How Human Population Density Affects the Frequency of Wildlife-Vehicle Collisions

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ABSTRACT

Human activities have damaged ecosystems through habitat fragmentation and degradation for decades. Part of habitat fragmentation is the construction and use of roads in which wildlife-vehicle collisions (WVCs) often occur. This study aimed to better understand which factors contribute to variations in the frequency of wildlife-vehicle collisions. I used San Francisco County, Kern County, and Inyo County in California to represent urban, suburban, and rural areas. Within those counties, I examined the U.S. Route 101 and CA State Routes 58 and 395. I compared the roadkill incidence rates of each of the three counties using an ANOVA test to determine if human population density influenced roadkill incidence frequencies. I found that roadkill incidence rates increased with increasing human population densities. I performed a similar test to determine whether seasonality influenced roadkill incidence rates and found that it did not. Further, I found that mule deer was the species most often involved in WVCs. However, racoons surpassed mule deer in highly urban settings as the species most often involved in WVCs. This study's findings suggest that anthropogenic activities have the largest effect on roadkill incidence rates. The findings that roadkill incidences are highly influenced by external factors demonstrates the importance of understanding the problem of wildlife-vehicle collisions in all its contexts. Future research on this topic would benefit from exploring the effect that specific roadway conditions have on WVC frequencies, such as speed limit, traffic volume, or presence of wildlife crossings.

KEYWORDS

habitat fragmentation, roadkill incidence rates, mule deer, motorist safety, California Roadkill Observation System

INTRODUCTION

The encroachment of humans on wild spaces disrupts ecosystems through habitat fragmentation and degradation. Urban land expansion is a large driver of habitat loss for a variety of wildlife due to restricted range size and limited viable habitat availability (Simkin et al. 2022). To sustain a healthy diversity of wildlife, it is necessary to spare natural vegetated habitat in and around urban areas, without which biodiversity suffers (Pioltelli et al. 2024). Wildlife-vehicle collisions (WVCs) are a persistent consequence of the overlap between wildlife habitat and anthropogenic activities (Collins et al. 2022, Iverson et al. 2024). Some approaches to mitigate the harmful effects of human-wildlife cohabitation incorporate a network of connected habitat patches in an urban area (Xia et al. 2024). Habitat fragmentation and degradation are persistent issues that require public attention to mitigate the harmful effects on biodiversity worldwide.

WVC frequency in an area is influenced by a variety of anthropogenic, environmental, and species-dependent factors. Potential determining factors of roadkill prevalence includes land cover variables like forests and water bodies, and road characteristics like speed limit (Filius et al. 2020). In less developed areas, factors such as time of day and wildlife behavior are found to have a more profound effect on WVC frequency (Gutema et al. 2023). Although there are some general trends in WVC frequency across many species in an area, analyzing roadkill incidences on a species-specific basis can provide more context to the patterns of spatial and temporal hotspots that emerge (Firmino Carvalho-Roel et al. 2023). Seasonal factors, like mean temperature, significantly increase the probability of WVCs involving mammals, birds, and reptiles, although the spatial pattern depends on the class of vertebrates assessed (Ascensão et al. 2022, Arca-Rubio et al. 2023). Most of the previous studies on WVCs focus on a limited area to understand the impacts within certain conditions and decline to evaluate the broader trends of their findings.

Human population density, seasonality, and species involved in WVCs have the largest impact on roadkill incidence rates. Dense road networks pose particular dangers to wildlife, even to species considered adapted to urban environments and human disturbance (Kent et al. 2021). Species that increase movement in the spring and fall tend to have a bimodal distribution in roadkill due to mate-searching and juvenile behavior (Raymond et al. 2021). Additionally, daylight savings time has been found to decrease the risk of wildlife-vehicle collisions by shifting the timing of heavy traffic and shrinking the overlap with nocturnal animal activity (Frank et al. 2023). Spatial roadkill patterns often vary between species, making it difficult for researchers to take a one-size fits all approach to understanding the where WVC hotspots are likely to occur (Firmino Carvalho-Roel et al. 2023). Although previous research has explored some variables related to WVCs in different parts of the world (Denneboom et al. 2024), it is unclear exactly how specific factors (such as human population density, seasonality, and species involved in WVCs) influence roadkill incidence rates in California.

This study aimed to better understand how wildlife-vehicle collision frequencies are influenced by anthropogenic and environmental factors such as human population density, seasonality, and species involved in incidences. I first tested whether there was a difference in roadkill incidence rates across varying human population densities and predicted that higher incidence rates would be associated with a higher human population density. Next, I tested whether there was a difference in roadkill incidence rates over the four seasons of the year and predicted that there would be higher incidence rates in the spring and fall due to the breeding and birthing seasons of problematic mammals like deer. Lastly, I examined which species are most often involved in WVCs and predicted that deer, racoons, and skunks would be the animals struck most often. The data from this project comes from the California Roadkill Observation System (CROS), courtesy of the Road Ecology Center at the University of California, Davis.

METHODS

Study site

I used data from San Francisco County, Kern County, and Inyo County in California to represent urban, suburban, and rural areas (Figure 1). I chose the counties based on population density in people per square mile between 2018-2022. Within these counties I selected to analyze U.S. Route 101 in San Francisco County, California State Route 58 in Kern County, and U.S. Route 395 in Inyo County (Figure 2). U.S. Route 101 is a scenic north-south highway that runs through the most densely populated county in California, San Francisco County with a population density of 18,209.42 people per square mile, representing an urban area. California State Route 58 is an east-west winding mountain road that runs through the agricultural Kern County in Southern California. Kern has the median population density in California with 111.48 people per square mile, representing a suburban area. U.S. Route 395 is a north-south highway that passes through the least densely populated county in California and home to Death Valley National Park, Inyo County with 1.85 people per square mile, representing a rural area.

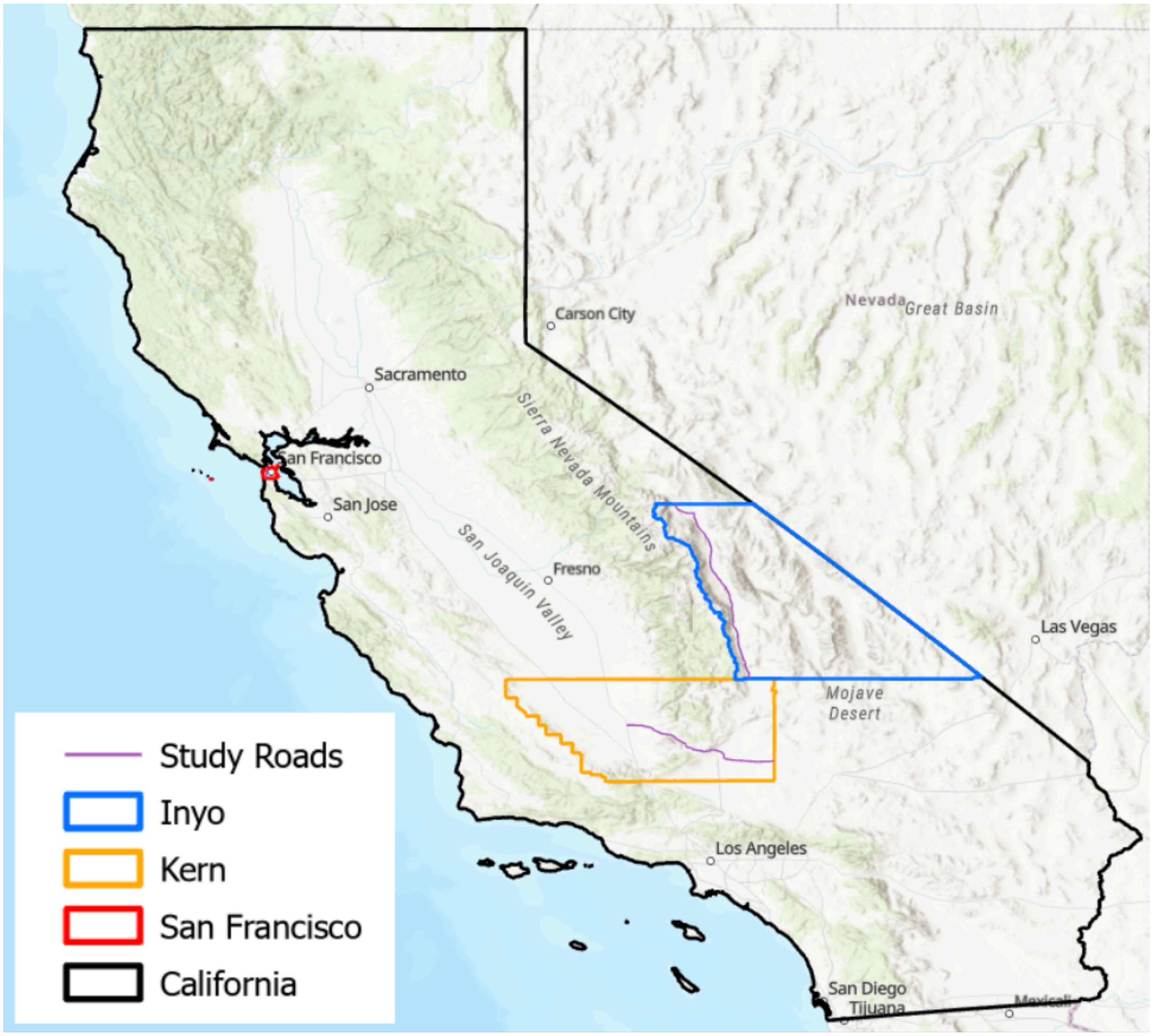

Figure 1. Location of California counties included in the study. These counties were chosen to represent the maximum, minimum, and median population densities in California. All study roads are purple, study counties shown in color, and California boundary shown in black.

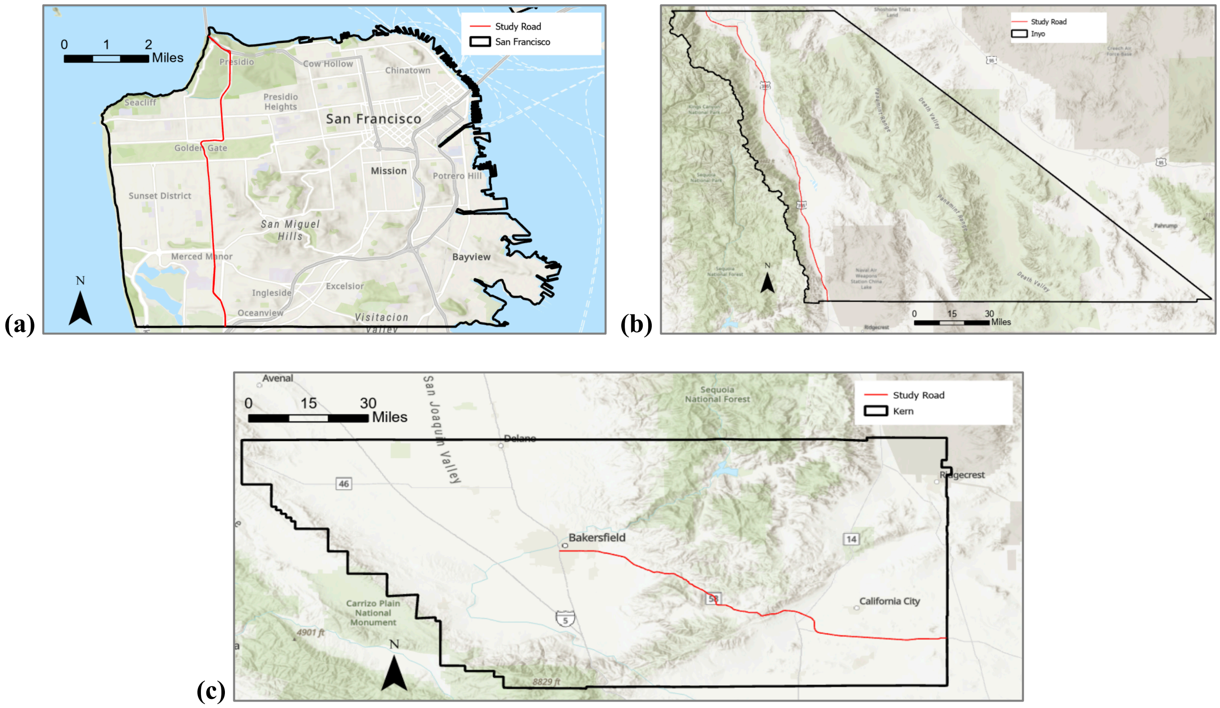

Figure 2. Detail of study roads within study counties. Study roads include (a) U.S. Route 101 in San Francisco County, (b) California State Route 395 in Inyo County, and California State Route 58 in Kern County. Study roads are highlighted red and county outlines are black.

Data collection

I collected two different datasets to help answer my research question. I found the population density data in the U.S. Census Bureau website. This dataset contained demographic information on California counties, which I used to find the population density of each of the three counties in the study. The roadkill data came from the California Roadkill Observation System (CROS). This dataset provided me with observations ranging from 1972 to 2023 of roadkill instances recorded by California Highway Patrol officers, scientists who work at the Road Ecology Center at UC Davis, and citizens who wish to report their observations. CROS records information about the incident such as date, location, identified species, and an image of the observation.

Data analysis

Population density determination

To determine which study sites I would use I searched for population density in "PolicyMap" (a website loaded with census data used to create maps) and filtered for counties in California. I downloaded the most recent dataset (2018-2022) to my computer and uploaded it to my RStudio where I could manipulate the data. Within RStudio I loaded the "tidyverse" library, which allowed me to use functions to determine which counties would be used in the study. I called counties with the maximum, median, and minimum population densities and assigned those counties to urban, suburban, and rural respectively. I confirmed that these counties were considered urban, suburban, and rural according to the California State Association of Counties website.

Roadkill incidence ANOVA

To determine if there was a difference in roadkill incidence rates with respect to human population density, I performed an analysis of variance (ANOVA) test. To perform this analysis, I first changed the unit of observation from individual incidences to incidence rates with units of incidences per mile per year. This change addressed the differences in sizes of each of the study areas. I found the incidence rates by dividing the total observations in each county per year by the length of the study road and created a new data frame with units of incidence rates per county per year. With this new data frame, I conducted an ANOVA test to determine if there was a statistically significant difference between any of the three counties' incidence rates. The results of the ANOVA test suggested that I needed to conduct a Tukey post hoc test, which I did using R.

To determine if there was a difference in roadkill incidence rates with respect to seasonality, I performed another ANOVA test. I used the incidence rates created for the counties data set but changed the unit of observation to incidence rates in each county per mile per month by dividing the total number of incidences in each county per month by the length of the study road. To assess seasonality without searching for each year's specific solstice and equinox dates I assigned the months of March through May to spring, June through August to summer, September through November to fall, and December through February to winter. I conducted an ANOVA test using this new data frame to determine if there was a statistically significant difference between any of the incidence rates of the four seasons.

Species most often involved in WVCs

To determine the species most often involved in WVCs I had to change the unit of observation from individual incidences to individual animals. To create this new data frame in R I grouped the observations by animal, summarized the total number of observations for each animal and divided the total observations by the length of the study road. These manipulations gave me the incidence rates of each animal at all three of the study sites. I selected the ten species most often involved in WVCs and plotted their incidence rates in each county a bar chart. The other 30 species were left out of the visualization because they only had one or two observations in the data set.

RESULTS

Population density

After conducting the ANOVA test to determine if there is a difference between any of the roadkill incidence rates of the counties, I found that the p-value was 0.00905. This low p-value means that there is a 0.905% probability that I would get this result, assuming null hypothesis is true. Since the p-value is lower than the significance level of 0.05 I rejected the null hypothesis that there is no statistically significant difference between any of the three counties' incidence rates. The roadkill incidence rates of all three of the counties differed slightly, with the greatest difference between the urban and rural counties (Figure 3). The Tukey post hoc test revealed that the only combination of counties that had a statistically significant difference was urban San Francisco County and rural Inyo County (Figure 4). The results mean that I can be 95% confident that the difference in means between San Francisco's incidence rates and Inyo's incidence rates is greater than zero. Hence there is a statistically significant difference between rural and urban roadkill incidence rates.

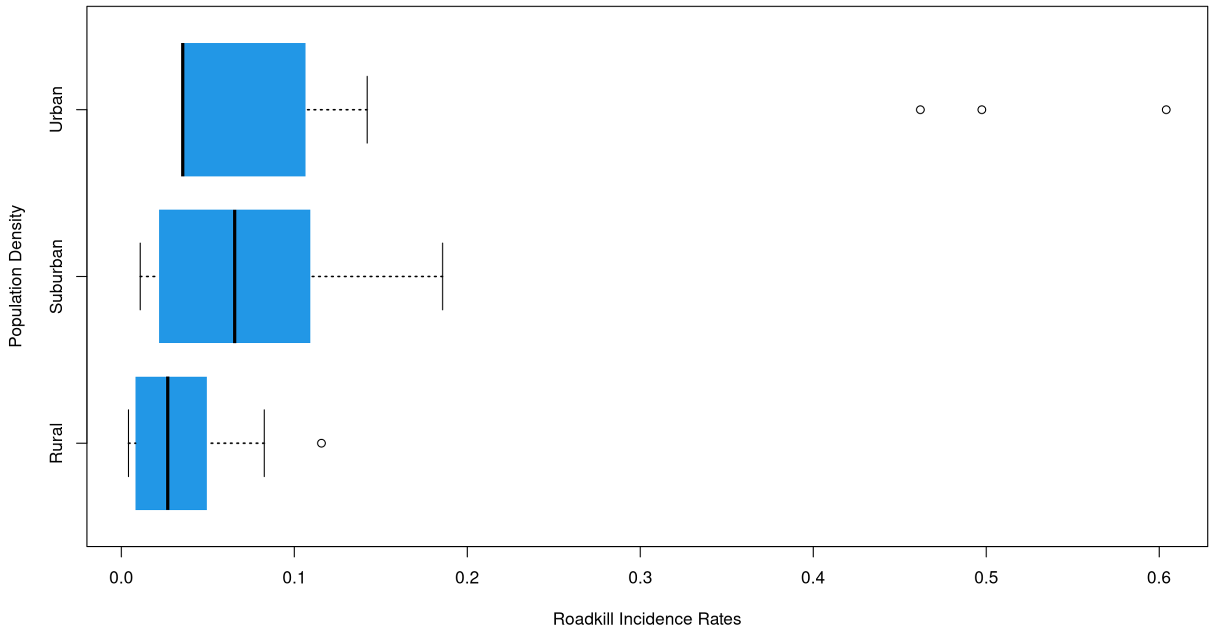

Figure 3. Roadkill incidences by human population density. San Francisco is represented by the "Urban" box in the plot, Kern by the "Suburban" box, and Inyo by the "Rural" box. Incidence rates are incidences per mile per year.

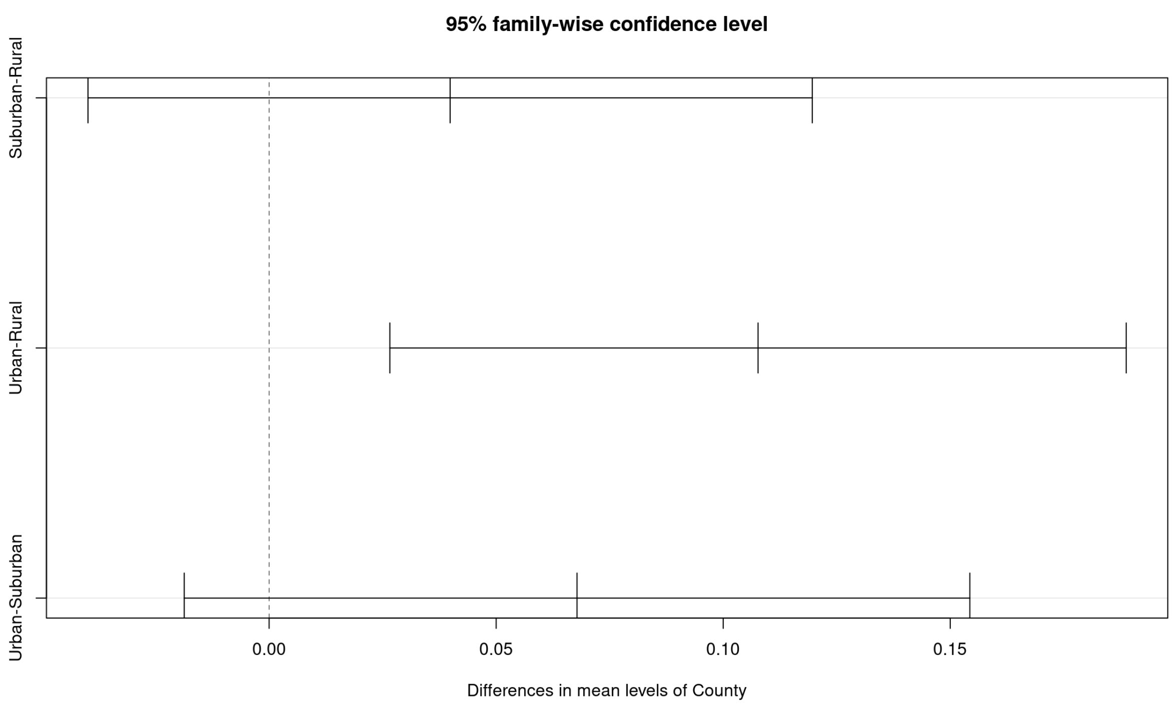

Figure 4. Results of Tukey post hoc test. The only combination of counties that has a statistically significant difference in means is urban San Francisco County and rural Inyo County.

Seasons

After conducting the ANOVA test to determine if there is a difference between any of the roadkill incidence rates of the seasons, I found that the p-value was 0.551. This result means that there is a 55.1% probability that I would get this result, assuming the null hypothesis is true. Since the p-value is greater than the significance level of 0.05, I failed to reject the null hypothesis. The results of the ANOVA test are consistent with the boxplot shown in Figure 5, where the median values of all four seasons are completely aligned with one another. Since there is no statistically significant difference between any of the seasons incidence rates, I did not conduct a post-hoc test on the data.

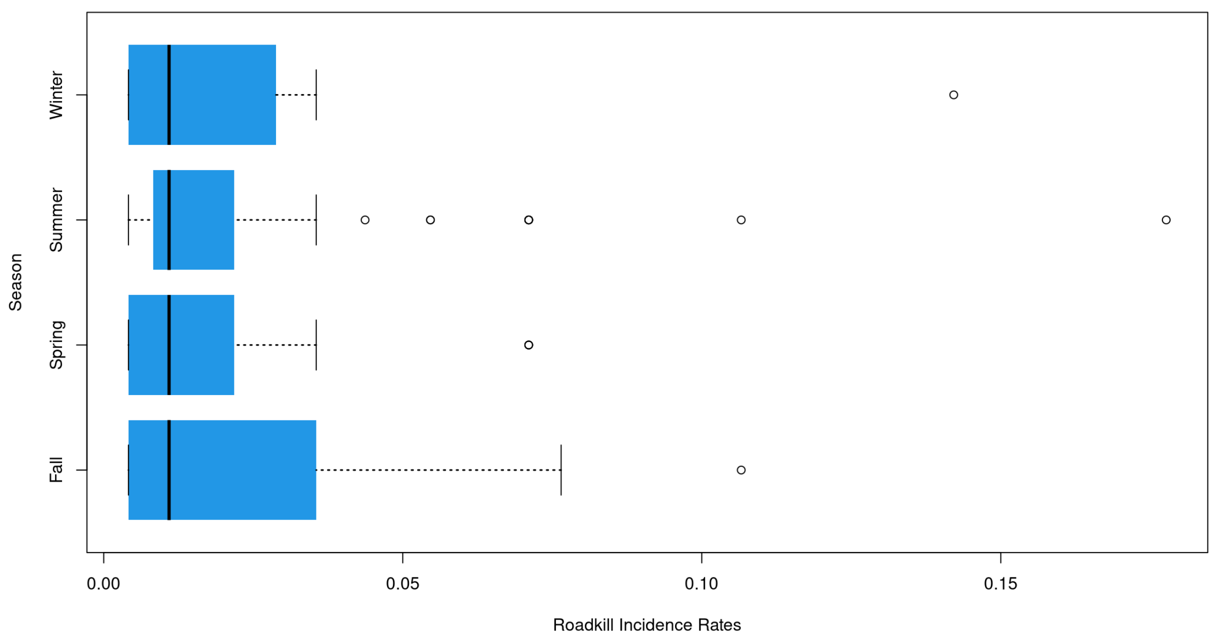

Figure 5. Roadkill incidences by season. Median incidence rates are identical between seasons. Incidence rates are in units of incidences per mile per month.

Species

I found that the most common species to be involved in WVCs over all the study sites were mule deer, racoons, striped skunks, coyotes, and black bears. The species with the highest incidence rates overall was the mule deer, which were particularly common in Inyo (rural) and Kern (suburban) counties. Additionally, mule deer was the only species to have observations recorded in all three counties assessed. Racoons however, made up the most incidences in the urban (San Francisco) county and had the highest incidence rates of any species in a single county. There was a total of 40 different species in the data set with most of the animals only having one or two observations.

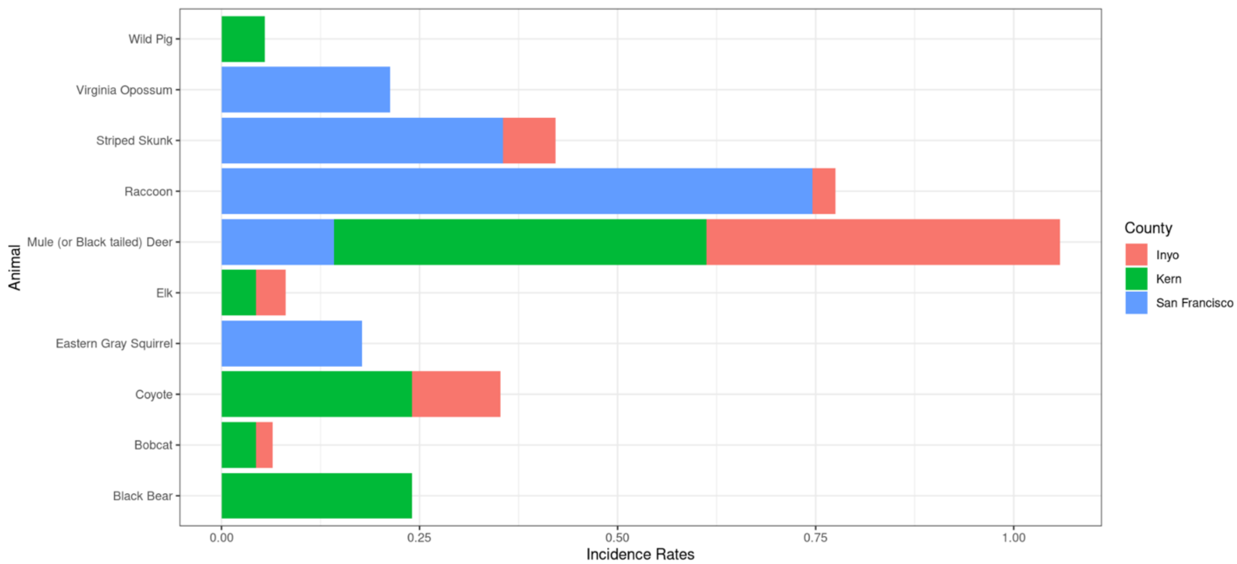

Figure 6. Species most often involved in WVC by county. The bar chart shows the top ten species most often involved in WVCs. The fill of each bar corresponds to the county for each incidence rate.

DISCUSSION

In this study I identified factors associated with the roadkill incidence rates such as human population density, seasonal variations, and species present in the area. My findings suggest that roadkill incidence rates are more dependent on human population density than they are on seasonality. Unsurprisingly, I also found that mule deer and racoons were the species most often involved in WVCs. Efforts to restore and maintain connected habitat regions over a fragmented landscape will be much more effective if policymakers understand what factors lead to higher risk for WVCs. Awareness of factors that increase WVC risk allow for opportunities to improve safety for wildlife and motorists.

Roadkill in urban, suburban, and rural settings

Using CROS data, I found statistically significant relationships between roadkill rates and human population density. Roadkill incidence rates increased with increasing human population density and had a statistically significant difference between rural and urban roadkill incidence rates. This finding is unsurprising given the extensive work showing that wildlife suffers from habitat loss in periods of urban expansion (Simkin et al. 2022, França Balbino Da Silva et al. 2022). In general, urban settings provide poor habitat conditions for most wildlife species, leading to densely human populated areas with more traffic and higher WVC frequency (Kučas et al. 2023, Simpson et al. 2023). Rural settings have less motorists per mile of road, which leads to lower WVC frequencies (Gonçalves et al. 2023).

Seasonal impact on roadkill rates

The finding of no significant change in roadkill incidence rates depending on the season was surprising due to previous studies finding relationships between WVC frequencies and seasons of the year (Kouris et al. 2024, Sahlean et al. 2024). Notably, I expected to see spikes in WVCs during daylight savings time changes when the timing of heavy traffic changes at dusk and dawn each day (Abeyrathna and Langen 2021, Balčiauskas et al. 2024). Additionally, migration, breeding, and fawning seasons for mule deer (a common roadkill species) occur during the spring and fall, (Gritter et al. 2024) contributing to my expectation of increased WVCs at those times.

Species associated with high roadkill incidence rates

Mule deer and raccoons being the most common species to be involved in WVCs suggests that species that are more adaptable to human activities are more likely to be involved in WVCs (Heigl et al. 2024). Deer are a particularly problematic animal to be involved in WVCs because they are not only large in size (causing extensive damage to the vehicle and motorist when struck), but they are also somewhat comfortable living in close quarters with humans (Mayer et al. 2021, Faull et al. 2024). Raccoons tend to use urban areas to their advantage, thus are often found in close quarters with humans and fall victim to WVCs (Chitwood et al. 2020). However, since raccoons are smaller in size, the collision causes less damage to the vehicle, unless the driver attempts to avoid the animal and damages property in the process (Balčiauskas et al. 2020).

How WVCs are influenced by anthropogenic and environmental factors

Studying roadkill incidence rates has given insight into the factors that affect WVC frequency in California (Ascensão et al. 2021). This study's findings suggest that WVC frequencies are more affected by human activities than by environmental factors. Roadkill incidence rates increasing with human population density is another form of evidence that urbanization is harmful to the wildlife in the area (Stark et al. 2020, Schell et al. 2021). The finding that seasonal changes had no effect on incidence rates suggests that WVC frequency is not dependent on the time of year, in contrast to other literature (Wang et al. 2022). The species most often involved in WVCs were animals like deer, raccoons, and skunks which are species known to inhabit areas where human disturbance has changed the landscape (Start et al. 2020).

Limitations

The experimental design adequately addressed the hypotheses posed in this study by evaluating roadkill incidence data against the factors of human population density, seasonality, and species affected. I conducted this study using data collected from outside sources for other purposes and thus the research questions had to be written to be feasible for the data at hand. The results of the seasonality analysis were unexpected and warrant further investigation. The research questions posed in this study were appropriate for the data on hand, however there are plenty of other questions that this data could be used to answer. The most impairing limitation of this study was the inability to collect data for questions instead of asking questions around available data.

Future directions

This study's findings suggest that there is a wide range of possible variables affecting roadkill incidence rates. Similar wildlife-vehicle collision data can be analyzed against many other external variables such as such as smaller or larger ranges of temporal variation, weather conditions, driver characteristics, as well as other locations to make the findings from this study more generalizable. This study could be improved by including some of these variables to better understand what factors affect the frequency of wildlife-vehicle collisions. Creatively utilizing data like the California Roadkill Observation System and expanding its contents can be a powerful tool in future research on ways to diminish WVCs.

Broader implications

The findings that roadkill incidences are influenced by human population density demonstrates the importance of understanding the problem of WVCs in urban areas. Roadkill incidence rates vary depending on characteristics of the area in question. The characteristics examined in this study are three levels of human population density, seasonal variations, and species involved in the collision. The results suggest that wildlife-vehicle collisions are a function of the number of people per square mile. With this information and future research on this topic, policymakers can make well-informed decisions to improve the safety of the roadways for the wildlife and motorists who use it.

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