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Research Article

Vehicle Collisions Cause Differential Age and Sex-Specific Mortality in Mule Deer

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As roads continue to be built and expanded, it is important that managers understand the effects that vehicle-related mortality can have on the population dynamics of wildlife. Our objective was to examine the frequency of mule deer (*Odocoileus hemionus*) vehicle collisions to determine if different demographic groups showed differential susceptibility to mortality when compared with their proportion in the population. We also compared vehicle collision rates of mule deer, elk (*Cervus canadensis*), and moose (*Alces alces*) to determine their relative vulnerability to vehicle collisions. We found that 65% of mule deer involved in vehicle collisions were female; of those, 40% were adult does ≥2 yrs. When we compared the proportion of bucks, does, and fawns killed in vehicle collisions to surveys of live deer, we found that bucks were killed at rate of 2.1–3.0 times their proportion in the population. Additionally, when we compared vehicle collision rates for 2010 and 2011, we found that mule deer were 7.4–8.7 times more likely to be involved in collisions than elk and 1.2–2.0 times more likely than moose. However, we were unable to detect a negative correlation ($P = 0.55$) between mule deer abundance and increasing traffic volume.

1. Introduction

Roads are being built and expanded throughout the developed world to accommodate the increasing human population and demand for transportation of people, goods, and materials [1–3]. An IEA 2013 report [4] suggested the following: the world will need to add nearly 25 million paved road lane km (~60% increase) between 2010 and 2050; between 45 000 and 77 000 km^2 of new parking spaces will be added to accommodate passenger vehicle stock growth; global travel in 2050 will double that of 2010 travel levels; passenger travel will account for 70% of this growth; and ~90% of travel growth is expected in developing countries. Laurance et al. [5] estimated that the total length of the projected new roads is equivalent to encircling the earth ~600 times. Clearly, it is increasingly important to understand the effects that roads have on wildlife; those effects appear to be overwhelming negative for most species [6–9]. Deer are commonly involved in vehicle collisions in Europe, North America, and Japan [10–12]. In the United States alone, there are an estimated 1-2 million vehicle collisions with large animals annually, most of which involve deer, that result in >$8 billion (USD) in damages and >200 human fatalities [13–15]. Additionally, vehicle collisions are nearly always fatal for deer [16].

Mule deer occur throughout western North America and are regularly involved in vehicle collisions [17–19]. The effects that vehicle-related mortality has on population dynamics of mule deer depend not only on the number of individuals killed but also on the demographic groups involved. Deer populations are commonly classified into demographic groups based on sex and life stage characteristics (e.g., fawns, yearlings, and adults) with distinct fecundity and survival rates [20]. In mule deer populations, adult females are the most important demographic group to population growth [21], because they have high survival rates and nurse fawns until the termination of parental care [22, 23]. Male demographic groups are relatively less important to population growth, because mule deer are polygynous and males do not contribute to the parental care of fawns [22, 24]. The age of adult deer can also influence their contribution [25], because survival and reproductive rates are highest for prime-aged individuals (2–7 yrs). As individuals age, survival and reproductive rates decline [25–28]. Factors such as tooth wear can contribute to senescence in deer [29, 30]. Overall, mortality factors that remove prime-aged females potentially exert a stronger influence on population potential of deer than those that primarily remove senescent females. Further, changes in population density have been suggested to influence sex ratios over longer time periods and thereby indirectly influence specific age and sex demographic group vulnerability to wildlife vehicle accidents (WVCs) [31]. However, recent work [32] has suggested that understanding the underlying spatiotemporal factors is key to understanding the reasons for WVCs. Although moose density was most important in explaining WVCs in Norway, traffic volume and snow depth were also implicated. The increase in the number of red deer (Cervus elaphus) killed on Norwegian roads was found to be primarily an effect of increasing population size [33]. Annual vehicle collision rates vary between ungulate species due to differences in behavior and habitat use [34]. For instance, several studies have shown that elk tend to avoid roads [35–38], which may in turn decrease their vulnerability to vehicle collisions. A few recent studies have reported that mule deer actually select habitats near roads [35, 36, 39], which predisposes them to vehicle collisions. Vehicle collisions rates of deer species with overlapping distributions have rarely been compared [11], but if differences exist, it would be beneficial to examine the causes of those differences and tailor mitigation to individual species.

Deer vehicle-collisions (DVCs) have negatively impacted some deer populations. In Florida, 50–74% of mortality for the endangered Key deer (*Odocoileus virginianus clavium*) was due to vehicle collisions [40]. Additionally, vehicle collisions were also the leading cause of death (34% of mortality) for female mule deer in northern Utah, and lower than average survival rates were reported [41]. However, for most deer populations, DVCs appear to play a minor role in population dynamics. For example, white-tailed deer (*Odocoileus virginianus*) are commonly involved in vehicle collisions [42–44]; nevertheless, the species has continued to increase in abundance and expand its distribution in North America [45, 46].

In Utah, mule deer are frequently killed in vehicle collisions and deer carcasses are regularly observed on roads [47], and as a result there is concern from management agencies, environmental and sportsmen organizations, and the public that DVCs may negatively impact populations. Our objective was to examine the frequency of mule deer (Odocoileus hemionus) vehicle collisions to determine if different demographic groups showed differential susceptibility to mortality when compared with their proportion in the population. Additionally, we wanted to assess the percentage of prime-aged individuals being removed. We also compared vehicle collision rates of mule deer, elk, and moose in Utah to determine the relative vulnerability of mule deer to vehicle collisions. Finally, we examined trends in mule deer abundance and traffic volumes to determine if roads were affecting abundance at the statewide scale extent.

2. Materials and Methods

2.1. Study Area. The study was conducted in the state of Utah (219,807 km^2), which is located in the southwestern United States on the western edge of the Rocky Mountains (Figure 1). Much of the state is semiarid (127–381 mm precipitation) [48]. Utah is the second driest state in the United States [49]. Topography, however, is highly variable (663–4,413 m) and precipitation increases with elevation [50]; as a result, some high elevation areas may receive in excess of >1,473 mm of precipitation [48]. The majority of Utah is comprised of three ecoregions: the Colorado Plateau, the Wasatch and Uinta Mountains, and the Central Basin and Range [51]. The landscape is ecologically diverse with vegetation cover types that vary from salt desert shrub to alpine tundra [52]. Utah is inhabited by a suite of ungulates that include mule deer, elk, moose, and white-tailed deer [46]. Of those species, mule deer were the most abundant (~300,000 individuals) and widely distributed [53], and their range coincided with or was adjacent to nearly all mountainous areas and major human population centers in the state. Elk were less abundant (~75,000 individuals) than mule deer, but elk abundance has consistently grown over the past decade [53]. The distribution of elk closely resembled that of mule deer but was more restricted in some locations. Moose were far less abundant (~2,700 individuals) than both mule deer and elk, and their range was generally limited to the central and northern portions of the state [53] but their distribution generally overlapped mule deer and elk distributions. White-tailed deer existed in very limited numbers in the extreme northern portion of Utah [46], and no estimates of abundance were available because populations were not monitored by the Utah Division of Wildlife Resources (UDWR). All deer species are harvested in Utah, with harvest being strongly biased towards males [53].

In Utah, 75% of the land area is federally or state owned, and, as a result, much of the state is rural [54]. Utah, however, is the 3rd fastest growing state in the United States and is rapidly becoming urbanized [55, 56]. The growing human population has increased demand for transportation, and traffic volumes have doubled in the past 30 years [57]. In 2010, 42.8 billion km were driven on 73,413 km of roads [57, 58]. Deer-vehicle collisions are a considerable public safety concern in Utah that has resulted in >$7 million (USD) in damages each year [59]. In the past, most reported DVCs in Utah have involved mule deer [47].

2.2. Demographics. To quantify the demographics of mule deer killed in vehicle collisions, we conducted carcass surveys

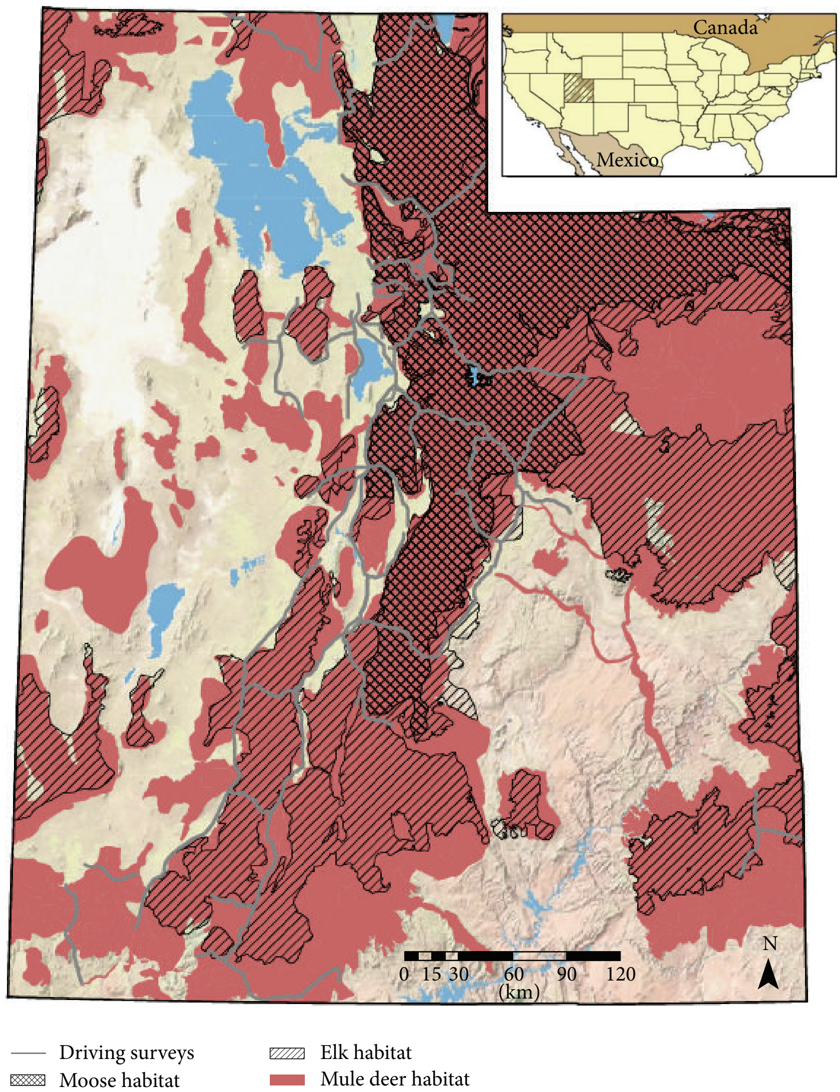

Figure 1: Mule deer, elk, and moose habitat in Utah, as well as the roads that were surveyed for carcasses of those species.

throughout northern, central, and southeastern Utah. Carcass survey transects (4.8 km) were selected using a proportional sampling design [60]. Transects were surveyed every 14 days by trained technicians employed by Utah State University using All-Terrain Vehicles (ATVs). During a carcass survey, the technician functioned as both driver and observer. ATVs were driven at 8–16 km/h on the shoulder and the median of roads within transects. Technicians recorded carcass locations using a Garmin GPS unit (Model eTrex Legend H, Garmin International, Inc., Olathe, Kansas, USA). They also documented the sex and stage class of carcasses (fawn, yearling, and adult) observed. All carcasses detected during surveys were marked with an orange, serial numbered tag that was placed around the hind leg to insure that carcasses were not double counted during future surveys. Technicians also examined and marked all deer carcasses that were opportunistically observed while driving to and from survey transects. Carcasses for which the stage class and sex could not be determined were excluded from the analysis. We tested for differences in the proportion of deer that were in each demographic using chi-square tests ($\alpha = 0.05$). All statistical analyses for this study were performed in R (R 2.14.1, http://www.cran.r-project.org./, accessed may 15, 2012) [61].

To determine if the frequency in which deer demographic groups were involved in vehicle collisions was proportional to the deer population, we compared carcass survey data to classification surveys of live deer. Classification surveys were conducted by Utah Division of Wildlife Resources (UDWR) biologists during late fall (November-December) when deer were congregated on winter ranges. Deer were classified as bucks (males ≥1.5 yrs old), does (females ≥1.5 yrs old), and fawns (males and females ≤0.5 yrs old). To make carcass survey data comparable to UDWR classification surveys, we combined adult and yearling groups for both males and females from carcass surveys to create buck and doe groups.

Additionally, we counted male and female fawn groups as one group (fawns). Classification data used for comparison was obtained from deer management units that coincided with carcass survey locations. We tested for differences between carcass survey data and live classifications using chi-square tests ($\alpha = 0.05$).

To estimate the age of adult deer, we extracted lower incisors from carcasses and sent them to Dr. R. Larsen's lab at Brigham Young University (Provo, Utah, USA) for cementum annuli analysis. Teeth were cross sectioned and stained, and age estimates were generated using standard techniques [62]. The accuracy of age estimates using this method is typically >90% for mule deer [63]. Age estimates were reported as the base year, and June 15th was used as transition date from one year to the next because that was the peak fawning date in Utah [27]. Because age distributions were skewed for both males and females, we reported medians instead of means and we tested for differences using a nonparametric Wilcoxon rank-sum test ($\alpha = 0.05$).

2.3. Vehicle Collision Rates. To quantify vehicle collision rates for mule deer, elk, and moose, we used carcass survey data that were collected by Utah Department of Transportation (UDOT) contractors using automobiles. Automobile surveys have been conducted in Utah since at least 1998 [19]. UDOT contractors drove ~2,750 km of roads 2 times per week throughout the year. Surveys were generally performed by a single person, who acted as driver and observer. Survey vehicles were driven at the posted speed limit. If the road had multiple traffic lanes, the survey vehicle was driven in the slow lane, nearest to the shoulder of the road. Undivided roads were surveyed in only one direction, while divided roads with a median were surveyed in both directions. During surveys, UDOT contractors removed all carcasses that were detected on the road surface, the median, and the road shoulder out to the reflective highway markers. They kept detailed records of the species removed and their locations. Driving surveys were minimum estimates of vehicle collision rates, because they do not account for carcass detection probabilities. We also quantified the overlap of mule deer, elk, and moose habitat using ArcGIS 10.1 and distribution layers that were generated by the UDWR for each species [64].

2.4. Mule Deer Abundance and Traffic Volumes. Mule deer abundance was estimated annually by the UDWR using a combination of ground and aerial counts for deer management units throughout the state; however, no measures of uncertainty were reported for abundance estimates [53]. Traffic volume data were obtained from the Utah Department of Transportation for the study area [65]. Traffic volumes were reported by UDOT as average annual daily traffic (AADT) during each calendar year.

3. Results

3.1. Demographics. From July 2010 to December 2011, we examined 1,257 carcasses of deer that had died within the road right of way and had injuries consistent with being involved in a vehicle collision. As expected, the frequencies with which deer demographic groups were involved in vehicle collisions differed between groups (χ^2 [2, n = 1,257] = 41.9, P < 0.01). Adult females comprised the largest group at 40%, a rate that was 2.8–3.9 times more than any of the other demographic groups whose collision rates ranged between 10% and 14% (Figure 2). Collectively, female adults, yearlings, and fawns represented 65% of all deer carcasses. We obtained age estimates for 524 adult mule deer that were killed in vehicle collisions. Ages of female and male deer differed (W = 29118, P < 0.01); the median age for females was 4 yrs and, for males, it was 3 yrs (Figure 3). Nearly, all adult females (98%) and males (98%) were between 2 and 7 yrs old and considered prime-aged individuals. The oldest observed female was 13 yrs old; the oldest male was 9 yrs old. When we compared the proportion of bucks, does, and fawns in carcass surveys to those in classification surveys of live deer, we found that they differed for both fall 2010 (χ^2 [2, n = 18,221] = 40.9, P < 0.01) and fall 2011 (χ^2 [2, n = 16,426] = 38.4, $P \leq 0.01$). During both years, there were fewer fawns (−13 to −28%) and does (−10 to −16%) in carcass surveys than in live surveys, but 95% confidence intervals for those groups overlapped indicating that the results were not statistically significant (Figure 4). The proportion of bucks did differ significantly and was 205–296% higher in carcass surveys than live surveys.

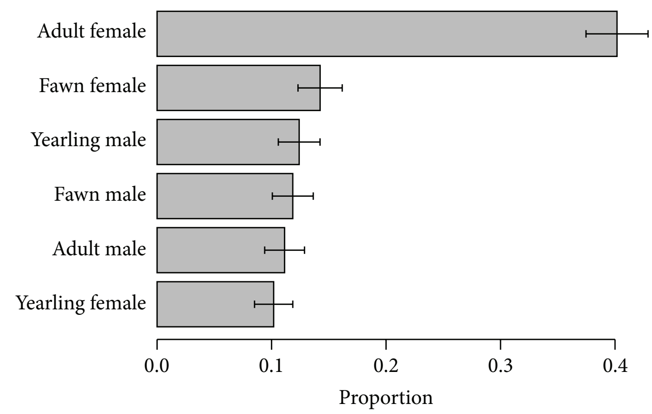

Figure 2: The proportion of each mule deer demographic group observed in carcass surveys conducted in Utah. Error bars represent 95% confidence intervals ($\alpha = 0.05$).

3.2. Comparative Vehicle Collision Rates by Species. The distribution of mule deer, elk, and moose in Utah overlaps to a large degree, with 96% of elk habitat and 99% of moose habitat corresponding with the distribution of mule deer (Figure 1). However, vehicle collisions rates varied widely among species (Figure 5). Mule deer experienced the highest vehicle collision rates during both 2009-2010 (18.3 per 1,000 deer) and 2010-2011 (18.3 per 1,000 deer), which were 739–869% higher than those experienced by elk (2.1–2.5 per 1,000 elk) and 119–197% than those experienced by moose (9.3–15.3 per 1,000 moose).

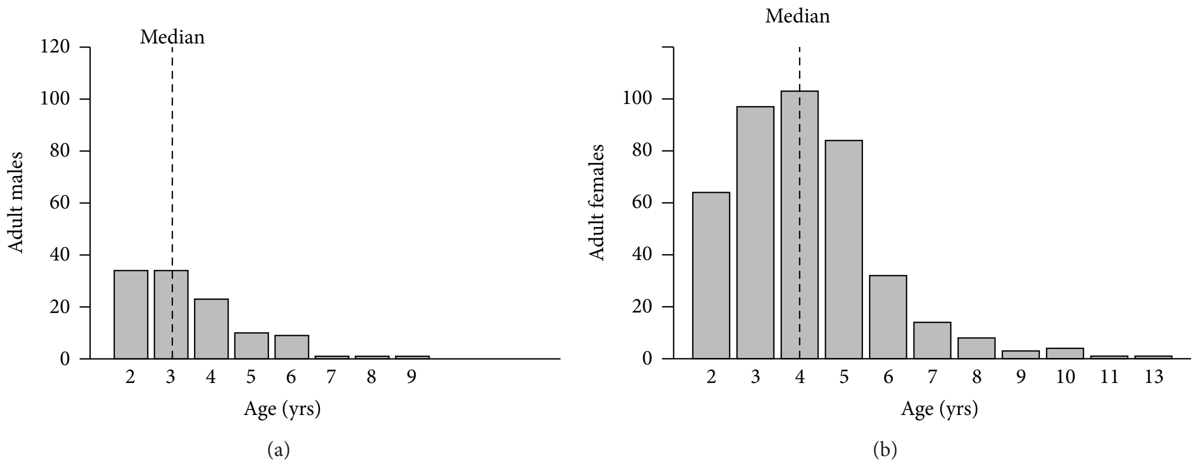

FIGURE 3: Age estimates in years for adult female ($n = 411$) and adult male ($n = 113$) mule deer observed in carcass surveys in Utah. Median age estimates for each group are indicated by vertical dashed lines.

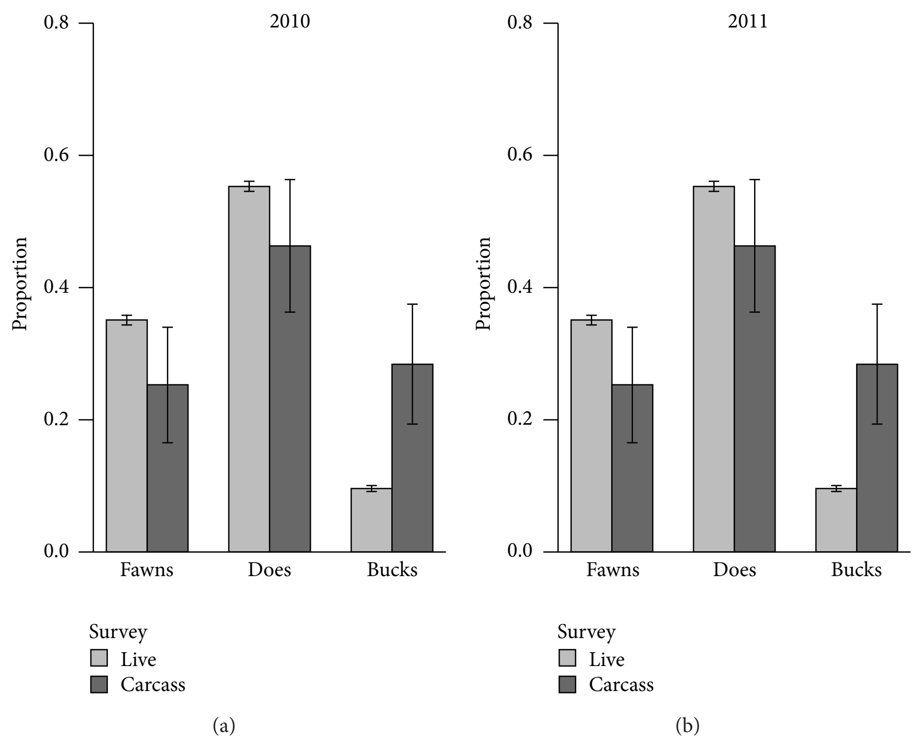

FIGURE 4: A comparison of mule deer bucks, does, and fawns in carcass surveys to those in classification surveys of live deer during fall 2010 and fall 2011 in Utah. Error bars represent 95% confidence intervals ($\alpha = 0.05$).

3.3. Mule Deer Abundance and Traffic Volumes. From 1992 to 2011, mean mule deer abundance in Utah was estimated at 291,044 individuals ($n = 20$, SD = 26,359) [53]. Abundance peaked in 1992, but declined to its lowest point in 1993 due to severe winter weather (Figure 6). Although mule deer abundance was highly variable over the 20-year period, there was no linear trend in abundance ($F_{1,18} = 0.28$, $P = 0.60$, and $R^2 = 0.02$). During the same time period, mean traffic volume for the state was 37.3 billion km/year ($n = 20$, SD = 4.0). The lowest traffic volumes occurred in 1992 and the highest in 2007 (Figure 6). There was a positive linear trend in traffic volume ($F_{1,18} = 178.8$, $P \leq 0.01$, and $R^2 = 0.91$), and traffic volumes increased 2% annually over the 20-year period. There was no evidence that mule deer abundance and traffic volumes were correlated at the statewide scale extent ($F_{1,18} = 0.38$, $P = 0.55$, and $R^2 = 0.02$).

4. Discussion

Deer demographic groups vary in their contribution to population growth [21]. As a result, the effect that DVCs have on population growth is determined not only by the number

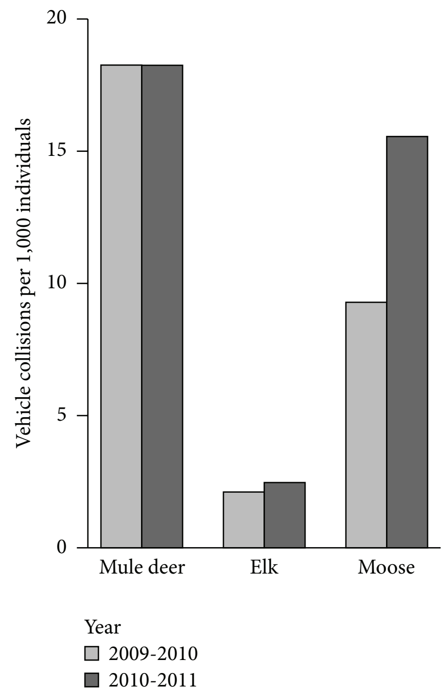

Figure 5: Vehicle collision rates (per 1,000 individuals) for mule deer, elk, and moose during 2009-2010 and 2010-2011 in Utah.

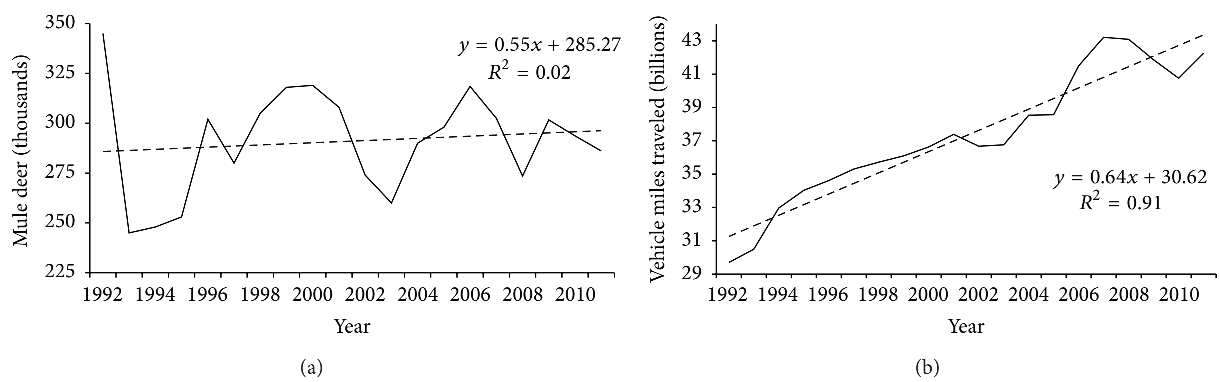

Figure 6: Mule deer abundance and traffic volume (vehicle miles traveled) estimates in Utah for 1992–2011.

of deer that are killed but also by the demographic groups that are differentially impacted. In polygynous species, females are more vital to population growth than are males. In deer, adult female deer are generally considered the most important demographic group [21]. We found that nearly two-thirds of mule deer killed in vehicle collisions in Utah were female and 40% were adult females. Our data suggest that vehicle collisions could have a strong negative influence on deer abundance, because a high percentage of vehicle collisions involved females, most of which were adult females.

It appears common that most vehicle collisions involve female deer. A previous study in central Utah reported that 68% of deer killed were female, which was almost identical to the results reported here [18]. Studies of white-tailed deer have reported similar findings with the frequency of vehicle collisions involving female deer ranging from 58 to 66% [16, 66]. Female deer are more frequently involved in vehicle collisions because, in most hunted deer populations, the demographics are strongly skewed towards females [22]. If we assumed a fawn sex ratio of 1 : 1 [27], then classification surveys of live deer indicated that 71–73% of the population consisted of females in Utah, which was only slightly higher than what we observed in carcass surveys (66%). The female-biased population structure in Utah is largely the result of the male-biased harvest strategy. During our study, 7.6–11.6 times more males were harvested than females, while males represented only 27–29% of the population [53]. In Wyoming and central Utah, research has also suggested that the female deer were killed in vehicle-collisions in proportion to their frequency in the population [67, 68]. Furthermore, populations of white-tailed deer that were experimentally reduced exhibited a proportional decrease in DVCs, indicating that

DVCs are a reflection of the deer population density in general [44].

Although the composition of DVCs generally resembles population structure, there are times when certain demographic groups may be more prone to vehicle collisions [33]. For example in Wisconsin, the number of DVCs involving white-tailed deer bucks increased sharply during fall (October-November), presumably in response to bucks increasing their movement rates to search for females during the breeding season [69]. The results from our study support that pattern, as the proportion of mule deer bucks killed in vehicle collisions, was 2-3 times their frequency in the fall population. However, a previous study conducted in central Utah reported that mule deer bucks were killed at a rate that was 2 times their frequency in the population not only during the fall season but throughout the year, suggesting that the pattern of increased buck mortality may not be strictly seasonal [67]. Regardless of whether increased buck mortality is a seasonal or annual pattern, managers may wish to explicitly consider vehicle collision losses when setting harvest quotas because bucks are already heavily harvested in Utah and other western states.

In addition to the fact that a high percentage of vehicle collisions involved adult females, nearly all (98%) of the adult deer killed were prime-aged individuals (2–7 yrs.). A similar result was reported in Central Utah, where all adult deer (100%) involved in vehicle collisions were prime-aged individuals. The implications are subtle but important, because prime-aged females typically have the highest survival and reproductive rates. For example in Utah, prime-aged females were reported to have 18% higher pregnancy rates and 30% higher fecundity rates than senescent females [25]. Additionally, data from southeast Idaho indicate that survival rates decrease ~4% annually for senescing female mule deer [70]. The effect that vehicle collisions could have on population abundance is likely strengthened because most adult females killed were prime-aged.

Mule deer also appeared to be more prone to vehicle collisions than other ungulate species in Utah. In our study area, the distribution of elk and moose largely coincided with that of mule deer, but vehicle collision rates for mule deer were 7.4–8.7 times higher than those for elk and 1.2–2.0 higher than those for moose. However, the comparative vehicle collisions rates that we reported were not corrected for carcass detection because even though we have detection probabilities for mule deer, no detection probabilities were available for moose and elk, we chose not to conduct a biased comparison. Previous studies have indicated that carcass surveys generally underestimate (i.e., detection is <1) the actual number of animals killed in vehicle collisions [71]. In an associated study in Utah, detection of mule deer carcasses during driving surveys was estimated to be only 0.41 [72]. Carcass detection rates for elk and moose are largely unknown and should be the focus of future research. If we could have corrected estimates for detection bias for moose and elk, the disparity in vehicle collision rates would likely have increased.

We know of no other peer-reviewed studies that have compared vehicle collision rates for mule deer, elk, and moose with overlapping distributions. The only comparable study that we are aware of was conducted in Norway, where vehicle collision rates for roe deer (*Capreolus capreolus*) were 3.2 times higher than those for red deer and 1.5 times higher than those for moose, suggesting a pattern similar to what we observed in Utah [11]. Roe deer are smaller than mule deer but fill a comparable ecological niche in Europe [73]. Some of the dissimilarity in vulnerability between the species is no doubt related to species-specific behavioral responses to roads. For example, studies that have evaluated habitat selection by elk with respect to roads have reported consistently that elk generally avoid roads [37, 74, 75]. However, similar studies conducted on mule deer have not produced consistent results. Several studies have documented that mule deer avoid roads [76–80], but an equal or greater number of studies have reported that mule deer respond neutrally [78, 80, 81] or, in many cases, may actually select habitats near roads [35, 36, 39, 82–84]. If mule deer are selecting habitats near roads and elk are avoiding roads, it may help explain a great deal of the differences in vehicle collision rates between the species.

The reasons why mule deer select habitat near roads in some areas are still uncertain. One explanation that has been put forth is that elk, which are socially dominated to mule deer and increasing in abundance, may be displacing deer from habitats that are farther from roads [35, 36]. This hypothesis is reasonable but still needs to be tested experimentally. Additionally species-specific responses of deer and elk to weather conditions may also be contributing to the disparity in vehicle collision rates, because mule deer are impacted by winter weather, especially snow depth, to a greater extent than elk. Snow accumulation may force mule deer into lower elevation habitats that are near roads with high traffic volumes, thus increasing vehicle collision rates [85].

Although it is uncommon for vehicle collisions to cause deer abundance to decline, some populations have been significantly affected by vehicle-related mortality [40, 41, 67]. In our study area, we were able to establish that a high percentage of vehicle collisions involved adult females and that mule deer were more vulnerable to vehicle collisions than other deer species, but we were unable to demonstrate that vehicle collisions were causing a decrease in mule deer abundance. Over the past 20 years in Utah, traffic volumes have increased 42% but the long-term trend for mule deer abundance has remained stable. Given that deer populations can sustain moderate removal levels [86], it is probable that vehicle-related mortality levels for mule deer are not yet high enough across the state to cause population decline, even though it has been estimated that 2–5% of the mule deer population was being killed in vehicle collisions each year in Utah [72]. Additionally, mitigation measures such as wildlife crossings and exclusionary fencing have been used in Utah since the 1970s to improve motorist safety and reduce deer mortality [47, 87, 88]. It is likely that mitigation has partially offset some of the effects of increasing traffic volumes and vehicle-related mortality on mule deer. As the road network is expanded and traffic volumes continue to increase, mitigation will likely become more crucial in reducing the negative effects of roads on deer.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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