

GILA MONSTER ROAD MORTALITY IN AND NEAR SAGUARO NATIONAL PARK:  
AN ANALYSIS OF ROAD AND LANDSCAPE CHARACTERISTICS THAT AFFECT  
ROADKILL

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## **Abstract**

Road and landscape characteristics that affect *Heloderma suspectum* are crucial for understanding factors that increase road mortality, predicting roadkill hotspots, and implementing effective mitigation measures. We investigated the impact of urbanization on Gila monster roadkill incidence through five factors: traffic density, speed limit, housing density, road density, and the number of lanes on the roads. We conducted field searches in Saguaro National Park and in nearby neighborhoods outside the park to record the date and GPS location of Gila monster road mortalities between 2011 and 2015. During this study, we recorded a total of 24 *Heloderma suspectum* road mortalities. The traffic density (vehicles/km) of roads had the most significant correlation with number of roadkill ( $p < 0.01$ ) and we found that speed limit, housing density, road density, and number of lanes alone are not sufficient to predict roadkill hotspots. These findings suggest that a combination of these factors with the addition of proximity to high population densities will give a better insight on predicting Gila monster roadkill hotspots and determining effective mitigation methods.

## Introduction

Roads have many direct and indirect effects on natural ecosystems such as increasing road mortality, altering habitats, creating barriers, obstructing animal movement, fragmenting natural ecosystems, changing animal behavior, and supporting the increase of human activity (Forman and Alexander 1998; Trombulak and Frissell 2000). Research in road ecology -the study of the complex interactions between roads, vehicles, and the environment- has become more significant to conservation, management, and policy due to the increase in road networks around the United States (Forman and Alexander 1998). Animal-vehicle collisions may have the most direct impact on the mortality of vertebrate animals in national parks and reserves, especially reptiles and amphibians (Fahrig et al. 1995; Garriga et al. 2012). Roadkill has been the cause of death for an estimated average of 29,377 (SE 6,807) vertebrates each year from 1994 to 1999 in Saguaro National Park, which is of great concern for species with low population densities and for the safety of drivers (Gerow et al. 2010).

The Gila monster (*Heloderma suspectum*) is an iconic lizard in the United States known for its venom and is easily recognized for its distinctive orange and black coloration (Beck 2005). Although there are hundreds of venomous snake species, there are only two known venomous species of lizards in North America: *Heloderma horridum* and *Heloderma suspectum*. Gila monsters have been the subject of myths and drug research has recently taken interest in their venom for managing type 2 diabetes, but surprisingly little is known about the ecology of the largest and only venomous lizard in the United States. Gila monsters are known to have a dangerous and painful bite due to their venom and tendency to latch on to their victim, which has given them a negative reputation. In fact, some drivers are seen purposely hitting *Heloderma*

instead of braking and implementing evasive maneuvers, increasing roadkill incidence (Beck 2005).

*Heloderma suspectum* may be more vulnerable to human harm and roadkill than other lizard species due to their life history characteristics and their slow and deliberate pace.

*Heloderma* have high longevity, late sexual maturity, and long gestation periods compared to other lizards in the desert, which may make them more vulnerable to habitat loss from human urbanization and roadkill (Beck 2005). Gila monsters also have low metabolic rates that allow them to survive in extreme conditions by storing energy in their tails and walking for long distances at a slow pace (Beck 2005). Unlike other lizards that can sprint away from danger, the maximum speed recorded of a Gila monster sprinting is only 1.9km/hour (Beck et al. 1995). Therefore, a Gila monster in the path of a fast-moving car may not be quick enough to escape the fate of roadkill, which may be their largest source of human caused mortality (D. Beck, 2005).

Surface activity patterns of *H. suspectum* may have a large effect on their roadkill incidence since their activity varies depending on season and time of day. Gila monster activity peaks in May during their mating season and during rainy periods such as the monsoon season (August) in Arizona (Beck 2005; Davis et al. 2016). *Heloderma suspectum* will leave their shelters to search for food, mates or other shelters. Gila monsters have a higher probability of falling victim to roadkill during these seasons. As ectotherms, Gila monsters must regulate their body temperature to maintain a mean activity temperature near 29.4°C to maximize physiological processes (Beck 1990). It is not well studied if Gila monsters are attracted to the heat retaining asphalt of roads to bask and maintain homeostasis, as it puts them at risk for animal-vehicle collisions.

Monitoring population characteristics and factors that might affect population density such as disease, predation, habitat destruction, climate change, human population growth, and roadkill, is important for the conservation of *H. suspectum*. Gila monster population sizes can be difficult to predict because they may spend over 92 percent of their time out of sight in shelters, especially during the winter season (Beck 2005). Population density estimates have been observed between 1980 and 1998 in Southern Arizona and ranged between 3.8 to 7.8 Gila monsters per km<sup>2</sup> (Data from unpublished manuscript referenced in Beck, 2005). A recent study in Saguaro National Park estimated the density of *H. suspectum* to be 5.7 individuals per km<sup>2</sup>, supporting the proposed population density range (Farrar et al. 2016). Although Gila monsters have been found to have healthy and robust populations in protected areas such as Saguaro National Park, overall the species is considered “Near Threatened” with various pressures in unprotected areas, including habitat destruction, fragmentation, rapid development, poaching, and roadkill (Beck 2005; Farrar et al. 2016). Few studies have compared the impact of specific road characteristics on road mortality of species like *H. suspectum* near National Parks and areas where they may be more abundant.

The purpose of this study was to investigate and compare the impact of roadkill mortality on Gila monster populations in areas within and adjacent to Saguaro National Park Rincon Mountain District. The questions addressed were: (i) How does urbanization affect *Heloderma suspectum* roadkill incidence in and near Saguaro National Park? (ii) Is there a correlation between traffic density, speed limit, housing density, road density, and number of lanes to road mortality? (iii) What mitigation measures can be taken to reduce Gila monster road mortality? Slower moving species with low reproductive rates like *H. suspectum* are suspected to be more at risk for population decline, possibly to the point of local extinction, due to roadkill (Kline and

Swann 1998). Previous studies have focused on estimating road mortality of vertebrates to determine its impact on wildlife populations (Kline and Swann 1998; Gerow et al. 2010; Garriga et al. 2012), and predicting hotspots through traffic volume, transects, and roadkill counts to implement effective mitigation measures (Fahrig et al. 1995; Langen et al. 2009; Santos et al. 2015; Saranholi et al. 2016). In this study, I focused on five road and habitat factors that may help predict Gila monster roadkill hotspots. These factors are: Traffic density, speed limit, housing density, road density, and the number of lanes on the roads of the study site.

Previous studies have established that high vehicle traffic may be the greatest contributor to road mortality (Trombulak and Frissell 2000). Traffic density is the number of cars that travel over a distance during some time interval. In general, roadkill increases with increasing traffic density (Rosen and Lowe 1994; Fahrig et al. 1995), but some studies have found that there may be a threshold where traffic density may become so high that animals exhibit a road risk-avoidance behavior in response to “avoidance effect”, i.e. the deterring effects of light, noise, and the overwhelming presence of moving vehicles (Forman and Alexander 1998; Jacobson et al. 2016). In a study that compared the responses of different species to increasing traffic density, hedgehogs, (most similar to Gila monsters in their life history characteristics [i.e. slow moving species with higher road mortality during dispersal and breeding periods]), was less affected by avoidance and barrier effects (Grilo et al. 2015). I hypothesized that Gila monster road mortality has a positive correlation with increased traffic density due to their slow nature. High traffic density in areas adjacent to protected quality Sonoran Desert habitat may have large impacts on the populations of rare and long-lived species with slow reproduction rates such as Gila monsters. Studying the density and timing of traffic peaks can be a simple predictor of the location of roadkill hotspots and determining when mitigation measures will be most effective.

Traffic density alone cannot predict roadkill because there may be other factors that affect animal-vehicle collisions. For example, a road with high traffic density and a low speed limit may cause less roadkill than a road with the same traffic density and a higher speed limit. In general, speed limits have a positive correlation with the occurrence of roadkill (Forman and Alexander 1998). A previous study in Spain estimated that 78.5% of road mortalities of roe deer and wild boar were found in areas with a speed limit higher than 60 km h<sup>-1</sup> (Valero et al. 2015). *Heloderma suspectum* may be more vulnerable on roads than other vertebrates due to camouflage with black asphalt and their small size. I predicted that higher speed limits increase the likelihood of animal-vehicle collisions because of the decreased distance before a Gila monster is visible on the road and the decreased time available for a driver to react. If a strong correlation is found, then suggestions can be made to mitigate speed limits during the planning of new roads and enforce them on existing roads in areas filled with wildlife, especially near national parks and reserves.

In addition to road factors, urbanization by roads that are near or previously part of Gila monster habitats may play a large role in the location of road mortality hotspots. According to the Arizona 2000 Census of Population and Housing, the number of housing units in Tucson from 1990 to 2010 has increased by approximately 25% (Bodman and Cooper 2003). Measuring housing density (the number of housing units per square kilometer) may give good insight on how urbanization may affect *H. suspectum* road kill hotspots. In 2010, the housing density in Tucson was reported to be 391.28 houses per km<sup>2</sup> (Bodman and Cooper 2003). This increase in housing density is of great concern for the wildlife in Saguaro National Park and the Tucson area. The incidence of *H. suspectum* roadkill may have a positive correlation with housing density due to high traffic density associated with increased human activity in developed areas. If

a relationship is found between housing density, traffic density and Gila monster road kill, then the combination of these two factors can help predict current and future road kill hotspots.

Road density is another factor related to human activity that should be considered in the study of *H. suspectum* road mortality. Road density is the average total road length per unit area of landscape ( $\text{km}/\text{km}^2$ ) (Forman and Alexander 1998). Road density can give us a general estimation of possible road effects such as habitat loss, animal movement, human access to remote areas, human disturbance, and road mortality (Forman and Alexander 1998). Road density is typically high in suburban areas such as the increasingly residential areas west of Saguaro National Park. In general, animals tend to occupy areas of low road density due to road avoidance behavior (Forman and Alexander 1998). A study conducted on squirrel gliders (*Petaurus norfolcensis*) found that like many other animals that actively avoid roads, squirrel activity decreased in areas of high road density (Francis et al. 2015). If Gila monsters are like other slow moving species, then their lack of road avoidance behavior may cause an insignificant difference in their preference to occupy areas near roads. Therefore, I predict that high road density increases the incidence of Gila monster road kill due to the increased chance of *H. suspectum* vehicle interaction and presumed habitat fragmentation.

Another road variable to be considered for road mortality is the number of lanes on each road segment. The number of lanes may be an indicator of areas with high populations and traffic densities resulting in more roadkill. A previous study found that the probability of a road being classified as a roadkill hotspot increased with increasing number of lanes (Hubbard et al. 2000). In addition, it has also been proposed that higher number of lanes may decrease the theoretical visibility of a driver, especially at night when the visibility is determined by the range of vehicle headlights (Lagos et al. 2012, Valero et al 2015). Similarly, I predict that Gila monster

road kill mortality will increase on roads with a greater number of lanes. These data can be used to compare road conditions that affect roadkill in and out of Saguaro National Park. If there is a positive correlation of roadkill with number of lanes, then smaller roads with less lanes would be advisable if new roads need to be constructed near Saguaro National Park. Overall, a better understanding of what specific types of road characteristics affect *H. suspectum* will be helpful in implementing more effective mitigation measures, predicting hotspots in other locations and for similar species, and for recommendations for future construction of roads that reduce the loss of wildlife diversity.

## Methods

### *Study Site*

This study was conducted in Saguaro National Park Rincon Mountain District in Tucson Arizona between 2011 and 2015 and in areas near the park. The city of Tucson is located between the two districts of Saguaro National Park, Tucson Mountain District (TMD) and Rincon Mountain District (RMD), and has been known to experience some of the highest growth rates in the United States in recent years (ACS 2015). The population of Tucson has grown to reach over 520,000 in 2010, and is projected to reach a population of 727,392 by 2020 (ACS 2015). Consequently, more roads and residential areas have been established on land adjacent to the protected areas of the parks. Now that urban areas adjacent to RMD have increased, it is expected that the roadkill mortality of vertebrates including Gila monsters will increase. Wildlife road mortality has been estimated through assessing roadkill detectability, carcass persistence on roads, and roadkill surveys (Kline and Swann 1998; Gerow et al. 2010). Changes in park

management such as limiting and monitoring the number of vehicles that drive on the roads within the park at different times of the day has decreased the prevalence of roadkill (Gerow et al. 2010). In addition, engineers have constructed fences, underpasses, overpasses, and culverts such as the wildlife-friendly culvert on Sandario Road in the RMD to lessen the need for animals to cross roads (Gerow et al. 2010). An estimate of the impact of road kill mortality of Gila monsters in and near Saguaro National Park is essential for the park's ability to lessen the impact of humans on their unknown population size and prevent population decline and local extinction.

### *Field Crew Searches*

Our team of students, park employees and volunteers collected data starting January 2011 as described in 2011 Year End Report prepared for Saguaro National Park (Park and Bonine 2012). We conducted field searches using two different methods: hiking on and off trails and driving on the loop road. Hiking searches primarily took place during the spring months in the morning (from 6am to 10am) and would sometimes continue into late afternoon. We did not conduct nocturnal searches during the spring. The driving searches began during the summer in the late afternoon or early evening to as late as 11pm. The hiking searches focused on four primary areas: The Javelina Picnic area, the Cactus Forest Trail area, the Loma Verde Wash area, and the Freeman Wash/Freeman Homestead Trail/ Tanque Verde Ridge Trail area. We conducted driving searches on Cactus Forest Loop Drive which is a one-way road approximately 8 miles in length.

### *Field Processing and Citizen Science*

Our team asked staff, volunteers and visitors to report any Gila monster sightings and road mortalities by methods including submitting a form to the park, using the iNaturalist phone application or emailing our email address ([GilaMonsterResearch@gmail.com](mailto:GilaMonsterResearch@gmail.com)). This collaboration allowed for a larger study site as general citizens can provide accurate data on locations of roadkill miles away from the park. We requested that submitters record date and time of sighting, location (GPS if possible or the closest cross streets), estimate body length, weather conditions and safely try to take photos if possible of both live and dead Gila monsters. The roads where roadkill was found were: Old Spanish Trail (Houghton to Camino Loma Alta), Freeman (Speedway to Broadway, and Broadway to Old Spanish Trail), Broadway (Houghton to

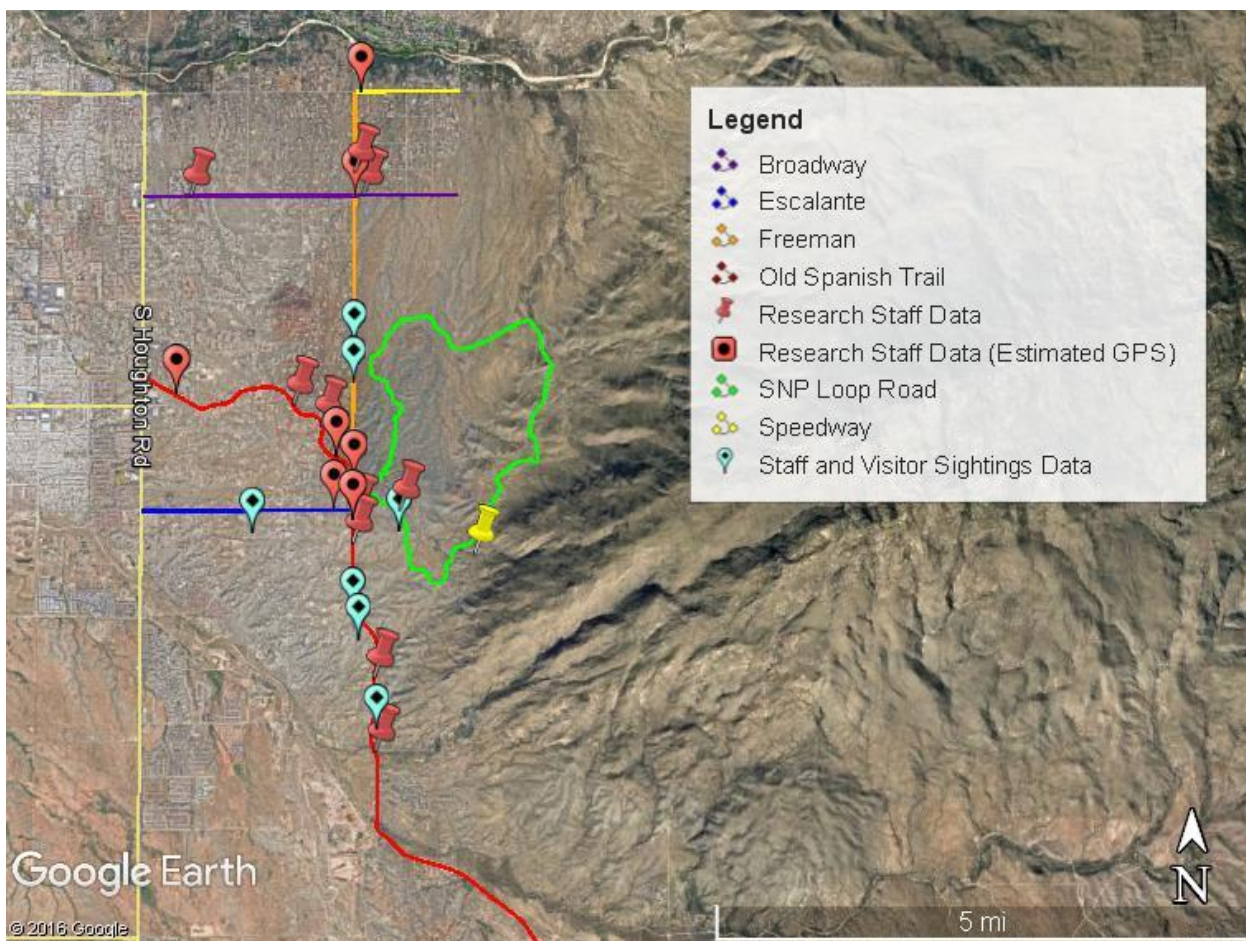


**Figure 1.** Location of sampling area near Saguaro National Park Rincon Mountain District. Each place marker represents the location where Gila monster Roadkill was found. Streets where road mortality occurred are outlined in color.

Freeman, and Freeman to Avenida Aguila), Escalante (Houghton to Old Spanish Trail), Speedway (Wentworth to Freeman), and Cactus Loop Drive (in Saguaro National Park). We used Google Earth Pro to display the locations of found roadkill using GPS coordinates and estimated locations (Figure 1).

### *Traffic Density*

We calculated traffic density using the traffic volumes from the Pima Association of Governments Traffic Count Database (PAG 2014). Since the average annual daily traffic volume (AADT) is recorded for one week every few years, the traffic volume closest to the year of the roadkill recorded for each road section was used. If roadkill was recorded at the midpoint year between two recorded traffic volumes, the average of the two traffic volumes was used for that year. We calculated traffic density by multiplying the traffic volume by the distance (in km) of each road section to give the average number of vehicles per day/km. Lastly, we compared the traffic density to the number of roadkill found per year in each road section.

### *Speed Limit*

We obtained speed Limit data through the Pima County GIS Database (Brice 2010). We recorded the speed limit for each road section (in mph) and compared it to the number of road mortalities found on each section from 2011 to 2015.

### *Housing Density*

We obtained housing density measurements by counting the number of buildings found within 100m of each road section. We chose this distance because most of the buildings closest to the roads observed in this study can be found within 100m of the roads. We measured the area

(m<sup>2</sup>) of each road section using a KML Buffer Tool with a buffer distance of 100m to create an area transect the length of each road by 200m (100m on each side of the road). Since the buffer tool area includes a semicircle at the end of each road segment, these areas were subtracted from the total area to prevent overlapping areas between roads. All buildings including houses, churches, schools and businesses were counted as “housing units” regardless of size because they are locations that involve human activity, decreased Gila monster habitat, and vehicle traffic. We calculated housing density (units/m<sup>2</sup>) by dividing the sum of the number of housing units on each side of the road by the total area calculated by the KML Buffer Tool. We then compared the housing density to the number of roadkill found on each road section.

#### *Road Density*

We obtained road density by taking a stratified sample of 4 areas that encompass the study site. We calculated the length of major roads within each area using the tools in Google Earth Pro. I then calculated road density (km/km<sup>2</sup>) by dividing the length of roads in each section by the area. Non-major roads and residential streets were not included in this calculation since data was collected on major roads. The calculated road density was then compared to the number of road mortalities found in each of the 4 selected areas.

#### *Number of Lanes*

We obtained a relationship between the number of lanes and roadkill by counting the number of lanes where each recorded roadkill was found. We recorded the roads and road sections of roadkill data to compare roads with different proximities from Saguaro National Park RMD. We weighted the proportion of roads with one, two or three lanes by calculating the percentage of total road length that fit into those three categories.

#### *Analysis*

We performed regression analyses for traffic density, speed limit, housing density, and road density data, with each of these variables as a function of the number of roadkill. We also analyzed the relationship between the number of lanes and roadkill by performing a single factor ANOVA test ( $p = 0.05$ ).

## Results

In total, 24 *Heloderma suspectum* road mortalities were recorded between 2011 and 2015 (Table 1). In all 5 years of this study, a total of 28 Gila monster deaths were recorded and 86% of them were road mortalities. In addition, the number of roadkill found decreased each year while there was no apparent difference in number of mortalities found off road. The highest number of roadkill was found in the month of May, followed by August and September (Figure 2). No road mortalities were recorded in the winter between the months of October and March.

| Gila monster Mortality On and Off Roads |                     |                  |                             |                  |                     |              |                                         |
|-----------------------------------------|---------------------|------------------|-----------------------------|------------------|---------------------|--------------|-----------------------------------------|
|                                         | Research Staff Data |                  | Staff and Visitor Sightings |                  |                     |              |                                         |
| Year                                    | # On Road Kills     | # Off Road Kills | # On Road Kills             | # Off Road Kills | Total On Road Kills | Total Deaths | % On Road Deaths out of Observed Deaths |
| 2011                                    | 4                   | 1                | 5                           | 0                | 9                   | 10           | 90                                      |
| 2012                                    | 4                   | 0                | 1                           | 0                | 5                   | 5            | 100                                     |
| 2013                                    | 4                   | 1                | 0                           | 0                | 4                   | 5            | 80                                      |
| 2014                                    | 3                   | 2                | 1                           | 0                | 4                   | 6            | 67                                      |
| 2015                                    | 2                   | 0                | 0                           | 0                | 2                   | 2            | 100                                     |

**Table 1.** Number of Observed Gila monster Deaths on and Off Roads between 2011 and 2015.

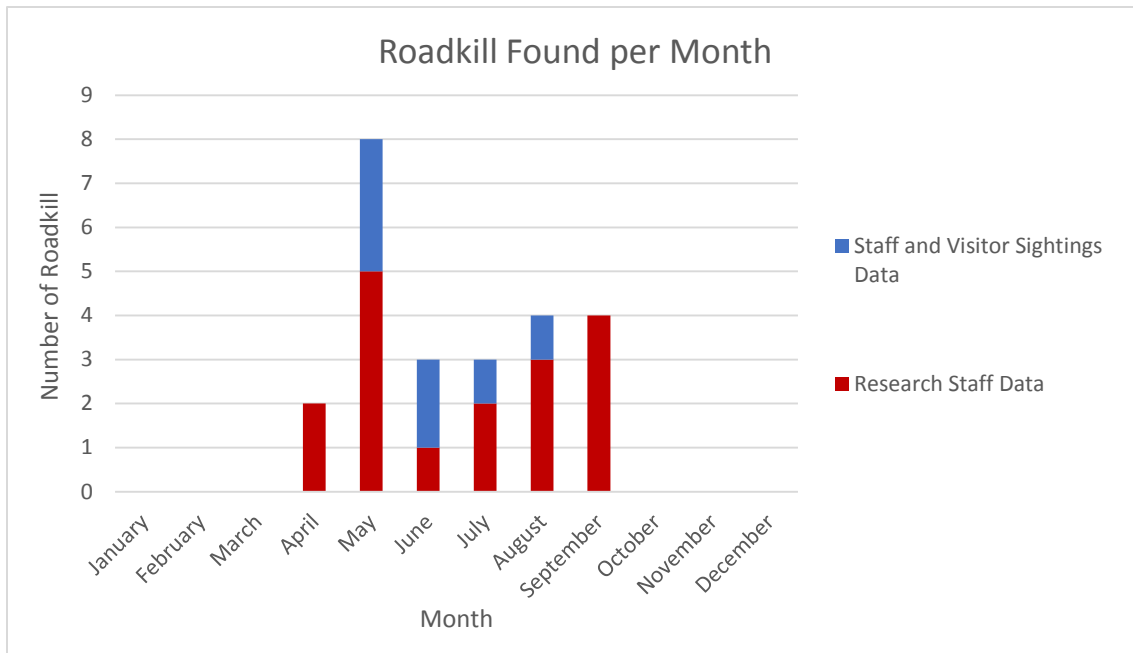


**Figure 2.** The number of roadkill found each month between 2011 and 2015.

### *Traffic Density*

Traffic density (vehicles/km) had a significant positive correlation with increased roadkill on each road section, ( $r = 0.66$ ,  $p < .001$ ,  $n = 41$ ) (Figure 3). Old Spanish Trail was the road with the highest traffic density and the highest number of roadkill, while Broadway had the lowest traffic densities and least amount of roadkill per year.

### *Speed Limit*

There was no significant correlation between speed limit and number of roadkill, ( $r = 0.16$ ,  $p > .05$ ,  $n = 10$ ) (Figure 4). Old Spanish Trail was the road with the highest speed limit and number of roadkill.

### *Housing Density*

Housing Density ranged between  $6.04\text{E-}07$  and  $1.52\text{E-}04$  properties/ $\text{m}^2$ . We found that housing density is negatively correlated with number of roadkill, but the relationship is not

statistically significant ( $r = 0.41$ ,  $p > 0.05$ ,  $n = 6$ ) (Figure 5). The data for Old Spanish Trail and Speedway Blvd were outliers in Figure 5, and if these data were removed, there would be a higher coefficient of correlation ( $r = 0.91$ ), but the correlation would still not be statistically significant ( $p > .05$ ,  $n = 4$ ).

#### *Road Density*

There was no significant correlation between the road density measured in 4 stratified sections or areas and roadkill ( $r = 0.08$ ). Although the correlation was not statistically significant ( $p > 0.05$ ,  $n = 4$ ), the areas that were closest to Saguaro National Park (Sections 2 and 3 in Figure 6) had the highest amount of roadkill.

#### *Number of Lanes*

The single factor ANOVA analysis comparing the number of lanes to roadkill occurrence reported no significant difference between roads characterized by 1, 2, or 3 lanes ( $p = 0.87$ ,  $n = 24$ ) (Figure 7). We determined that 67% of the total length of roads observed in the study site had 2 lanes, 30% of roads had 1 lane, and only 3% had 3 lanes.

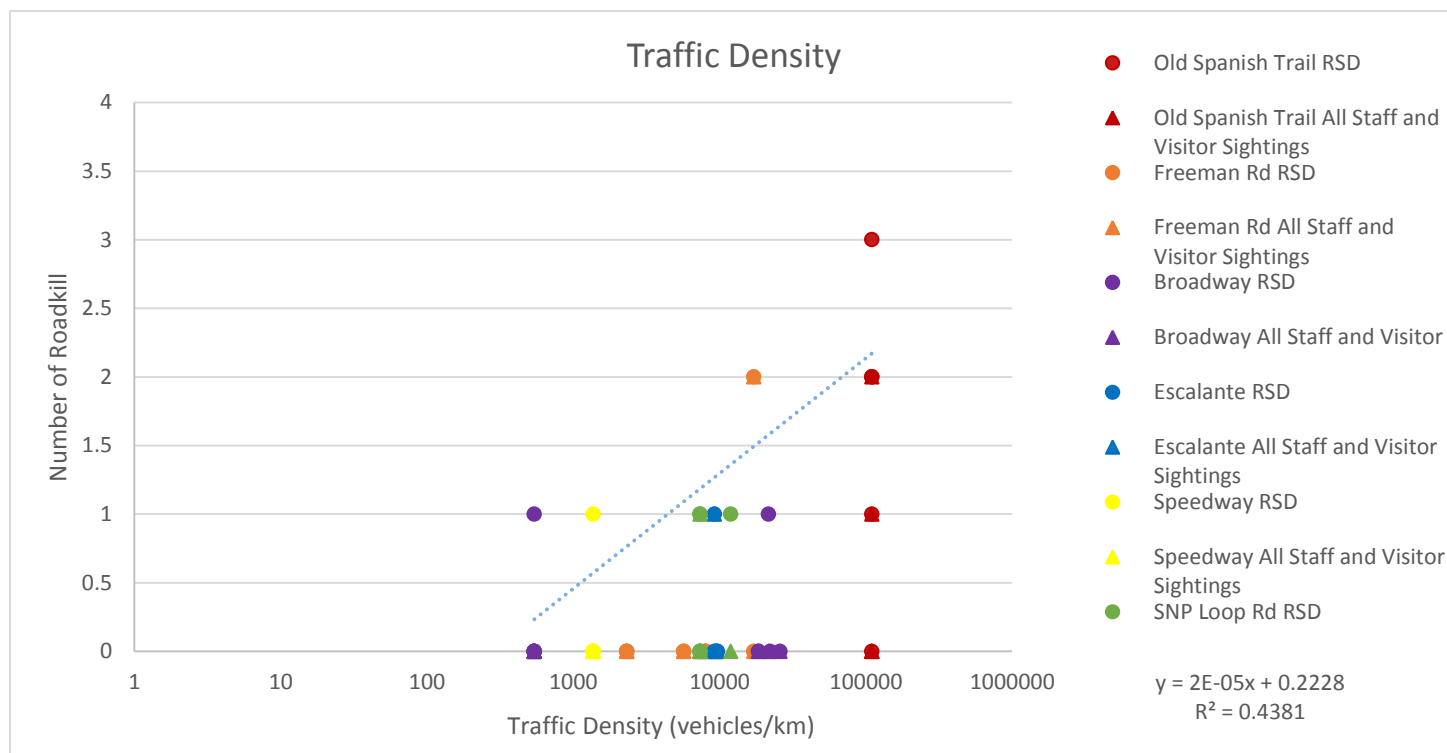


**Figure 4.** The traffic density of each road section where roadkill was found corresponding to the number of roadkill ( $p = 2.44E-06$ ). Our Research Staff data (RSD) is represented with circle markers and all data collected from the Saguaro National Park staff and volunteers are represented with triangle shaped markers.

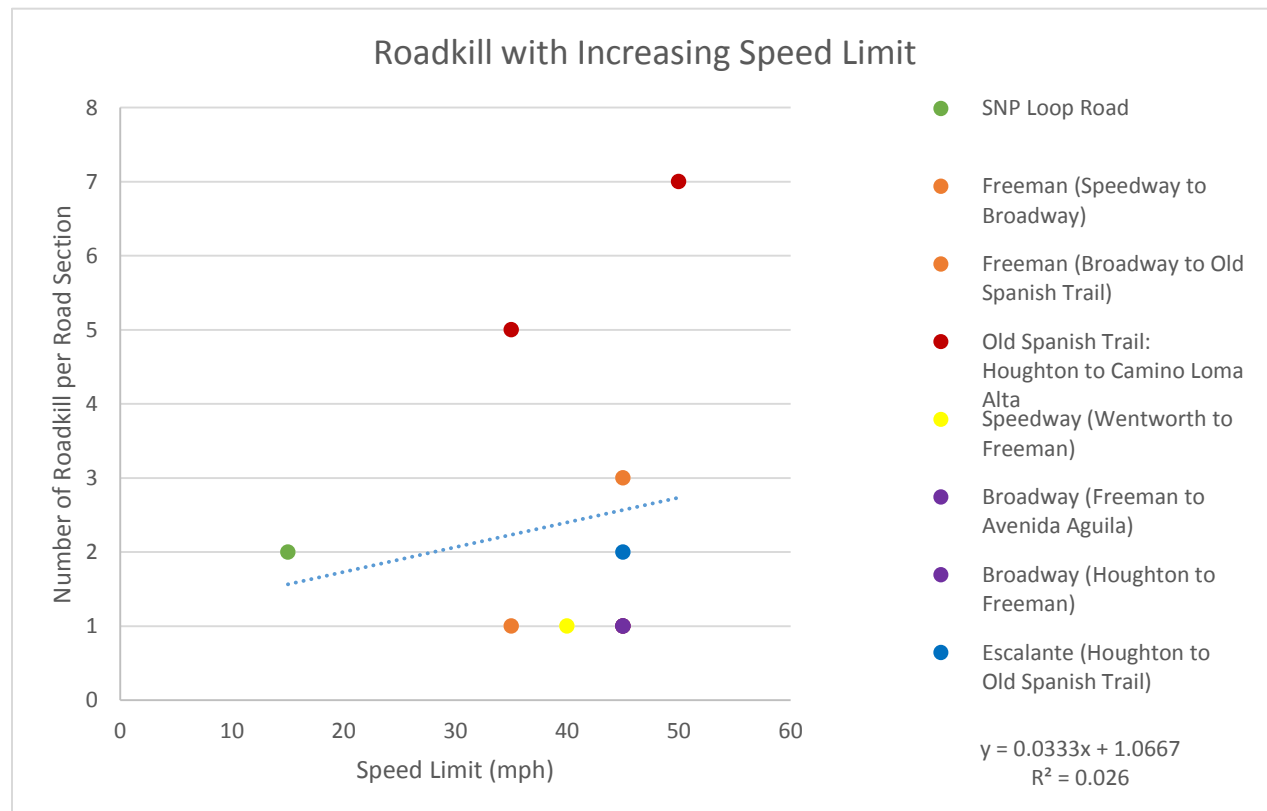


**Figure 3.** Speed Limit in miles per hour (mph) where each *H. suspectum* roadkill was found ( $p = 0.65$ ).

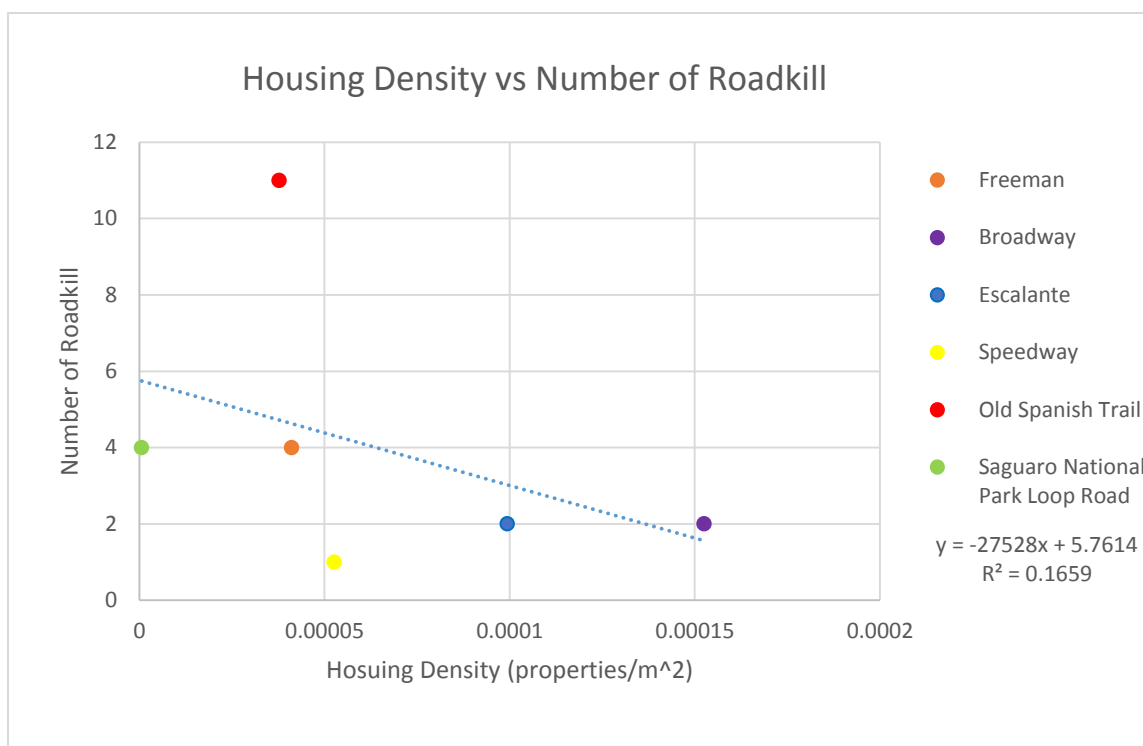


**Figure 5.** The relationship between housing density (the number of properties/area) and number of roadkill on each road ( $p = 0.42$ ). The area for each road included buildings that were within 100m of the roads.

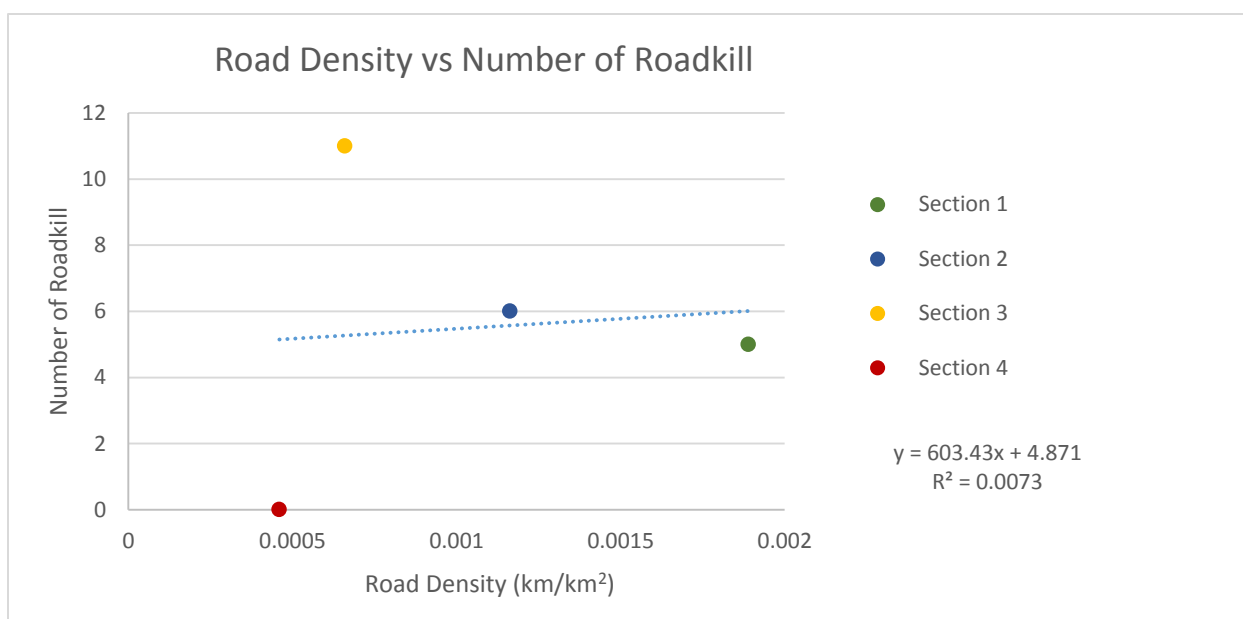


**Figure 6.** The relationship between road density and roadkill found in those four sections ( $p = 0.91$ ).

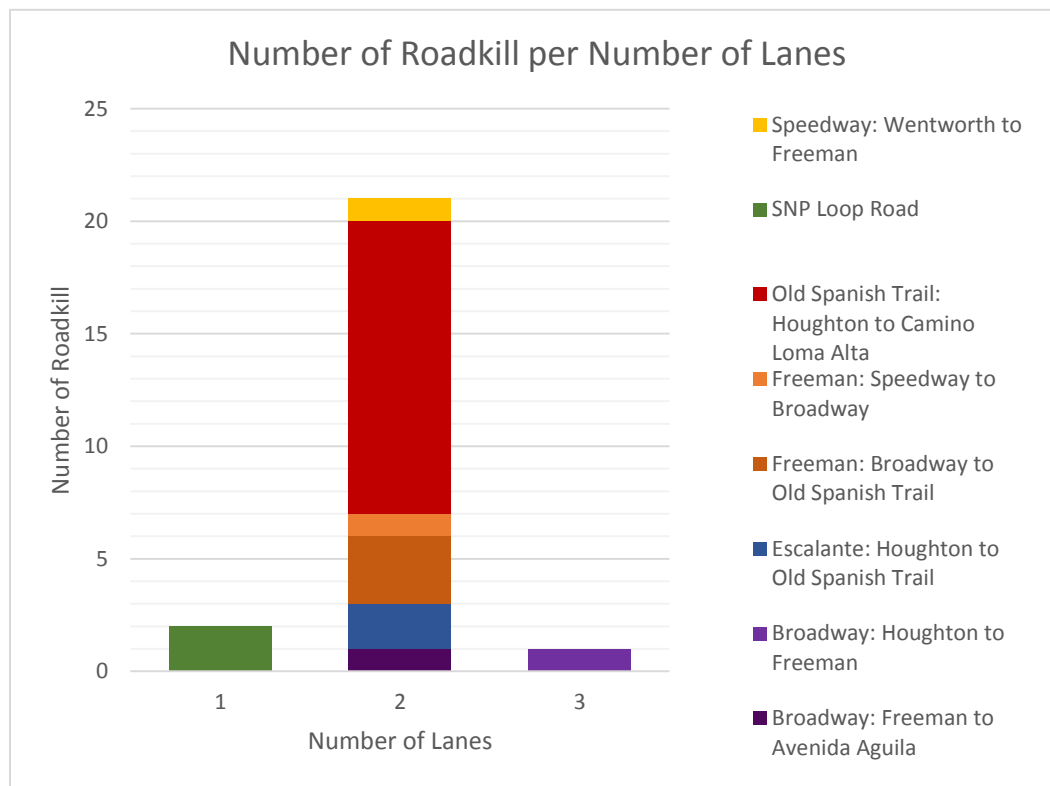


**Figure 7.** The number of roadkill found in 1, 2 or 3 lane roads ( $p = 0.87$ ).

## Discussion and Conclusions

Although the effects of traffic density on road mortality of mammals and amphibians were studied extensively (for reviews see Trombulak and Frissell 2000; Coffin 2007; Gunson et al. 2011), these data are the first to focus on road and landscape factors that affect road mortality of *Heloderma suspectum*. We confirmed that traffic density is the most significant human development factor to consider when studying road mortality of Gila monsters. The results of this study also indicate that speed limit, housing density, road density, and number of lanes alone are not able to predict roadkill hotspots.

As predicted, the traffic density of a road has a direct significant relationship to the number of *Heloderma suspectum* roadkill that are found on those roads each year. These results agree with studies on other taxa that traffic density is the greatest contributor to the road mortality of animals (Kline and Swann 1998; Trombulak and Frissell 2000). This is likely due to loss of habitat, habitat fragmentation, the low response of *H. suspectum* to road deterrents (the lights, sound and physical presence of moving vehicles). Gila monsters may cross roads to reach an area that was previously part of their habitat, to find mates, or to reach a habitat that they may find attractive (due to food and shelter). Further studies on habitat characteristics at the location of Gila monster road mortalities may help determine species-specific roadkill hotspots. In addition, the number of roadkill observed per month between 2011 and 2015 (Figure 2) closely follows the monthly activity patterns of Gila monsters as reported in Figure 33 of *The Biology of Gila Monsters and Bearded Lizards* (Beck 2005), suggesting that *H. suspectum* activity levels may also play a large role in predicting roadkill hotspots.

There was also no clear evidence found to suggest that a threshold traffic density affects roadkill, since the number of roadkill did not plateau or decrease at high traffic densities (Figure 4). The high occurrence of roadkill at low traffic densities may suggest that Gila monsters have a similar road-avoidance effect response to other slow moving animals such as hedgehogs (Grilo et al. 2015). The exact behaviors of Gila monsters caught on the road in the face of oncoming traffic is not clear. Based on Jacobson's study (2016) on behavior responses to the perceived risk of high traffic volumes, Gila monsters may be considered "non-responders" (animals that attempt to cross roads regardless of traffic density) or "pausers" (animals that stop in the realization of danger) due to the incidence of road mortality at high traffic volumes. Regardless of their

reaction to oncoming traffic, traffic density has consistently shown to have a significant impact on Gila monster road mortality due to their slow sprinting speed to evade collision.

Our regression analysis indicates that there was no significant correlation between speed limit and number of roadkill. This is likely due to the small amount of roadkill recorded and the small range in speed for the roads in this study. Most roads had a speed limit between 35 and 45 mph and the Loop Road at SNP (15mph) and Old Spanish Trail (50mph) are the only two roads that were outside of this range. However, it appears that roads with higher speed limits that are closer in proximity to Saguaro National Park tend to have higher incidence of roadkill. In addition, the Loop Road in Saguaro National Park (SNP) had more roadkill than expected for a road with low speed limit. This can be explained by the area being more heavily studied as park staff, volunteers and visitors are present and can report data more frequently in the park and the research staff conducted more field searches inside the park since it is where Gila monster sightings are the most frequent.

Contrary to the prediction of high roadkill in areas with high housing density due to increased traffic density in the area, housing density was inversely related to the number of roadkill found. Our regression analysis indicates that the negative relationship is not statistically significant, but the negative relationship may be explained by less desirable habitat (no shelter, food or mates) in urban areas and deterrents of human activity such as lights and loud noises. Further studies on housing density in relation to areas with high *Heloderma suspectum* populations may give insight on target areas for mitigation measures to reduce roadkill.

The results of this study indicate that road density alone has no significant relationship to high roadkill incidence. High road density may fragment Gila monster habitat, discouraging their desire to cross a road. However, there seems to be a pattern if distance to Saguaro National Park

(SNP) is considered. Gila monster road mortality was highest in section 2 and 3, which were the areas with the proximity to SNP. Of the two sections, section 2 had the lowest road density, and consisted of the roads with the highest speed limits (Figures 3 and 4). This may suggest that road density can have an impact on roadkill incidence when location and speed limit are considered.

Contrary to our prediction, the ANOVA analysis shows no significant difference of roadkill occurrence based on the number of lanes where roadkill was found. The large percentage of roads observed with 2 lanes in the area may explain the lack of statistical difference between the three categories of lanes. The number of lanes in the study area seemed bias because most roads have 2 lanes, therefore further studies with an increased sample size for each category of lanes may provide a more significant result. It is a challenge to gather a large sample size as roadkill can occur at any time of the day, Gila monster populations are elusive, and roadkill may not persist long enough to be found (Santos et al. 2011). However, expanding the study site may be beneficial for comparison and increased observations.

Overall, the results of this study suggest that roads with the combination of high traffic density, high speed limit, low housing density, and proximity to Saguaro National Park are most susceptible to Gila monster roadkill. Effective mitigation measures may consist of limiting road use of the Saguaro National Park loop road during months of high Gila monster activity, especially during the months of April, May, and August. Mitigation measures outside of Saguaro National Park may be more challenging as it can be politically unpopular (road closures) and expensive (Kline and Swann 1998). Surveys on the timing of *Heloderma suspectum* surface activity have determined that Gila monsters are most active between 0800 and 1100 (Data from unpublished manuscript referenced in Beck, 2005). Pima County may want to consider

temporary closures or lowering the speed limits of roads with high traffic densities near SNP (such as Old Spanish Trail) during the times and months of high activity.

Continuing to monitor this species at a consistent schedule with the help and support of Saguaro National Park staff, volunteers, visitors, and neighbors will enable us to gain a more comprehensive understanding of road and habitat factors that affect Gila monster road mortality. In addition, public outreach can be an inexpensive and effective way to promote awareness for local wildlife when driving in areas prone to road mortality. Ultimately, the combination of traffic density, speed limit, housing density, number of lanes, activity patterns and proximity to high population densities (Saguaro National Park) may be needed to successfully predict Gila monster roadkill hotspots.

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