Supplemental Material for

Association of between precipitation events, drought, and animal operations on with *Campylobacter* incidence infections in the Southwest US, 2009-2021

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Summary of Study
Using public health surveillance, meteorological, and farm animal census data from Arizona, Colorado, New Mexico, and counties in Utah, this ecological study aims to assess the association between precipitation and the incidence of *Campylobacter* infections by county from 2009–2021 and determine how this association is modified by prior drought level and animal operations. We merged 38,782 cases counts of campylobacteriosis cases by reported in 121 counties with total precipitation (inches), temperature (average °F), Palmer Drought Severity Index (PDSI, category), and animal census data (presence, density per square mile) by week from 2009–2021. Negative binomial generalized estimating equations adjusted for temperature with a 3-week lag were used to explore the acute association between precipitation and campylobacteriosis with resulting Incidence Rate Ratios (IRR). We then conducted stratified analyses to explore the association with precipitation following antecedent drought level, presence of farm operations, and type of animal density (per square mile) on this association.

Data used in this study is available at the following link:

https://github.com/austhofe/RainDroughtCampy/

This research compendium includes all relevant code to merge datasets in R, code used for analysis in Stata, and post-hoc analyses suggested by reviewers. Health data is not included in this repository as it requires a data use agreement with each state health department and is not publicly available.

Supplemental Material

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Table S1. Case Definitions

Case definitions for *Campylobacter spp.* include clinically compatible illness (an illness of variable severity commonly manifested by diarrhea, abdominal pain, nausea and sometimes vomiting. The organism may also rarely cause extra-intestinal infections such as bacteremia, meningitis or other focal infections) and the following laboratory criteria. See CSTE Position Statement 14-ID-09 for more information.

Case Definition Year	Confirmed	Probable	Suspect
2015	Isolation of *Campylobacter spp*. from a clinical specimen *	Detection of *Campylobacter spp*. in a clinical specimen using CIDT OR epidemiologically linked to a confirmed or probable case	N/A
2012	Isolation of Campylobacter spp. in a clinical specimen	A clinically compatible case that is epidemiologically linked to a confirmed case	Detection of *Campylobacter spp*. in a clinical specimen using non-culture based laboratory method
1990	Isolation of *Campylobacter spp*. in a clinical specimen	A clinically compatible case that is epidemiologically linked to a confirmed case	N/A
FoodNet Case Definition	Isolation of *Campylobacter spp*. in a clinical specimen	Detection of *Campylobacter spp*. in a clinical specimen using CIDT Epidemiologically linked cases are not counted as cases	N/A

* A case should not be counted as a new case if laboratory results were reported within 30 days of a previously reported infection in the same individual.

Table S2. Data Sources

Data Sources for analysis

- PRISM, meteorological data daily and 30-year normals
  - https://prism.oregonstate.edu/explorer/
- NOAA, drought severity county time series
  - https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/time-series
- NOAA, NCEI Southern Oscillation Index
  - https://www.ncei.noaa.gov/access/monitoring/enso/soi
- USDM, drought severity time series
  - https://droughtmonitor.unl.edu/dmData/Timeseries.aspx
- USDA Animal Census, presence and density data

    - https://www.nass.usda.gov/Data_and_Statistics/County_Data_Files/Livestock_County_Estimates/index.php
- Köppen-Geiger climate zone, sensitivity analysis
    - Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data. 2018;5(1):180214. doi:10.1038/sdata.2018.214
- US Census, land area by county
    - https://www.census.gov/geographies/reference-files/time-series/geo/gazetteer-files.html
- US Census, population estimates
    - https://www.census.gov/data/datasets/time-series/demo/popest/2010s-counties-total.html
    - https://www.census.gov/data/tables/time-series/demo/popest/2020s-counties-total.html

Table S3. QIC Statistics

Pan's quasi likelihood (QIC) metrics for determining the best model for different variable combinations exploring the outcome of campylobacteriosis (lag 3 weeks). We used the QIC package in Stata 17, specifying a negative binomial distribution with an autoregressive correlation structure. While models including county population were the best fit according to QIC, estimates were largely unstable. Therefore we chose to include total precipitation, average temperature, and PDSI in the final model (bolded and highlighted in green in the table).

	p	**Trace**	**QIC**	**QICu**	**Estimates diverging**	**Final Chosen Model**
Total precipitation	2	1346.8	94456.4	91766.8		
Average temperature	2	576.0	85824.0	84676.0		
PDSI	2	1372.2	94462.4	91722.1		
County population	2				Yes	
Total precipitation and Average temperature	3	588.7	85594.3	84422.9		
Total precipitation and PDSI	3	1385.2	94506.8	91742.4		
Total precipitation and County population	3				Yes	
Average temperature and PDSI	3	586.6	85550.8	84383.5		
Average temperature and County population	3	930.8	70575.7	68720.0		
PDSI and County population	3				Yes	
Total precipitation, Average temperature, and PDSI	4	587.6	85265.5	84098.4		Yes
Total precipitation, Average temperature, and County population	4	1065.0	70756.5	68634.6		
Average temperature, PDSI, and County population	4	557.0	73078.2	71972.2		
Total precipitation, PDSI, Average temperature, and County population	5	715.8	69703.2	68281.7		

Legend: p, number of parameters; trace, the product of the independent and robust variance estimators; QIC, Pan's quasi likelihood under the independence model criterion; QIC_u, the QIC when trace approximates an independent covariance structure and is equivalent to the number of parameters; Total precipitation, total precipitation in inches in a week; Average temperature, average temperature in °F in a week; PDSI, Palmer Drought Severity Index standardized from 0 to 20 with larger values indicating more severe drought in a month; County population, the county population from 2020 US Census estimates.

In a post-hoc analysis suggested by a reviewer of the manuscript, we explored the model fit using QIC for different lags with the same parameters as the final chosen model above.

	p	**Trace**	**QIC**	**QICu**	**Estimates diverging**	**Final Chosen Model**
Lag 1, Total precipitation, Average temperature, and PDSI	4	598.5	85097.3	83908.4		
Lag 2, Total precipitation, Average temperature, and PDSI	4	771.6	85313.1	83777.8		
Lag 4, Total precipitation, Average temperature, and PDSI	4	620.2	85514.3	84281.8		

Legend: p, number of parameters; trace, the product of the independent and robust variance estimators; QIC, Pan's quasi likelihood under the independence model criterion; QIC_u, the QIC when trace approximates an independent covariance structure and is equivalent to the number of parameters.

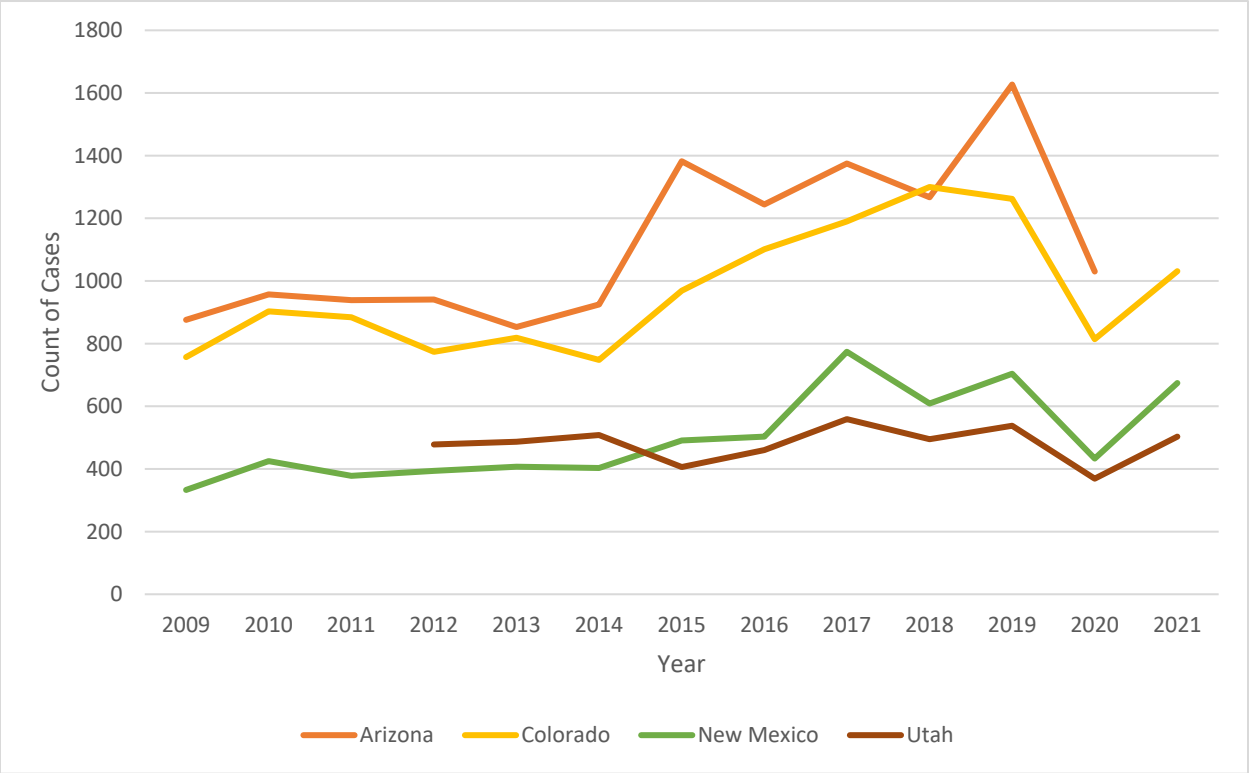
Table S4. Moran's I Statistics

Moran's I statistics exploring spatial autocorrelation among counties in each state for 2019. We estimated the Moran's I for a random sample of 4 years in each state and observed values were the same across all. Moran's I was calculated in R using the ape package on a scale of -1 to +1. Minimal to no spatial autocorrelation is indicated by an observed value close to 0.

	Observed	Expected	Standard Deviation
Arizona	-0.04	-0.001	0.00
Colorado	0.05	-0.001	0.00
New Mexico	-0.00	-0.001	0.00
Utah	0.03	-0.001	0.00

Figures

Figure S1. Count of *Campylobacter* cases by state from 2009-2012



The following pages include maps of farm operations with sales by county for Arizona, Colorado, New Mexico, and Utah from the 2017 USDA Animal Census for cattle, chicken and poultry, goats and sheep, and sheep. USDA defines a farm operations with sales as any place that produced and sold—or normally would have produced and sold—at least $1,000 of agricultural products during a given year. USDA uses acres of crops and head of livestock to determine if a place with sales less than $1,000 could normally produce and sell at least that amount.

Figure S2. Cattle Operations with Sales by County

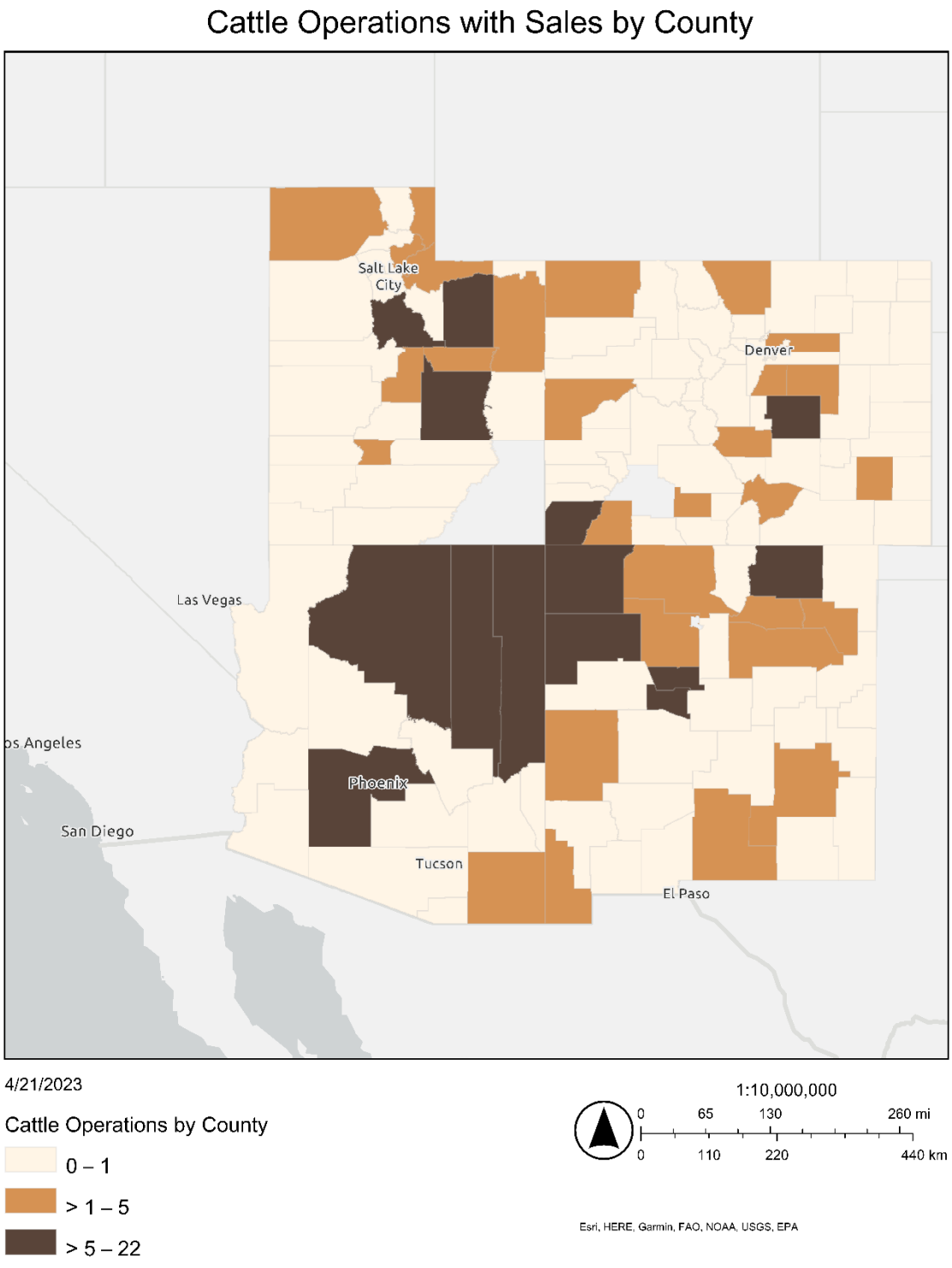


Figure S3. Chicken Operations with Sales by County

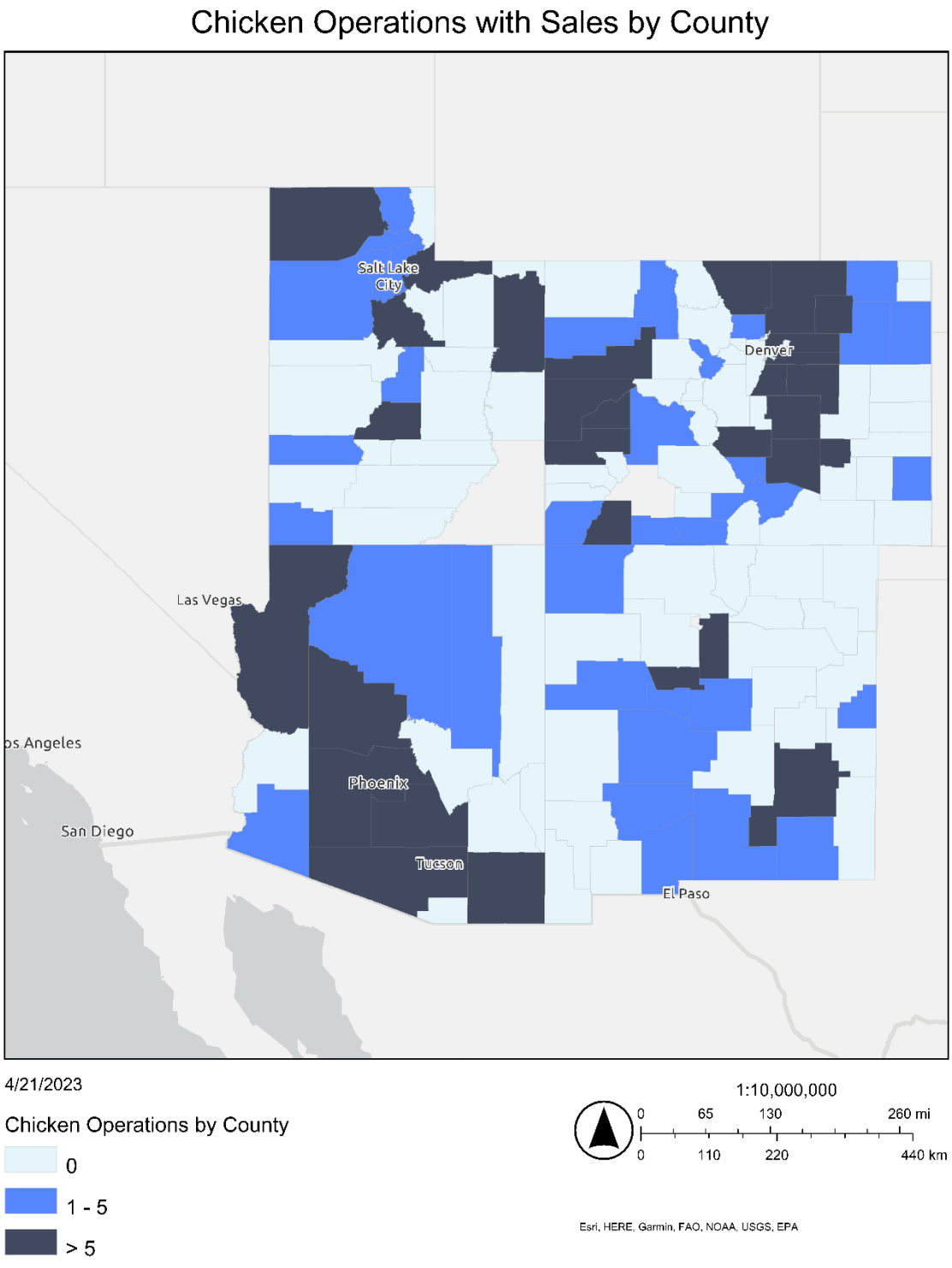


Figure S4. Goat and Sheep Operations with Sales by County

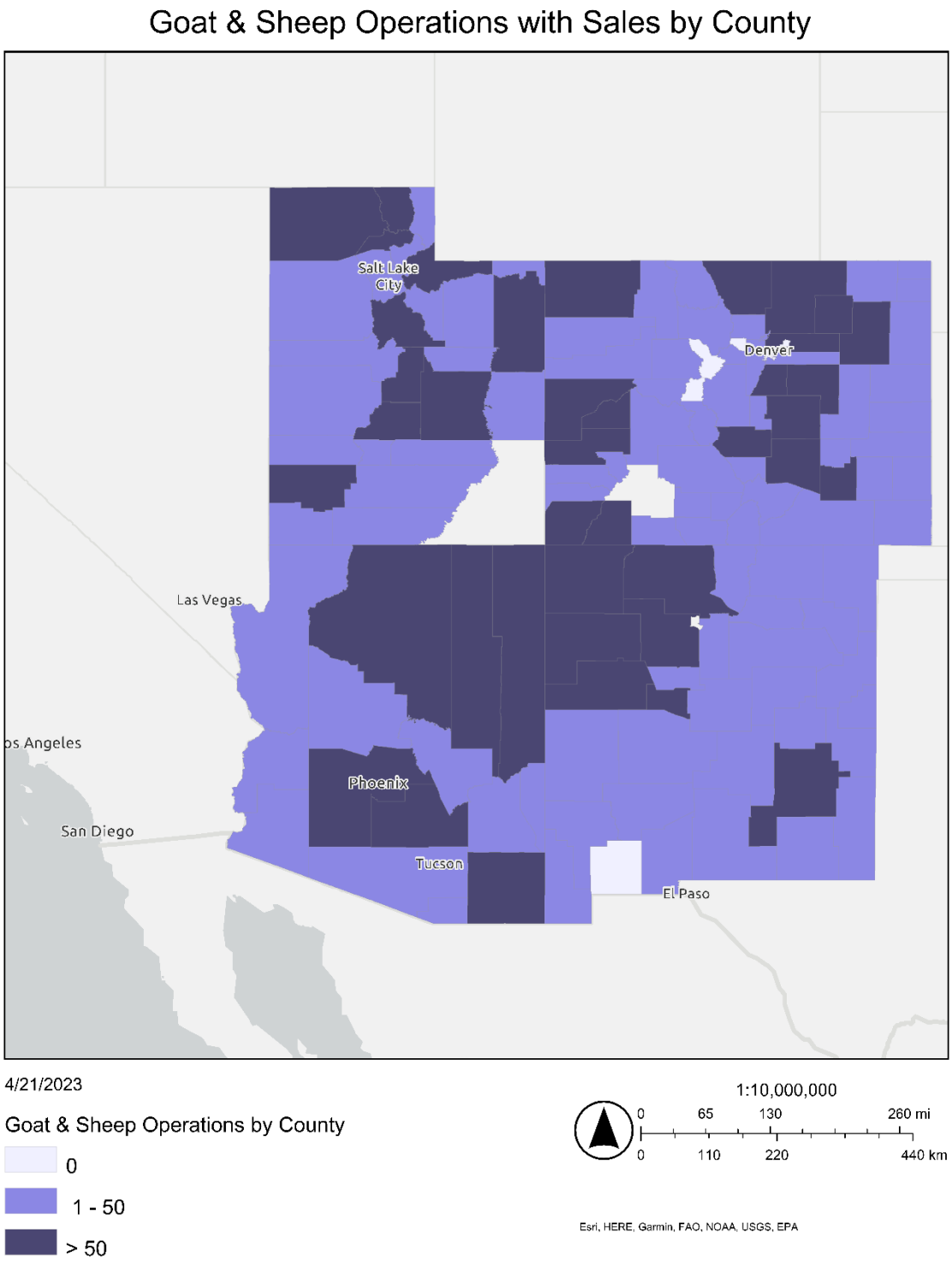


Figure S5. Sheep Operations with Sales by County