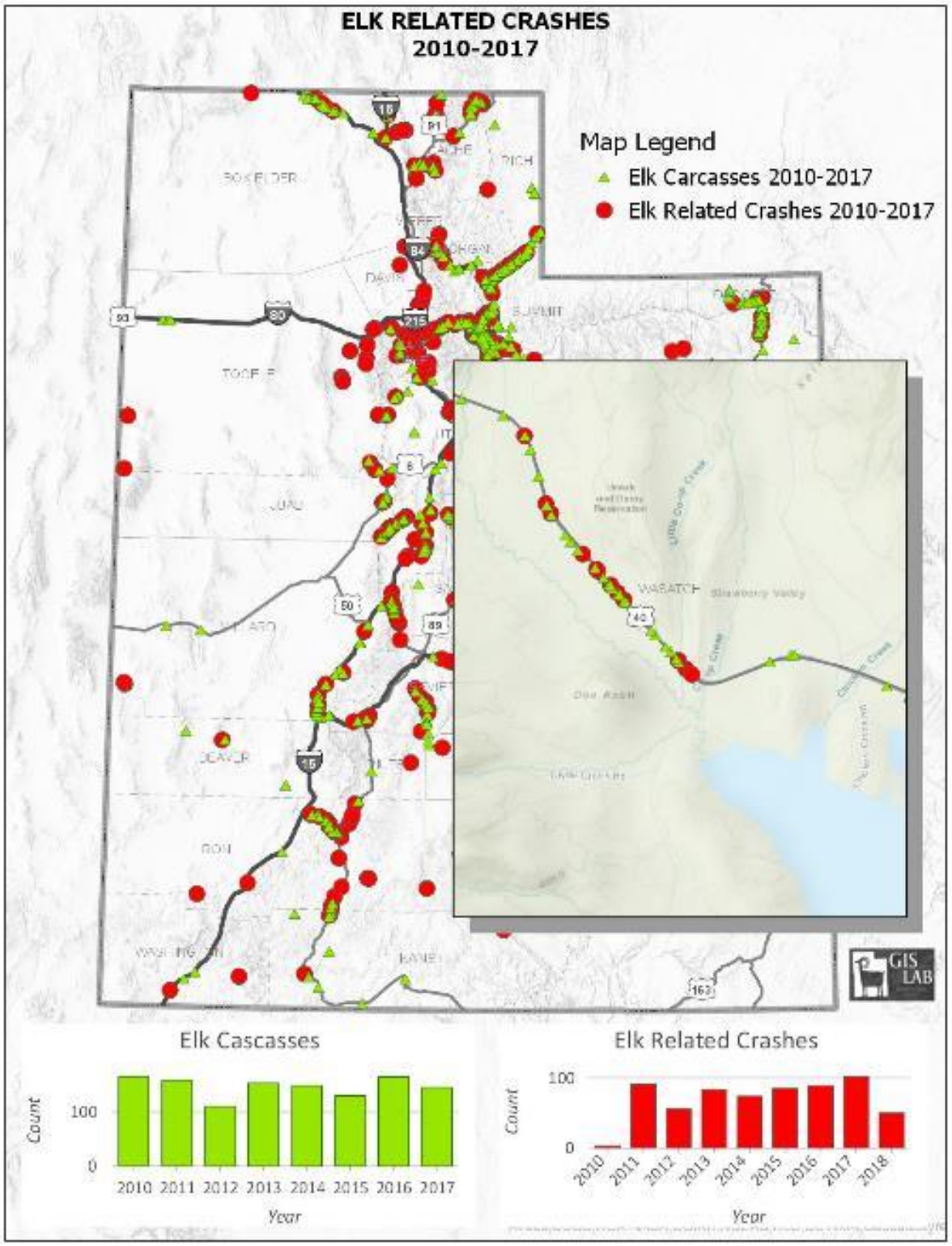

Figure 52. Elk Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Elk in the Narrative 2010 - 2017, with an inset of the US 40 Strawberry Reservoir Area.

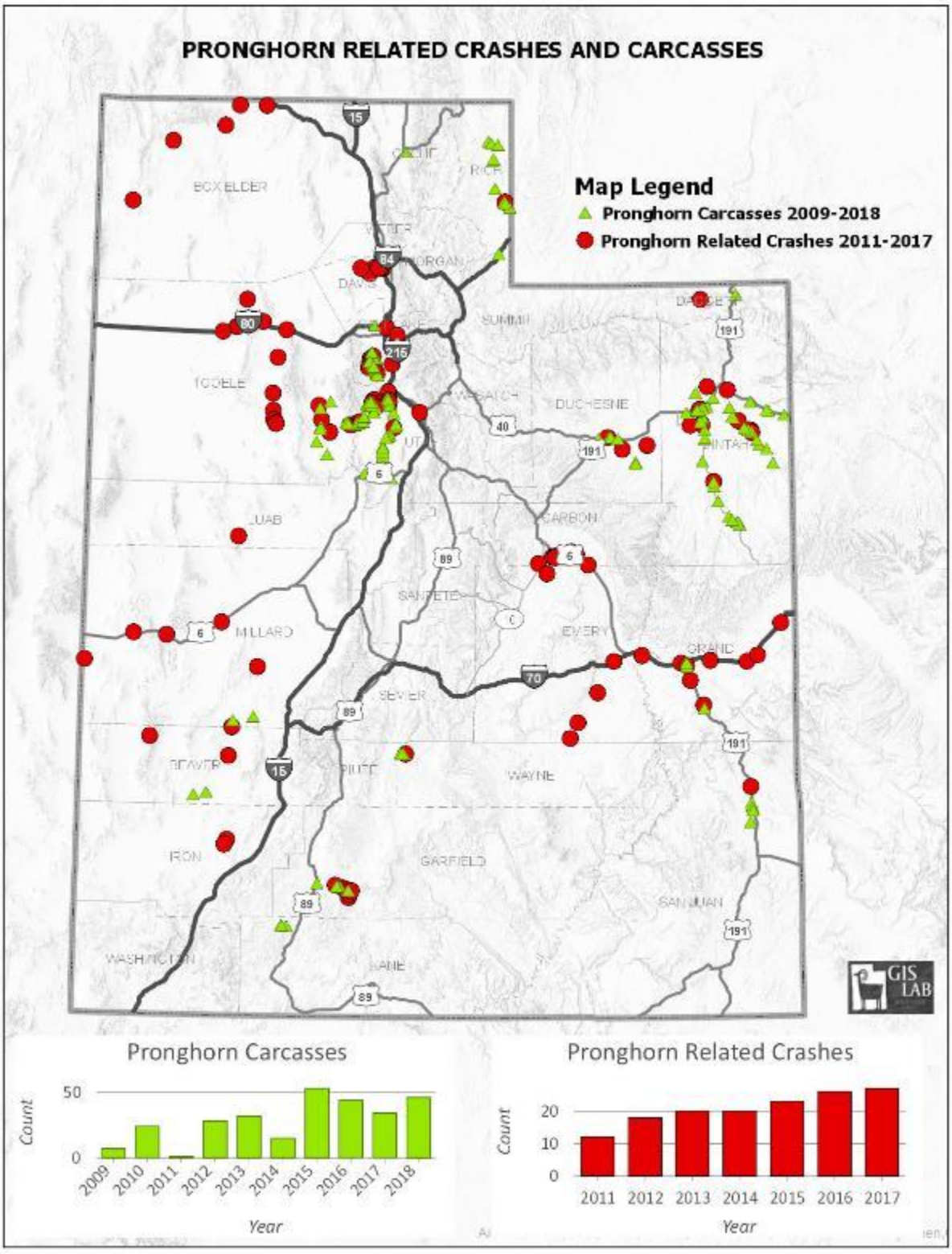

Figure 53. Pronghorn Antelope Carcasses Reported from 2009 - 2018 and Reported Crashes with the Word Antelope in the Narrative 2010 - 2017.

Livestock and Domestic Animal Crashes and Carcasses

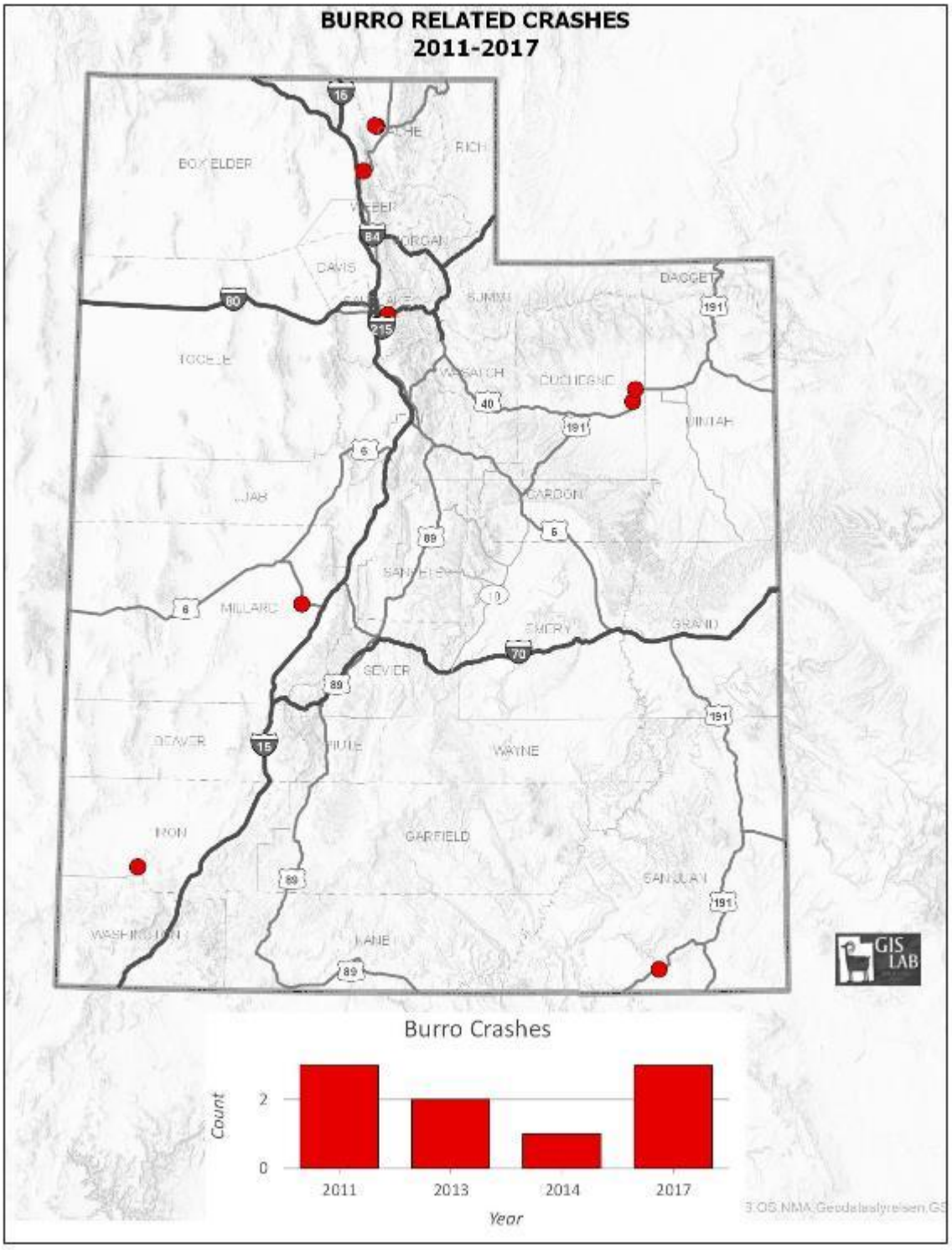

Figure 54. Reported Crashes with the Word Burro in the Narrative 2010 - 2017. There Were No Burro Carcasses Collected from 2009 – 2018.

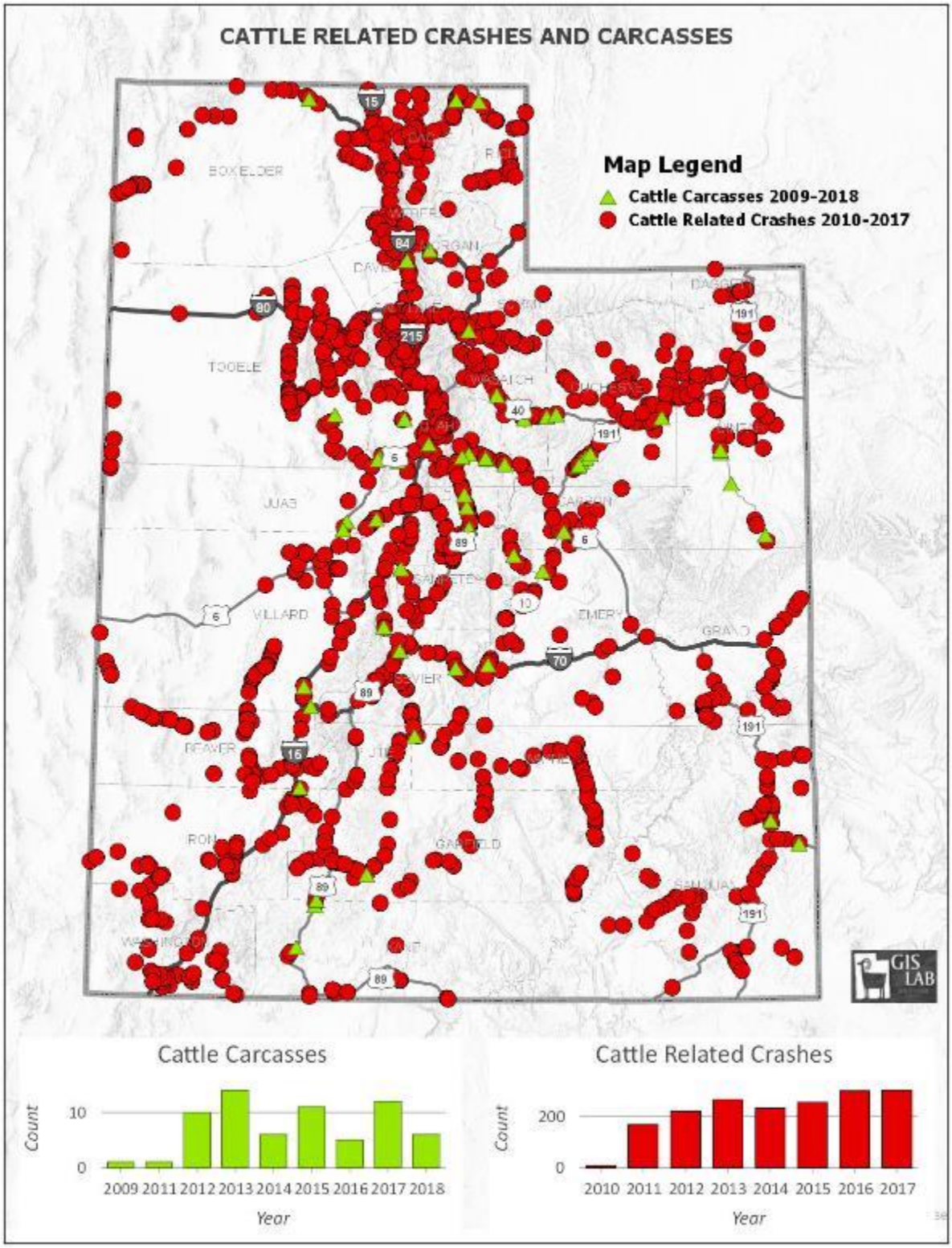

Figure 55. Cow, Cattle, and Bull Reported Carcasses from 2009 - 2018 and Reported Crashes with the Words Cow, or Cattle, or Bull in the Narrative 2010 - 2017.

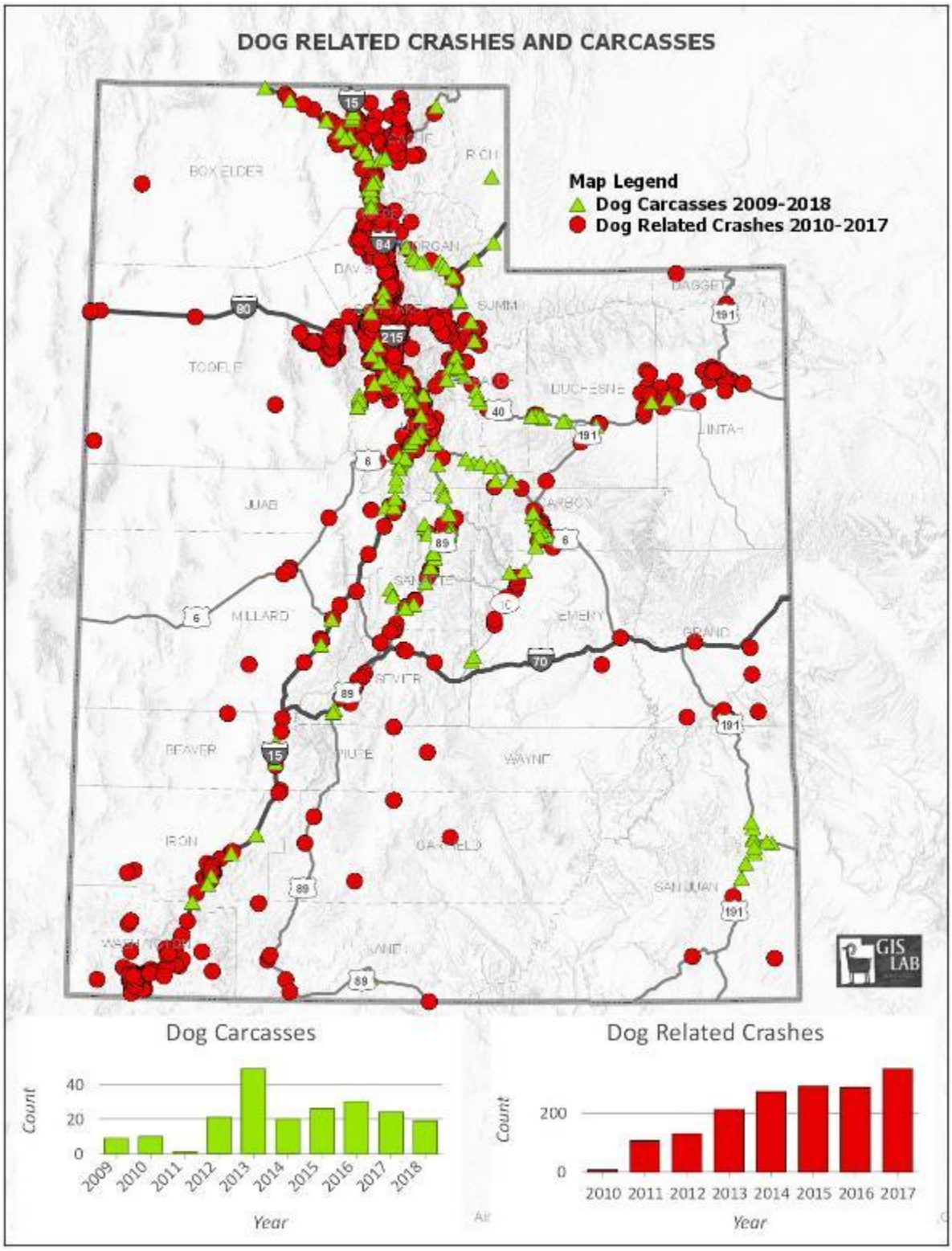

Figure 56. Dog Reported Carcasses from 2009 - 2018 and Reported Crashes with the Word Dog in the Narrative 2010 - 2017.

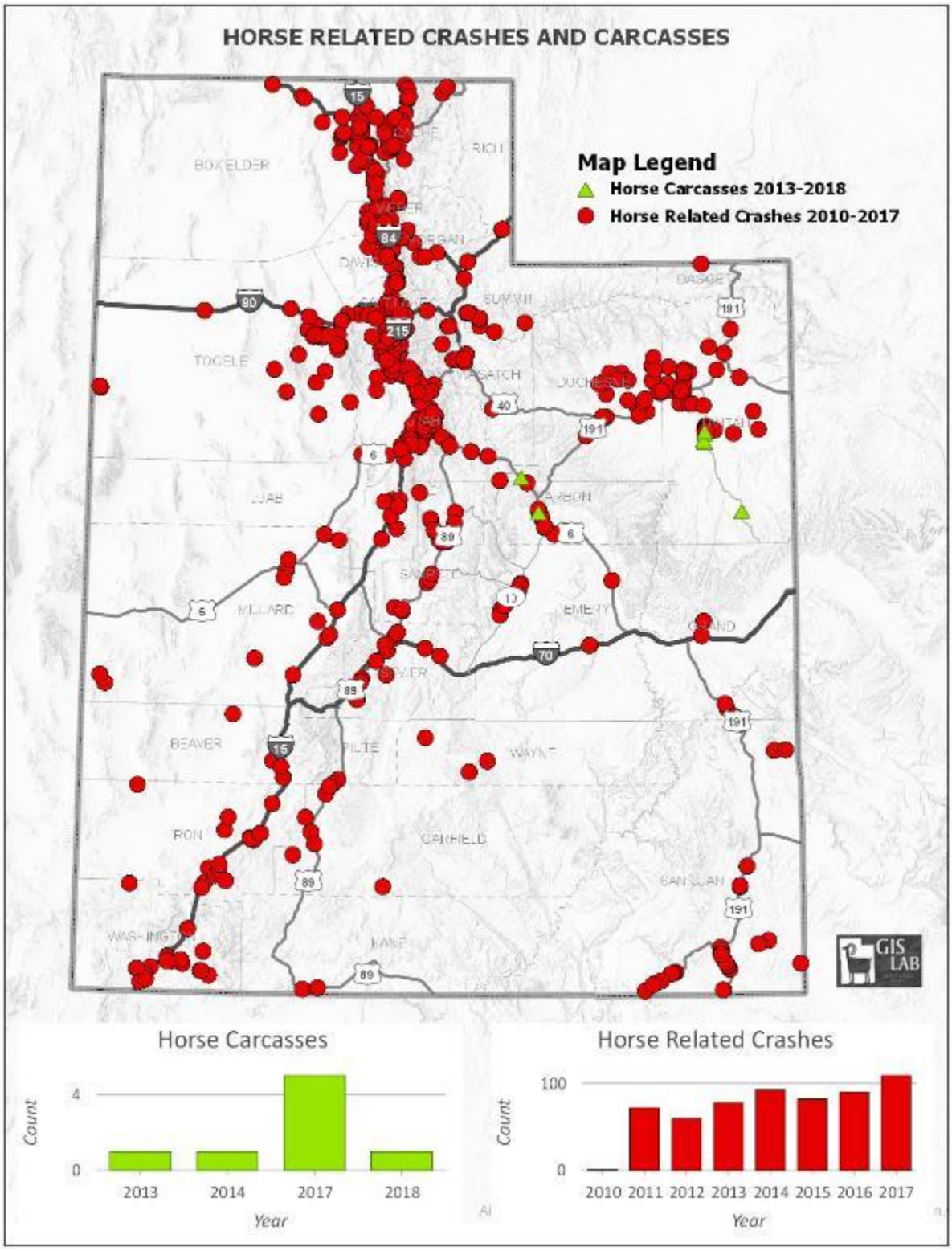

Figure 57. Horse Reported Carcasses from 2009 - 2018 and Reported Crashes with the Word Horse in the Narrative 2010 - 2017.

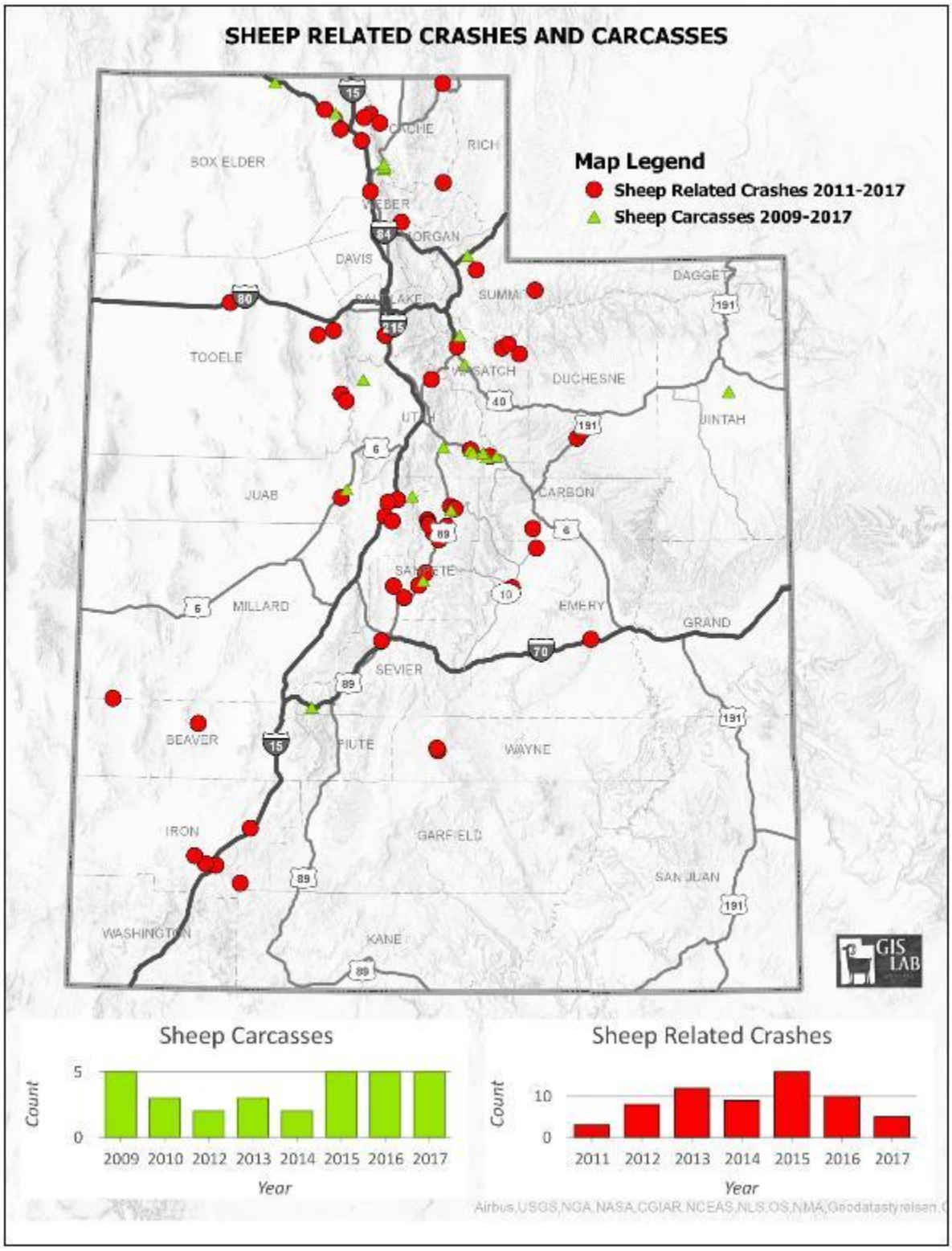

Figure 58. Sheep Reported Carcasses from 2009 - 2018 and Reported Crashes with the Word Sheep in the Narrative 2010 - 2017.

APPENDIX C: MAPS OF THE TOP 25 WILDLIFE-VEHICLE CRASH HOTSPOTS ON UTAH HIGHWAYS AND TOP 25 HOTSPOTS ON LOCAL ROADS MERGED WITH UDWR WILDLIFE SPECIES' HABITAT MAPS

The top 25 WVC hotspots on highways and top 25 hotspots on local roads were mapped over each of the habitat maps of seven species of wild mammals, including maps of the three subspecies of bighorn sheep. The maps represent the known ranges of the following species: black bear, bison, California bighorn sheep, desert bighorn sheep, Rocky Mountain bighorn sheep, moose, mule deer, pronghorn, and Rocky Mountain elk.

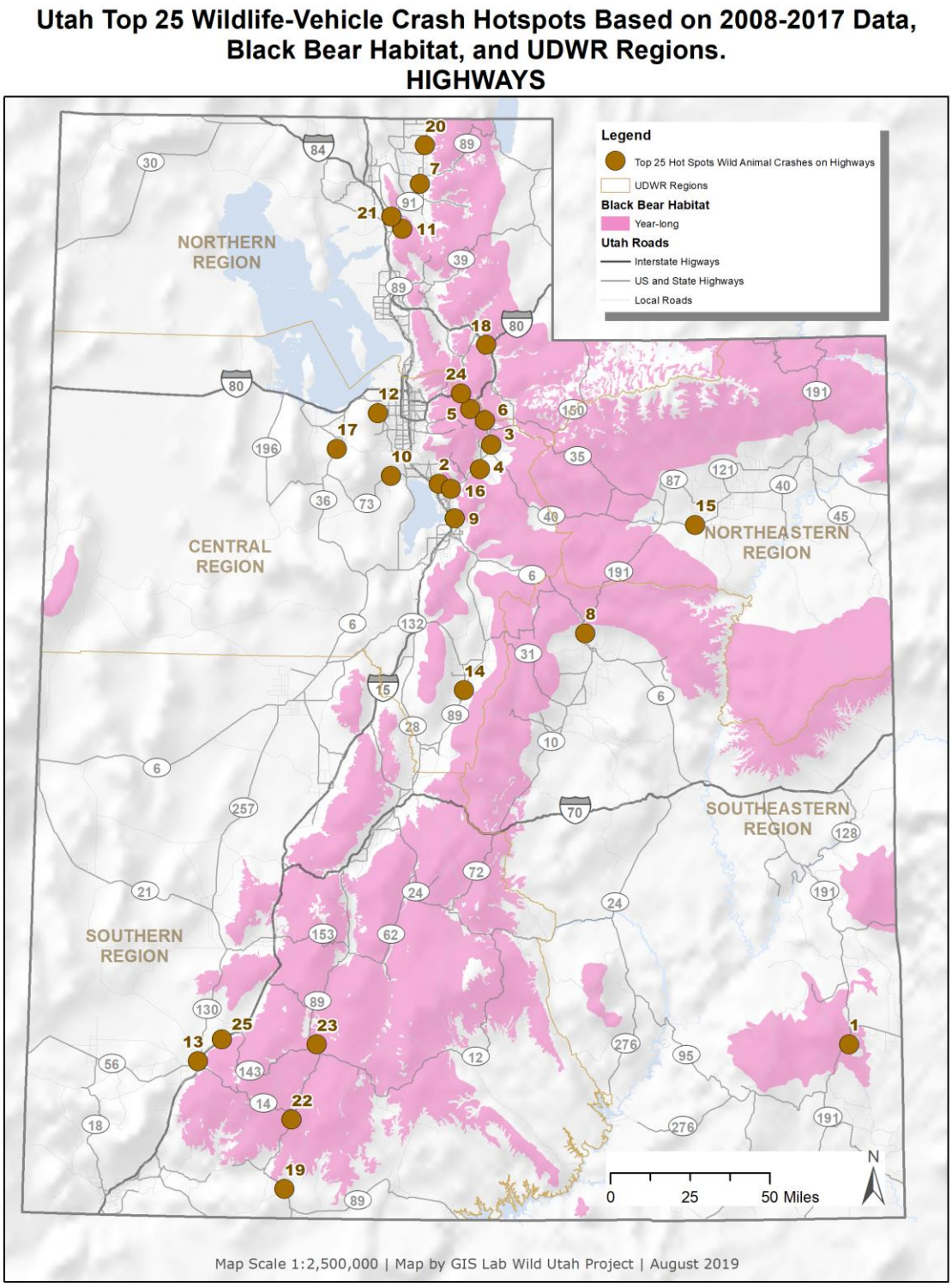

Figure 59. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR Black Bear Habitat Map.

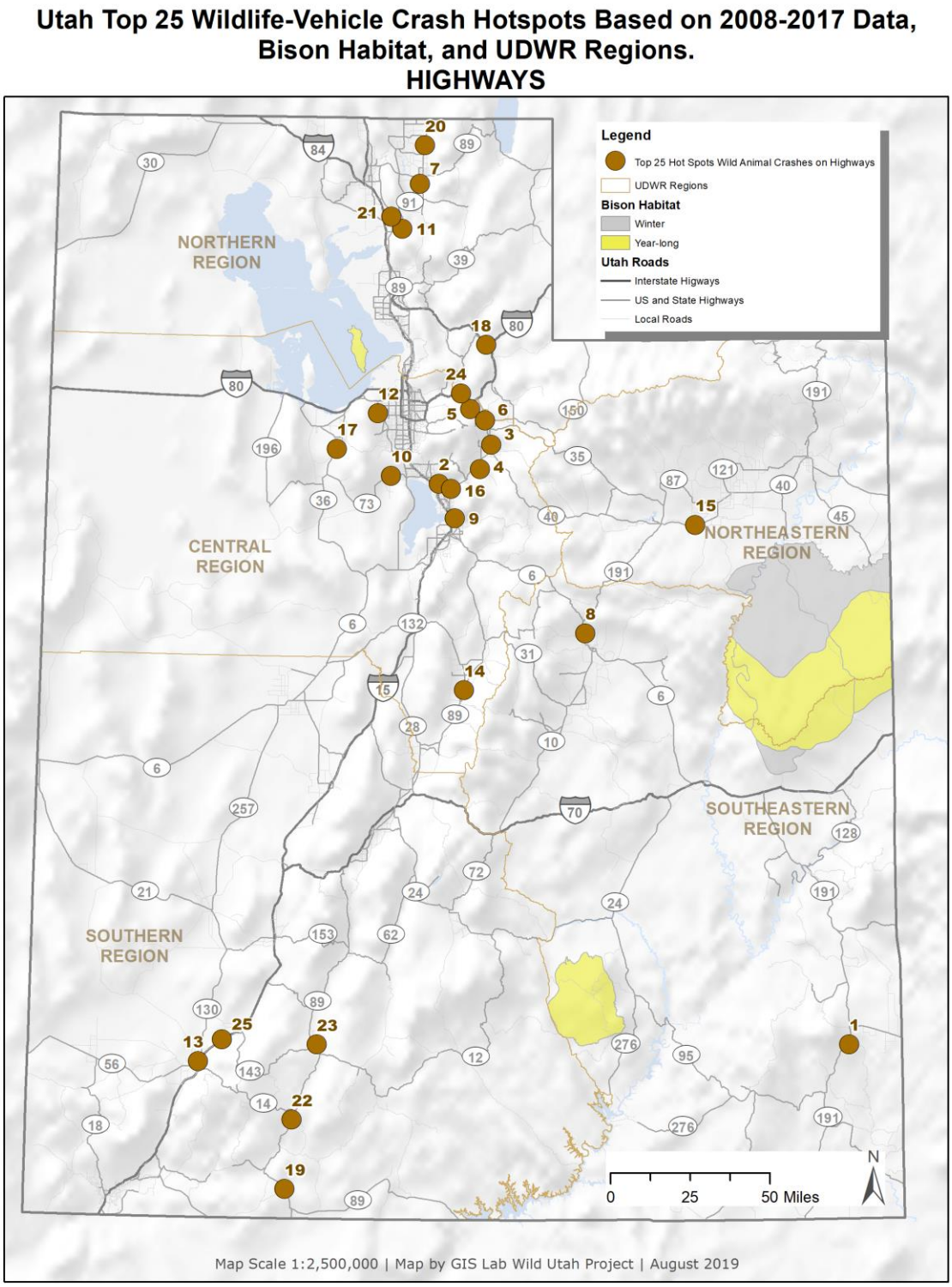

Figure 60. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR Bison Habitat Map

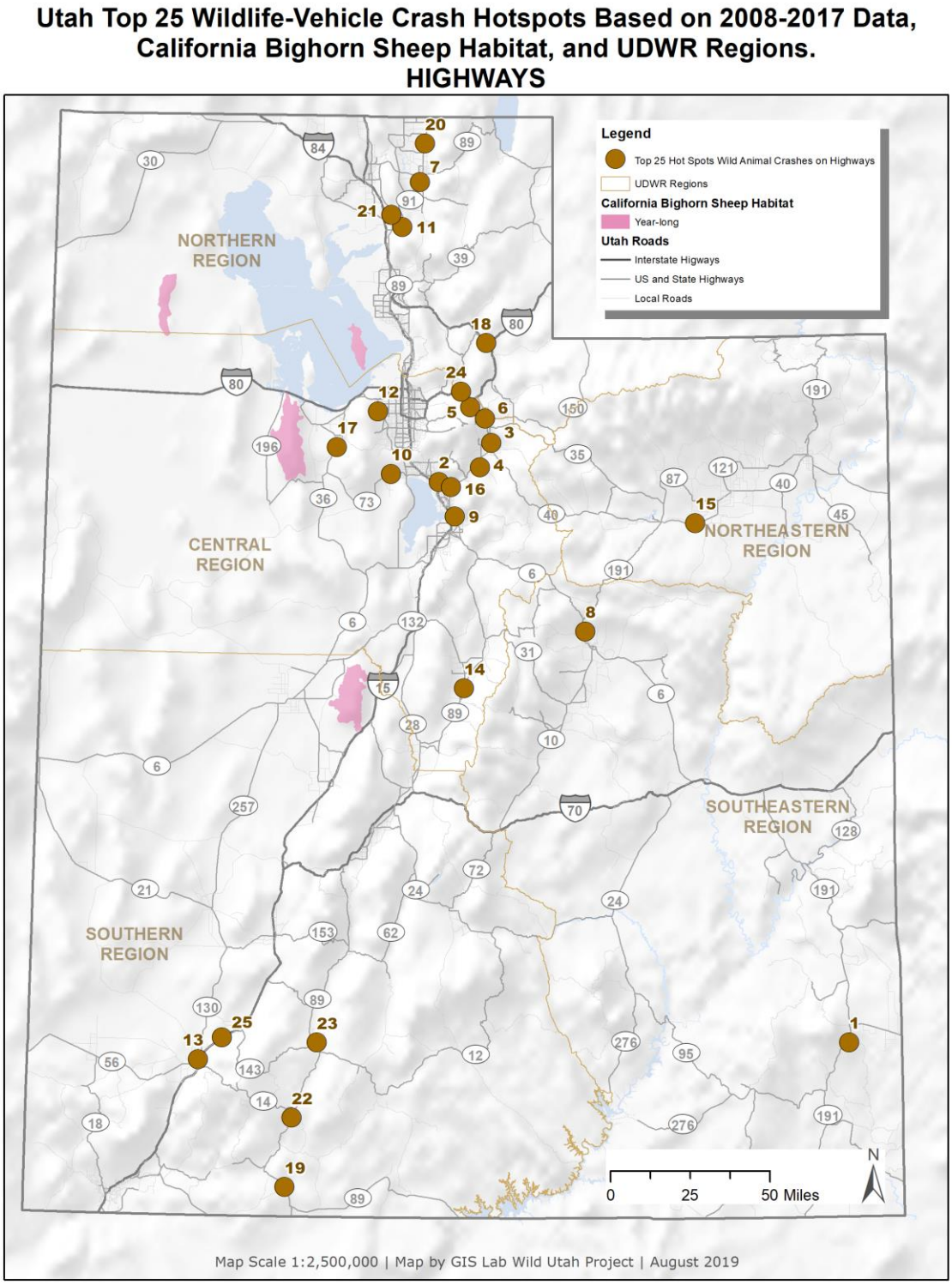

Figure 61. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR California Bighorn Sheep Habitat Map.

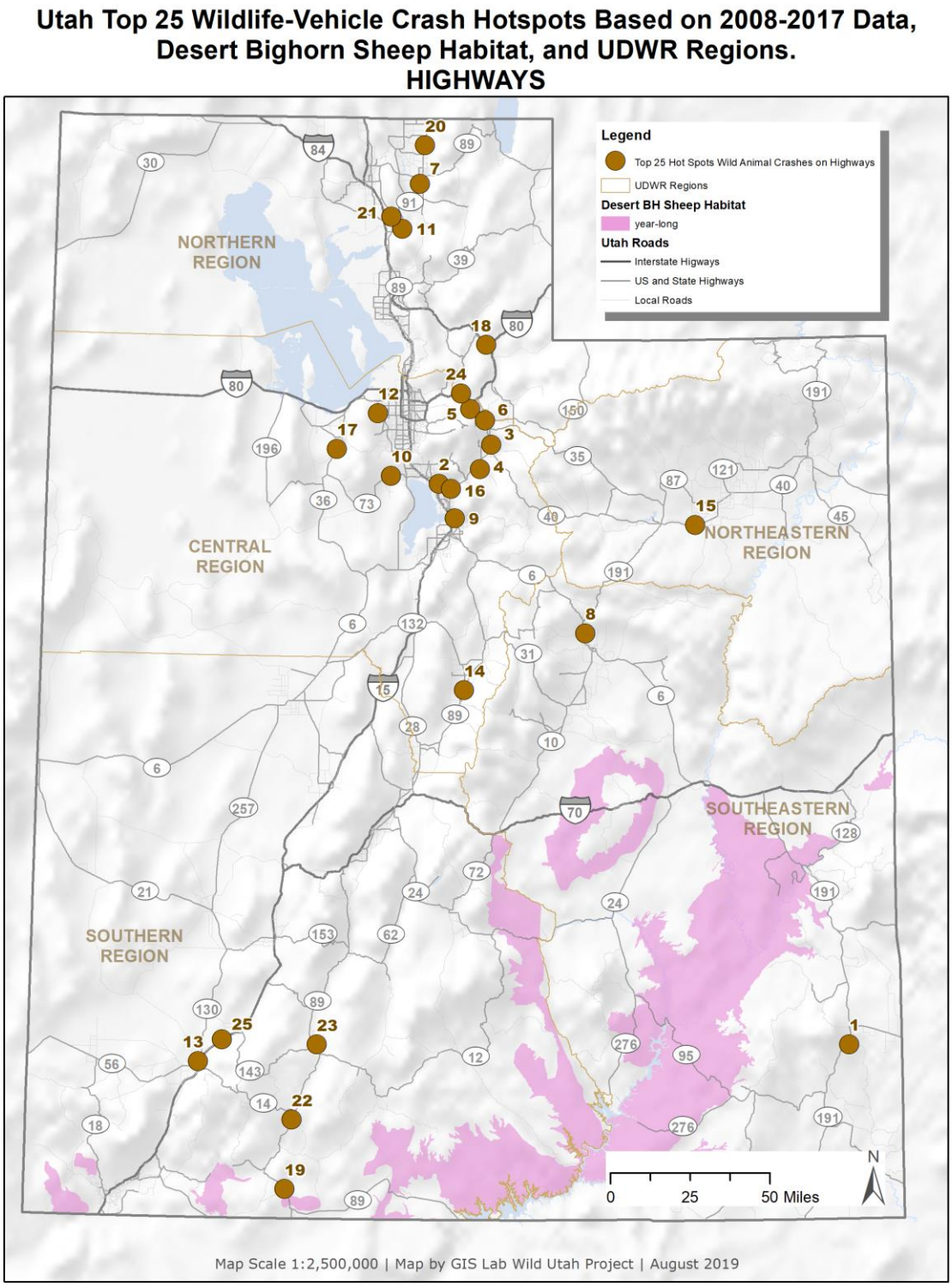

Figure 62. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR Desert Bighorn Sheep Habitat Map.

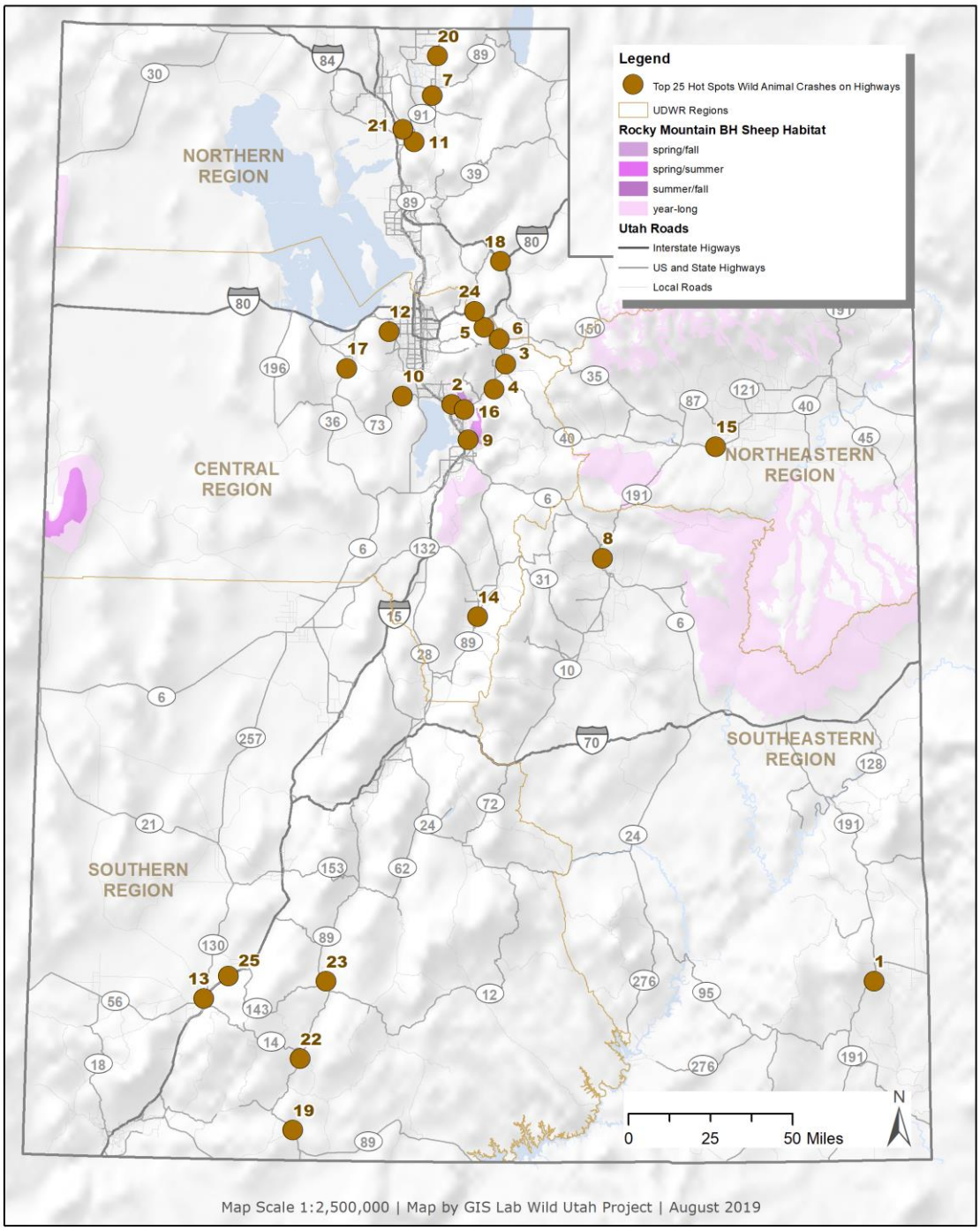

Figure 63. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR Rocky Mountain Bighorn Habitat Map.

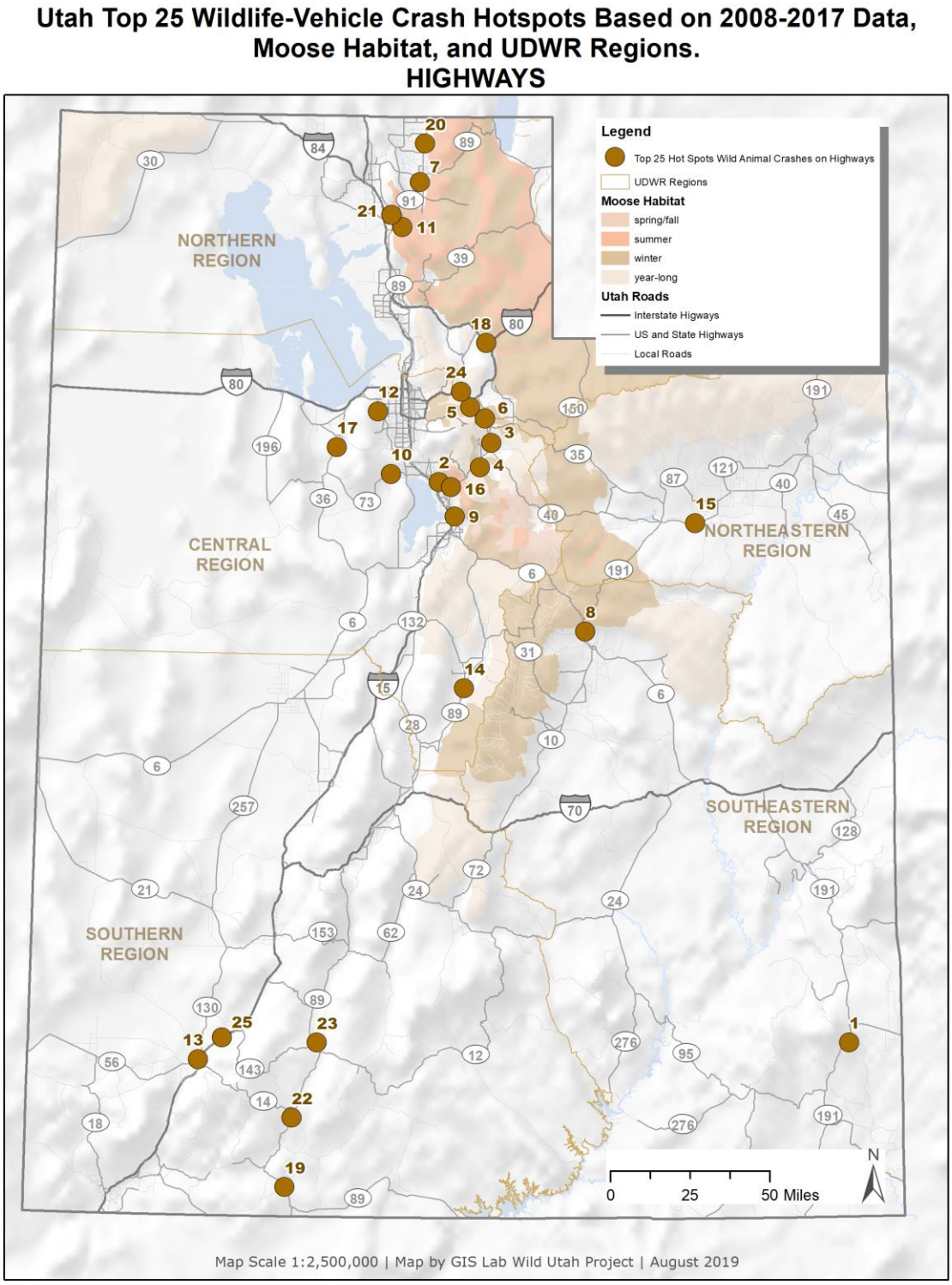

Figure 64. Top 25 Wildlife-Vehicle Hotspots on Highways on UDWR Moose Habitat Map.

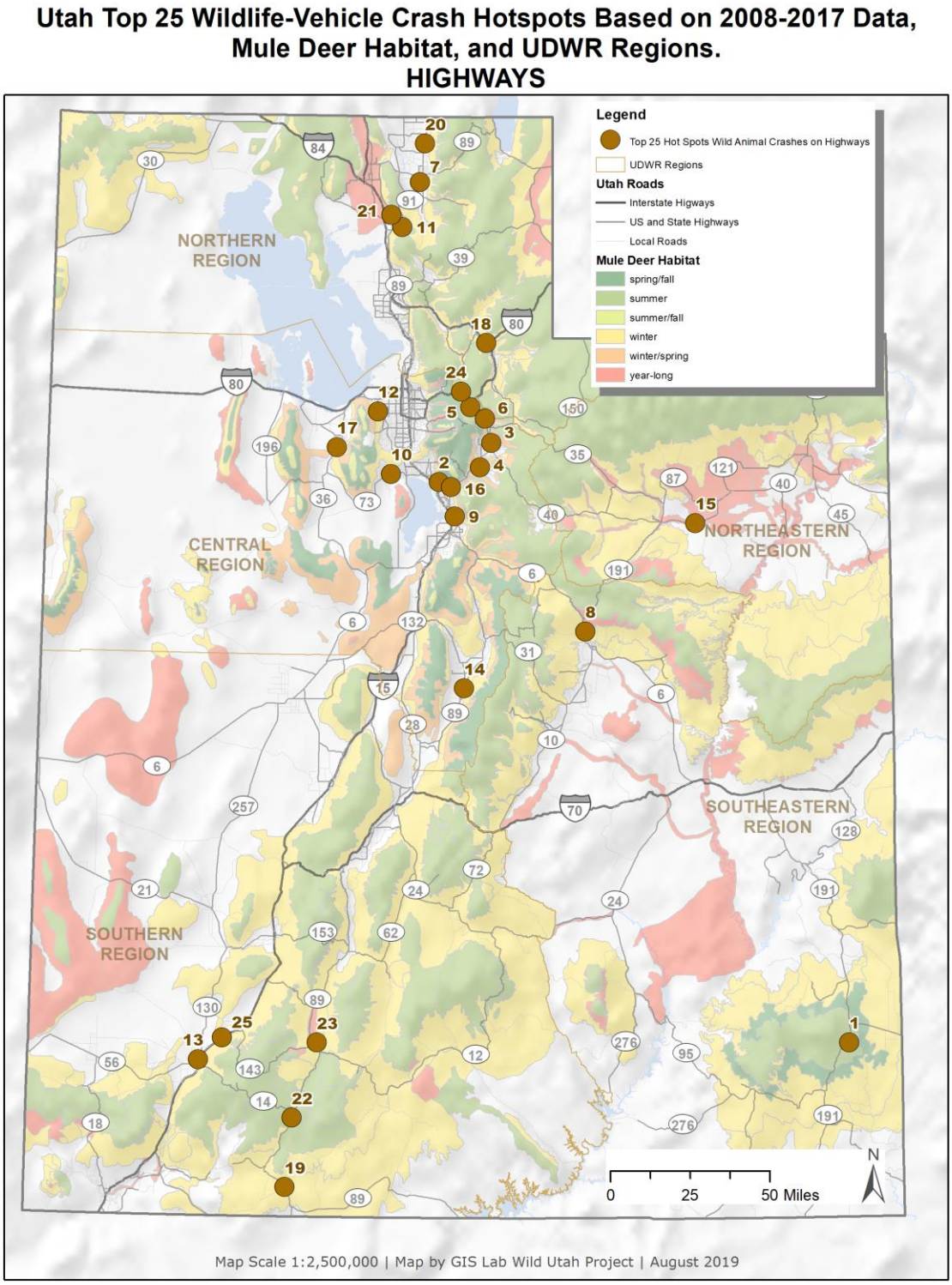

Figure 65. Top 25 Wildlife-Vehicle Crash Hotspots on Highways on UDWR Mule Deer Habitat Map.

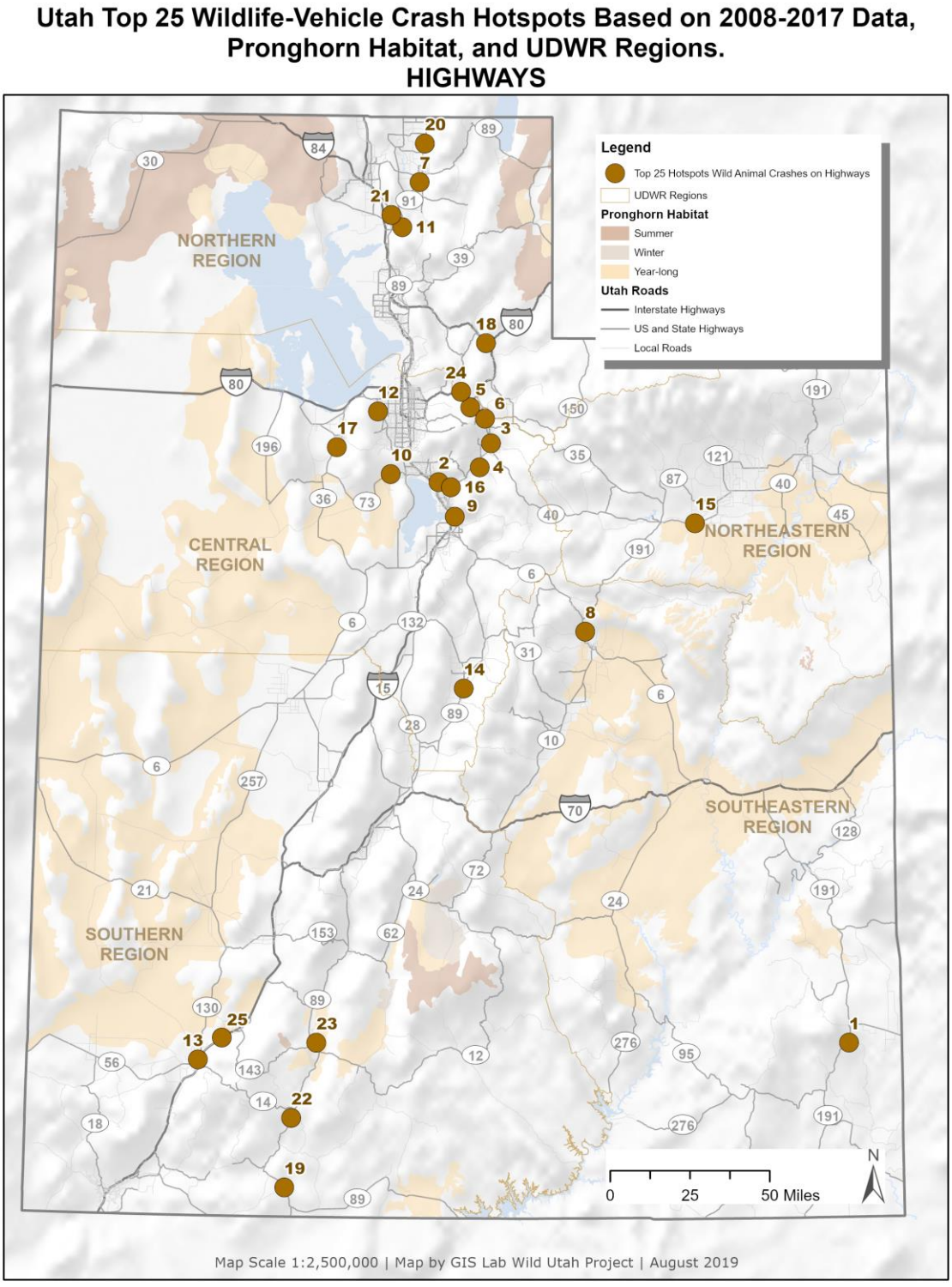

Figure 66. Top 25 Wildlife-Vehicle Crash Hotspots on Highways and UDWR Pronghorn Antelope Habitat.

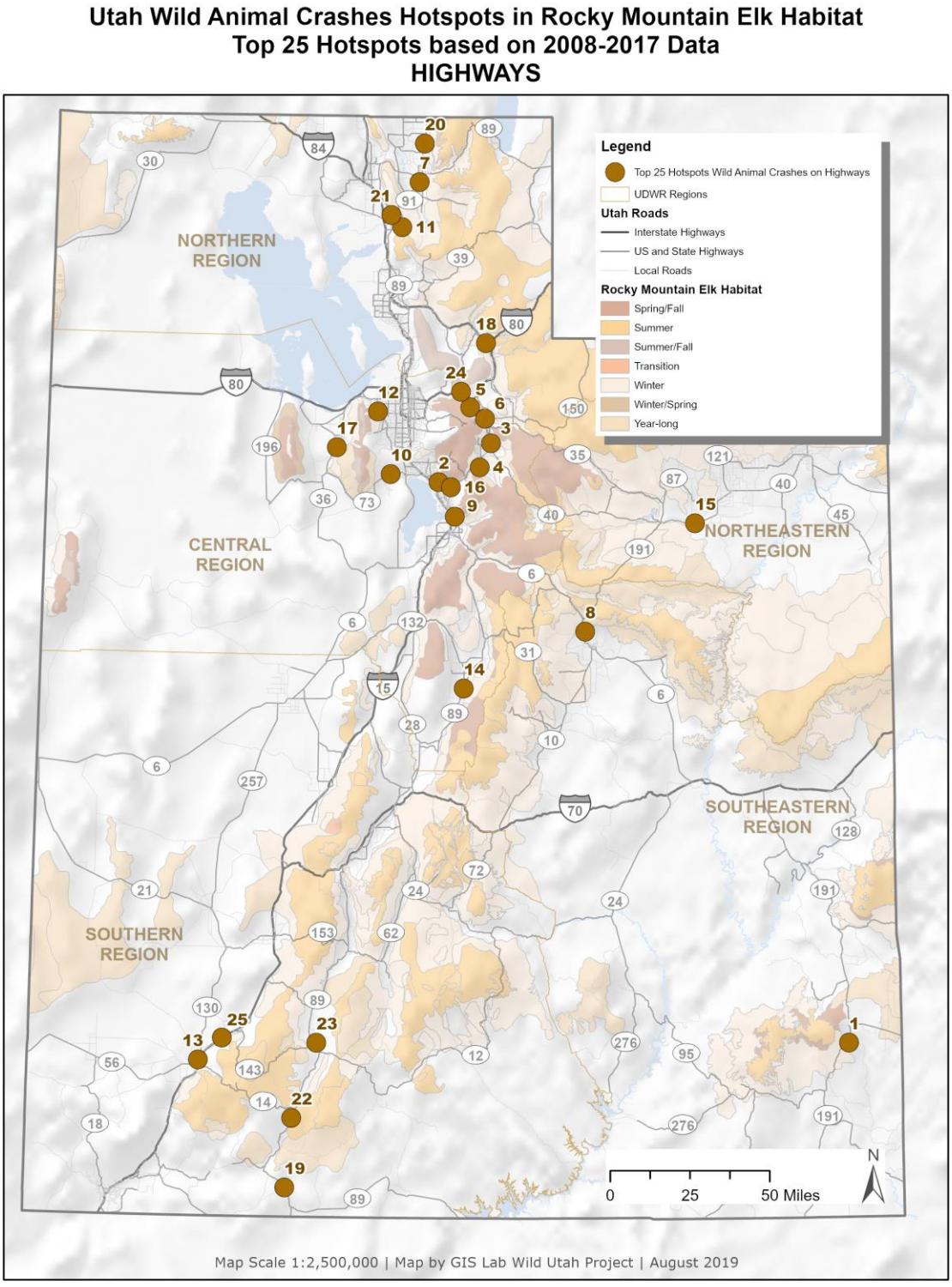

Figure 67. Top 25 Wildlife-Vehicle Crash Hotspots on Highways and UDWR Rocky Mountain Elk Habitat.

The top 25 wildlife-vehicle crash hotspots on local roads were mapped on different species of wildlife habitat maps. Only maps where there was some overlap between these crash hotspots and specific species' habitat maps are presented below.

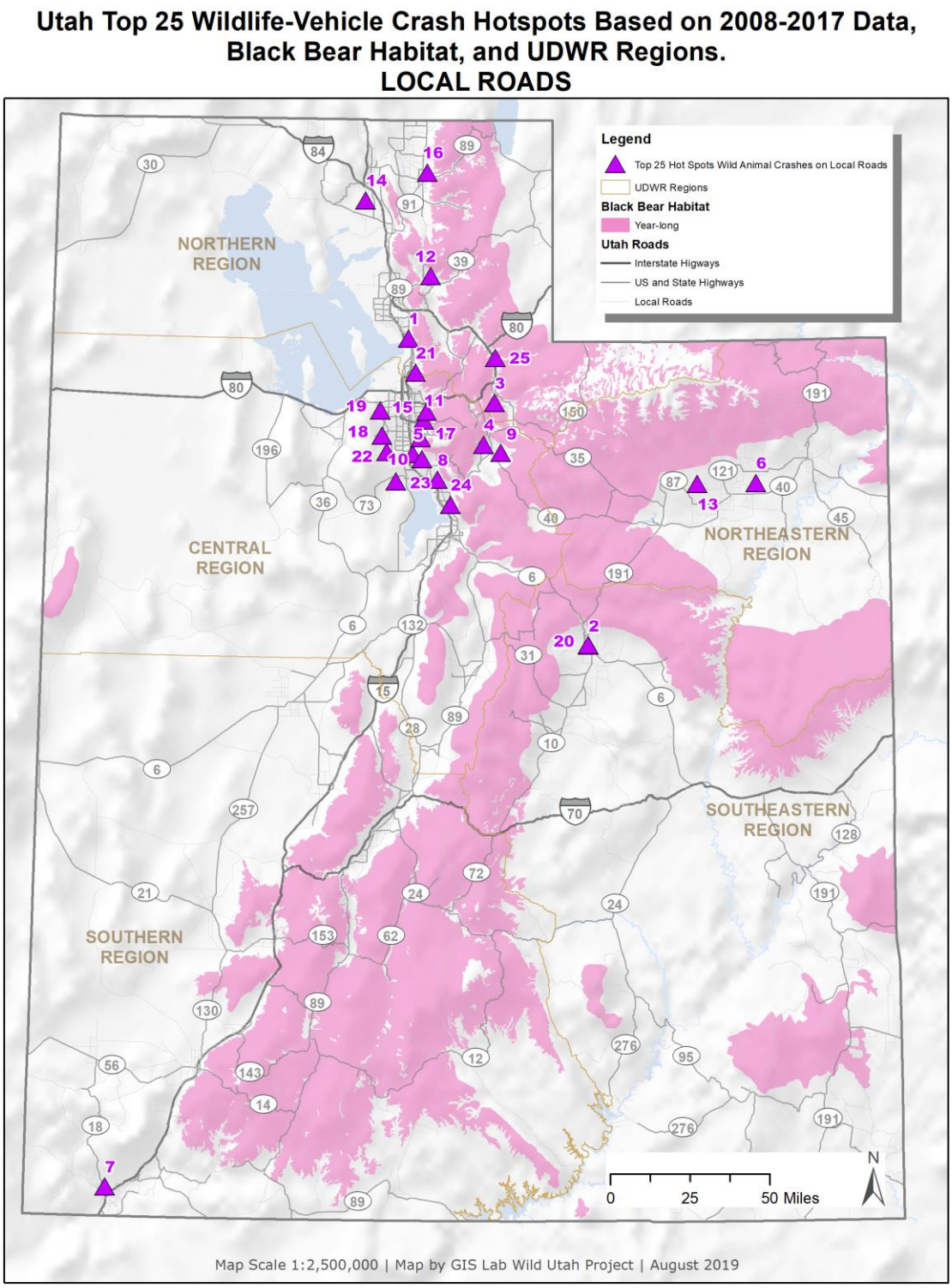

Figure 68. Wildlife-Vehicle Crash Hotspots on Local Roads and UDWR Black Bear Habitat.

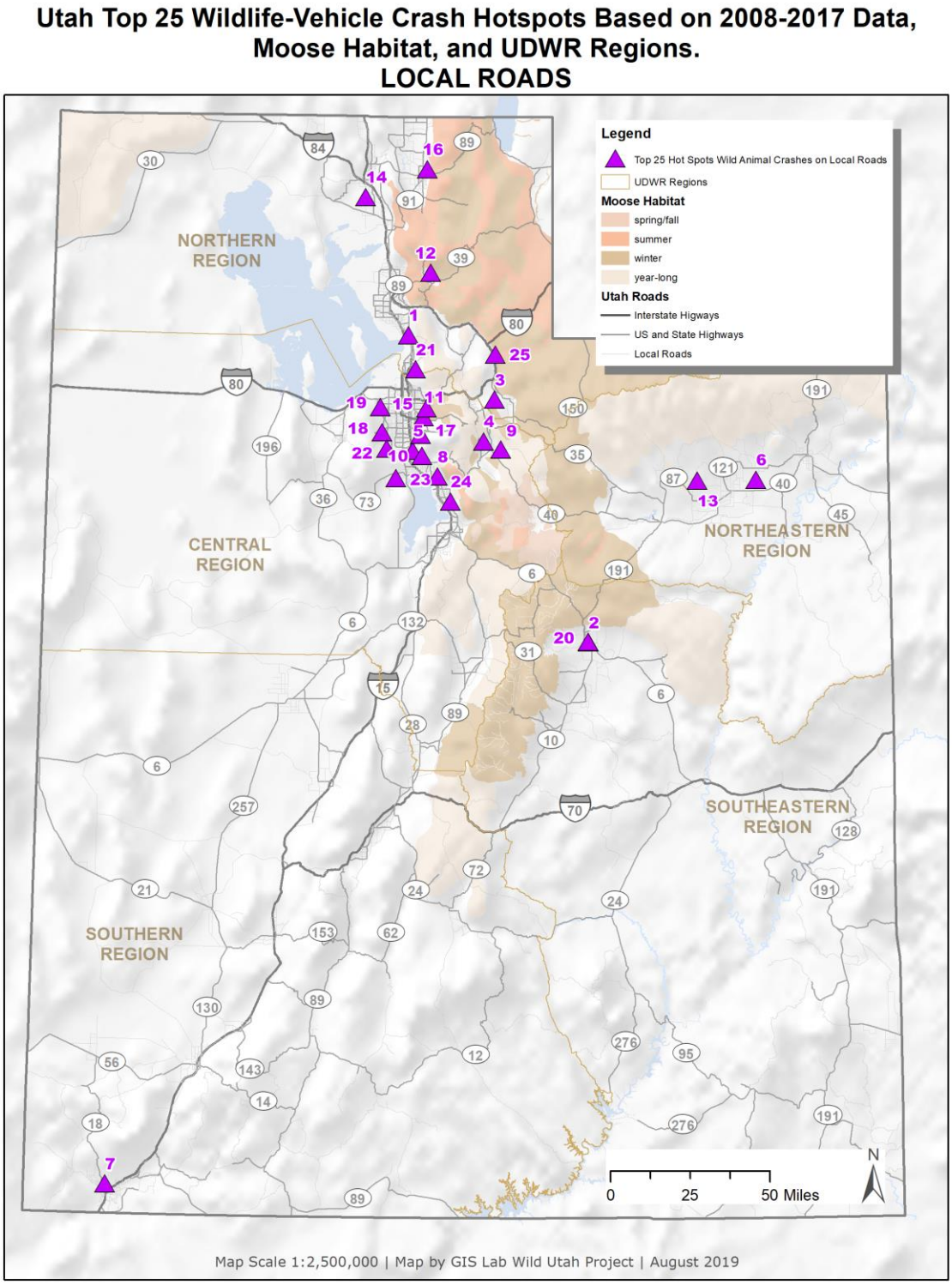

Figure 69. Wildlife-Vehicle Crash Hotspots on Local Roads and UDWR Moose Habitat

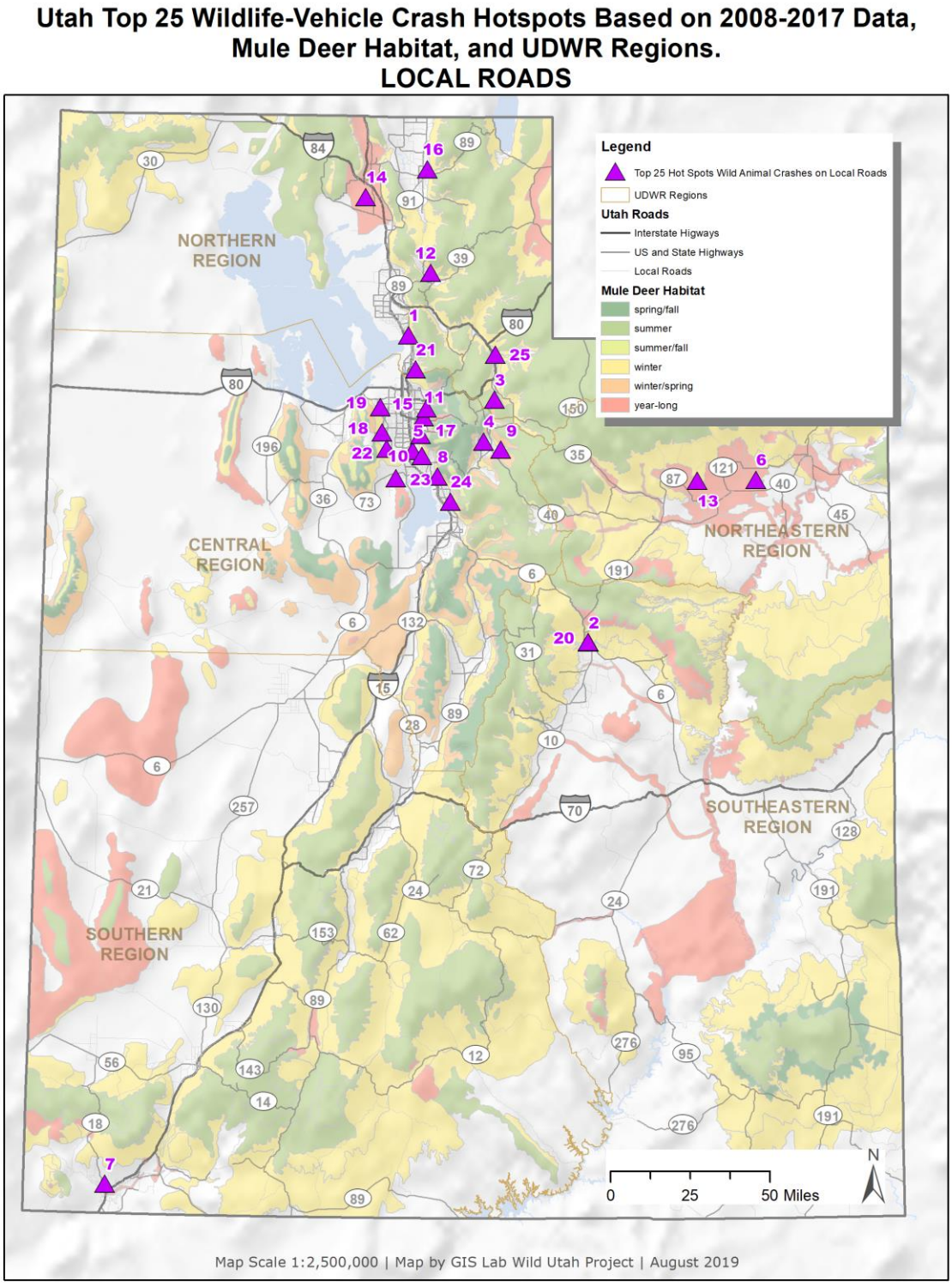

Figure 70. Wildlife-Vehicle Crash Hotspots on Local Roads and UDWR Mule Deer Habitat

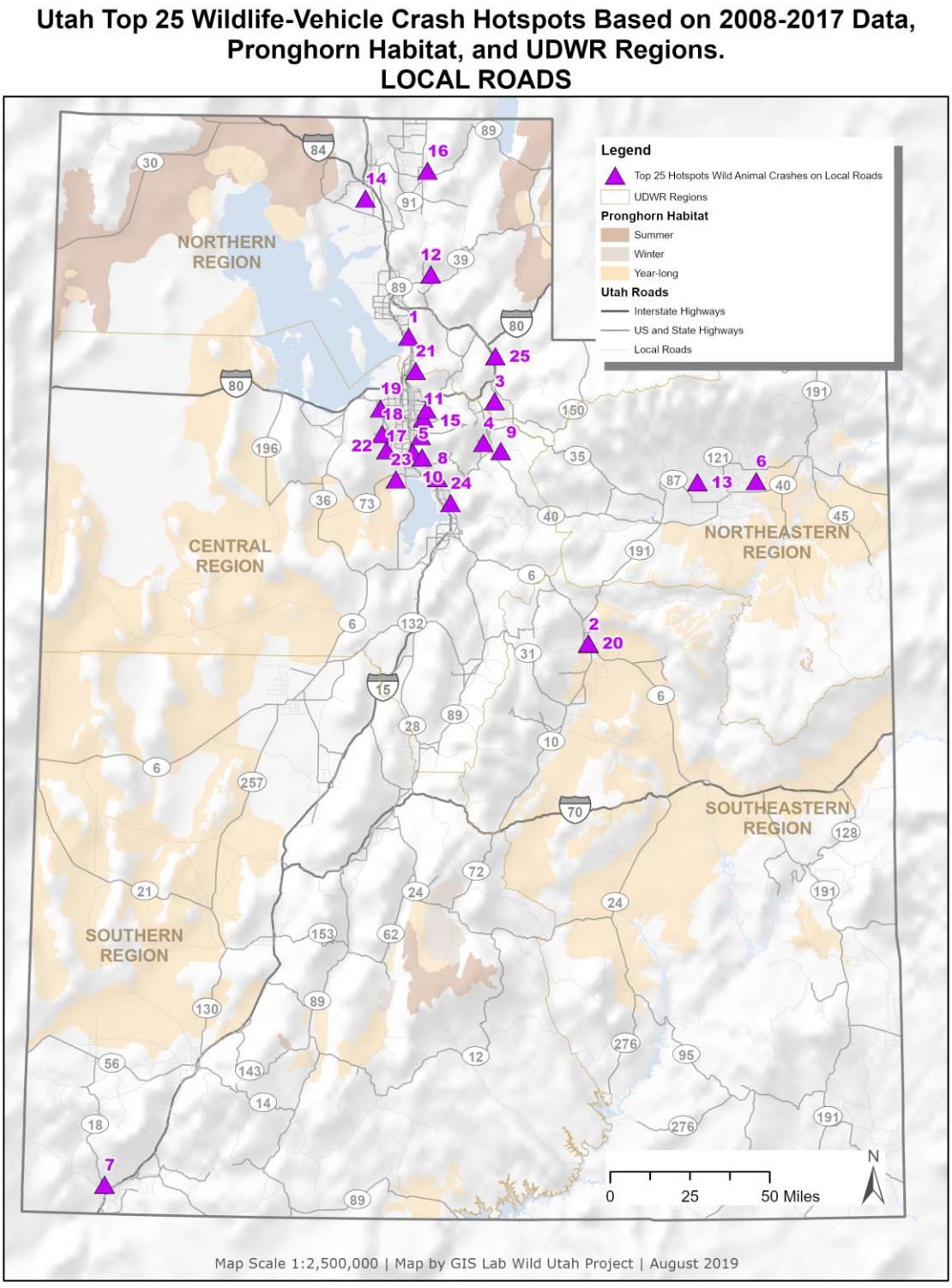

Figure 71. Wildlife-Vehicle Crash Hotspots on Local Roads and UDWR Pronghorn Antelope Habitat

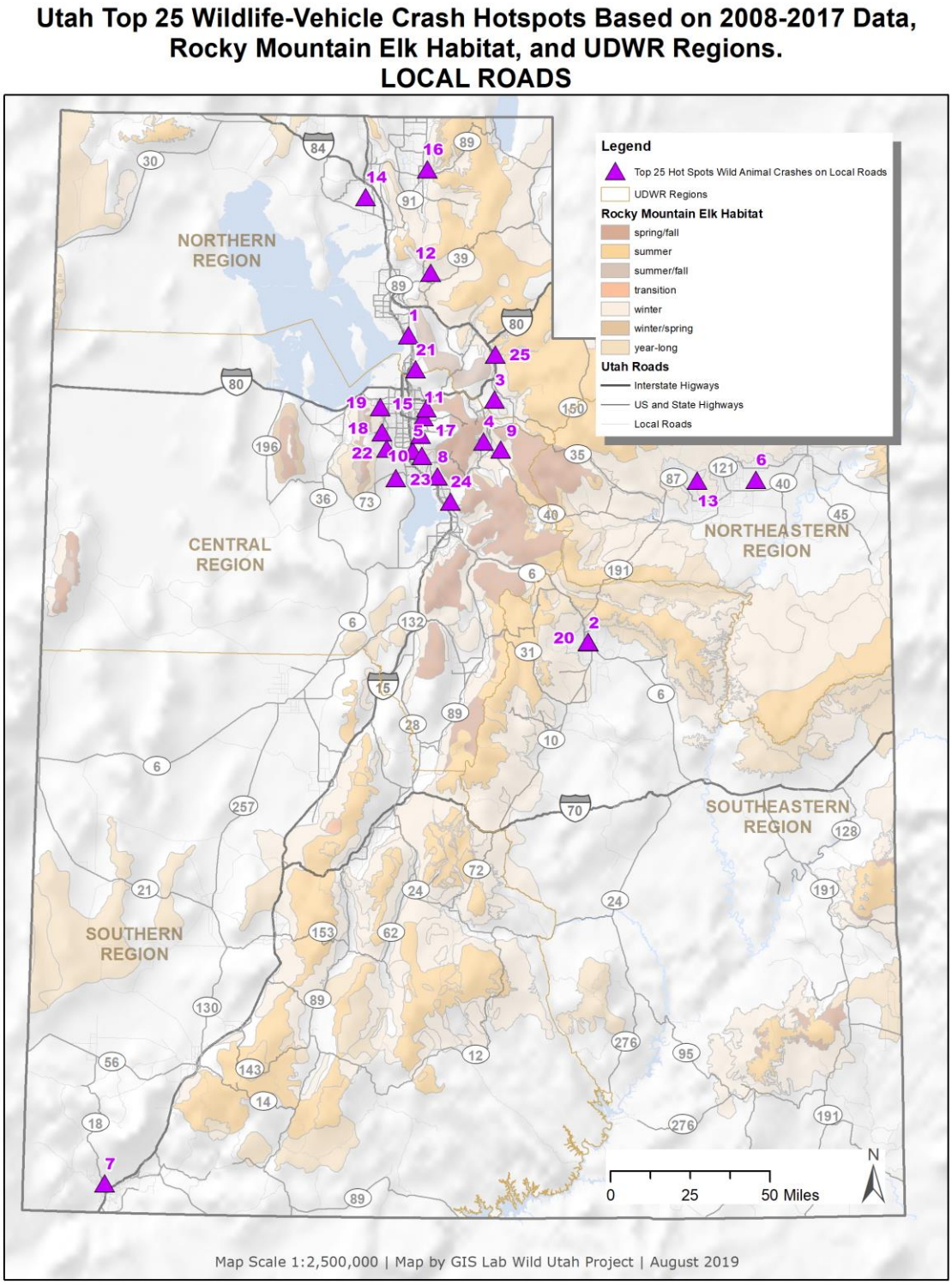

Figure 72. Wildlife-Vehicle Crash Hotspots on Local Roads and UDWR Rocky Mountain Elk Habitat

APPENDIX D: MAPS OF THE TOP 25 WILD UNGULATE CARCASS HOTSPOTS ON HIGHWAYS AND TOP 25 HOTSPOTS ON LOCAL ROADS BASED ON 2008-2019 DATA MERGED WITH UDWR SPECIES' HABITAT MAPS

The wild ungulate carcass top 25 hotspots on highways and top 25 hotspots on local roads were mapped on the UDWR species maps. The maps below present the species maps where there was overlap between the ungulate carcass hotspots and species' habitat.

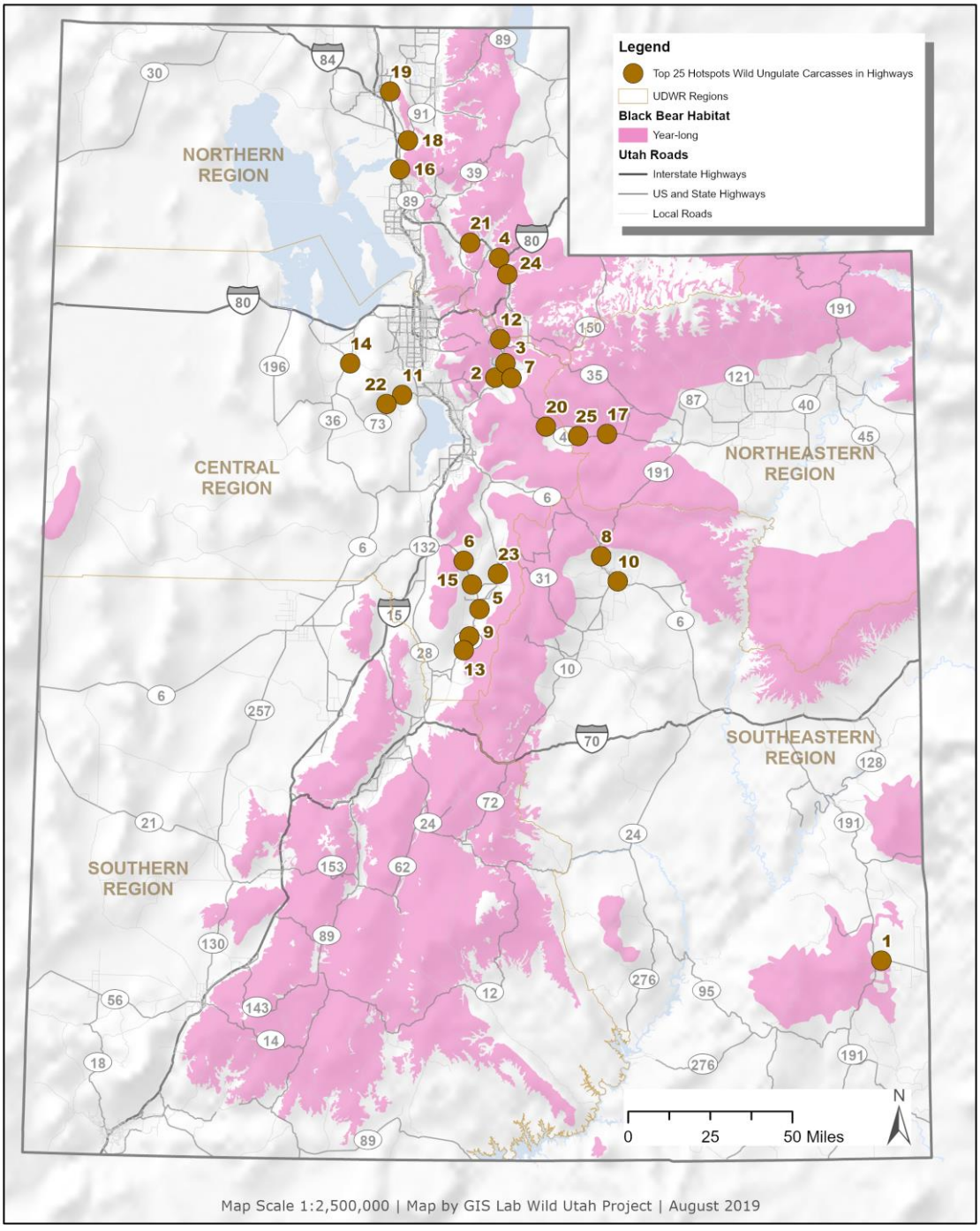

Figure 73. Ungulate Carcass Hotspots on Highways and UDWR Black Bear Habitat Map.

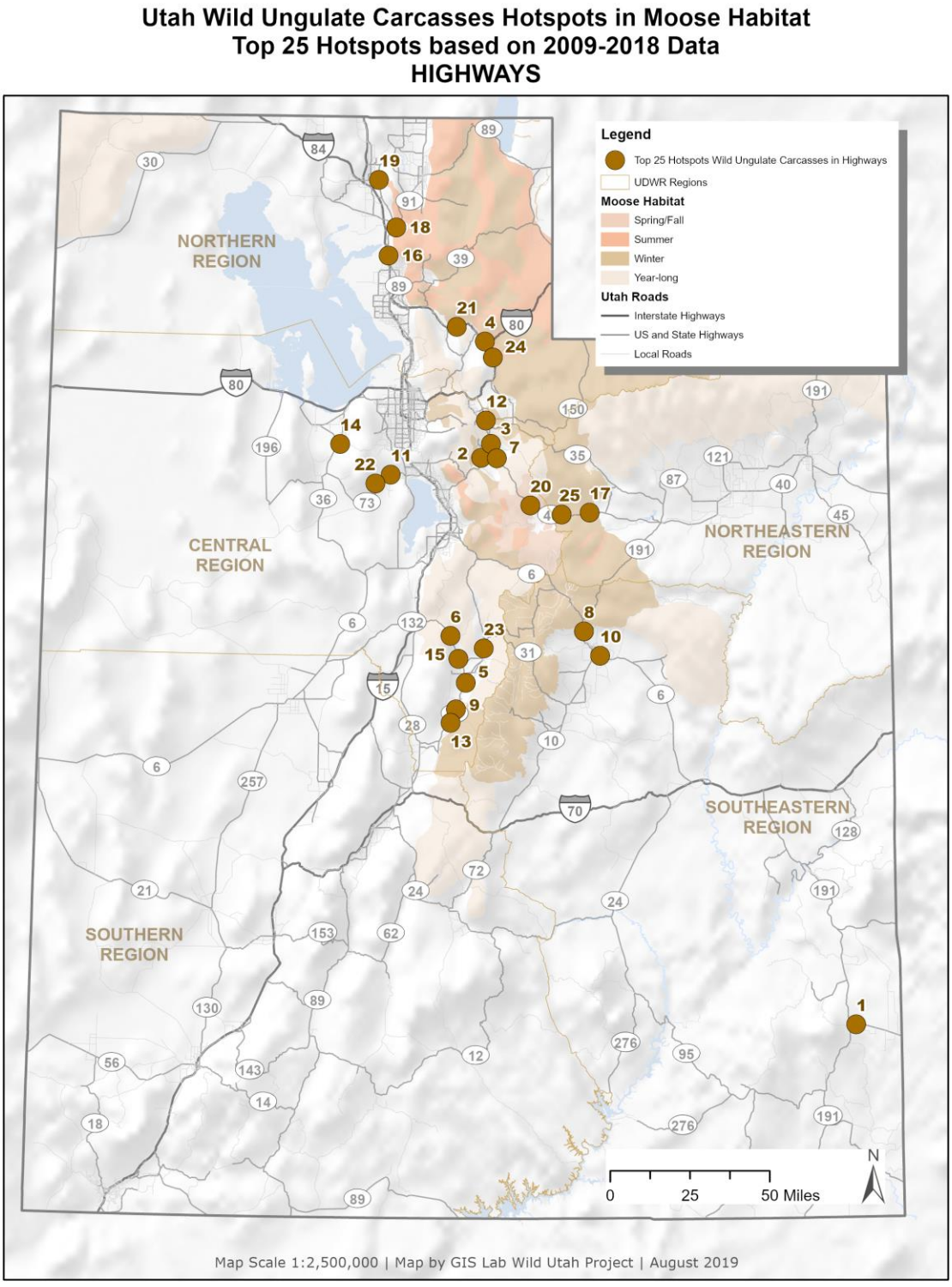

Figure 74. Ungulate Carcass Hotspots on Highways and UDWR Moose Habitat Map.

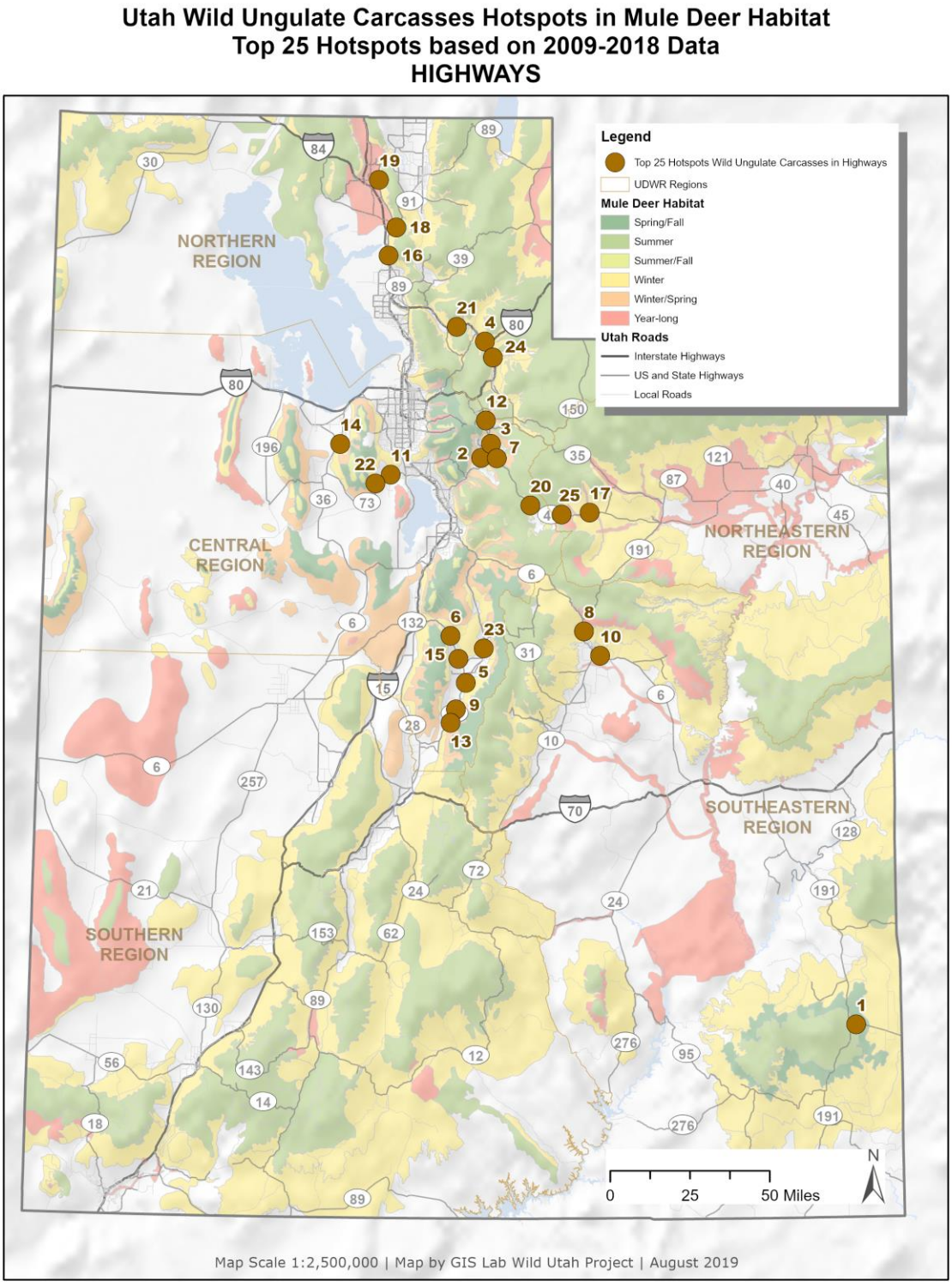

Figure 75. Ungulate Carcass Hotspots on Highways and UDWR Mule Deer Habitat Map.

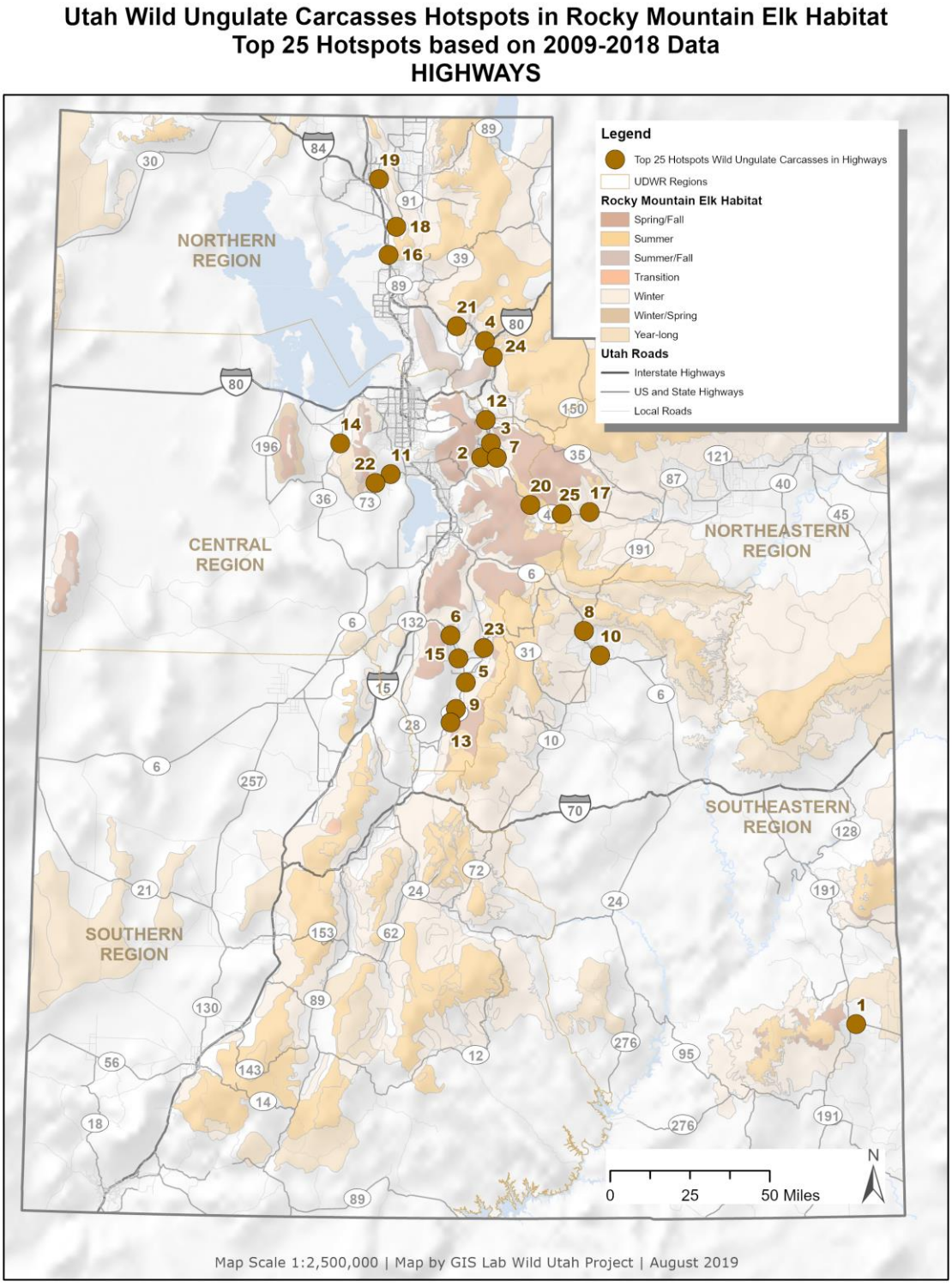

Figure 76. Ungulate Carcass Hotspots on Highways and UDWR Rocky Mountain Elk Habitat Map.

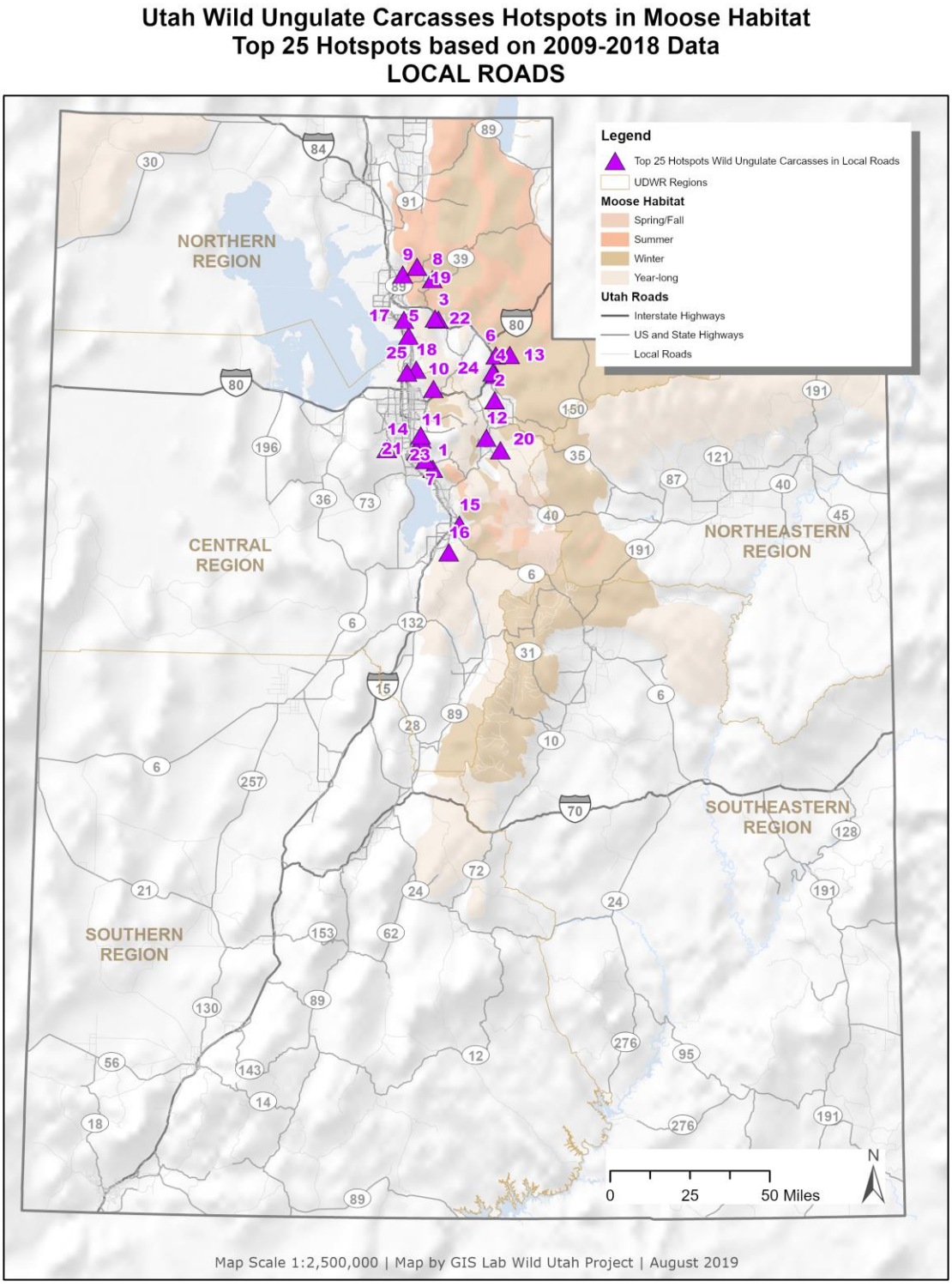

Figure 77. Ungulate Carcass Hotspots on Local Roads and UDWR Moose Habitat Map.

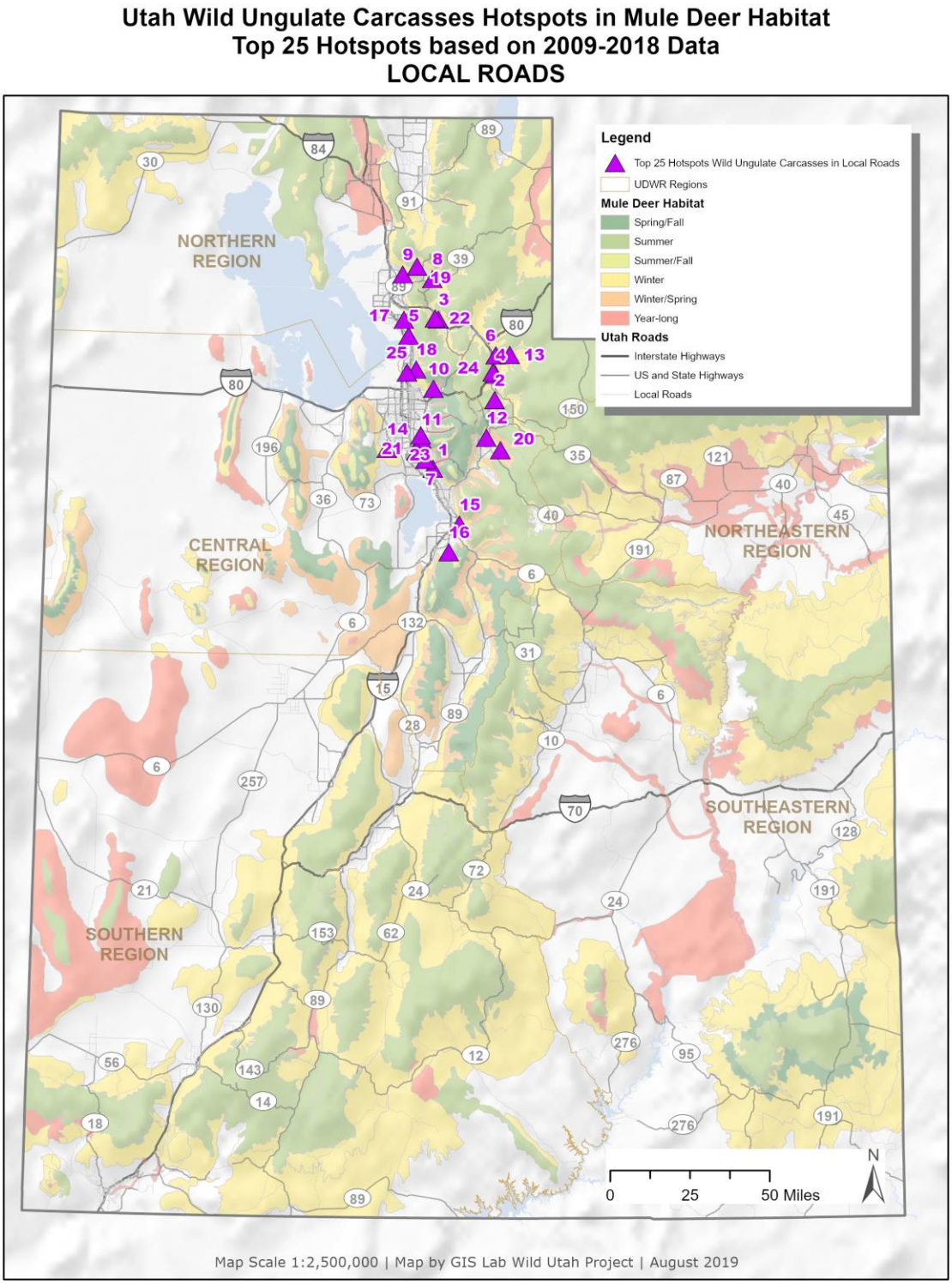

Figure 78. Ungulate Carcass Hotspots on Local Roads and UDWR Mule Deer Habitat Map.

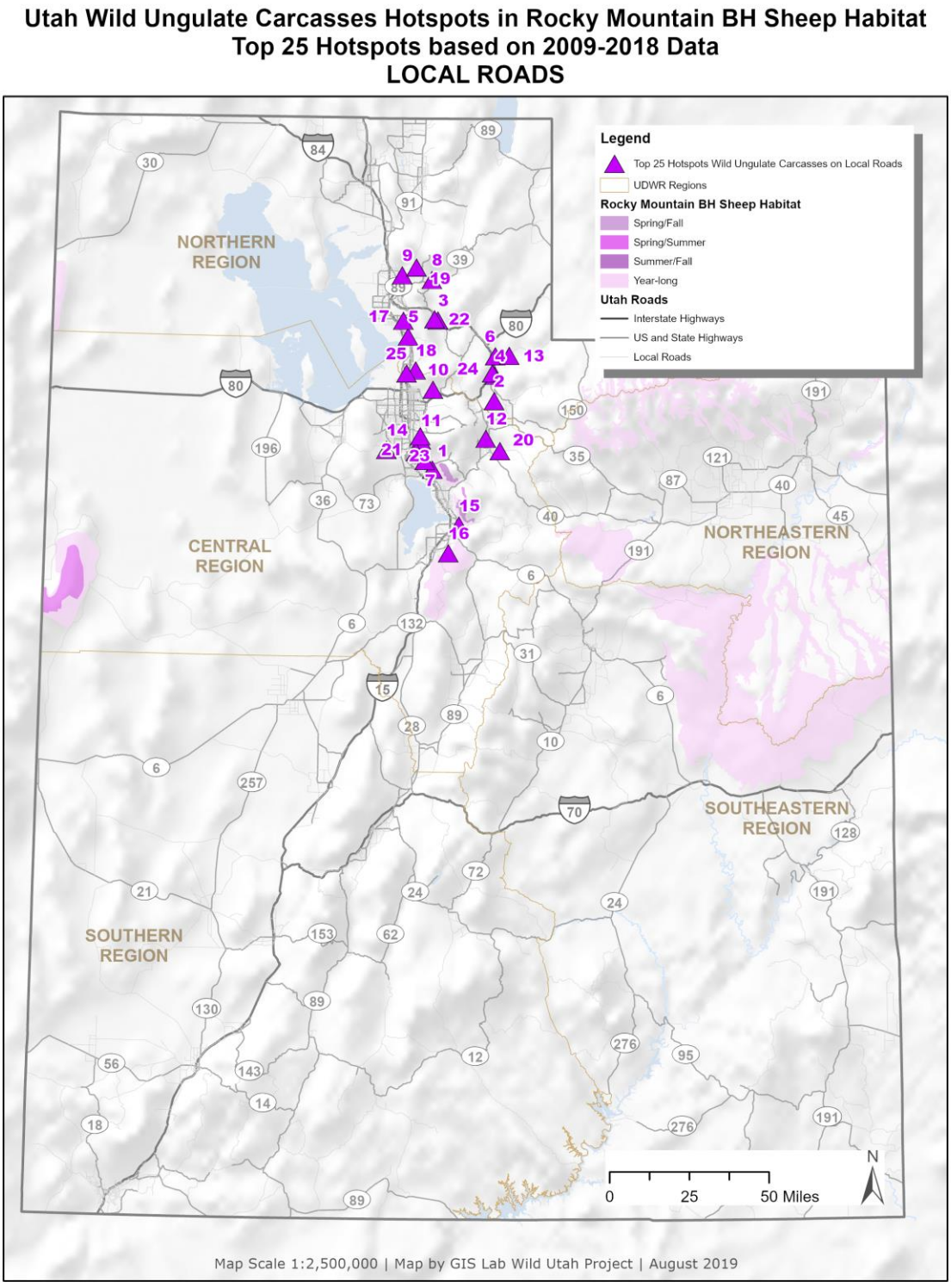

Figure 79. Ungulate Carcass Hotspots on Local Roads and UDWR Rocky Mountain Bighorn Sheep Habitat Map.

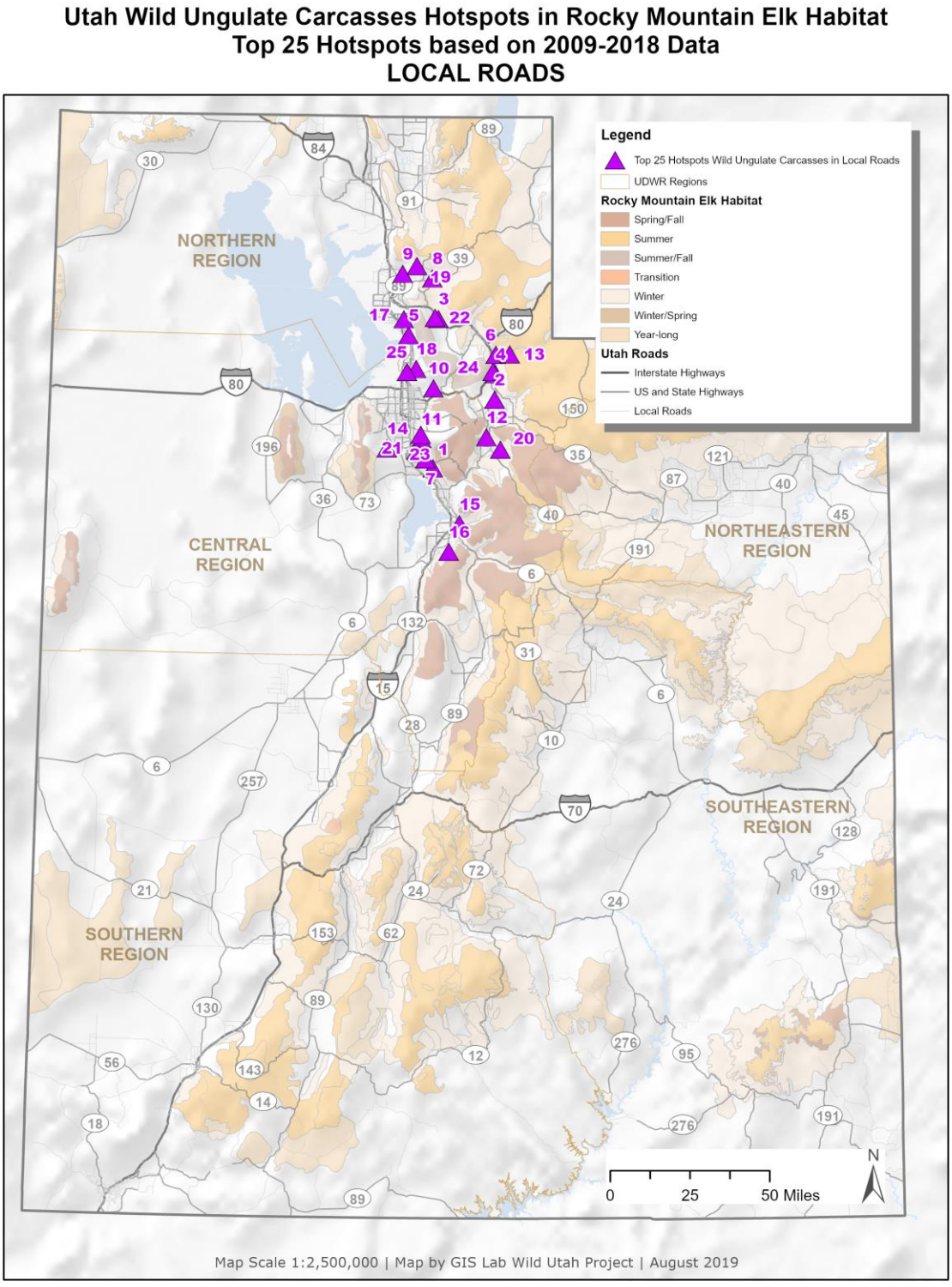

Figure 80. Ungulate Carcass Hotspots on Local Roads and UDWR Rocky Mountain Elk Habitat Map.

APPENDIX E. GUIDE TO DELIVERED GIS FILES: ARCGIS MAP DOCUMENTS, GEODATABASES, LAYERS, AND FIGURES FOR UPLAN

The GIS file deliverables for this project will be, at the time of this writing, or were at a later date, uploaded to the UPLAN website (http://uplan.maps.arcgis.com/home/index.html). These deliverables along with the final report and guidelines document fulfill the Task 7 deliverable.

Below, the contents of the delivered GIS files are defined for ease of finding map documents (*.mxd projects), geodatabases, layers, raw data, and exported maps to digital format files.

Table 16. Folders and Files Found in the Folder: 2018-2019_UTAH_AVC_ OPTIMIZEDHOTSPOTSANALYSIS 20191119.

Folder Name	Sub-Folder	Sub-Folder	Files and description
data			
	Layers	Basemaps	Contains 6 basemaps stored as layer files (*.lyr). These basemaps were customized to the purpose of this project and are being used in all final map products.
	Scratch.gdb	-	Geodatabase created with the purpose of proving a temporary location to intermediate layers. Intermediate layers are created when running a geoprocess. Upon completion of a given geoprocess, intermediate layers can be safely deleted since they are being stored in a separate location from the final output dataset. None of the contents in this geodatabase should be considered final data products.
	udot_wvc_2018.gdb	-	Master geodatabase of the project, it holds all input and output data of this project. Contents in this geodatabase include input and output data organized into feature datasets (e.g., admin_boundaries, basemap, etc), tables, rasters, and toolbox.
data_ exploration maps_arcmap			Three map document files (*.mxd) with data exploration visualizations as described below: 1) Figure 7 Map of Frequency AVC Crashes per County: map of counties rated by frequency of animal-vehicle crashes. 2) Figure 13 Map of Mule Deer Estimated Densities by WMU: map of population

			density for mule deer using historical population estimates from UDWR and Wildlife Management Units (WMU) as the population density aggregation units. 3) Figure 14 Map of Mule Deer Estimated Densities and AADT: map of the resultant mule deer estimated densities by WMU overlaid onto Annual Average Daily Traffic data of 2016.
data-exploration maps_arcpro			Data exploration maps created in ArcGIS Pro. During the data exploration phase of this project, we utilized ArcGIS Pro to generate data queries, data charts, and data exploration figures or maps. We found ArcGIS Pro better equipped to perform these tasks compared to ArcMap. As a result of our data exploration process, we created 20 maps and associated data charts. In ArcGIS Pro, navigate to the "Layouts" folder using the Catalog window to access the final data exploration maps.
final_exported_maps			
	arcgis_pro_maps		Destination folder for all final map products created in ArcGIS Pro and exported as *.png files. In this folder there are 20 PNG files in total.
	arcmap_maps		Destination folder for all final map products created in ArcMap and exported as *.png files. In this folder there are 58 PNG files in total.
gis_data_preparation			Contains two map document files (*.mxd) created with the purpose of preparing and implementing data quality checks on crash and carcass data. Files in this folder are: 1) UDOT Crash Data.mxd and 2) UDOT UDWR Carcass Data.mxd.
gis_ohsa_maps			Contains 58 map document files (*.mxd) that correspond to the final map products of this project. Final maps were exported as *.png files to the final_exported_maps/arcmap_maps folder.
gis_ohsa_modeling			Five map document files (*.mxd) that contain the process of modeling hotspots based on crash and carcass data. Below is a list of the files in this folder: 1) Optimized Hot Spots Analysis All Animal Crashes.mxd

			2) Optimized Hot Spots Analysis Domestic Animal Crashes.mxd 3) Optimized Hot Spots Analysis Wild Animal Carcasses.mxd 4) Optimized Hot Spots Analysis Wild Animal Crashes.mxd 5) Optimized Hot Spots Analysis Wild Ungulate Carcasses.mxd
gis_roads_data_preparation			One map document file (UDOT LRS Routes Data Preparation.mxd) that contains the process of preparing the roads dataset (UDOT LRS) prior to the Optimized Hot Spots Analysis (data modeling phase).
	FinalLRSHighways_AggPolygons.gdb		Destination geodatabase that stores the derived 0.5-mile aggregation polygons (buffered 0.5-mile road segments) and 0.5-mile road segments derived from selected highways. These are input datasets to the Optimized Hot Spots Analysis data modeling process.
	FinalLRSLocal Roads_AggPolygons.gdb		Destination geodatabase that stores the derived 0.5-mile aggregation polygons (buffered 0.5-mile road segments) and 0.5-mile road segments derived from selected local roads. These are input datasets to the Optimized Hot Spots Analysis data modeling process.
	python_script		Contains the standalone python script (createOHSAAggregationPolygonsAndSegments_sa.py) and python script used as ArcGIS tool (createOHSAAggregationPolygonsAndSegments_arcgis.py). Both scripts take a prepared roads dataset as input to generate aggregation polygons (buffered 0.5-mile road segments) and 0.5-mile road segments.
	roads_ohsa.gdb		Contains input and output datasets used in the roads data preparation process. These data files correspond to the step previous to running the python script described above. All data in this geodatabase has been organized into a feature dataset, standalone feature classes, and a toolbox with GIS workflows developed in ArcGIS ModelBuilder.
Tabular data			
	udot		
		AnimalNarrativeQueries	Original and modified (GIS used) crash datasets from narratives (years 2010-2018) provided by UDOT in Excel spreadsheet format.

		CrashData_2008_2017	Original and modified (GIS use) crash datasets (years 2008-2017) provided by UDOT in Excel spreadsheet format.
	udwr		Original and modified (GIS use) Mule Deer historical population datasets (years 2000-2017) provided by UDWR in Excel spreadsheet format.