Spatial Auto-Logistic Regression Modeling of South Central Skunk Variant Rabies in the Four Corners States

Benjamin White, MPH

2018

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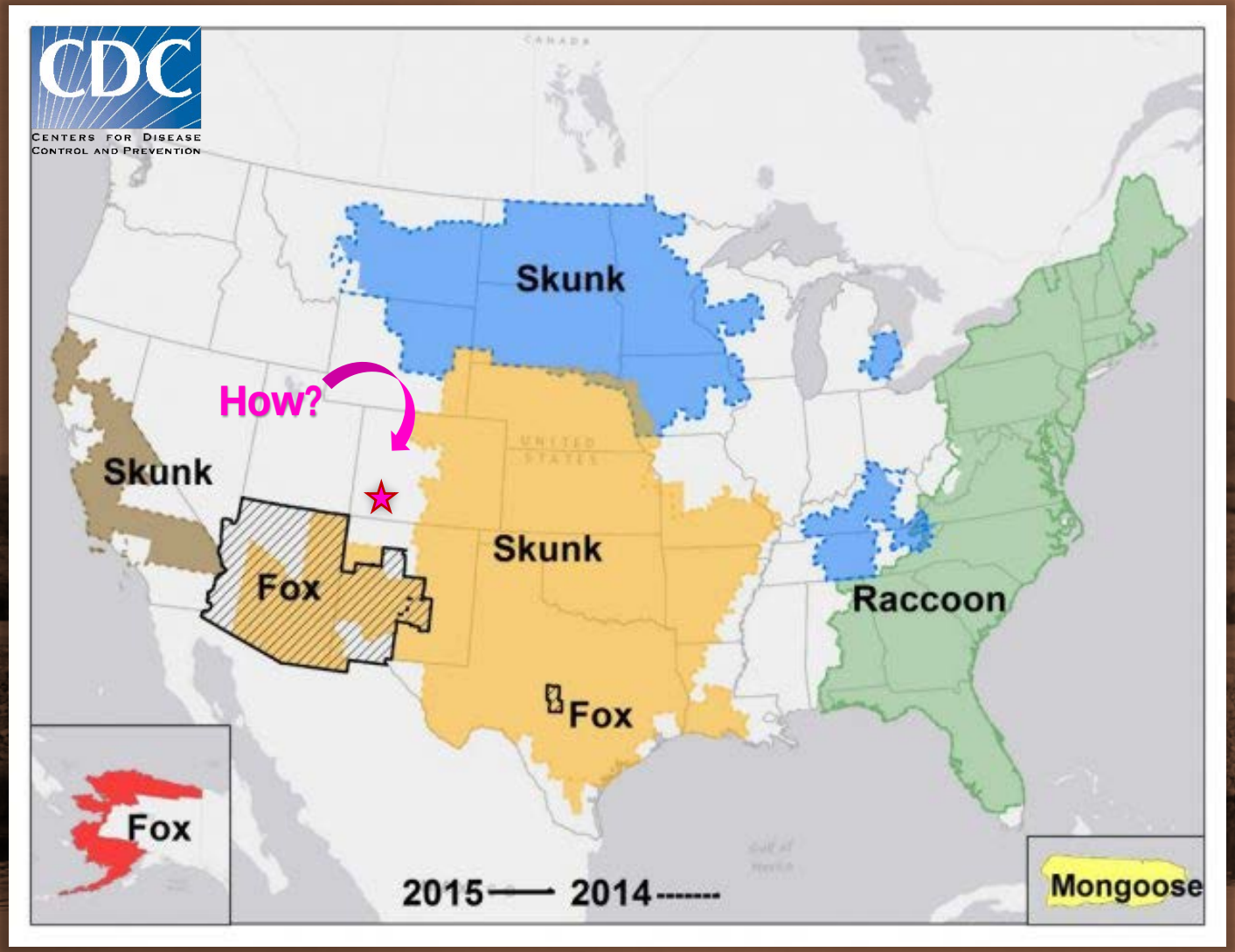

Distribution of Terrestrial *Rabies* Virus Variants, United States, 2008 to 2015

THE Durango HERALD

DH News Local/Region Education Health Southwest Life Travel Nation & World

Free article

Health department warns of rabid skunks in Durango

Video shows sickened animal near 11th Street and East Second Avenue

By Mary Shinn City & health reporter

Friday, Nov. 3, 2017 5:45 PM Updated: Friday, Nov. 3, 2017 8:36 PM

November 2017

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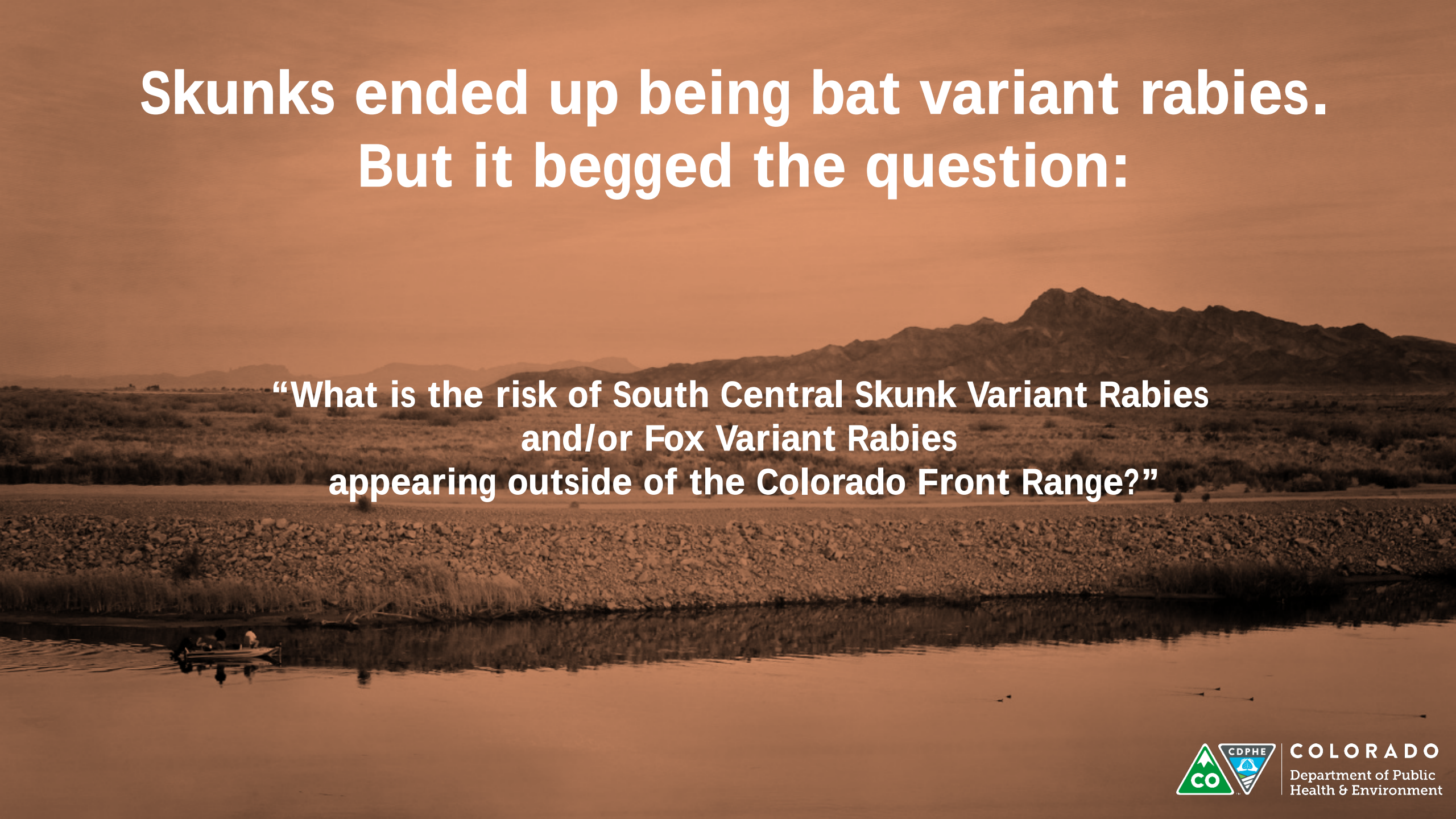
Skunks ended up being bat variant rabies. But it begged the question:

“What is the risk of South Central Skunk Variant Rabies and/or Fox Variant Rabies appearing outside of the Colorado Front Range?”



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Geocoding of Four Corners Rabies Specimens

- Data compiled by CO State Public Health Veterinarian
- Re-geocoded by CDPHE-GIS using:
  - Centrus (MapMarker version 29)
  - US Census Bureau Geocoder
  - Google Earth

- **709** Specimens submitted to CDPHE by Four Corners States
- **681** (96.1%) Geocoded successfully
  - 175 (24.7%) omitted due to no variant typing/non-terrestrial variant
  - 42 (5.9%) omitted due to being outside 2013-2017 study period
- **492** Specimens for analysis

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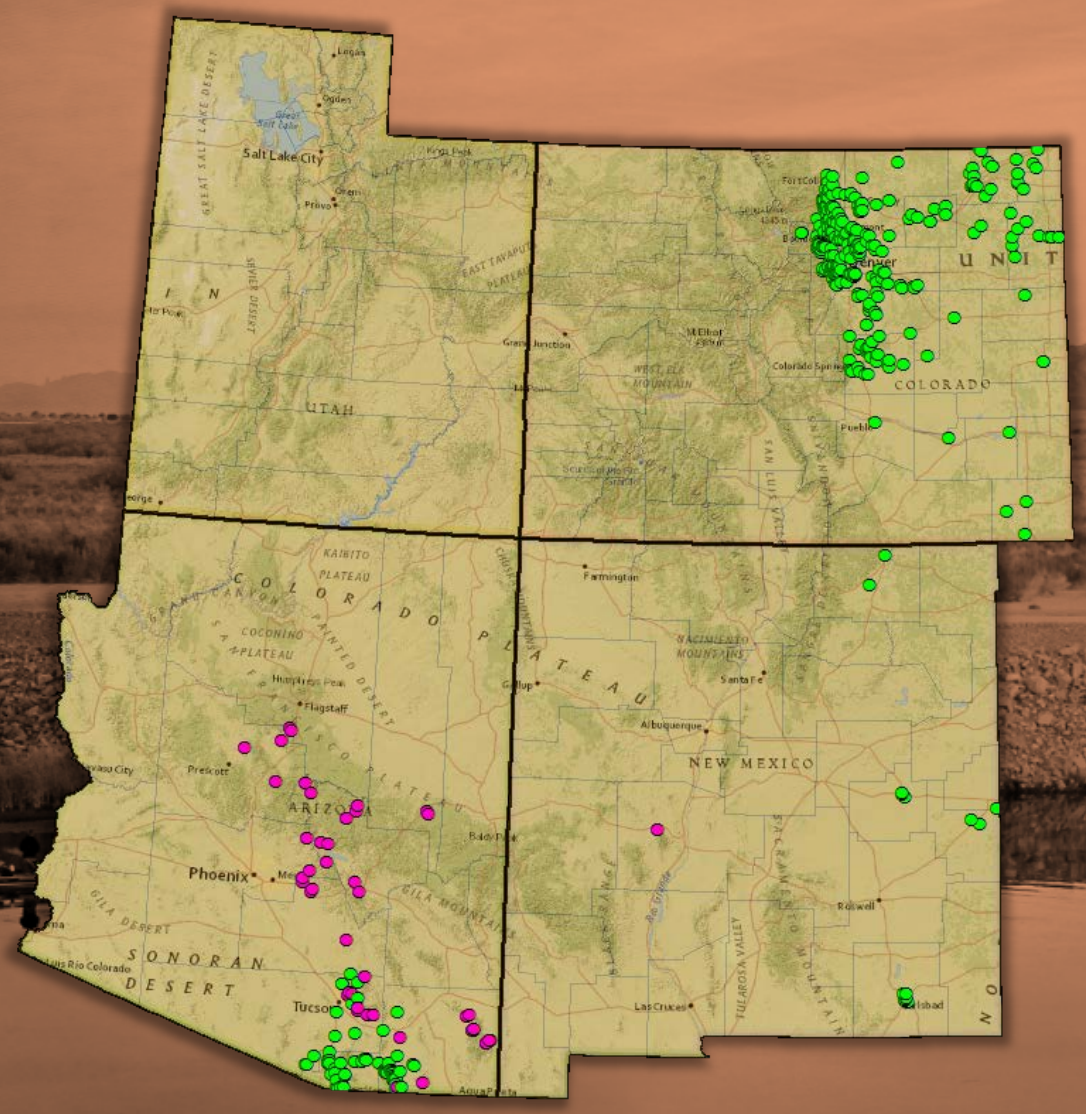
RABV+ Specimens Locations, 2013-2017



SC Skunk Variant, Confirmed & Suspect

AZ Grey Fox Variant, Confirmed & Suspect

Fox variant is over 200 miles away from Colorado

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Descriptive Analysis

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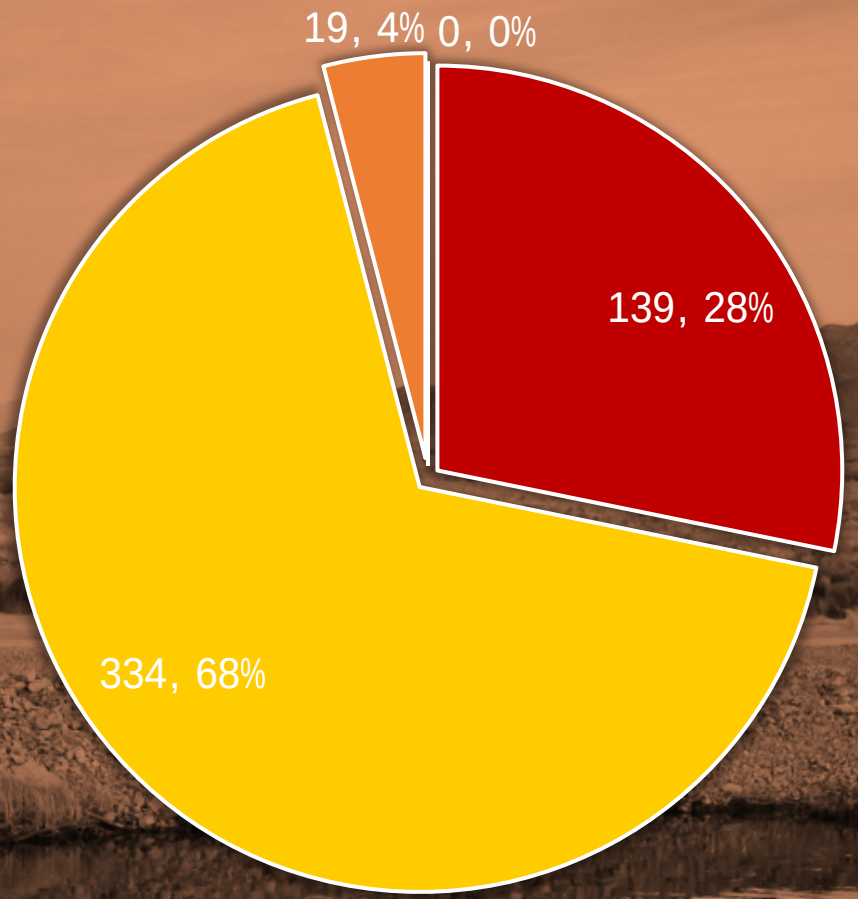
Specimens by State, 2013-2017



N= 492

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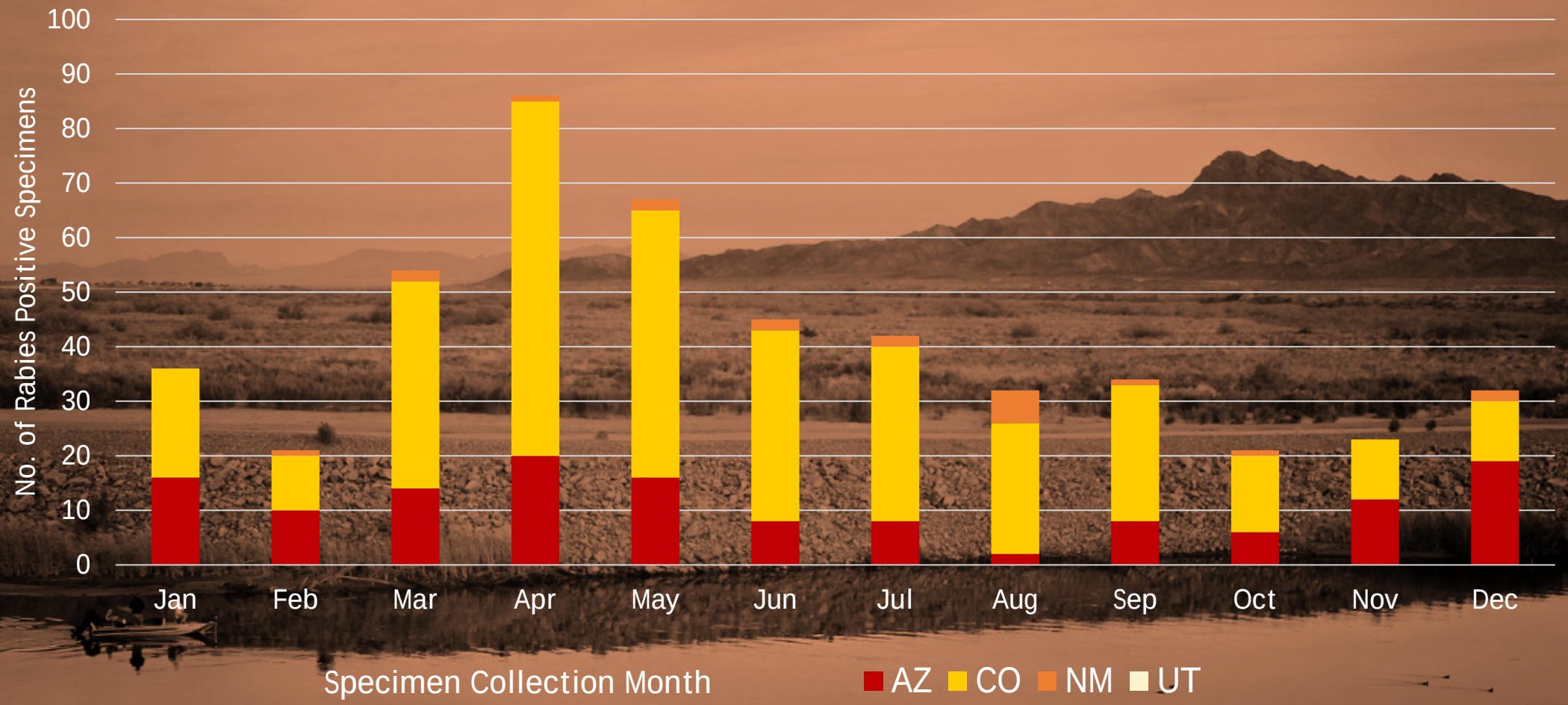
Specimens by Collection Month, 2013 - 2017



N= 492

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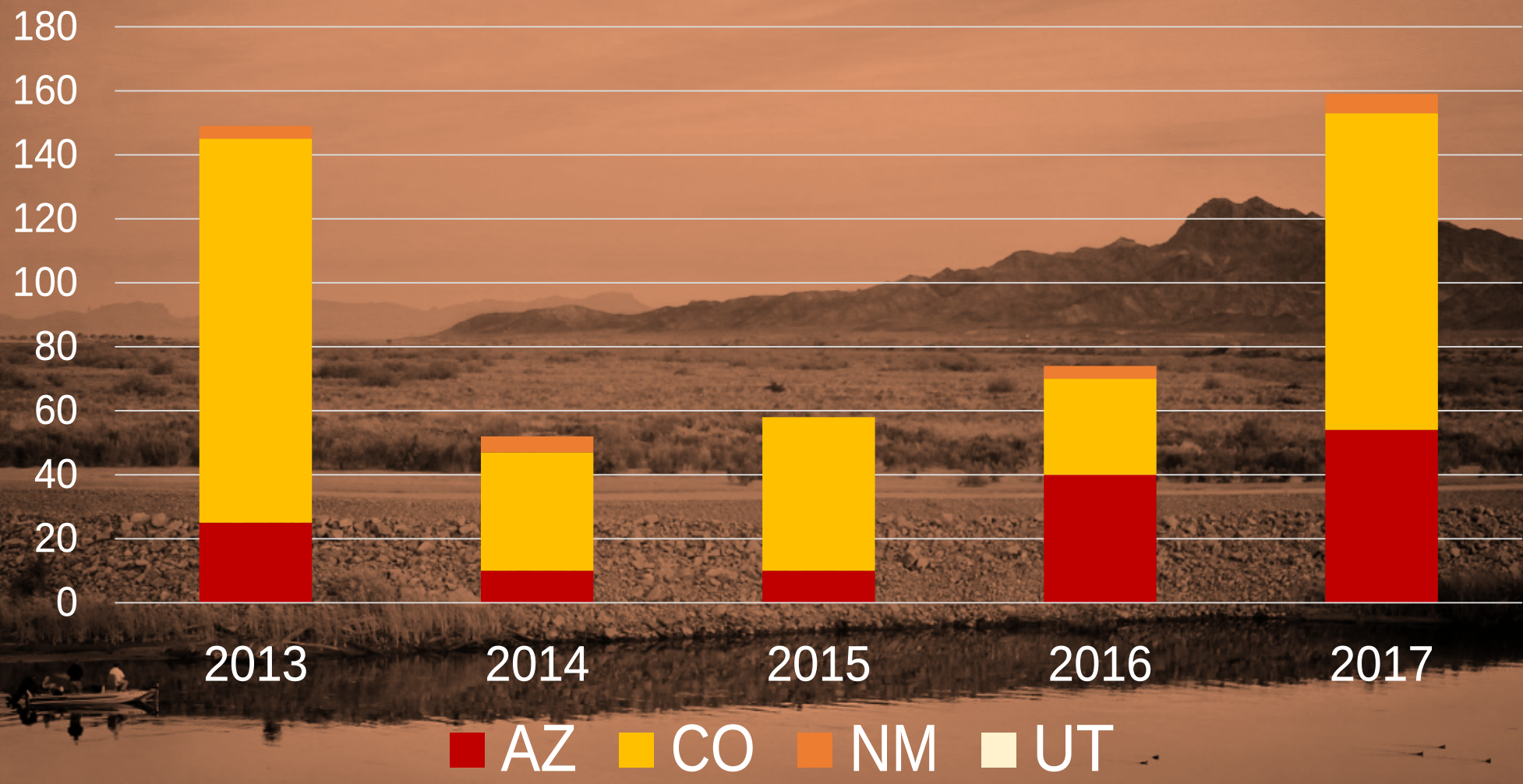
Specimens by Collection Year, 2013-2017



N= 492

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Specimens by Species, 2013-2017

11.2% Grey, Kit, and Red Foxes

6.7% Hooded, Hog-Nosed, E. & W. Spotted Skunk Species

6.1% Other Wild Animals – Coyote, Javelina, Bobcat, Raccoon

3.8% Domestic Animals - Cats, Dogs, Horses, Cattle

N= 492

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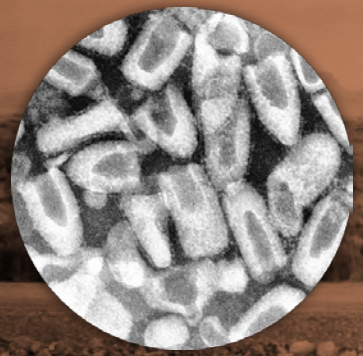
Specimens by RABV Variant, 2013-2017



	SC Skunk		Grey Fox	
	Confirmed	Suspect	Confirmed	Suspect
AZ	80	5	49	5
CO	10	324	0	0
NM	8	8	3	0
UT	0	0	0	0
Total	98	337	52	5

N= 492

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Proximity and Hot Spot Analysis

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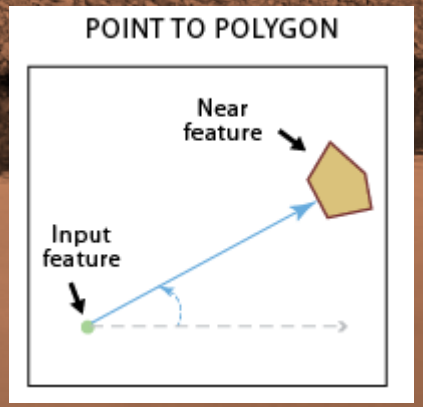
Variant Distance to Bordering States (Miles)

Skunk Rabies Variant

Specimen State	Distance to Bordering State			
	Arizona	Colorado	New Mexico	Utah
AZ		326.1	18.3	310.1
CO	259.6		20.1	188.0
NM	245.7	6.6		246.6
UT	--	--	--	

Fox Rabies Variant

Specimen State	Distance to Bordering State			
	Arizona	Colorado	New Mexico	Utah
AZ	--	201.1	5.5	141.4
CO	--	--	--	--
NM	104.4	200.8	--	225.4
UT	--	--	--	--



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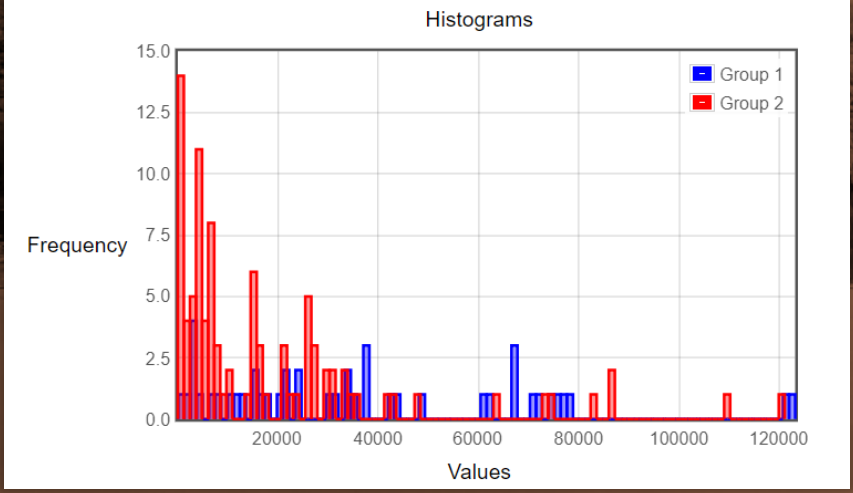
Variant Distance from Urban Areas*

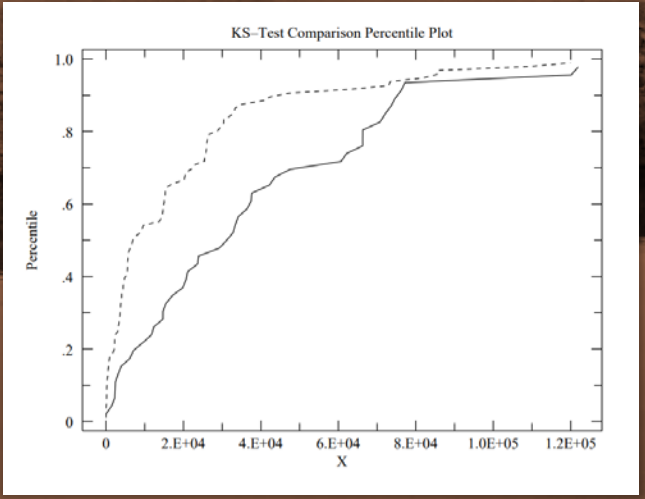
Confirmed SC Skunk Variant (N=95): Median 2.8 Miles/Mean 11.5 Miles
Confirmed AZ Gray Fox Variant (N=45): Median 19.4 Miles/Mean 22.5 Miles

There is a statistical difference between the rabies variants and their proximity to urban areas (*census tracts >=1,000 per SQMI)

Two-Tailed Mann-Whitney U:
U= 4947 Z = -5.6243, P <.00001

Kolmogorov-Smirnoff:
D = 0.43, P <0.001





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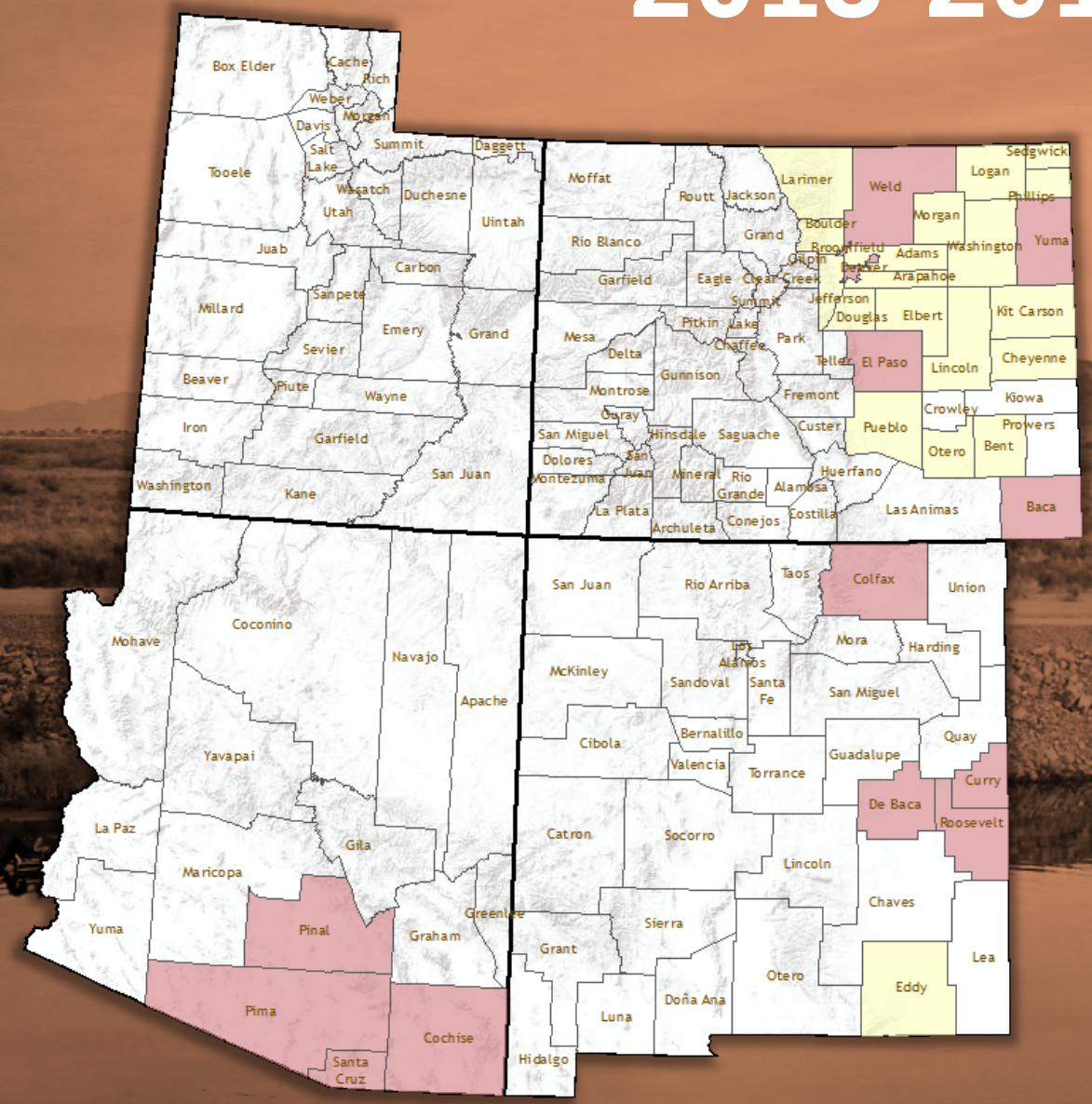
SC Skunk Variant Presence by County, 2013-2017



Variant Confirmed

Variant Suspected

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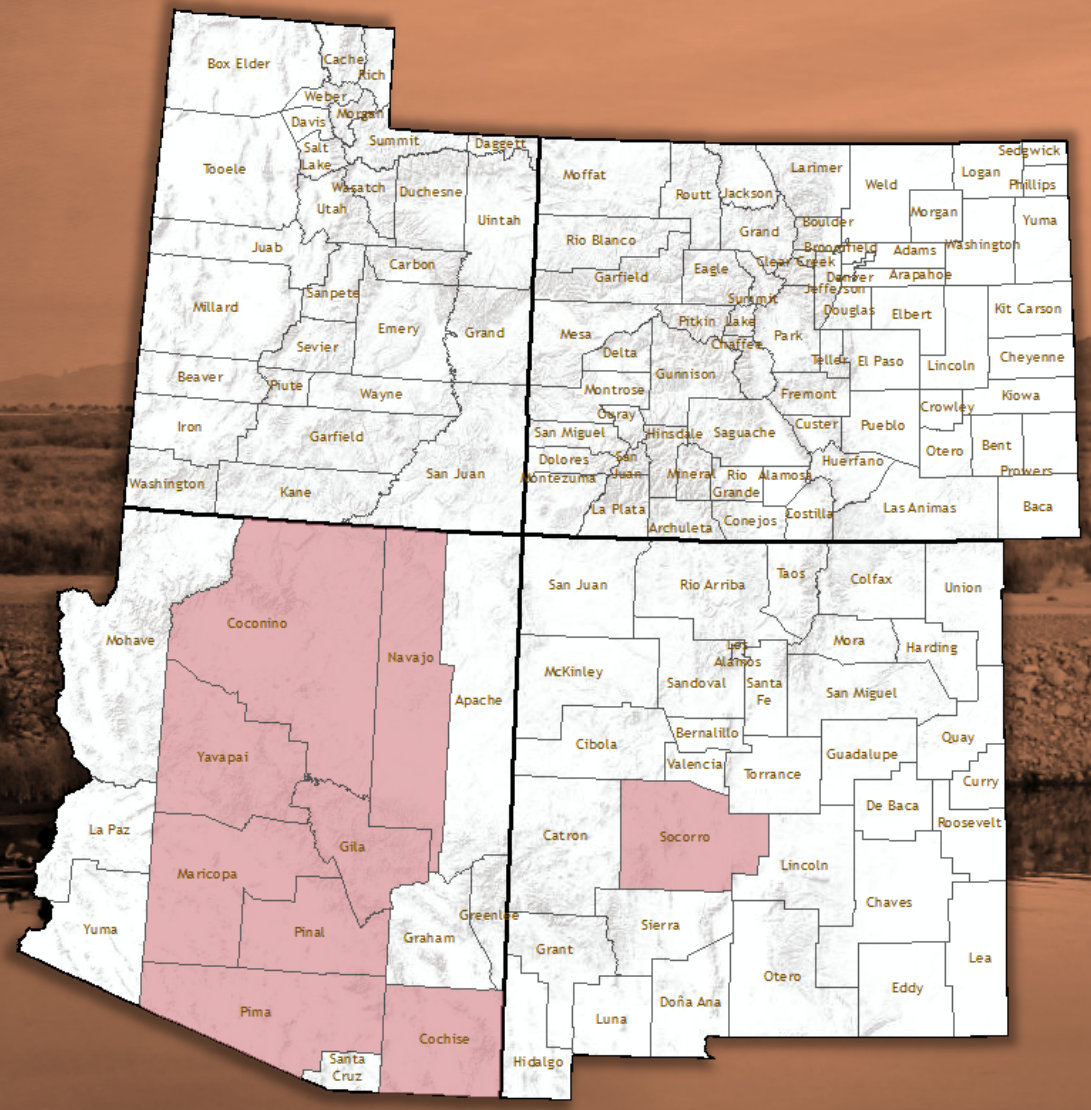
AZ Gray Fox Variant Presence by County, 2013-2017



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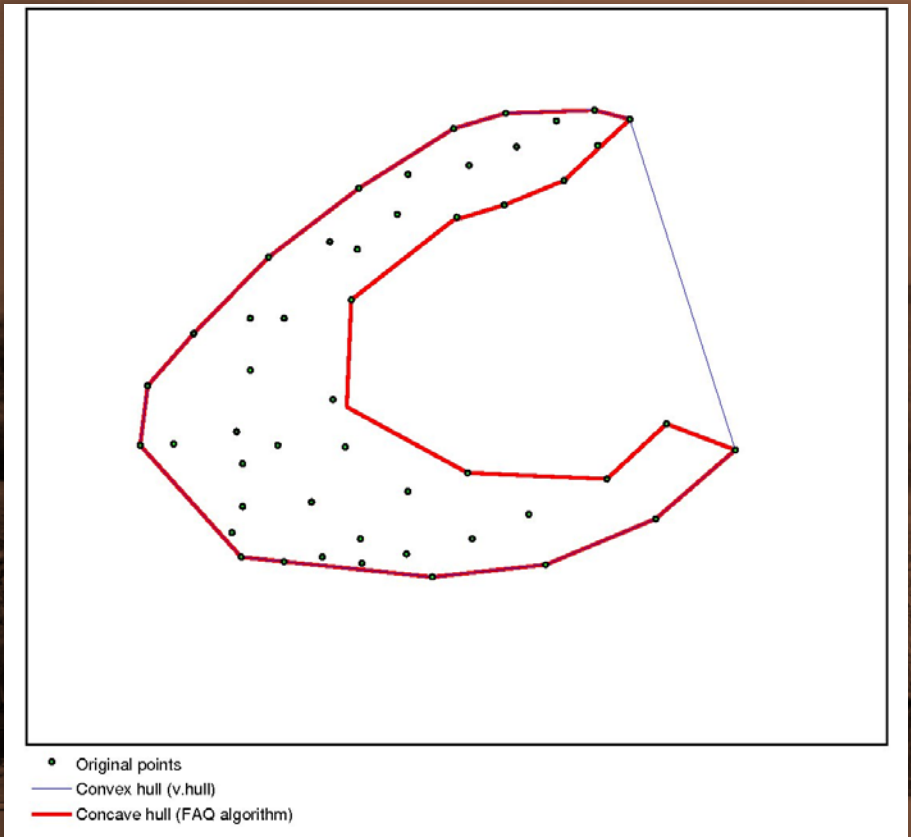
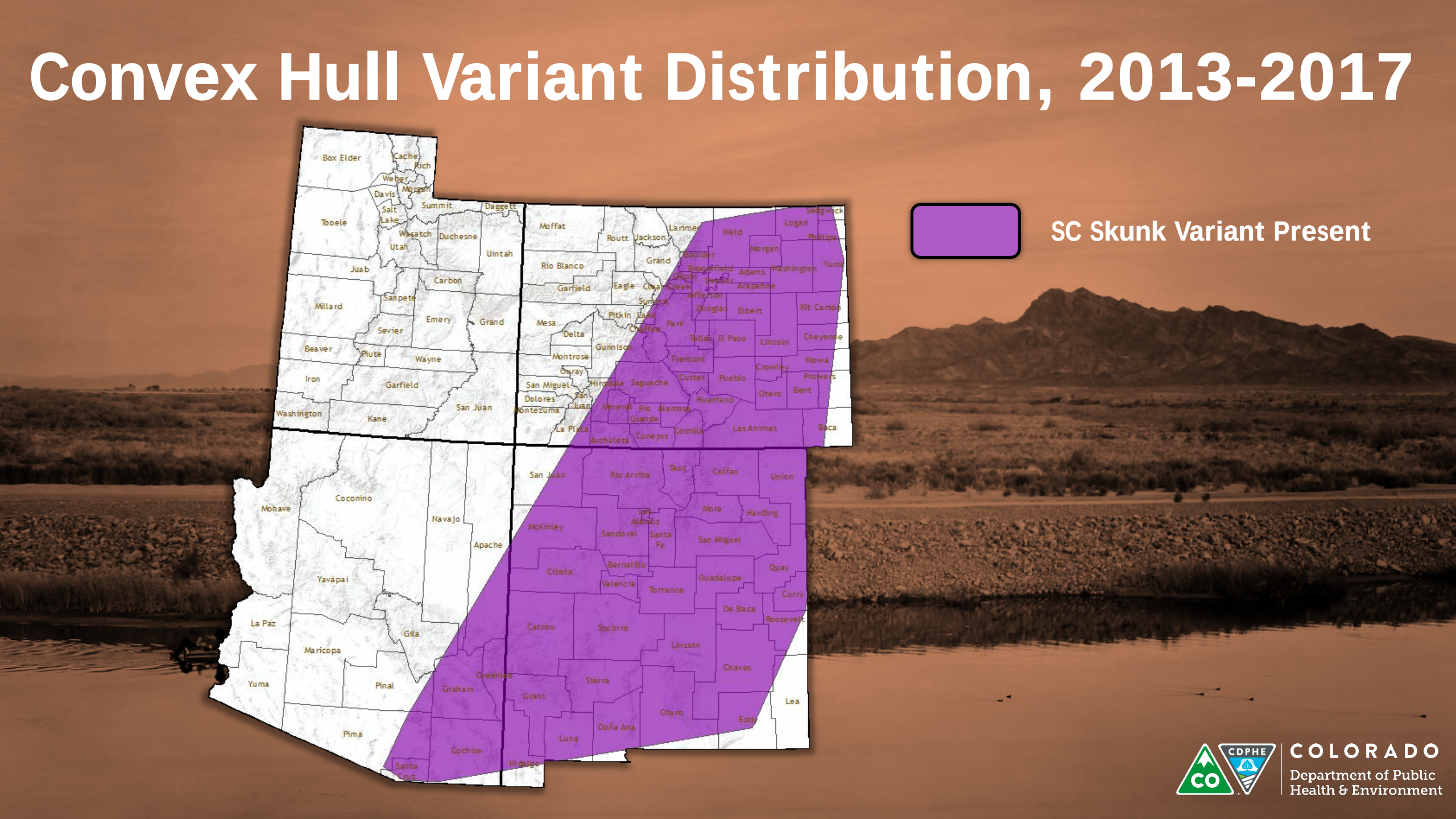
Convex-Hull Boundaries



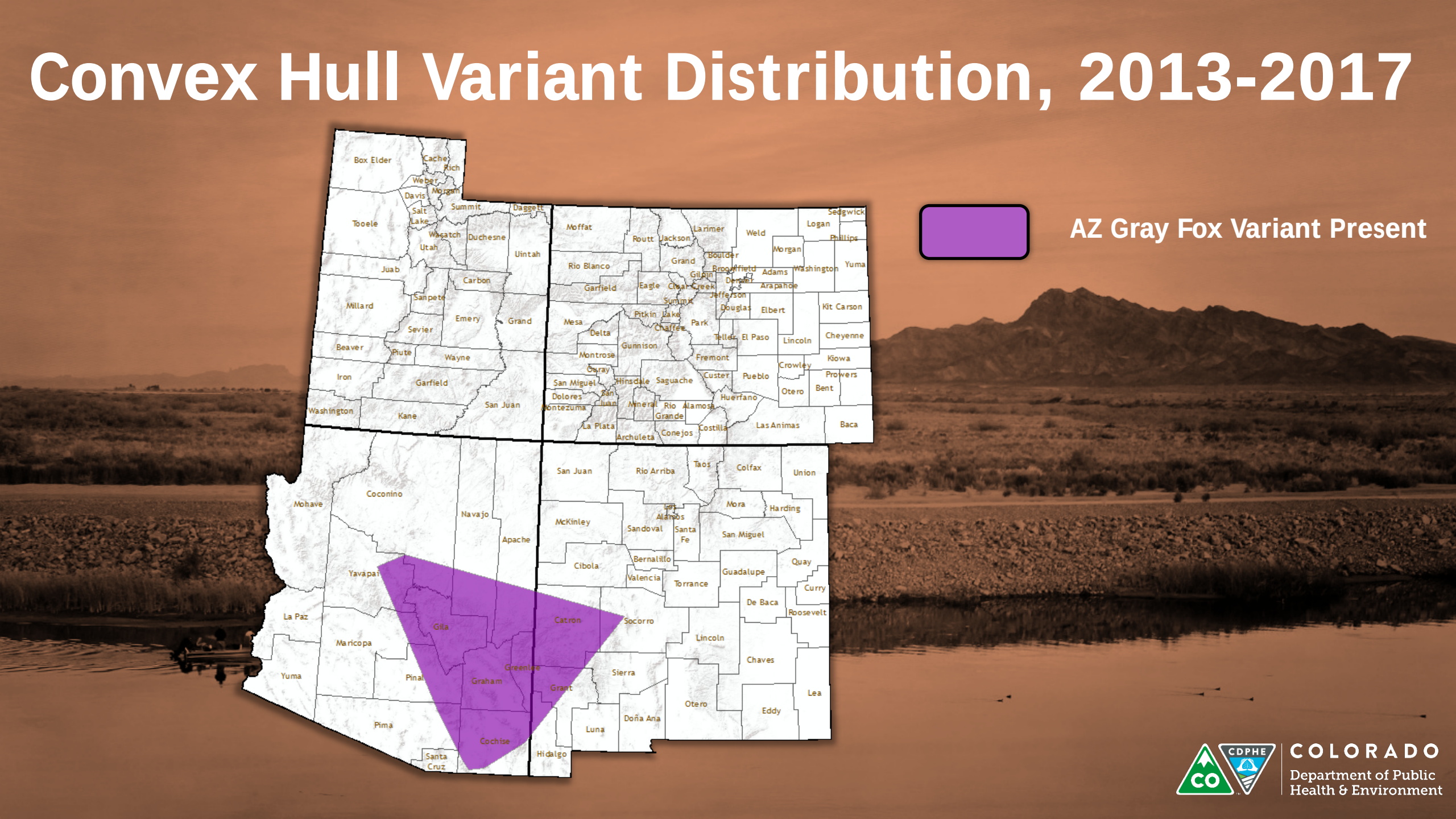
"The convex hull of a set Q of points is the smallest convex polygon P for which each point in Q is either on the boundary of P or in its interior."

i.e. drawing a bounding box around all the points

Convex Hull Variant Distribution, 2013-2017



Convex Hull Variant Distribution, 2013-2017



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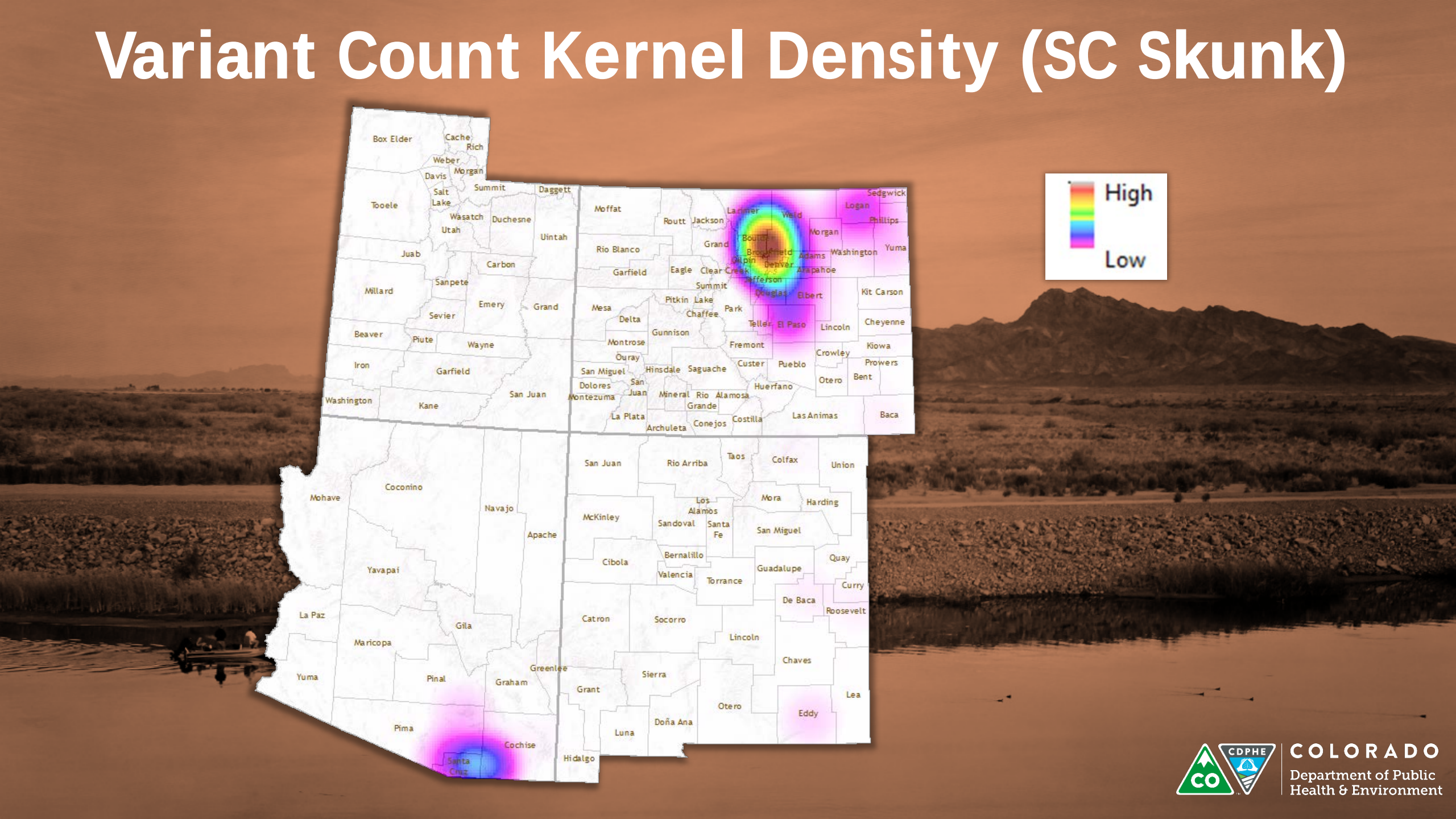
Kernel Density

"The Kernel Density tool calculates the density of features in a neighborhood around those features. It can be calculated for both point and line features. Possible uses include finding density of houses, crime reports, or roads or utility lines influencing a town or wildlife habitat." - ESRI

i.e. making an estimated smooth surface of RABV+ specimen density based on our specimen points

Variant Count Kernel Density (SC Skunk)



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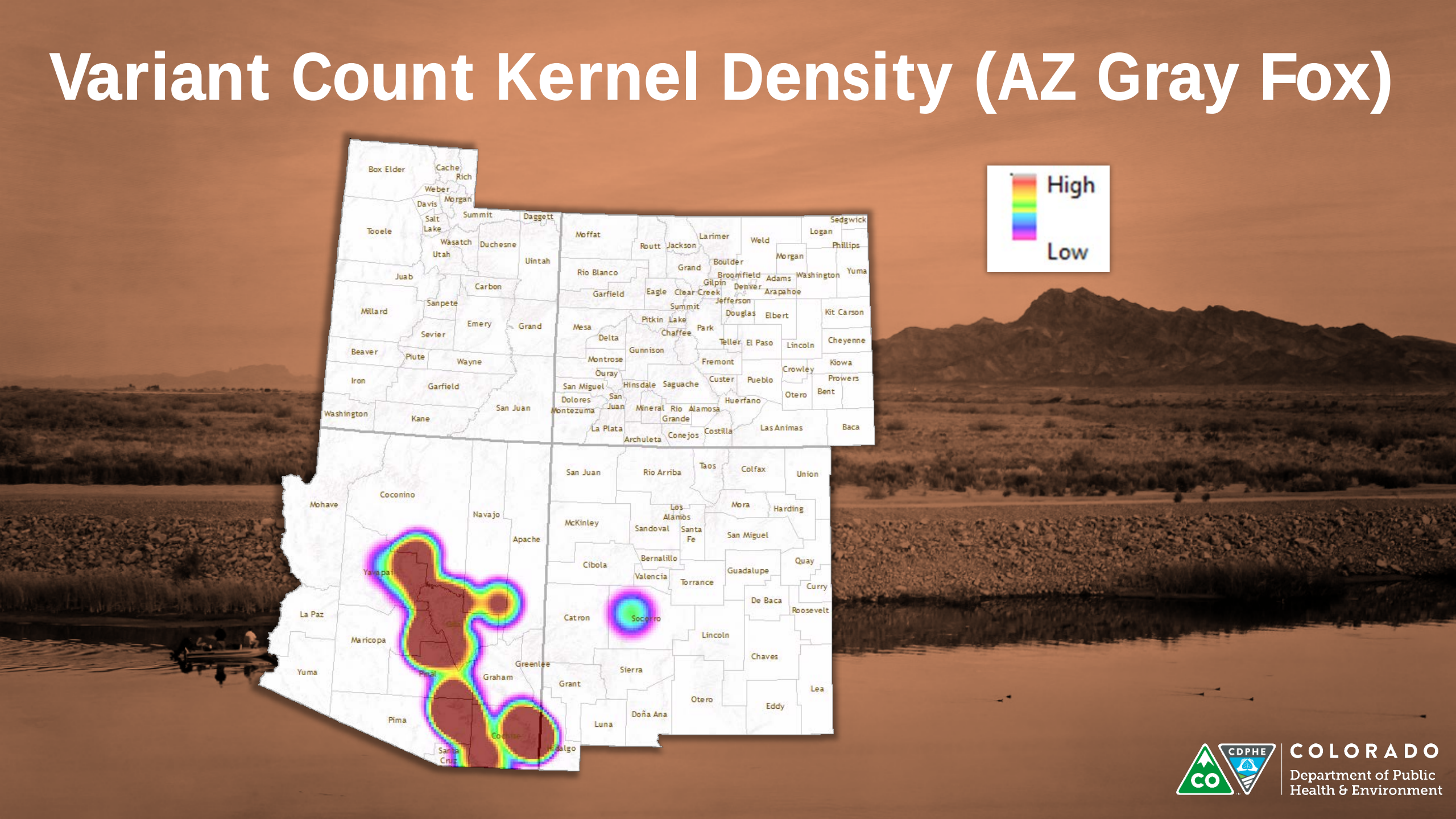
Variant Count Kernel Density (AZ Gray Fox)



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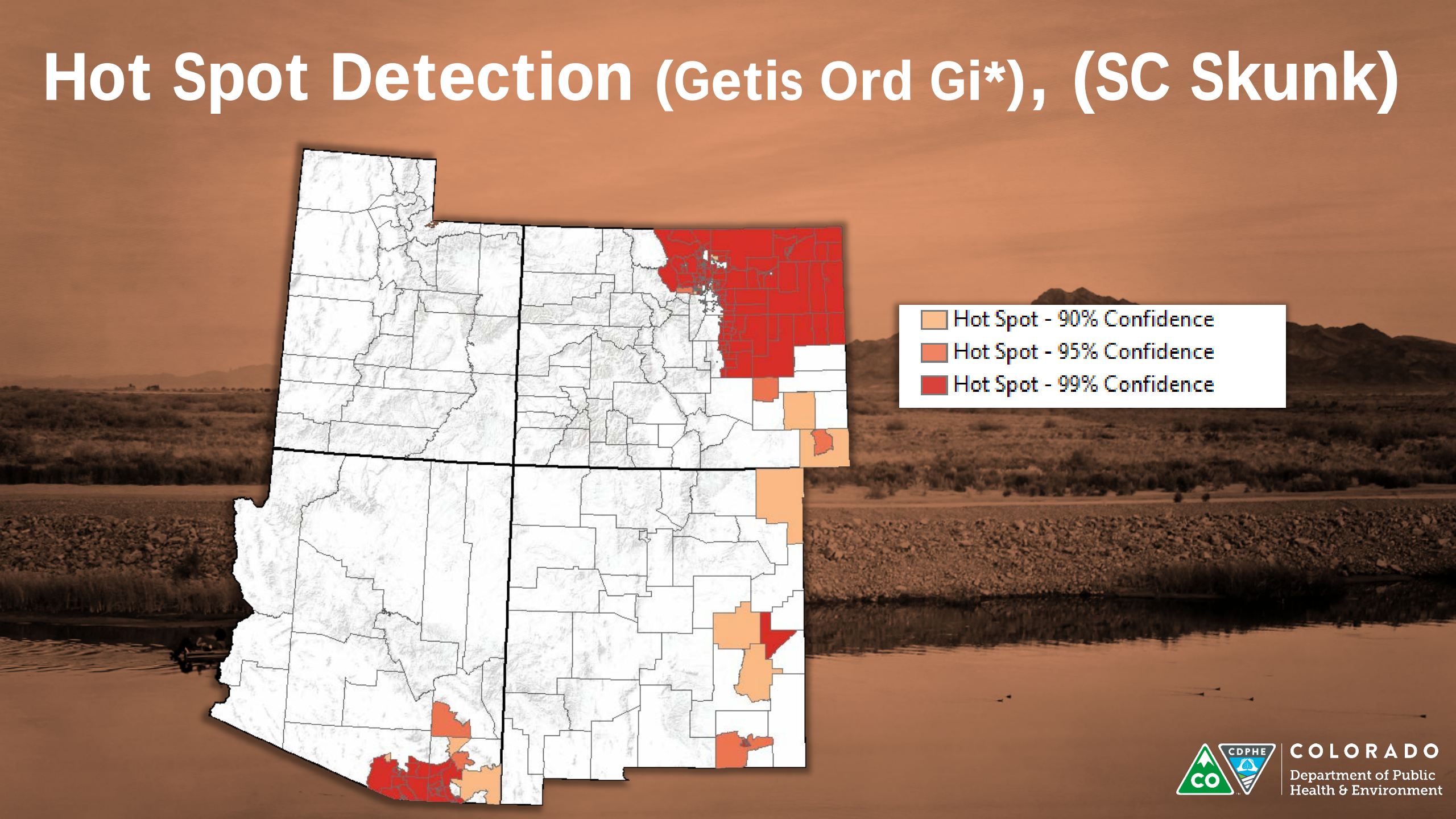
Hot Spot Detection (Getis Ord Gi*)

In this instance, hot spot analysis works by comparing the total number (count) of RABV+ animals within a census tract to it's neighbors. We've defined neighbors by "queen rules", that is contiguity of edges/vertices. The total number of positive animals in a tract and its neighbors is also compared to the entirety of census tracts.

Hot Spot Detection (Getis Ord Gi*), (SC Skunk)



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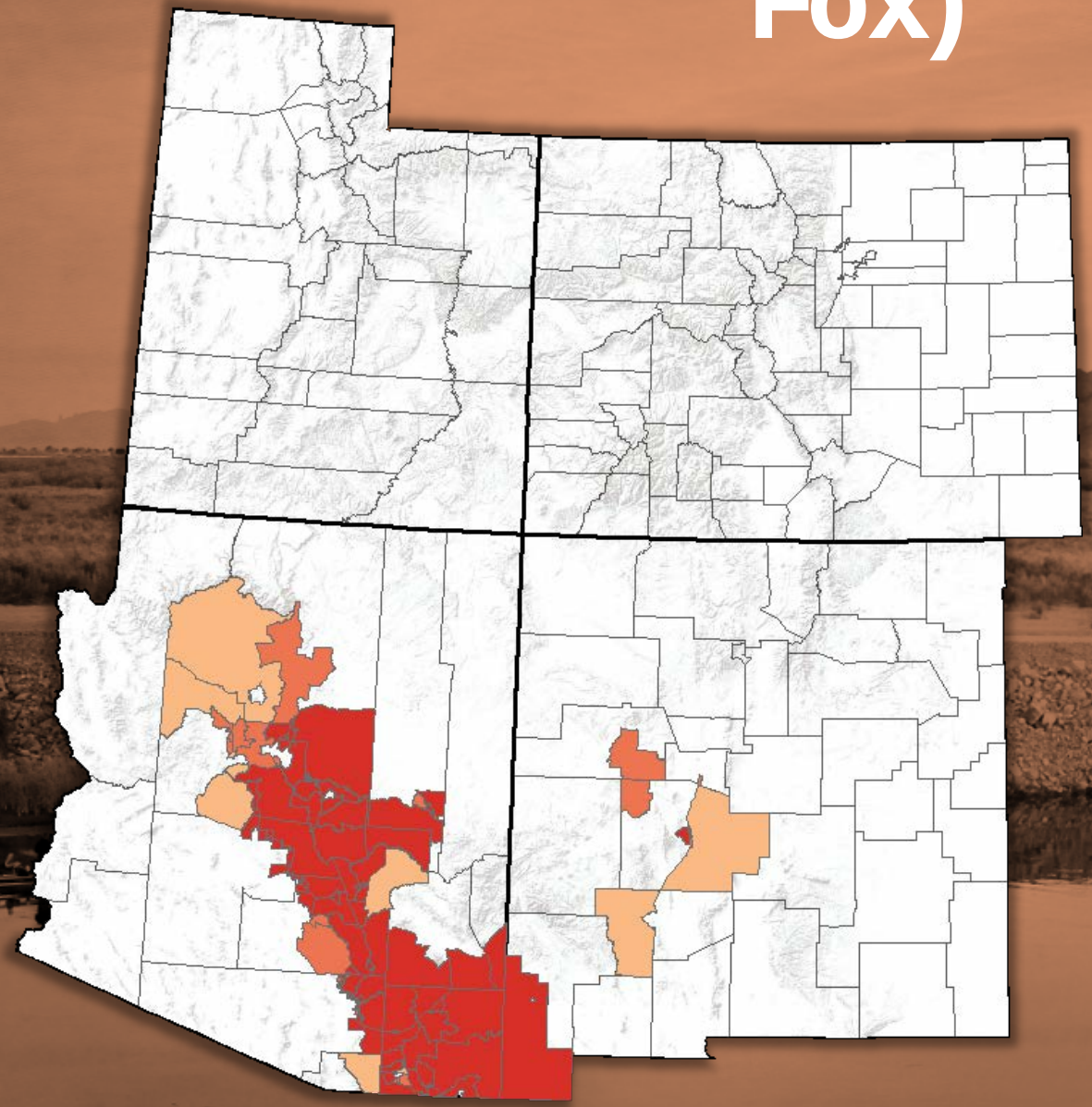
Hot Spot Detection (Getis Ord Gi*), (AZ Gray Fox)



Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence

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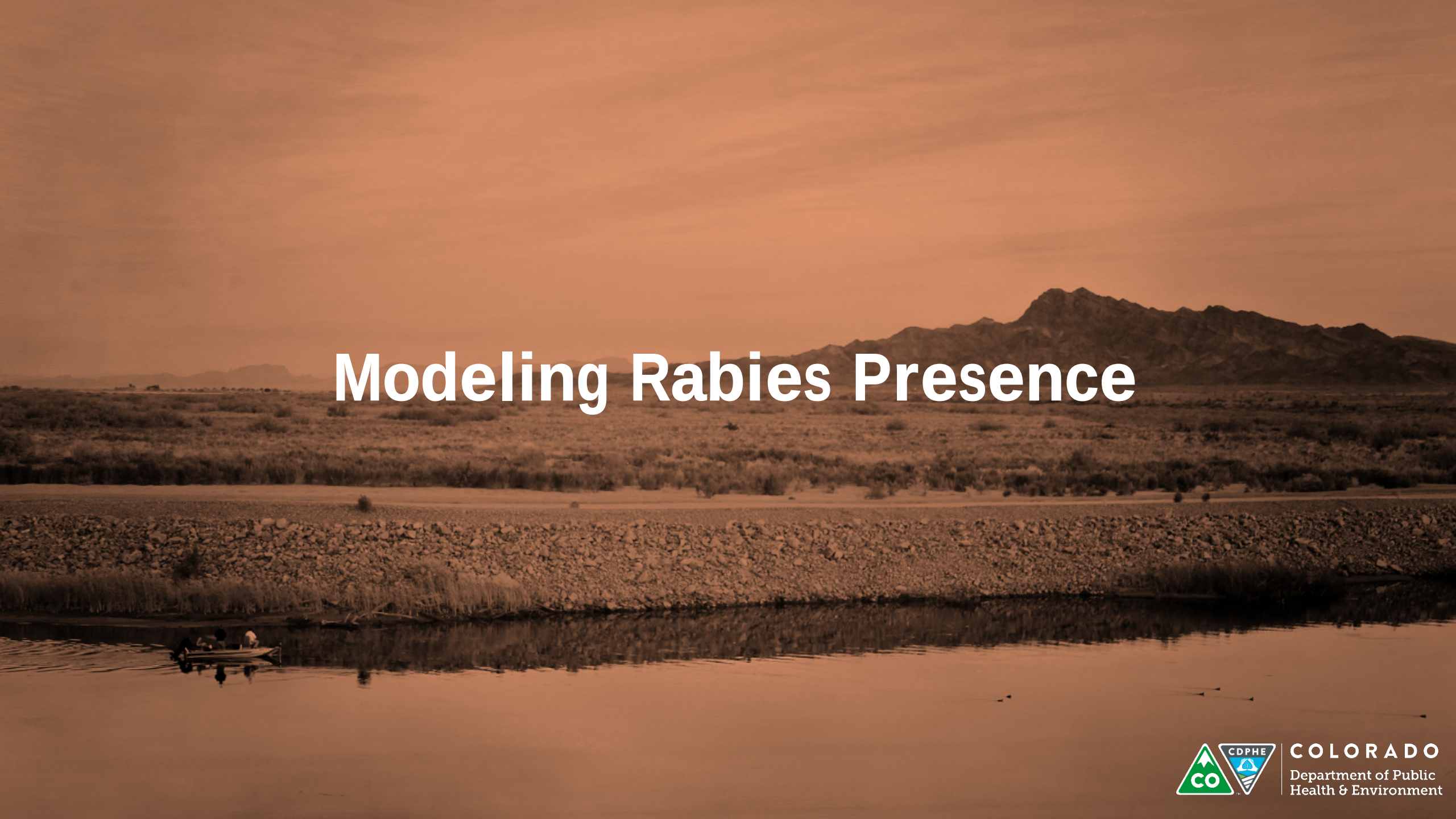

Modeling Rabies Presence

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Spatial Auto-logistic Regression Model Steps

- Geocoding, cleaning of case data
- Literature review
- Covariate Data Mining, Cleaning & Descriptives
- Correlation and Variance Inflation Assessment
- Non-spatial logistic Regression Modeling Building
- Spatial Autocorrelation Assessment
- Spatial (Autologistic) Regression modeling
- Boot Strapping and Model Confidence Intervals
- Output & Interpretation

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Which Type of Model to Use?

Occupancy Modeling

Presence/Absence Modeling

First introduced in MacKenzie et. al *"Estimating Site Occupancy Rates When Detection Probabilities are Less Than One" Ecology, 83(8),2002, pp. 2248-2255*

Models the probability a site is occupied and probability of detecting a species during your visit

Requires "Replication" a.k.a. revisiting of sites

Assumes randomly selected sites, sites are closed to changes in occupancy state between sampling, no detection bias, occurrence constant across sites or explained by covariates

Autologistic Regression

Presence/Absence Modeling

Produces Odds Ratios (ORs) for geographic unit

First introduced in 1974

Mirrors epi logistic regression models

Most widely used for measuring spatially correlated presence/absence data

The model introduces a spatial autocorrelation term in the form of weighting coefficients and solves the problem of spatial autocorrelation effects in the process of statistical analysis.

Landscape Genetics

Models movement and flow

Individual and population dynamics due to landscape/terrain

Forecasting, prediction

Geneflow as "electric current"

Bayesian Generalized Linear Spatial Model (BGLSM)

Partial Least Squares Regression

Species Distribution Modeling with Presence-Only Data MAXENT/"Maxlike" in R

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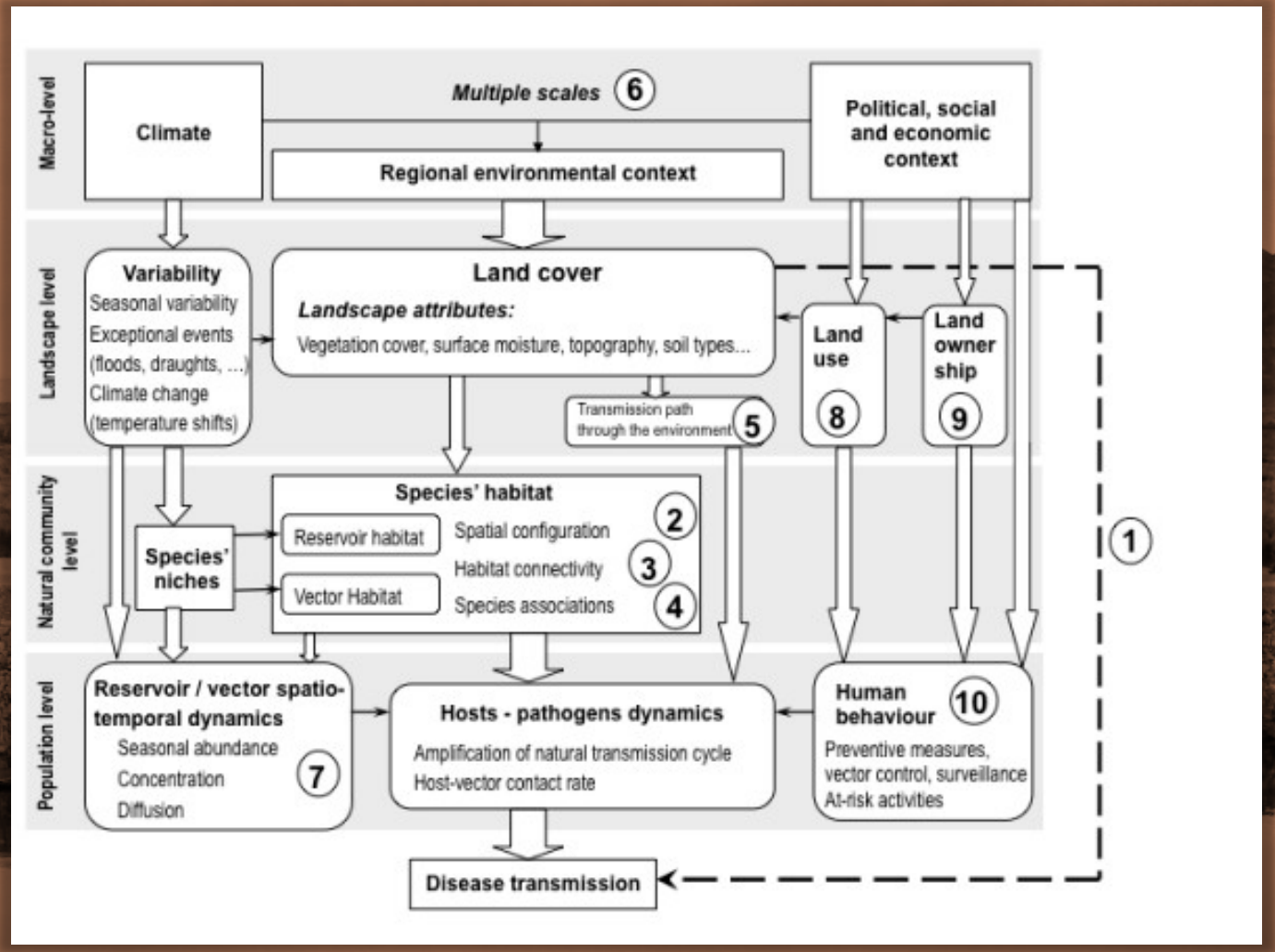
Autologistic Regression Model

$$P_i\left(y_i = 1 | \beta_0, \beta, r\right) = \frac{\exp\left(\beta_0 + \beta_1 x_{1,i} + \ldots + r Auto\ \mathrm{cov}_i\right)}{1 + \exp\left(\beta_0 + \beta_1 x_{1,i} + \ldots + r Auto\ \mathrm{cov}_i\right)}$$

The predicted result P_i denotes the probability of an event occurring for every geographic unit. x is independent variables. *Autocov* is the autocovariate variable. β and r are the coefficients of variables in the equation. i is the index of the geographical units.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4022446/

Landscape Epidemiology of Disease



Lambin et al. International Journal of Health Geographics 2010 9:54

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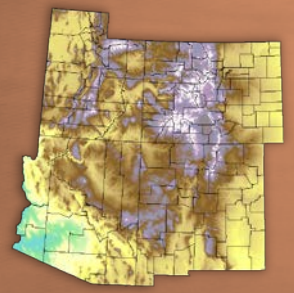
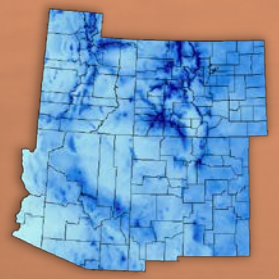
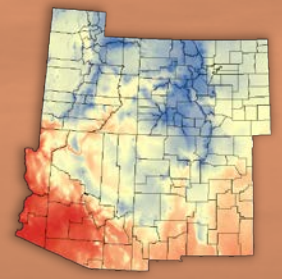
Model Covariates Based on Literature



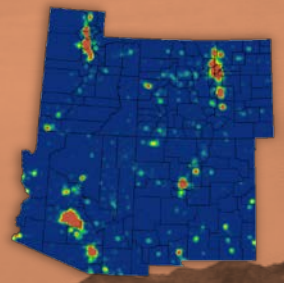
Elevation



Monthly Precipitation

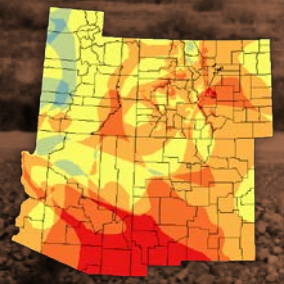


Monthly Temperature

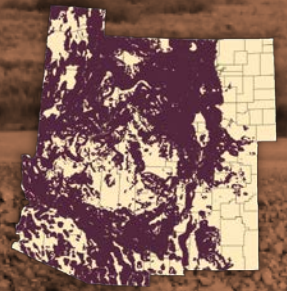


Human Population

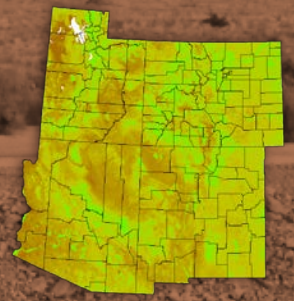
Distance From Lakes & Streams



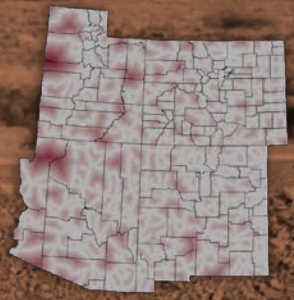
Terrestrial RABV+ Species Ranges



Mountainous Areas & Slope



Monthly Enhanced Vegetation Index (EVI)



Distance from Major Roads

Land Cover Type (NLCD 2011)

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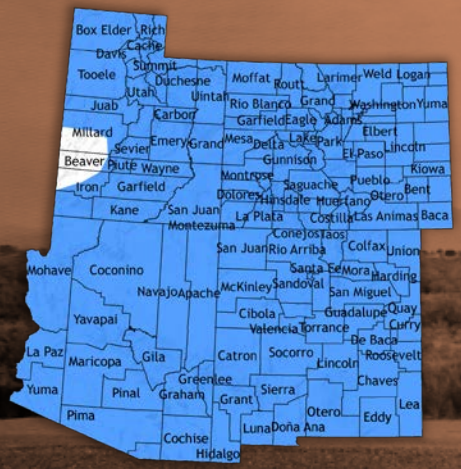
Skunk Species Ranges: Four Corners

(Geographic Range)



Striped Skunk

W. Spotted Skunk

E. Spotted Skunk

Hog-Nosed Skunk

Hooded Skunk

RED LIST Guiding Conservation for 50 Years

www.iucnredlist.org

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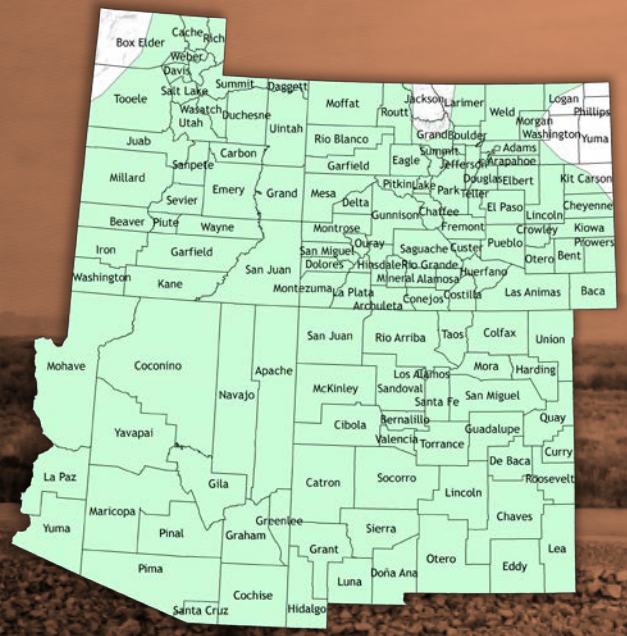
Fox Species Ranges in the Four Corners

(Geographic Range)



Grey Fox

Red Fox

Kit Fox

RED LIST
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www.iucnredlist.org

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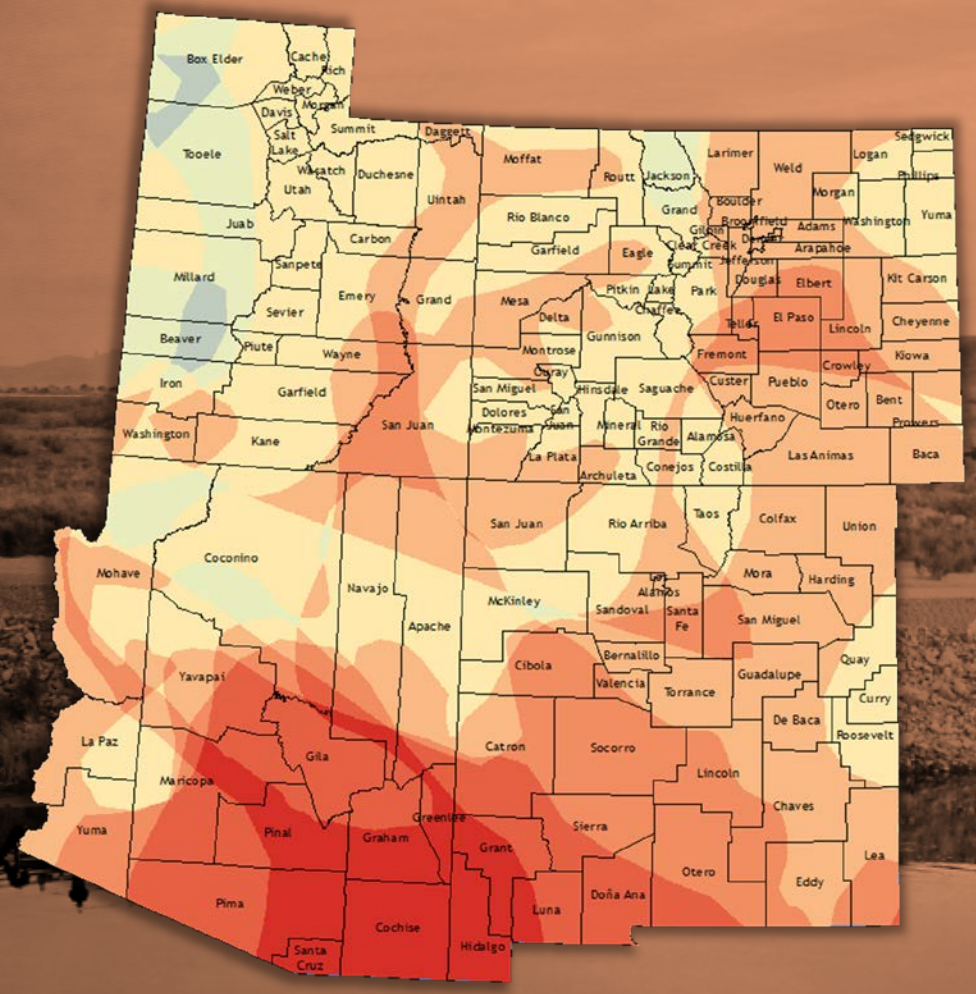
Where is the Most Overlap Among Wildlife Terrestrial Rabies -Positive Species Ranges?



1 Species	**SC Skunk RABV+ Species (2013-2017)**
2 Species	*Javelina*
3 Species	*Northern Raccoon*
4 Species	*Bobcat*
5 Species	*Coyote*
6 Species	*Grey Fox*
7 Species	*Red Fox*
8 Species	*Kit Fox*
9 Species	*Striped Skunk*
10 Species	*Western Spotted Skunk*
	Eastern Spotted Skunk
	Hog-Nosed Skunk
	Hooded Skunk

NOT a model for species interaction

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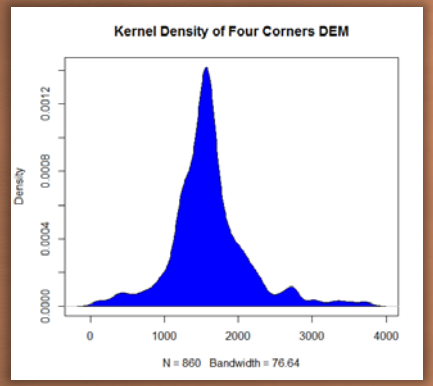
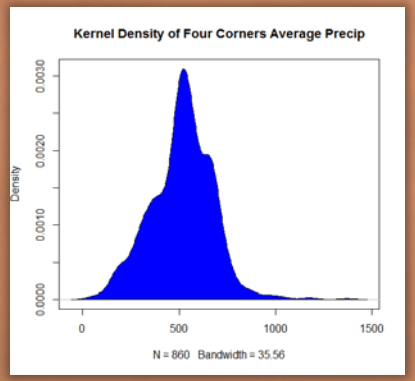
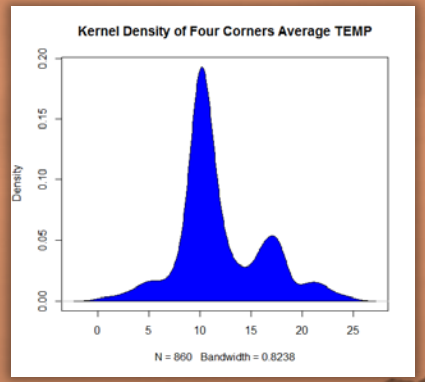
Distributions of Model Covariates



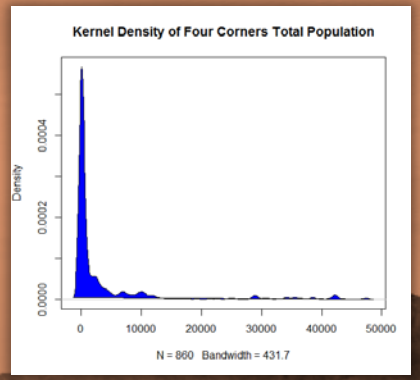
Elevation



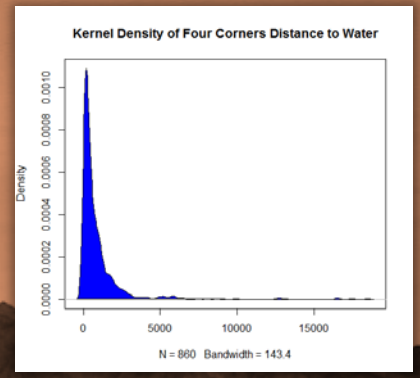
Monthly Precipitation



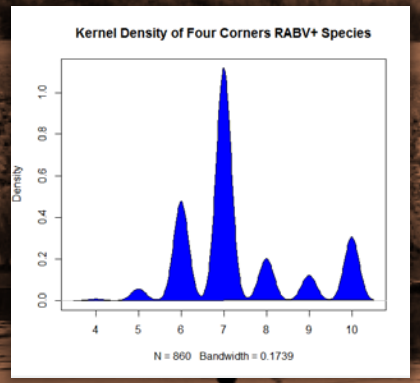
Monthly Temperature



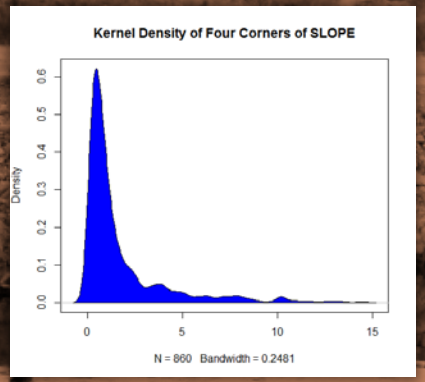
Human Population



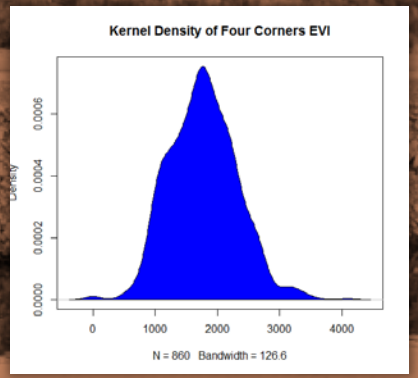
Distance From Lakes & Streams



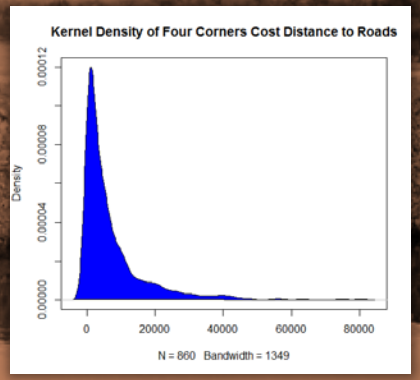
RABV+ Species Present (Categorical)



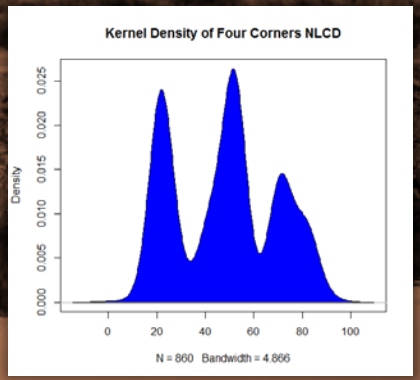
Slope



Monthly Enhanced Vegetation Index (EVI)



Distance from Major Roads

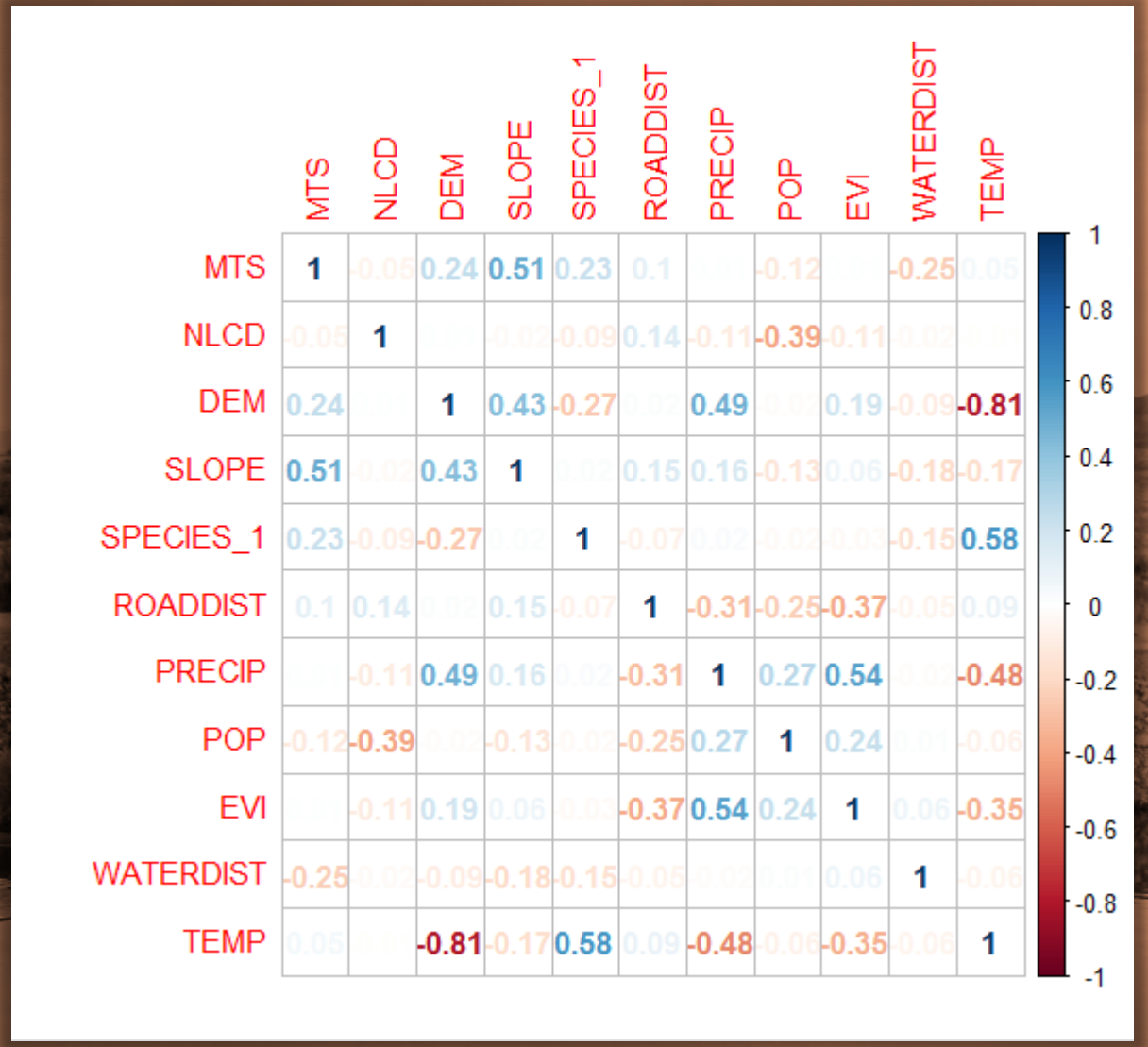


Land Cover Type (NLCD 2011) (Categorical)

Model Covariate Descriptives

	vars	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
SKUNK	1	0.49	0.50	0.00	0.49	0.00	0.00	1.00	1.00	0.02	-2.00	0.02
MTS	2	0.47	0.50	0.00	0.46	0.00	0.00	1.00	1.00	0.12	-1.99	0.02
NLCD	3	47.99	20.90	52.00	47.13	28.17	0.00	95.00	95.00	0.09	-1.16	0.71
DEM	4	1603.68	515.91	1557.50	1576.68	327.65	55.00	3768.00	3713.00	0.77	2.88	17.59
SLOPE	5	1.70	2.26	0.82	1.17	0.75	0.00	14.46	14.46	2.58	7.23	0.08
SPECIES_1	6	7.33	1.32	7.00	7.20	1.48	4.00	10.00	6.00	0.82	0.00	0.04
ROADDIST	7	6981.77	9737.67	3410.26	4881.73	4274.91	0.00	80515.90	80515.90	2.82	10.97	332.05
PRECIP	8	515.20	161.43	524.66	517.89	154.86	46.39	1369.26	1322.87	0.15	1.41	5.50
POP	9	3782.98	8885.58	131.63	1364.80	195.16	0.00	47347.58	47347.58	3.15	9.48	303.00
EVI	10	1771.50	542.93	1756.00	1756.79	557.46	0.00	4086.00	4086.00	0.26	0.41	18.51
WATERDIST	11	908.50	1738.30	402.49	566.35	463.30	0.00	18485.94	18485.94	5.89	44.88	59.28
TEMP	12	11.94	4.18	10.74	11.72	2.16	0.16	24.75	24.60	0.59	0.47	0.14
LAT	13	37.23	3.27	38.76	37.49	2.51	31.36	42.00	10.64	-0.57	-1.23	0.11
LONG_	14	-107.19	3.35	-105.30	-106.96	2.91	-114.66	-102.11	12.55	-0.52	-1.08	0.11

Model Covariate Correlations (Spearman)



- Elevation (DEM) and Temperature are highly inversely correlated (-0.81)
- # Species and Temperature are inversely correlated (-0.58)
- Slope and Mountains are positively correlated (0.5) (only???)
- Precipitation and Vegetation Index (EVI) are somewhat positively correlated (0.54)

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Model Covariates: Variance Inflation Factor (VIF)

$$\mathrm{VIF}_i = \frac{1}{1 - R_i^2}$$

Variable	VIF
Precipitation	2.4
Temperature	11.5
EVI	1.8
Elevation	9.6
Slope	2.3
Road Distance	1.1
Population	1.3
Species	5.6
Water Distance	1.1
Mountain Areas	2.3
NLCD	8.1

- Variance Inflation Factor (VIF) is a test for multicollinearity
- It estimates how the variance of a regression coefficient is inflated due to multicollinearity in the model.
- Rough subjective guide:
- 1: not correlated
- 1-5: somewhat correlated
- 5-10: highly correlated
- **Above 10: Do Not Use**
- **Omitting Temp, Elevation, & NLCD out of caution**

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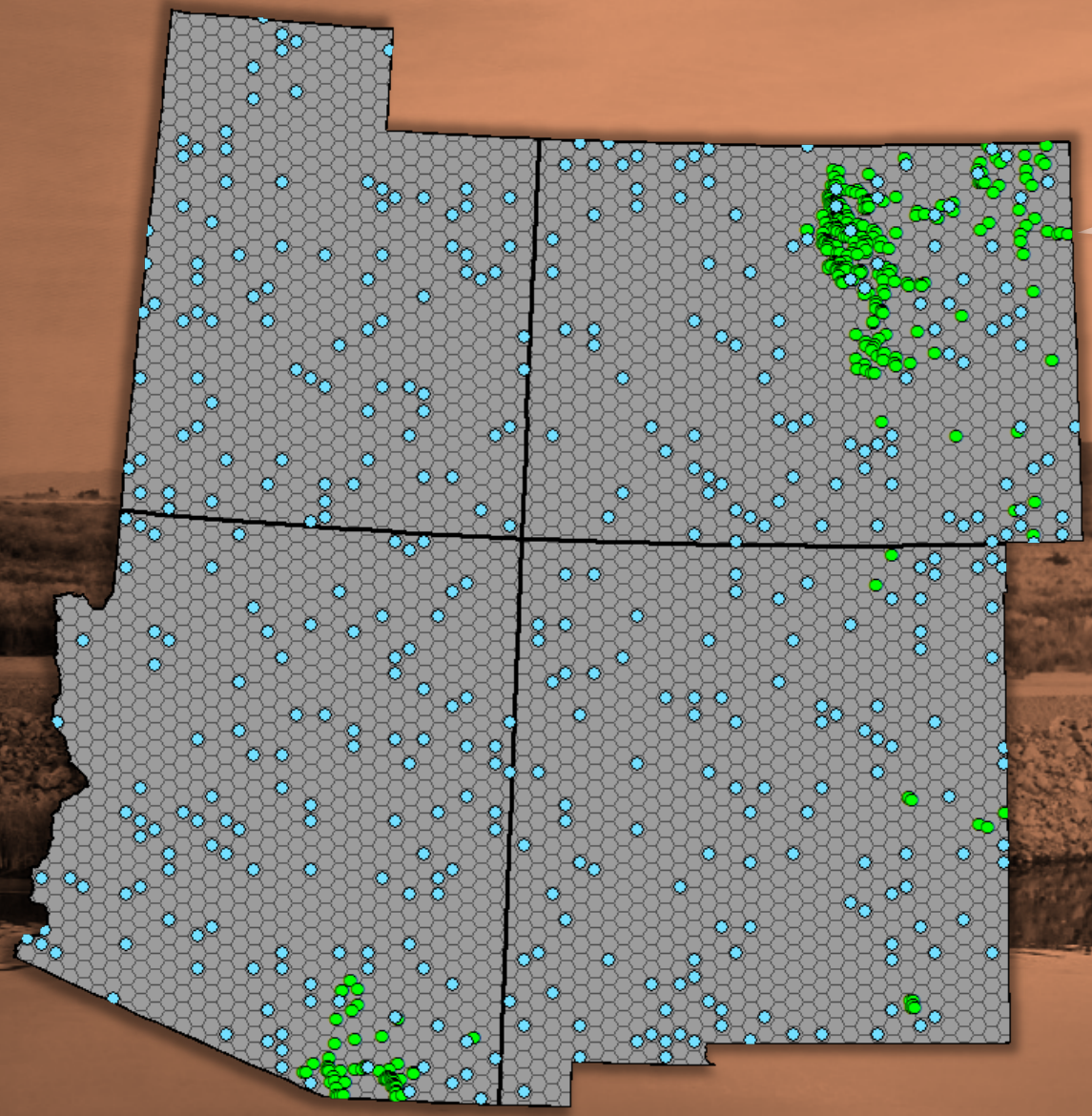
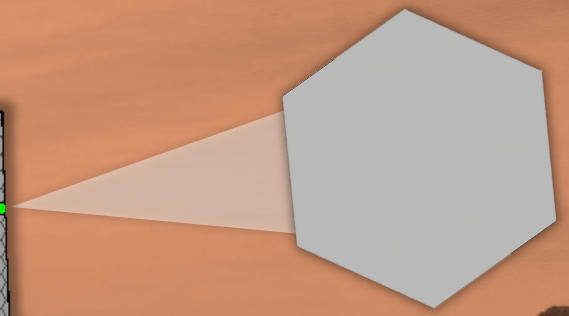
Hexagon* Fishnet Grid Sampling Schema

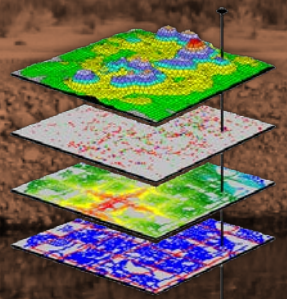




= 285 km^2
Mean Census Tract Size

Skunk Variant+ Specimen (Cases)

Randomly selected Fishnet Hex Grid Centroids (Controls)



Extract explanatory variable values at points

*Hexagonal cells reduce edge effect over square cells

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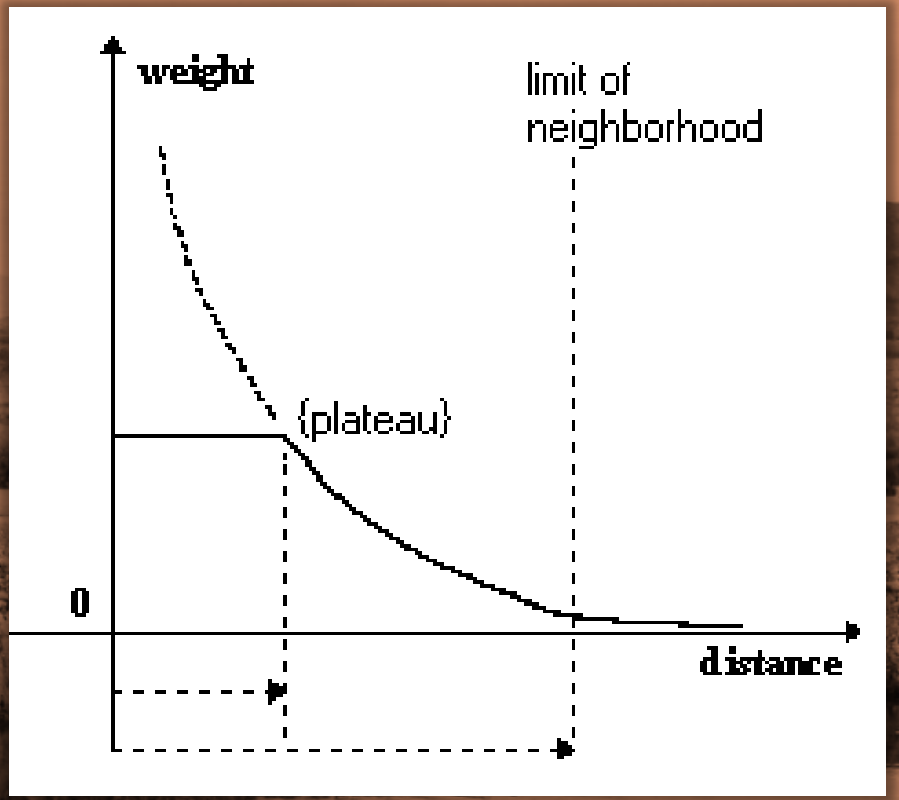
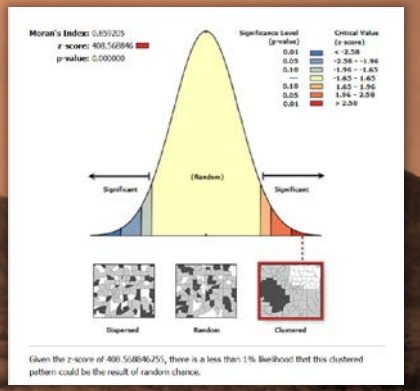
Modeling of Spatial Relationships

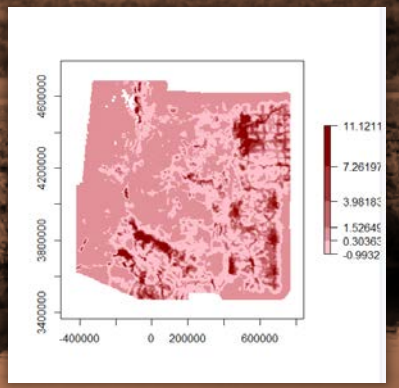
Inverse Distance Weighting with 5 mile neighborhood threshold

Range: 0.5 – 1.5 miles,
up to 5 square miles
(breeding season)

$$Autocov_i = \frac{\sum_{j-1}^{k_i} w_{ij}\hat{P}_j}{\sum_{j=1}^{k_i} w_{ij}}$$







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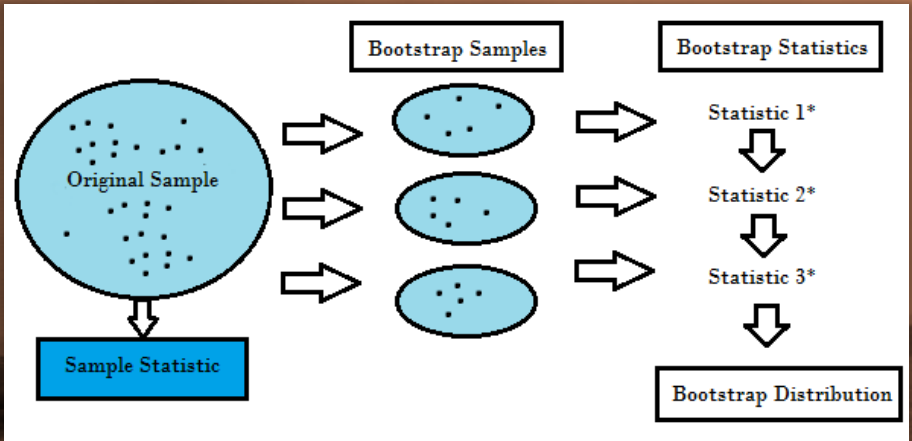
Bootstrap the Skunk Autologistic Regression Model



Variable	Estimate	Standard Error	95% CI High	95% CI Low
(Intercept)	11.26	1.51	-7.96	-13.93
Enhanced Vegetation Index	0.002	0.00	0.0034	0.0014
Dist. From Roads	-0.001	0.00		
No. RABV+ Species	0.678	0.11		
Human Population	0.001	0.00	0.000	0.0005
Mountainous (cat)	-0.670	0.32	-0.049	-1.25
Precipitation (mm)	0.004	0.00	0.0064	0.0024
Slope	-0.257	0.64	-0.3811	-0.1471
Autocovariate (0-1)	1322.81	270.42	1878	837

- A Monte Carlo method applied to modeling
- Subsets your sample into multiple smaller random samples, runs model on it
- Creates “estimates of your estimates”
- Helps correct model overfitting
- Hundreds to thousands of sub-sampling iterations; I chose 1000
- Had 14 instances (1.4%) of times where perfect separation

Skunk Spatial Stepwise Modeling Results

Variable	Estimate	Standard Error	Z-value	P value
(Intercept)	-11.2661	1.310747	-8.595	<0.0001
Enhanced Vegetation Index	0.002342	0.000333	7.037	<0.0001
Dist. From Roads (meters)	-0.00014	0.000023	-5.908	<0.0001
No. RABV+ Species	0.677989	0.109112	6.214	<0.0001
Human Population (per person)	0.000121	0.0000368	3.272	<0.01
Mountainous (cat)	-0.67041	0.299421	-2.239	<0.05
Precipitation (mm)	0.004184	0.000955	4.383	<0.0001
Slope (%)	-0.25729	0.062597	-4.11	<0.001
Autocovariate (0-1)	1322.814	275.9775	4.793	<0.001

	Non-Spatial Model	Spatial Model
AICC	589.09	568.89
McFadden's Pseudo R2	0.52	0.54
Chi Square (X^2)	571.09	550.89
ROC	0.94	0.94

$$P_i\left(y_i = 1 | \beta_0, \beta, r\right) = \frac{\exp\left(\beta_0 + \beta_1 x_{1,i} + \ldots + r Auto\ \mathrm{cov}_i\right)}{1 + \exp\left(\beta_0 + \beta_1 x_{1,i} + \ldots + r Auto\ \mathrm{cov}_i\right)}$$

Autocovariate is high due to the scale of unit, small sample size, and high clustering of RABV+ specimens

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Skunk Spatial Model: Odds

Variable	Odds	95% High	95% Low
Enhanced Vegetation Index	1.00	1.00	1.00
Dist. From Roads (meters)	1.00	1.00	1.00
No. RABV+ Species	1.97	1.60	2.46
Human Population (person)	1.00	1.00	1.00
Mountainous (cat)	0.51	0.28	0.92
Precipitation (mm)	1.00	1.00	1.01
Slope (%)	0.77	0.68	0.87

$$OR_X = e^{\beta}$$

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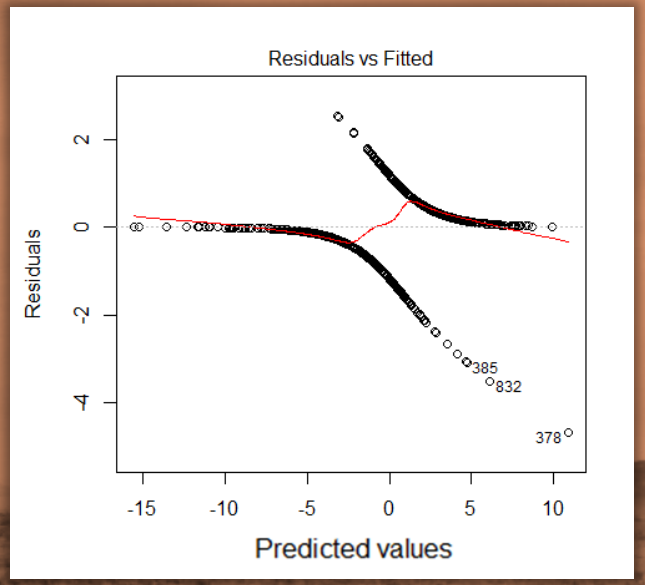
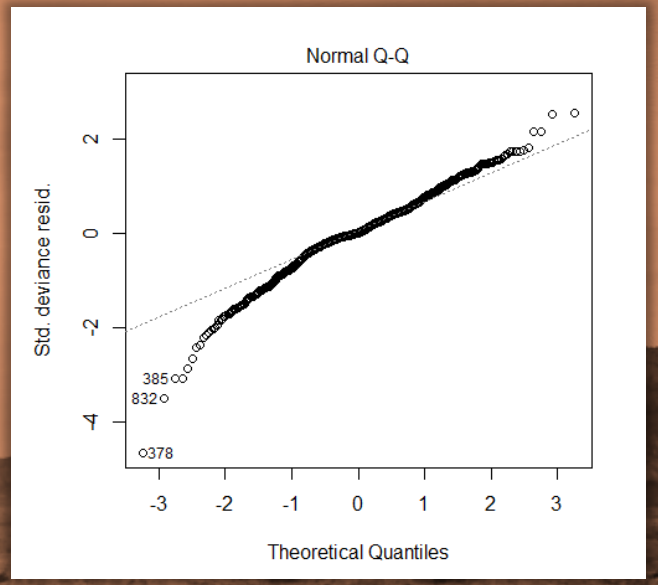
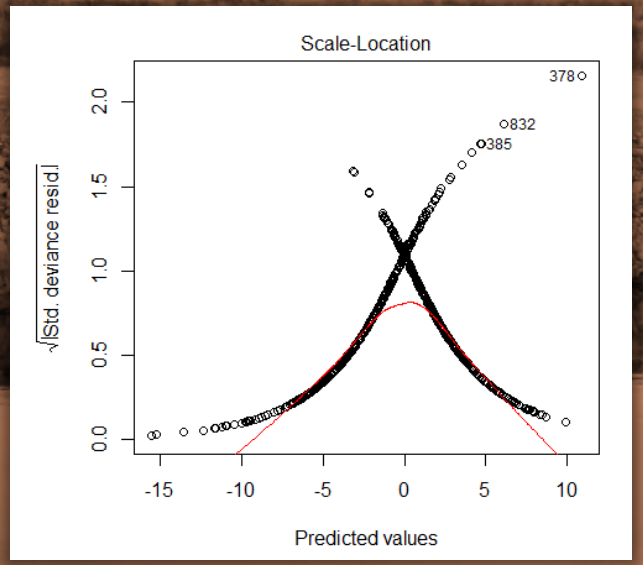
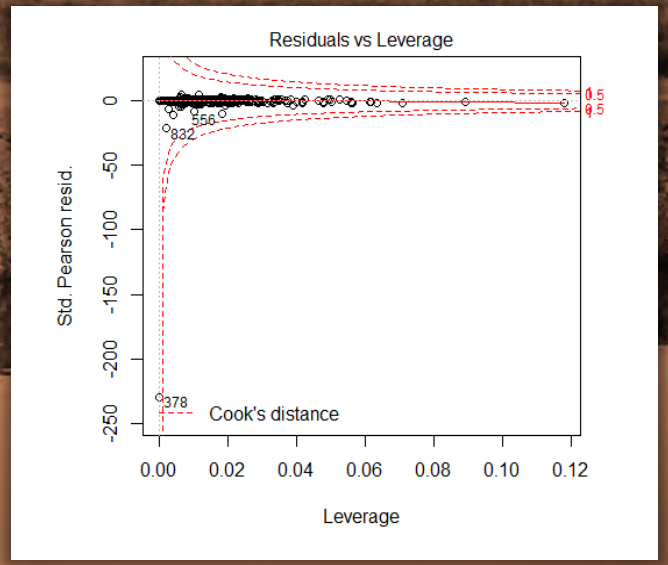
Skunk Spatial Stepwise Modeling Diagnostics









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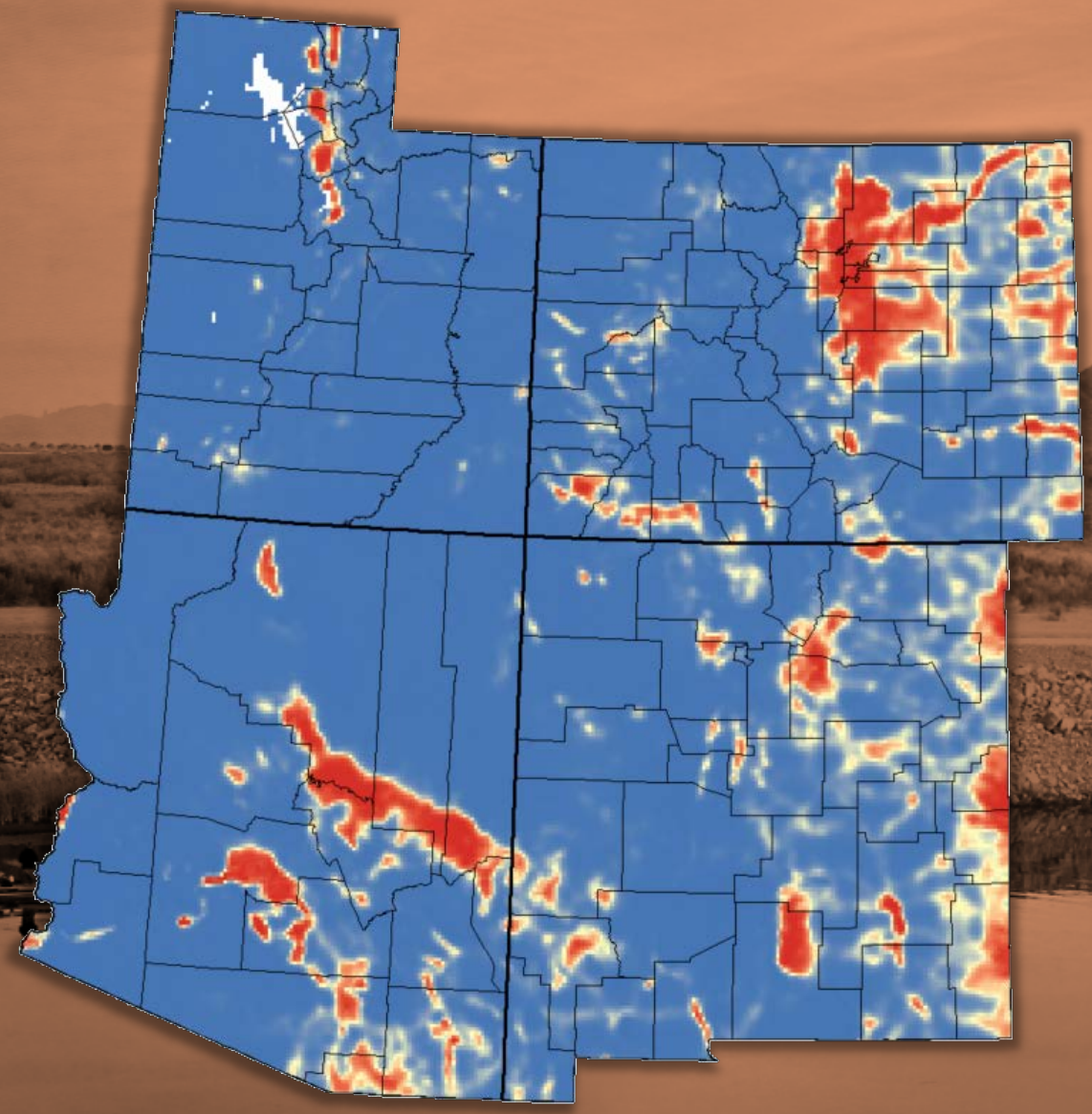
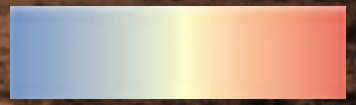
Skunk Variant Model Risk Results



SC Skunk Variant Probability

Low Risk



High Risk

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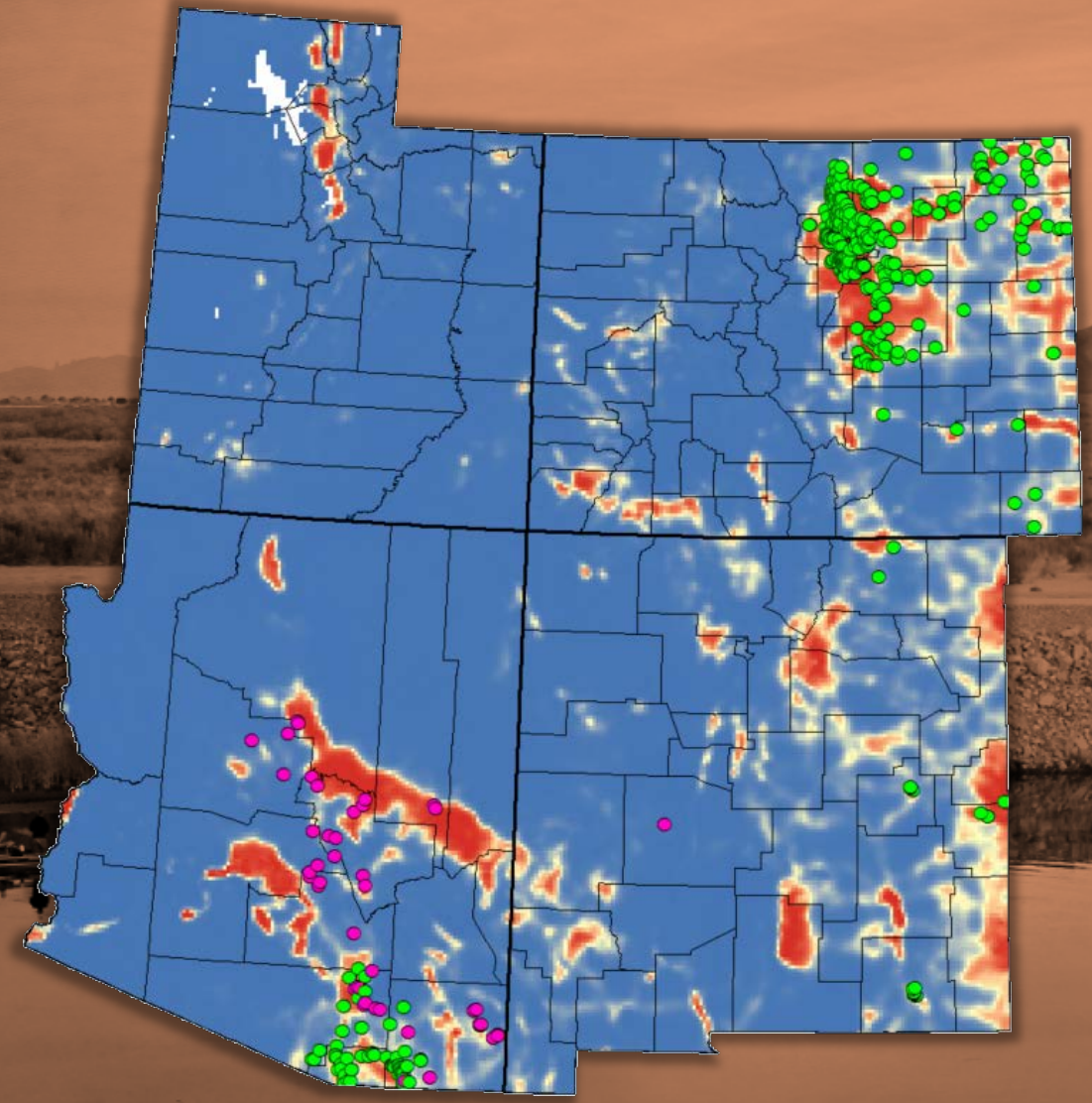
Skunk Variant Model Results: Risk vs. 2013-2017 Known RABV+



SC Skunk Variant Rabies Probabilities

SC Skunk Variant, Confirmed & Suspect

AZ Gray Fox Variant, Confirmed & Suspect

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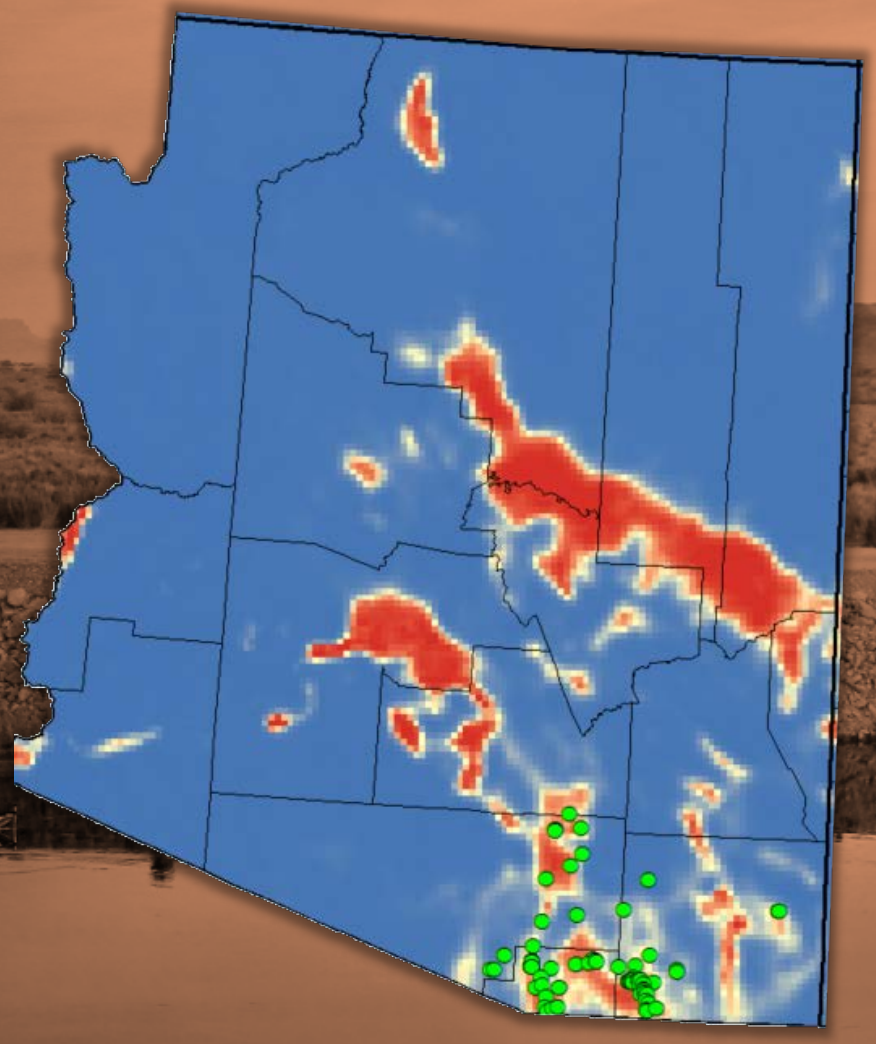
AZ Skunk Variant Model Results: Risk vs. 2013-2017 Known SCSK RABV+



SC Skunk Variant Rabies Probabilities

Value
High : 0.99
Low : 0.00

SC Skunk Variant, Confirmed & Suspect

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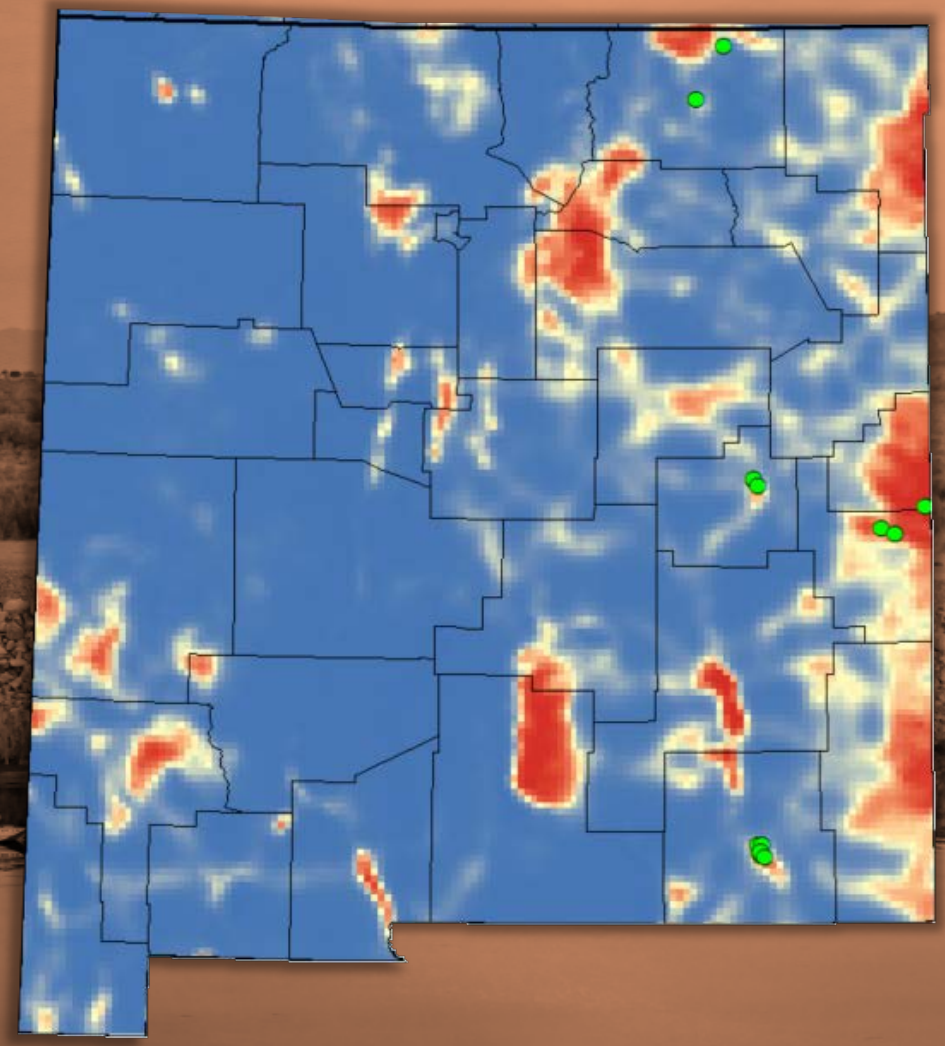
NM Skunk Variant Model Results: Risk vs. 2013-2017 Known SCSK RABV+



SC Skunk Variant Rabies Probabilities

Value
High : 0.99
Low : 0.00

SC Skunk Variant, Confirmed & Suspect

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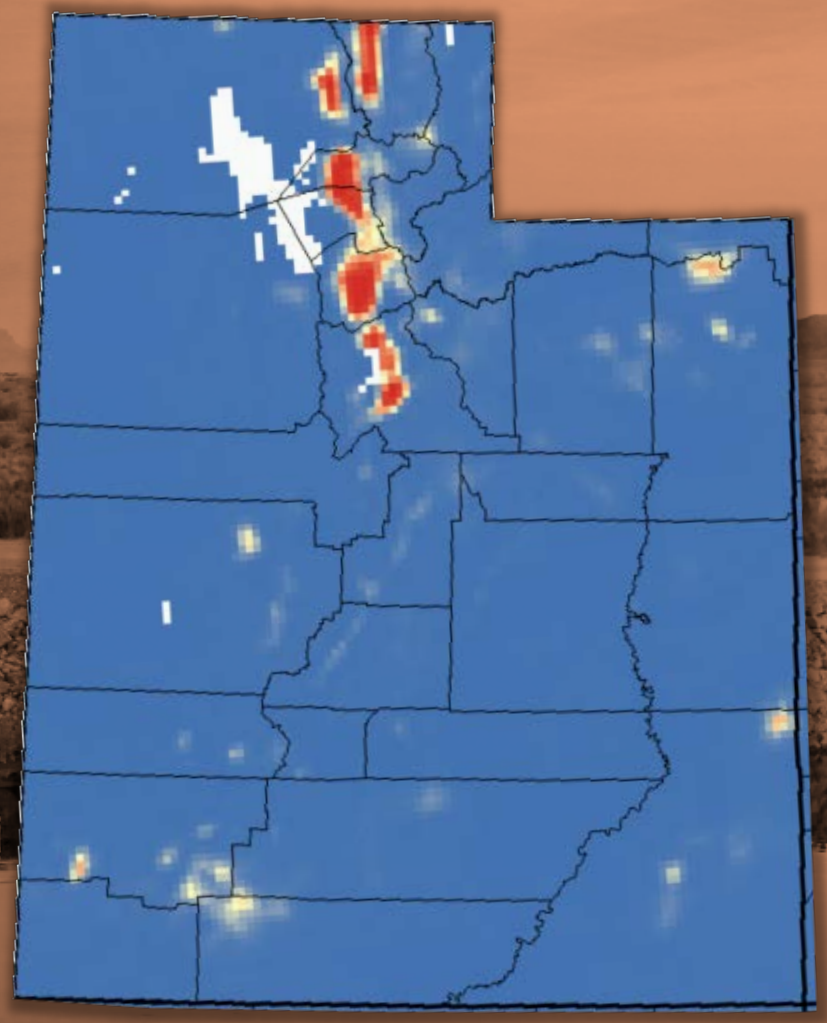
UT Skunk Variant Model Results: Risk vs. 2013-2017 Known SCSK RABV+



SC Skunk Variant Rabies Probabilities

Value
High : 0.99
Low : 0.00

SC Skunk Variant, Confirmed & Suspect

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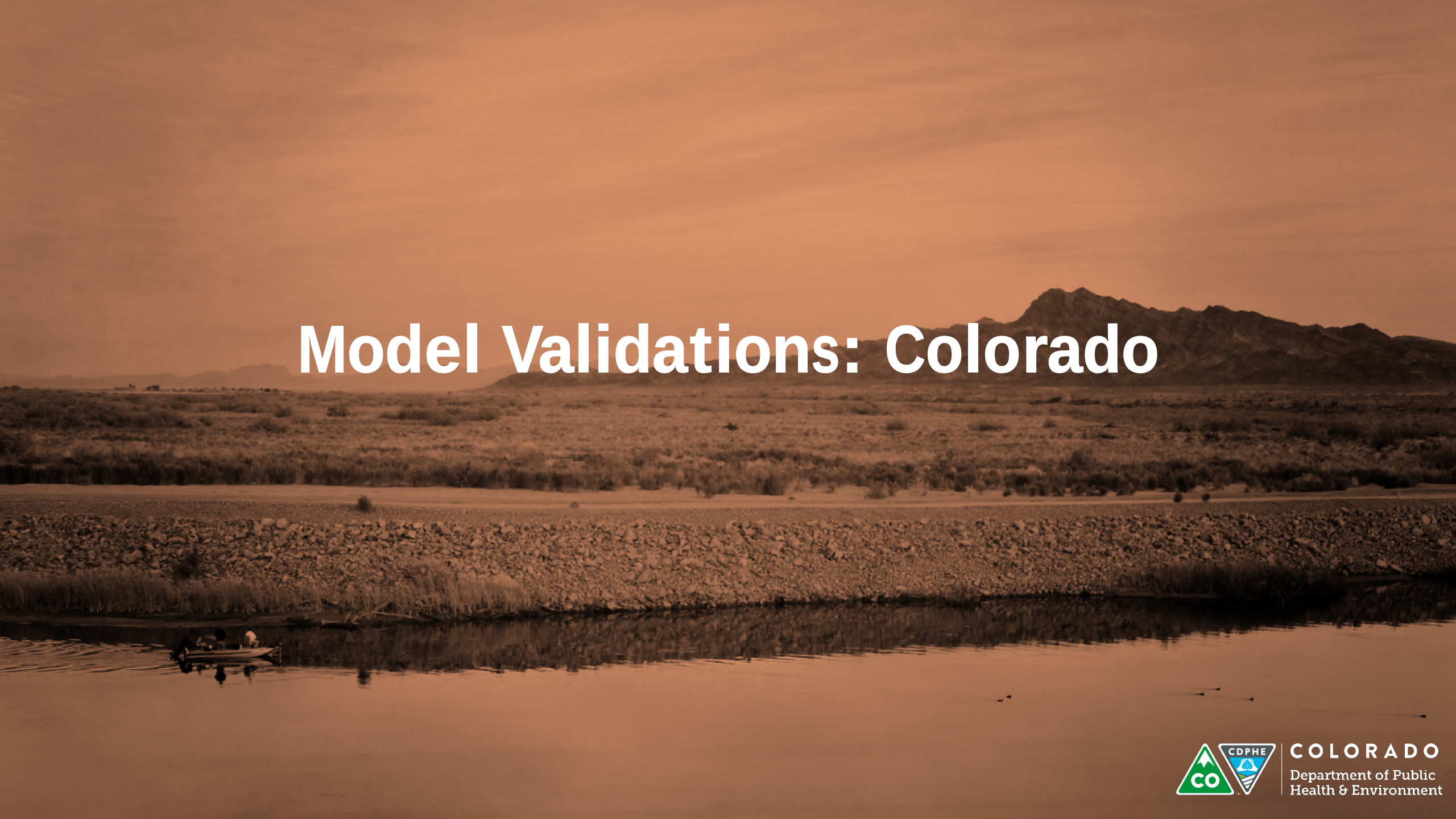
Model Validations: Colorado



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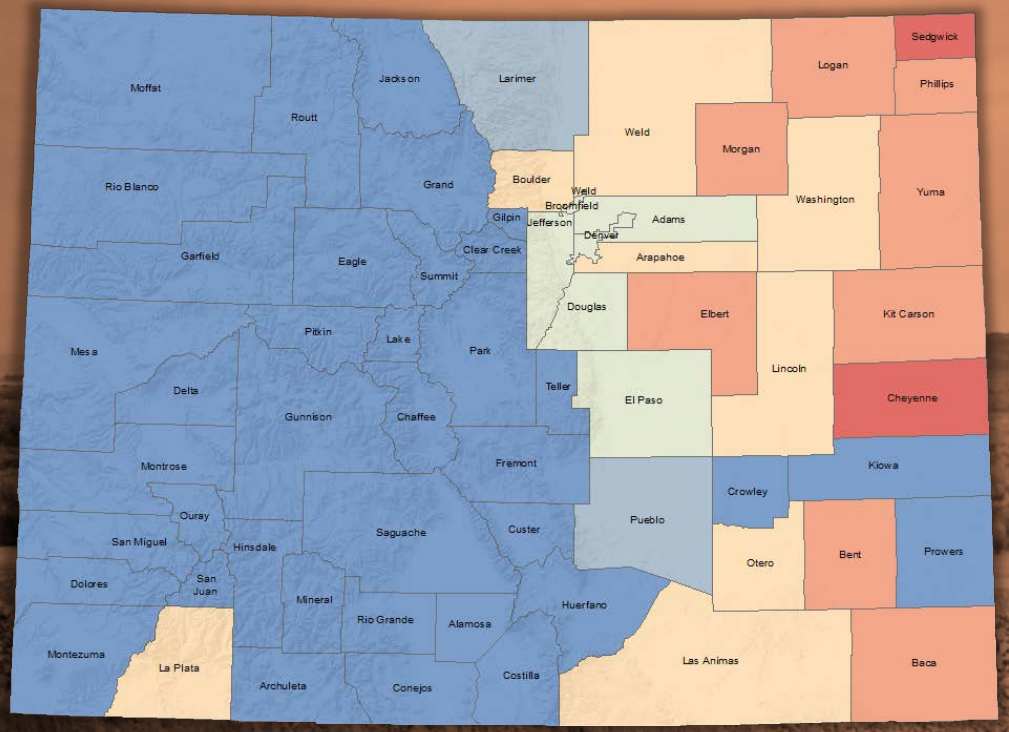
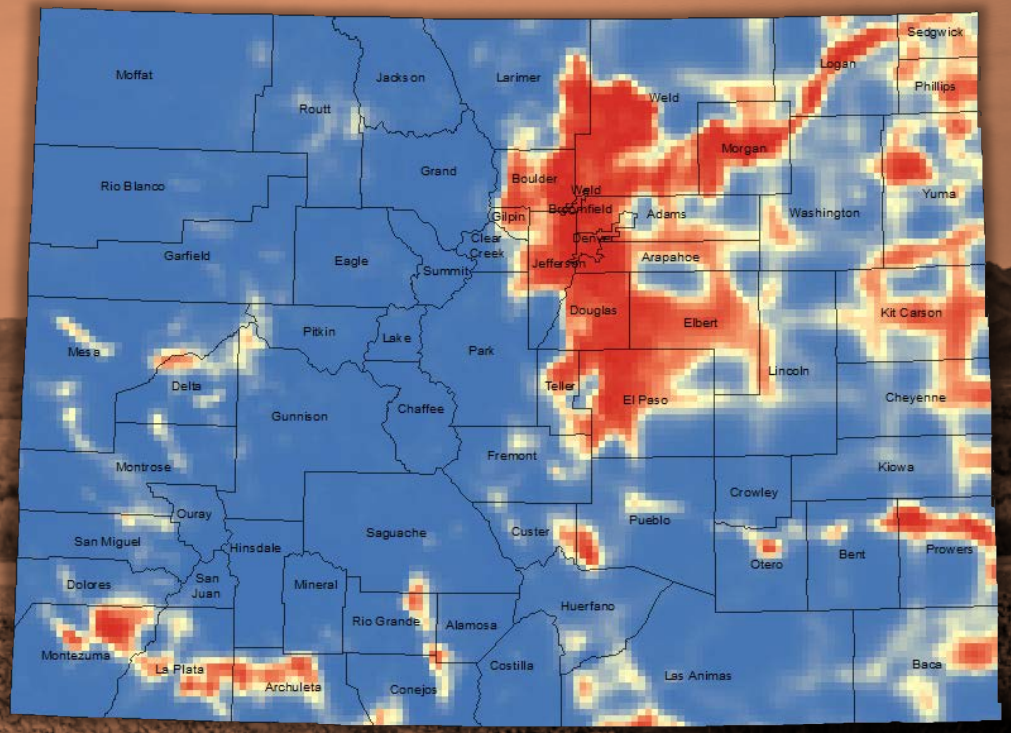
Percent of RABV+ Terrestrial Wildlife Specimens All Variants, Colorado, 2013-2017





- 0%
- 0.1% - 5.8%
- 5.9% - 17.8%
- 17.9% - 35.2%
- 35.3% - 72%
- 72.1% - 100%

Low Risk — High Risk

*Excludes Untested Submitted Specimens and Rodents

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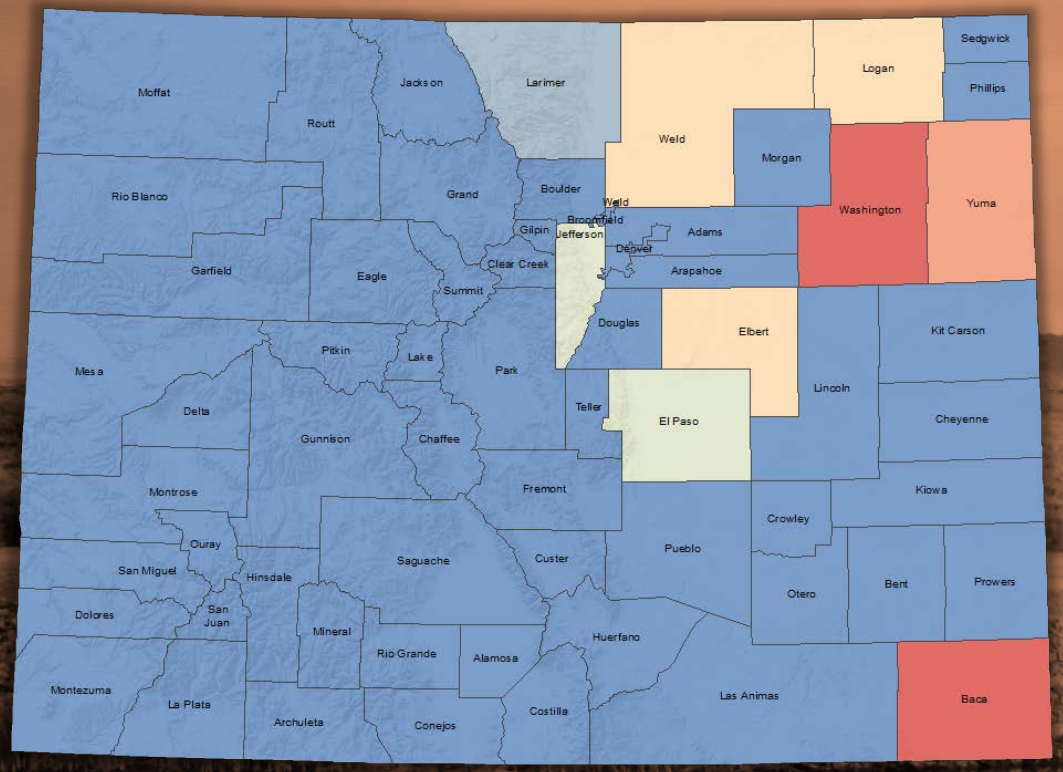
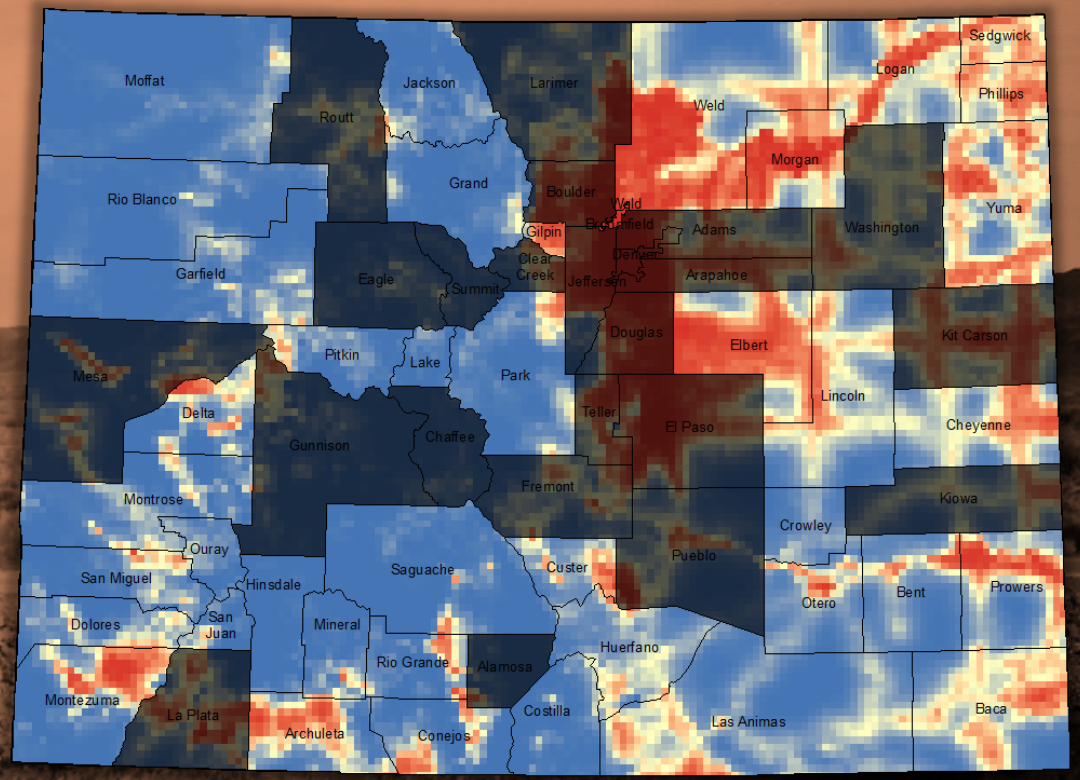
Percent of RABV+ Domestic Animal Specimens, All Variants, Colorado, 2013-2017





- 0%
- 0.1% - 0.2%
- 0.3% - 0.4%
- 0.5% - 3.3%
- 3.4% - 16.7%
- 16.8% - 100%

Counties Requiring Dog or Cat Rabies Vaccination are darkened/grayed out. Those visible do not.

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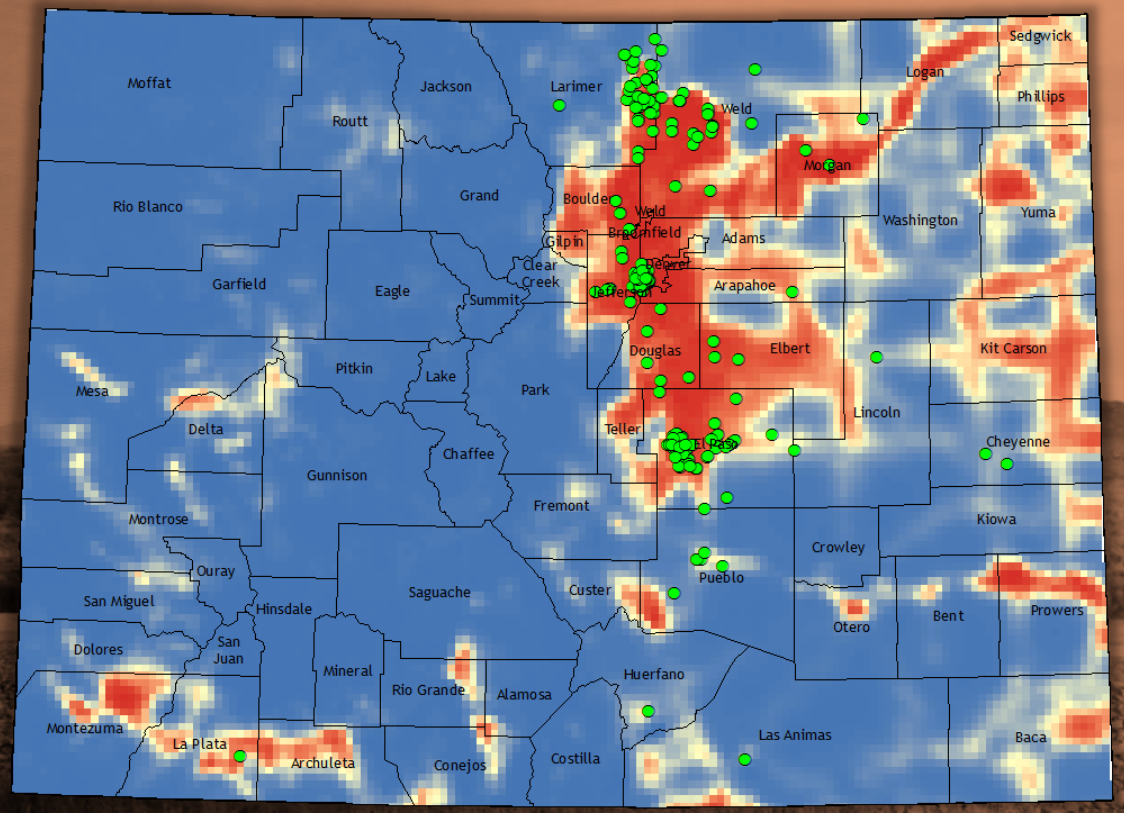
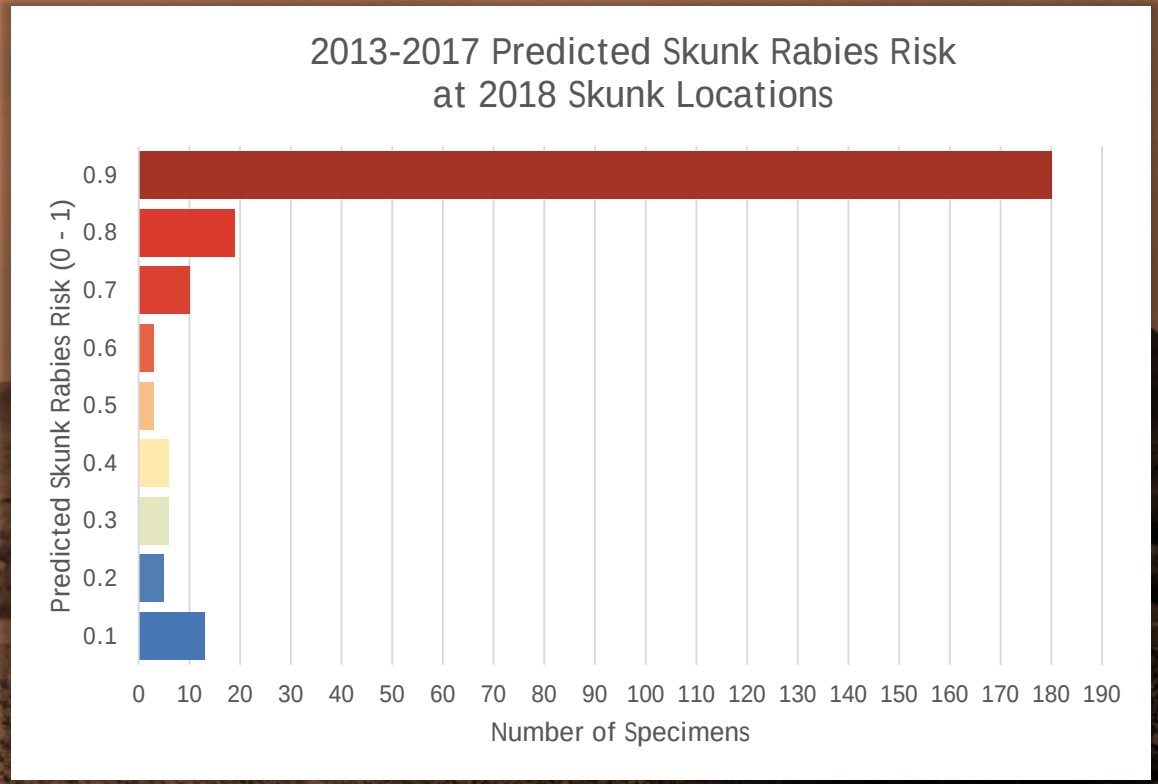
Rabies Risk vs. Colorado Rabid Skunks (2018)





N = 245, Range: 0.29 – 0.98, Med: 0.95, St.Dev: 0.24

Low Risk — High Risk

2018 Colorado Rabid Skunks

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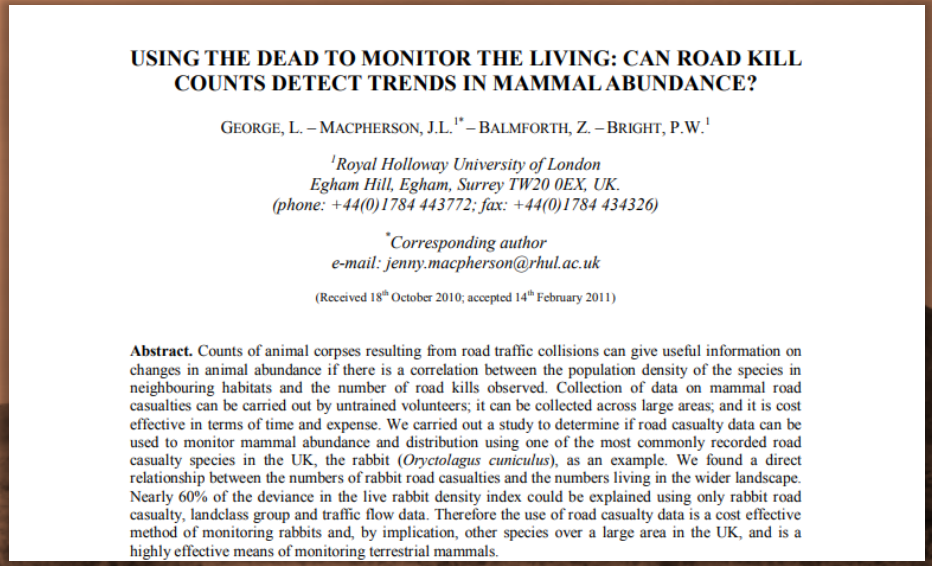
Estimating Colorado Skunk Density

- MacPherson et. Al (2011) found a direct relationship between roadkill counts of rabbits and live trap population count methods in the UK
- Rather than a population estimates, road kill surveys are used to estimate an indexed abundance.
- Calculate Road kill rate per 1,000 miles



USING THE DEAD TO MONITOR THE LIVING: CAN ROAD KILL COUNTS DETECT TRENDS IN MAMMAL ABUNDANCE?

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Abstract. Counts of animal corpses resulting from road traffic collisions can give useful information on changes in animal abundance if there is a correlation between the population density of the species in neighbouring habitats and the number of road kills observed. Collection of data on mammal road casualties can be carried out by untrained volunteers; it can be collected across large areas; and it is cost effective in terms of time and expense. We carried out a study to determine if road casualty data can be used to monitor mammal abundance and distribution using one of the most commonly recorded road casualty species in the UK, the rabbit (*Oryctolagus cuniculus*), as an example. We found a direct relationship between the numbers of rabbit road casualties and the numbers living in the wider landscape. Nearly 60% of the deviance in the live rabbit density index could be explained using only rabbit road casualty, landclass group and traffic flow data. Therefore the use of road casualty data is a cost effective method of monitoring rabbits and, by implication, other species over a large area in the UK, and is a highly effective means of monitoring terrestrial mammals.

Outdoor News

Outdoor News Minnesota Wisconsin Mich

Roadkills are good indicators of wildlife populations

August 22, 2016 by Steve Pollick

Roadkills are easily and usually overlooked, but they can be important indicators of abundance or scarcity of various wild species, as Ohio wildlife biologists have learned.

They have been conducting regular counts of roadkills since 1979 and now have amassed a significant string of numbers that are telling indicators about the status of raccoons, skunks, opossums, and woodchucks.

"Roadkill surveys provide the most reliable indices to population change for relatively abundant species," said Suzie Prange, furbearer specialist with the Ohio Division of Wildlife. She noted that until 2003, muskrats, gray and red foxes, mink, rabbits, and squirrels also were

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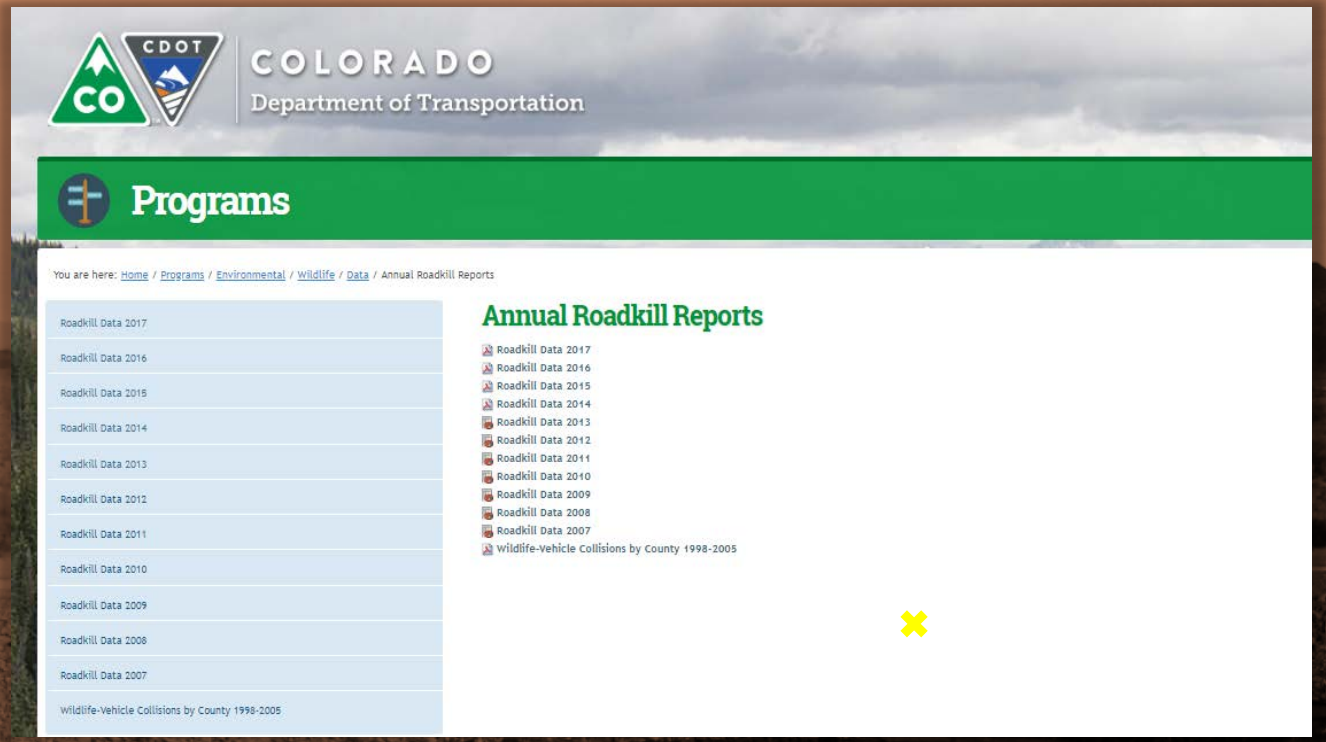
Estimating Colorado Skunk Density

- CDOT roadkill reports for foxes and skunks (2013-2017)
- Mile post -> Lat Long provided by Jeff Peterson (CDOT)
- Roadkills reported by region; reporting done by work crews
- CAVEAT: Regional data quality and reporting variation; no formal training by staff; efforts not uniform across CDOT regions



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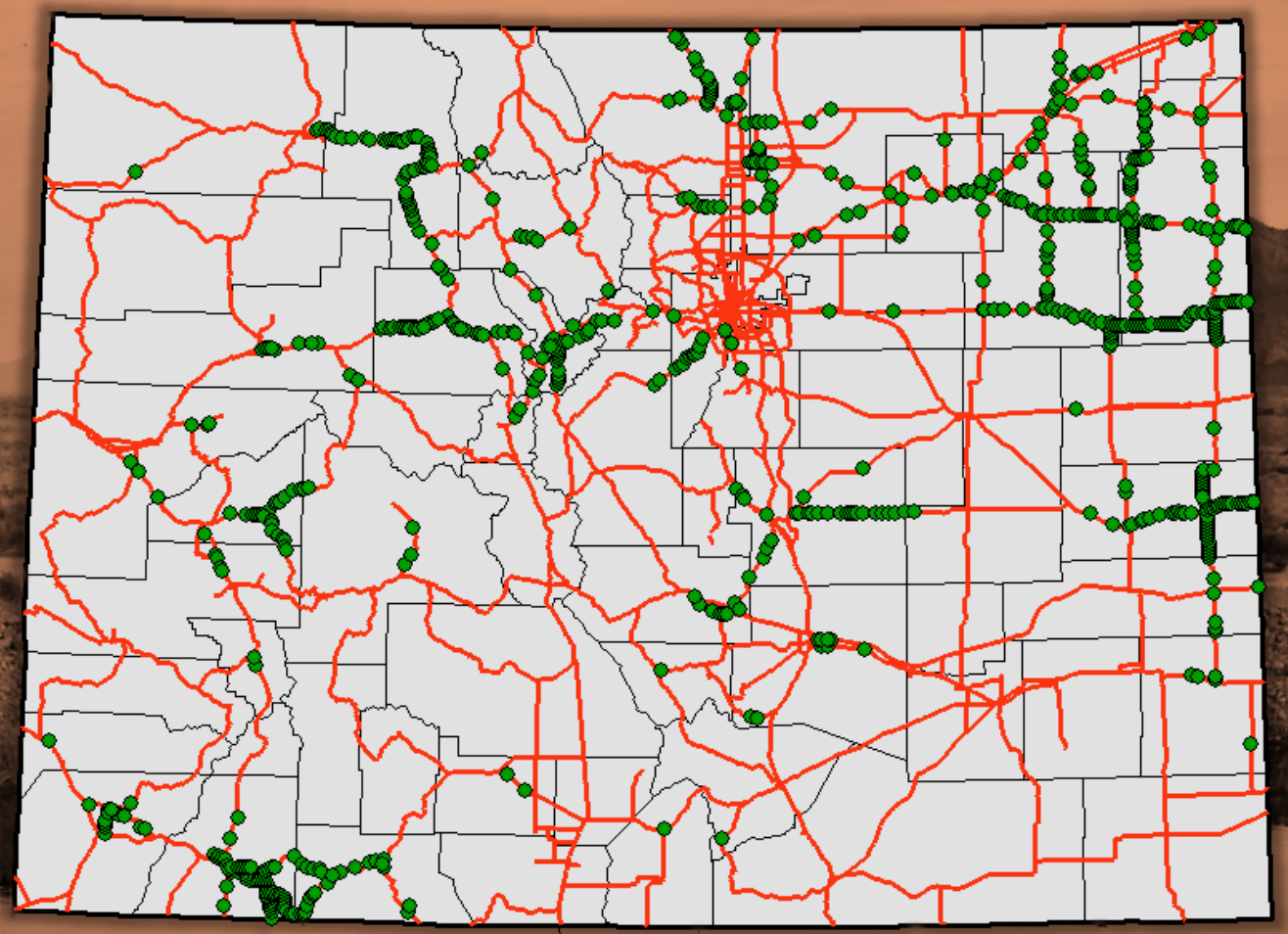
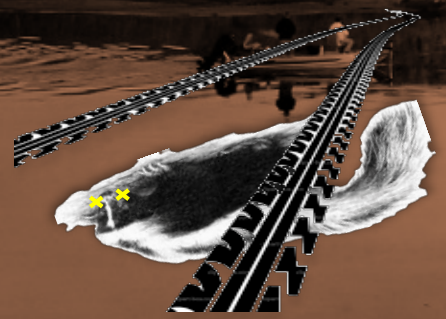
Skunk Roadkills, CDOT, 2013-2017





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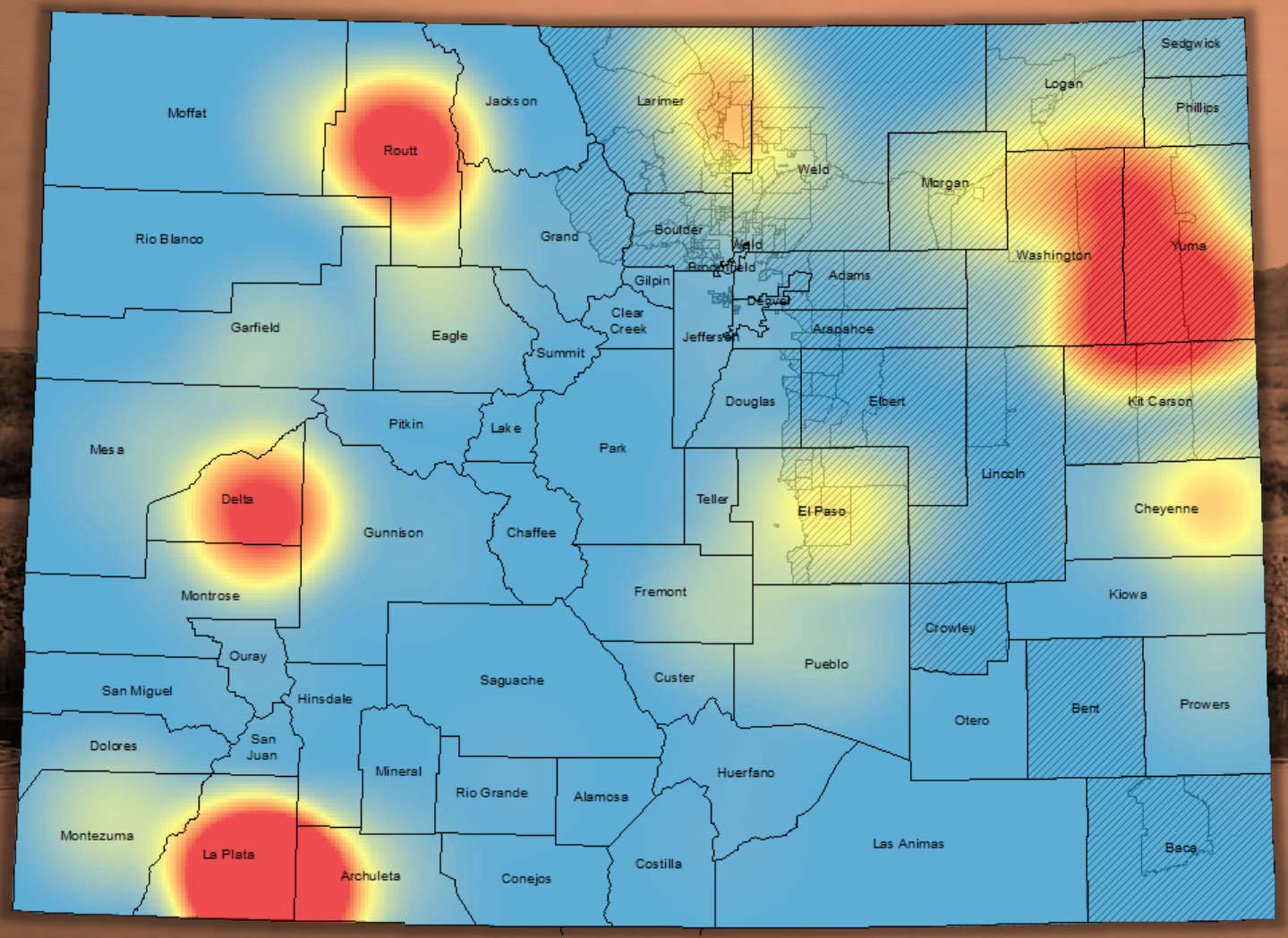
Skunk Roadkill Density and Rabies Hot Spots, Colorado, 2013-2017



Skunk Rabies Variant Hot Spot

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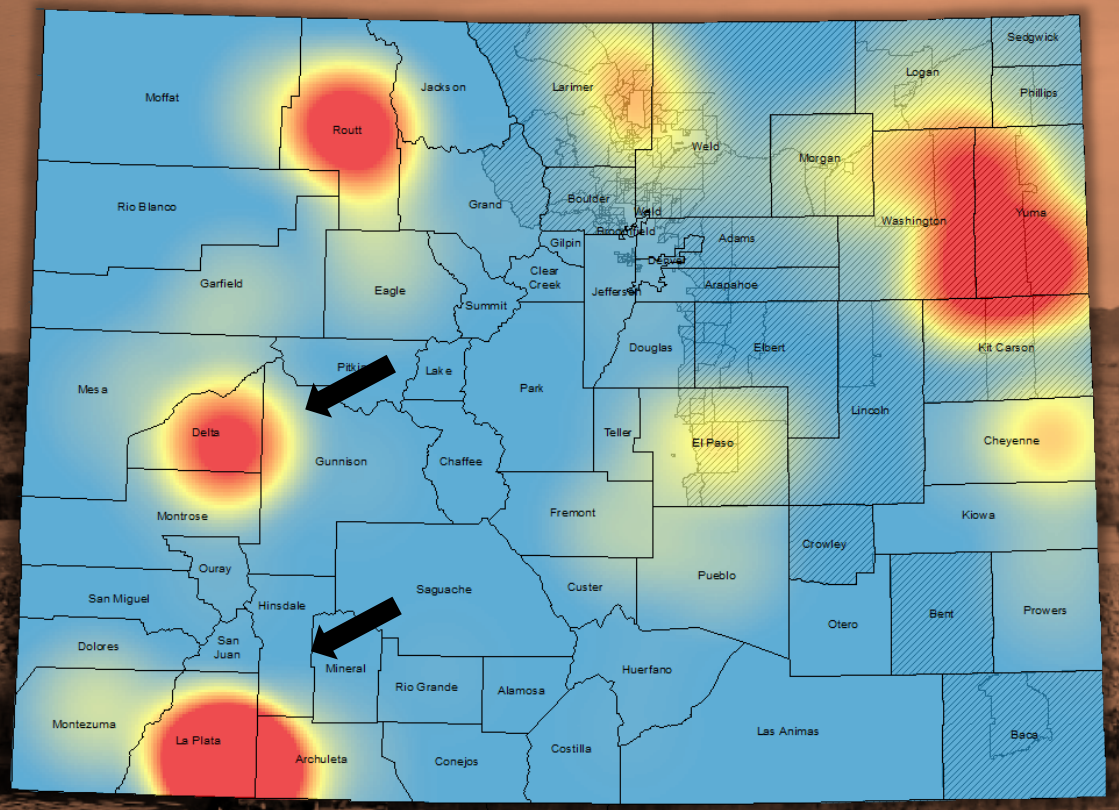
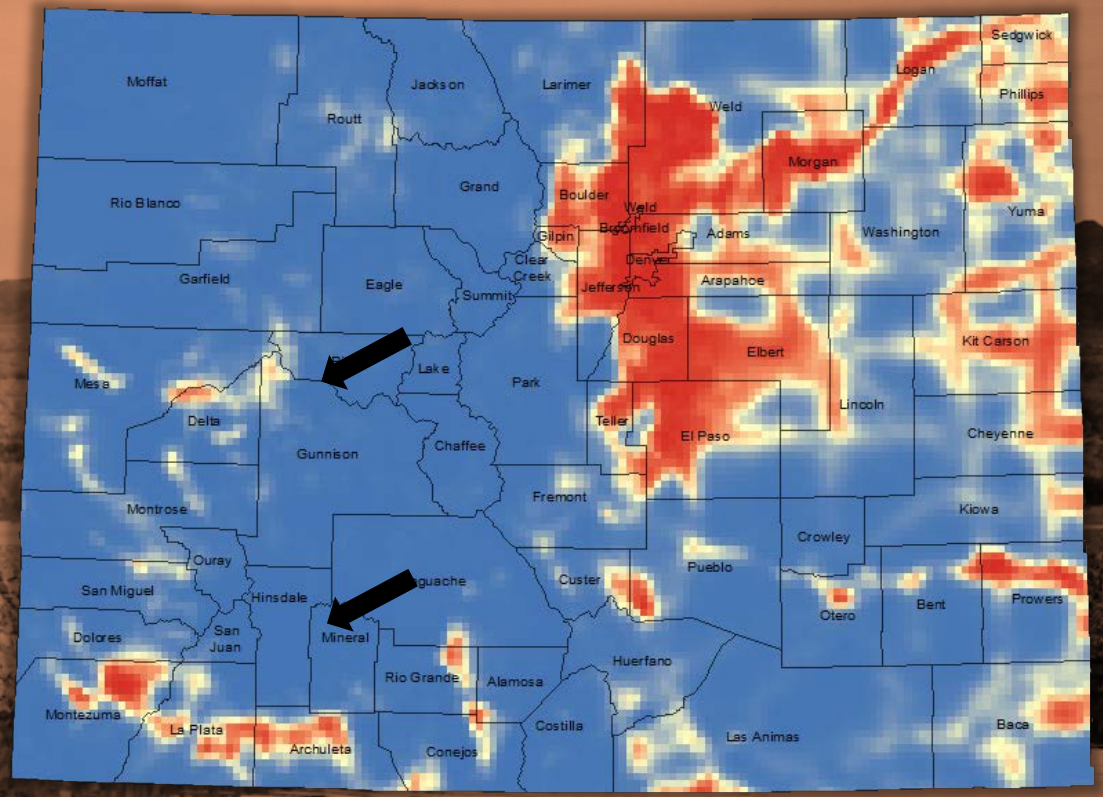
Skunk Roadkill Density* (CDOT) vs. Modeled Rabies Risk





High : 0.03

Low : 0

Skunk Rabies Variant Hot Spot

Low Risk

High Risk

* Assessed by Colorado Dept. of Transportation road clean up crews; excludes 'unknown'

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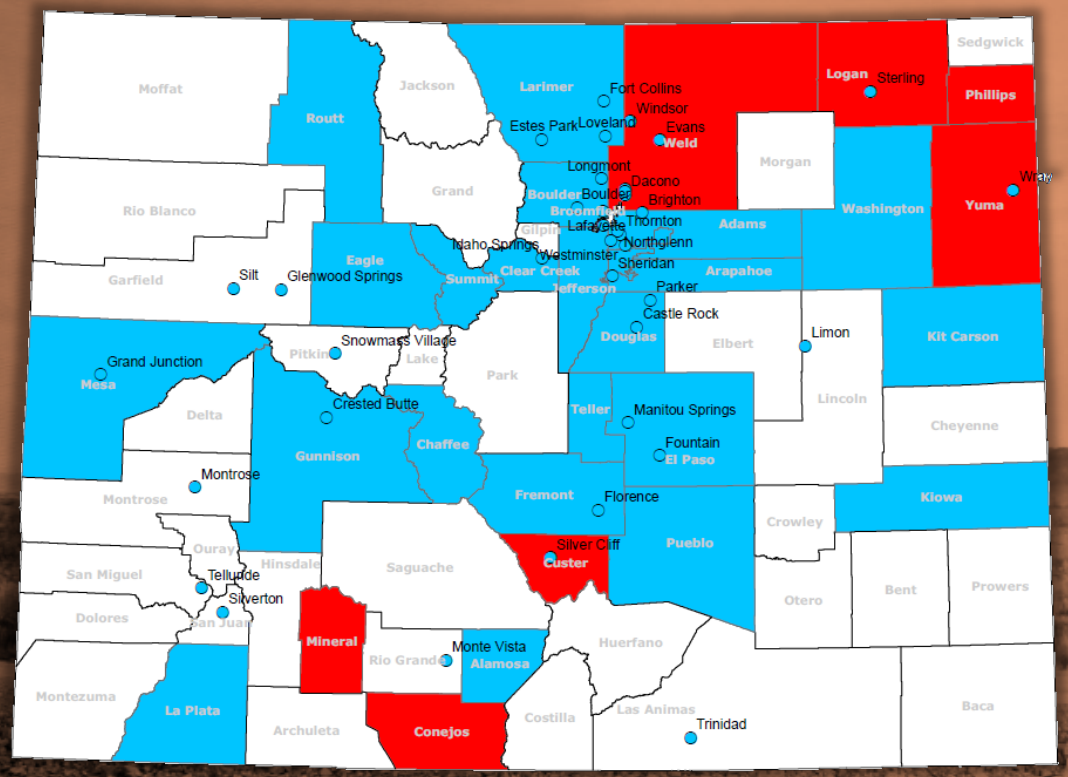
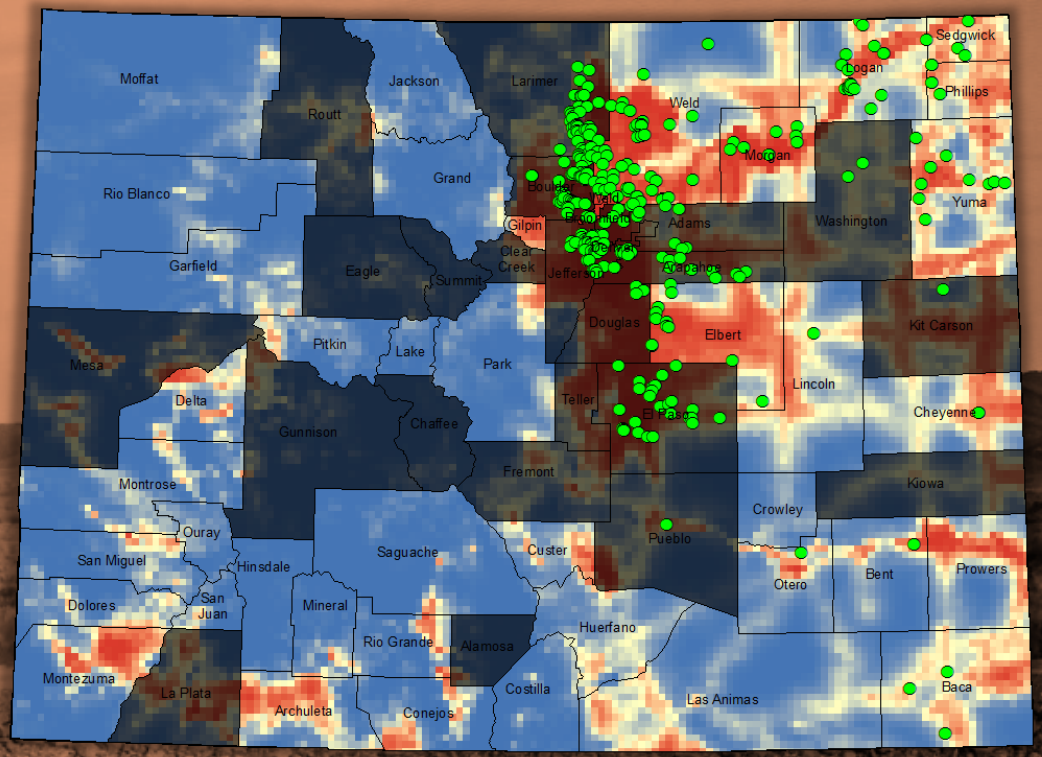
Rabies Risk vs. Dog Vaccine Requirements (2015)





Legend

Dog Vaccination Required?

Counties

- Yes
- No
- No Response

Cities

- Yes

SC Skunk Variant, Confirmed & Suspect

Counties Requiring Dog Rabies Vaccination

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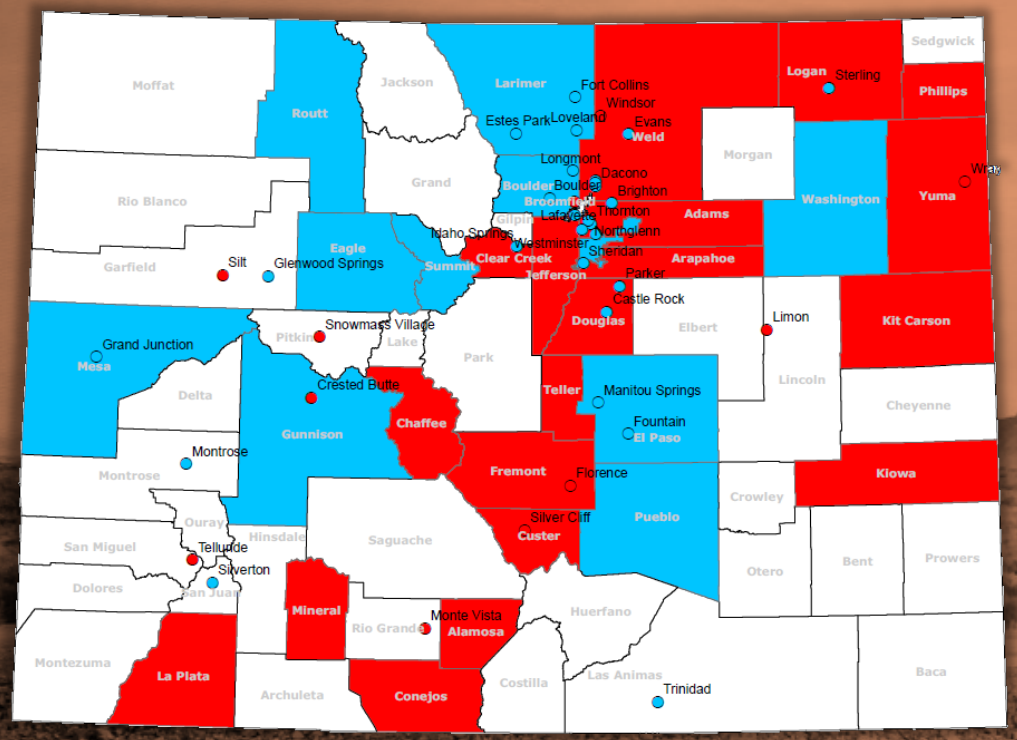
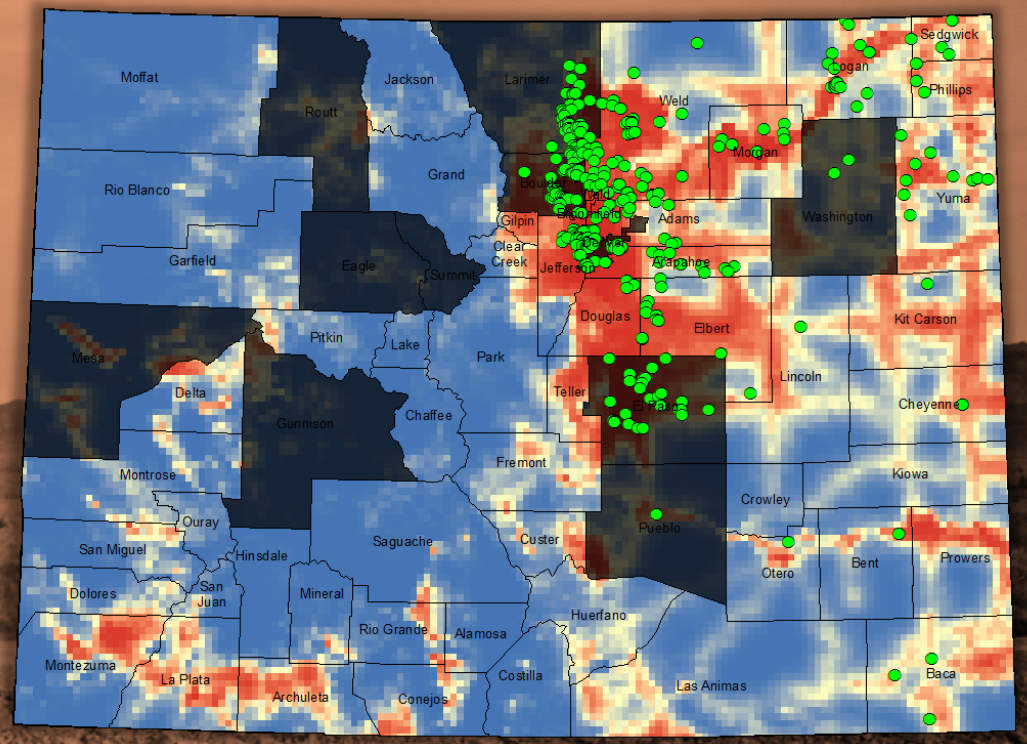
Rabies Risk vs. Cat Vaccine Requirements (2015)





Legend

Cat Vaccination Required?

Counties

- Yes
- No
- No Response

Cities

- Yes
- No

SC Skunk Variant, Confirmed & Suspect

Counties Requiring Cat Rabies Vaccination are darkened/grayed out. Those visible do not.

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Improvements to Consider

- More years, greater sample size
- Higher case-control ratio (3:1? 4:1)
- Different explanatory variables
- Seasonality/years (Poisson)
- Bayesian modeling techniques
- Presence-Only Ecological modeling (MAXLIKE)
- Different sampling structure?

QUESTIONS?

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