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An Experimental Evaluation of Potential Scavenger Effects on Snake Road Mortality Detections

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***Abstract*.—As road networks expand and collisions between vehicles and wildlife become more common, accurately quantifying mortality rates for the taxa that are most impacted will be critical. Snakes are especially vulnerable to collisions with vehicles because of their physiology and behavior. Reptile road mortality is typically quantified using driving or walking surveys; however, scavengers can rapidly remove carcasses from the road and cause underestimation of mortality. Our objective was to determine the effect that scavengers might have had on our ability to accurately detect reptile road mortality during over 150 h and 4,000 km of driving surveys through arid shrublands in southwest Wyoming, which resulted in only two observations of mortality. We developed unique simulated snake carcasses out of Burbot (*Lota lota*), a locally invasive fish species, and examined removal rates across three different road types at three study sites. Carcass size was not a significant predictor of time of removal, and carcass removal was comparable during the daytime and nighttime hours. However, removal of simulated carcasses was higher on paved roads than unpaved or two-track roads at all study sites, with an average of 75% of the carcasses missing within 60 h compared to 34% and 31%, respectively. Scavengers may therefore negatively impact the ability of researchers to accurately detect herpetofaunal road mortality, especially for paved roads where road mortality is likely the most prevalent.**

Key Words.—driving surveys; experiment; reptiles; road mortality; road type; scavengers; simulated carcass; snakes

Introduction

Collisions between vehicles and wildlife are a common occurrence along roadways, and something that even the most conscientious driver has likely experienced firsthand. Nearly all taxa are impacted to varying degrees by collisions with vehicles (Forman and Alexander 1998); however, snakes are especially vulnerable. As ectotherms, snakes are sometimes drawn to road surfaces for thermoregulatory purposes (Sullivan 1981; Rosen and Lowe 1994). Roads often have characteristics of an ideal basking location; they are generally exposed to direct sunlight, even in areas that are otherwise densely vegetated, and artificial road surfaces (e.g., asphalt, cement) absorb heat and hold it longer than many natural ground surfaces (Shine et al. 2004). Snakes are often found on roads in stationary basking positions, leaving them exposed to collisions with automobiles (Rosen and Lowe 1994; Ashley and Robinson 1996; Andrews and Gibbons 2005). In addition, snakes are often slow and unable to move out of the way of oncoming traffic (Rosen and Lowe 1994; Ashley and Robinson 1996), and some venomous species are more likely to freeze instead of flee when approached by a vehicle (Andrews and Gibbons 2005). Finally, the vulnerability of some snake species is heightened by motorists who purposefully aim for animals in the road with the intention of hitting them (Langley et al. 1989). Because snakes are especially susceptible to road mortality, wildlife managers would benefit from an increased understanding of the severity and scope of snake-road interactions.

In 2009, we attempted to quantify reptile road mortality in southwest Wyoming using extensive daytime driving surveys on three types of roads: paved (asphalt, cement, or chip sealing), unpaved (dirt or gravel surface), and two-track (delineated tire tracks with vegetation between). Between late May and late July, we surveyed 1,368 km of paved roads, 1,920 km of unpaved roads, and 762 km of two-track roads (not counting back-tracked mileage) over 27 days and 158 h. However, we only observed two road-killed snakes, both on paved roads: one Great Basin Gopher Snake (*Pituophis catenifer deserticola*) and one Midget Faded Rattlesnake (*Crotalus oreganus oreganus*), a species of conservation concern in Wyoming.

The ability to accurately quantify road mortality varies depending on the survey method used (e.g. driving or walking), weather (Kostecke et al. 2001; Santos et al. 2011), and road and traffic conditions (Enge and Wood 2002; Langen et al. 2007; Coleman et al. 2008; DeGregorio et al. 2010; Gerow et al. 2010). However, another possible explanation for our low number of snake road mortality detections, despite extensive effort, was high rates of carcass removal by scavengers. Some scavengers are known to actively scavenge along roads (Meunier et al. 2000; Kostecke et al. 2001; Dean and Milton 2003), thus eliminating evidence of mortality events prior to detection and potentially impacting the accuracy of road mortality estimates, sometimes drastically (Slater 2002; Antworth et al. 2005; DeGregorio et al. 2011). Scavenger effects on carcass removal have been examined for a variety of taxa and across a diverse range of natural habitats and anthropogenic features. Over 67% of bird carcasses were scavenged within two days along power lines in Spain (Ponce et al. 2010). Similarly, most road-killed animals were scavenged within 2 d, but the maximum persistence time varied for different carcass taxonomic groups (Santos et al. 2011). Approximately 97% of snake carcasses were removed from a paved road surface within 36 h during an experiment in the Atlantic coastal habitat (i.e., scrub, hammock, and coastal stand) of central Florida (Antworth et al. 2005). Likewise, snake carcass removal on a barrier island in North Carolina varied by habitat but was thorough (40% in dune and 100% in maritime forest) and rapid (12 h and 8 h, respectively; DeGregorio et al. 2011). However, little is known about the extent of reptile carcass removal in arid ecosystems, or how carcass removal varies across different road types.

Our objective was to better understand the potential influence of scavengers on the accuracy of snake road mortality counts. All previous scavenger studies involving snakes have required the procurement of real snake carcasses for experimentation, which is not always feasible. We conducted an experiment using simulated snake carcasses fashioned from a locally invasive fish to quantify carcass removal rates across three different road types (paved, unpaved, and two-track). Because this was the first study to use fish as simulated carcasses to test scavenger effects, we could not assume that the carcasses would be removed. Thus, to support the null hypothesis of no scavenging of simulated carcasses, we predicted negligible disappearance rates at all study sites and on all road types. Likewise, if road surface treatment did not affect simulated carcass removal, we predicted comparable percentages of missing carcasses across the three road types.

MATERIALS AND METHODS

Study area.—We conducted our experiment in late June and early August 2010 in two areas of southwest Wyoming, USA: the Moxa Arch Area natural gas field and Flaming Gorge National Recreation Area. Located northwest of Green River, Wyoming in Lincoln, Uinta, and Sweetwater counties, the Moxa Arch Area is a well established natural gas field with an extensive network of access roads. Average daily traffic volume for a subset of secondary paved roads and unpaved roads in this study area was 368 and 24 cars per day, respectively (data collected from traffic counters installed for a week during the summer of 2010). The Flaming Gorge National Recreation Area is located south of Green River, Wyoming in Sweetwater County, and contains a diverse assemblage of roads that provide recreational traffic access to the Flaming Gorge Reservoir and surrounding area. Average daily traffic volume for a subset of secondary paved roads and unpaved roads in this study area was 506 and 40 cars per day, respectively. Potential scavenger species included: Golden Eagle (*Aquila chrysaetos*), Turkey Vulture (*Cathartes aura*), Common Raven (*Corvus corax*), American Crow (*Corvus brachyrhynchos*), Black-billed Magpie (*Pica hudsonia*), American Badger (*Taxidea taxus*), Coyote (*Canis latrans*), Red Fox (*Vulpes vulpes*), Northern Raccoon (*Procyon lotor*), Striped Skunk (*Mephitis mephitis*) and several species of weasel (*Mustela spp.*).

Site selection.—We selected three study sites; one in Moxa Arch, one in eastern Flaming Gorge, and one in western Flaming Gorge. These three sites differed in elevation, topography and habitat characteristics, which allowed for examination of scavenger effects across different ecological contexts. Study sites were separated by ≥ 10 km, and consisted of three experimental road sections stratified under the same three road classifications (paved, unpaved and two-track) used during the 2009 driving surveys. Starting points for road sections were randomly selected using a geographic information system (GIS). Individual road sections were 4–5 km in length (total road length of 12–15 km per study site) and were, for researcher safety purposes, located on straight stretches of road with no steep hills or curves. We chose sections of each road type that were generally comparable between the three study sites with regards to width (e.g., all sections of paved road were two lanes wide) and daily traffic volume. In these areas, paved roads are the only road type consistently associated with power lines.

Scavenger experiment.—We based our methodology closely on the "snake trial" methodology described by Antworth et al. (2005), with some modifications. Due to lack of availability, using real snake carcasses was not a viable option and we were averse to killing snakes for the experiment. We therefore created simulated snake carcasses out of strips of Burbot (*Lota lota*; Fig. 1), an illegally introduced fish species in parts of Wyoming. Burbot are long-bodied with skin that resembles snake skin from a distance. Each carcass was fashioned from 1–2 strips of Burbot, which were hand-processed and frozen until use in the experiment. We initially intended to make the simulated carcasses comparable in size to an

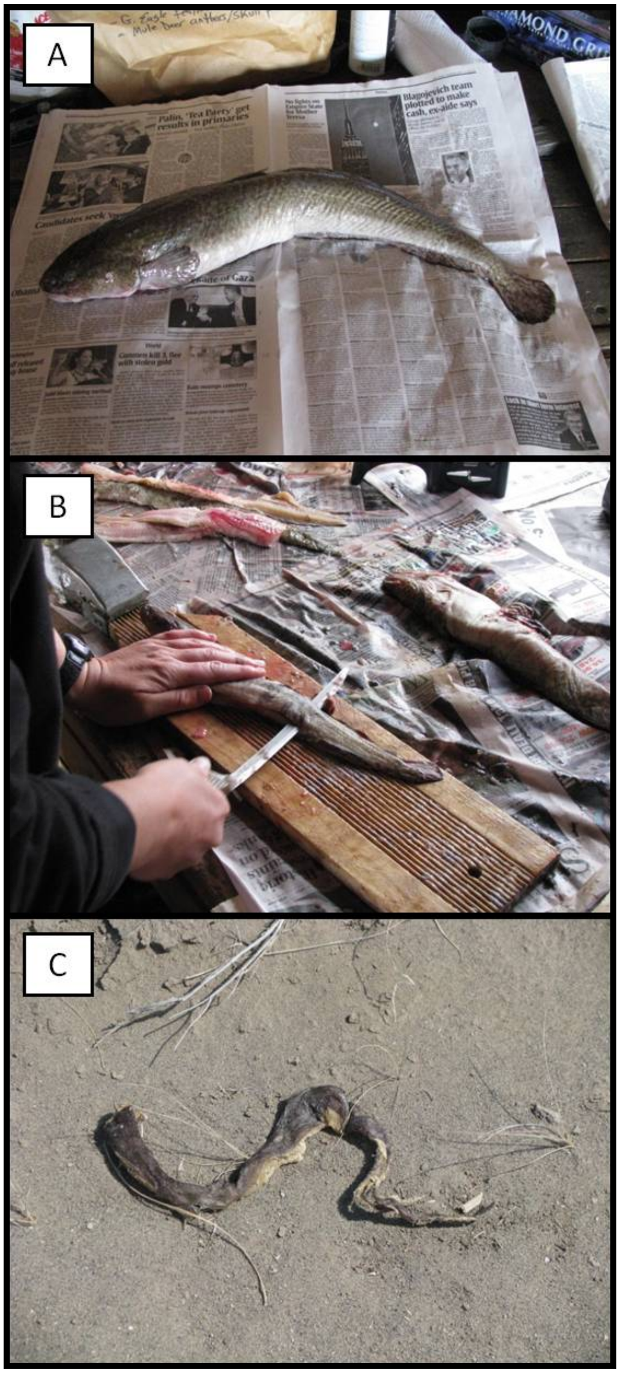

FIGURE 1. Simulated snake carcasses used in a scavenger removal experiment in Southwest Wyoming. A: A Burbot (*Lota lota*) carcass prior to processing; B: Using a filet knife to cut the Burbot into strips; C: A simulated carcass placed on a road. (Photographed by Kaylan A. Hubbard).

adult Midget Faded Rattlesnake (SVL = 41 cm for females and 44 cm for males; Parker and Anderson 2007). However, we were limited by the size of the Burbot provided to us, and many of the fish were relatively small (Fig. 1B). The simulated carcasses, which were thawed and measured prior to placement, ranged in size from 36–62 cm (average 48 cm) in total length and 3.0–7.7 cm (average 4.7 cm) at the point of maximum width. Thus, many of our carcasses, even those fashioned from two strips of Burbot, were smaller than an average adult Midget Faded Rattlesnake.

We completed four experimental trials during the summer of 2010. We conducted the experiment twice on the same road sections in Moxa Arch, once from 29 June to 1 July and once from 9 to 11 August, to assess potential seasonal effects. We conducted the experiment once at each of the Flaming Gorge study sites; western Flaming Gorge from 22 to 24 June and eastern from 3 to 5 August. All simulated carcasses (n = 9 per road type, n = 27 per experimental trial, n = 108 total) were in place by 0900 on the first day of the experiment, and were positioned approximately 0.5 km apart to limit spatial autocorrelation by potential scavengers. We placed all carcasses on the edge of the road, even on the outside of the rumble strip when possible, to minimize driver distraction, risks to scavengers, and the potential for carcasses to be run over by passing vehicles. Carcasses placed on two-track roads were positioned in one of the tire ruts, close to the outside edge. Each carcass was marked with GPS and an orange pin flag, located approximately 5 m from the road edge, to preserve its exact location after removal. We ran each experimental trail for 60 consecutive hours, and checked carcasses every 6 h until sunset (i.e., 0900, 1500, and 2100). One unpaved road carcass at the western Flaming Gorge study site was completely destroyed after being run over by a passing vehicle, and was removed from the experiment. Five paved road carcasses were destroyed by vehicles within the first 6 h of the August Moxa Arch trial, but we were able to replace them with spare carcasses. All remaining carcasses and marker flags were collected at 2100 on the third day of the experiment.

Statistical analysis.—We conducted all statistical analyses in Minitab 16 (Minitab Inc., State College, Pennsylvania, USA). We summarized data as the percentage of carcasses missing at 12 h increments (e.g. 12, 24, 36, 48, 60 h) for each study site. We used a paired *t*-test to examine potential seasonal effects at the Moxa Arch study site, with the percentage of carcasses missing at 60 h for each road type per trial as the response variable. To examine potential effects of simulated carcass size on latency of disappearance, we used multiple linear regression with carcass length and maximum width as continuous predictor variables. Due to small sample sizes, we combined all sites and trials for chi-square analysis, with assumed equal proportions, to compare the number of simulated carcasses missing at 60 h for each road type. Finally, to examine the relative importance of nocturnal versus diurnal scavengers in carcass removal, we calculated the percentage of carcasses removed during the daytime (0900–2100) and nighttime (2100–0900) hours within the first 48 h across all study sites. We confirmed that there was no multicollinearity between multiple regression predictor variables, verified that all linear regression model residuals displayed approximately normal distribution and equal scatter, and defined statistical significance as $\alpha \leq 0.05$ for all tests.

RESULTS

The percentage of carcasses missing after 60 h did not vary seasonally in Moxa Arch (t = 2.00; df = 2, P = 0.18), so we averaged results from the two trials for this site. For carcasses removed from the road, neither carcass length nor maximum width were significant predictors of latency of disappearance at any site (Table 1). Paved roads had higher than expected removal of simulated carcasses, based on assumed equal proportions, while carcass removal on unpaved and two-track roads was lower than expected (χ^2 = 17.52, df = 2, P < 0.001). At the Moxa Arch study site, 78% of carcasses were missing from the paved roads after 60 h, while an average of 33% were missing from the unpaved and two-track roads (Fig. 2). There was a similar pattern after 60 h at the western Flaming Gorge and eastern Flaming Gorge study sites, with 67% and 78% of carcasses missing, respectively, from paved roads, and an average of 35% and 28% removed, respectively, from the unpaved and two-track roads (Fig. 2).

Because we did not find a seasonal effect at the Moxa Arch site, we chose to use the June Moxa Arch trial, which had a lower number of carcasses disturbed by vehicles, for comparison of daytime versus nighttime carcass removal. Daytime and nighttime removal of carcasses was comparable across sites during the first 48 h, with 56% of carcasses removed during the day and 44% removed during the night. Small sample sizes meant that statistical analysis on time of day effects was not feasible.

TABLE 1. Multiple linear regression test statistics and P-values for effects of simulated carcass size on time of disappearance, based on 12 h increments up to 60 h, for those carcasses that were removed at each of the three study sites in southwest Wyoming.

	Length		Maximum width	
	Test statistic	P	Test statistic	P
Moxa Arch	t_{19} = -0.19	0.85	t_{19} = 0.25	0.81
W Flaming Gorge	t_8 = 1.16	0.28	t_8 = 1.20	0.26
E Flaming Gorge	t_9 = 1.16	0.28	t_9 = 0.24	0.82

DISCUSSION

As road networks continue to expand, quantifying wildlife road mortality, particularly for species that are vulnerable and/or rare, may be an increasingly important component of successful management. However, the accuracy of mortality counts can be compromised by scavengers that remove carcasses from roads prior to observation. We predicted that simulated carcass removal rates would be low across all road types and study sites if scavengers were not removing simulated carcasses from roads during our experiment. Likewise, we predicted that the percentage of carcasses missing would be comparable across road types if surface treatment had no effect on carcass removal. Simulated carcasses were indeed removed from all three study sites and all three road types, and the percentage of carcasses removed after 60 h varied significantly between road surface treatments.

Paved roads had higher than expected removal rates, based on assumed equal proportions, with an average of 75% of the simulated carcasses missing after 60 h. Simulated carcasses were probably more visible, especially from the air, against the dark asphalt of the paved roads than they were against the dirt or gravel substrate, which is likely also true of road-killed snakes. Ultimately, scavengers could have negatively impacted our ability to accurately detect snake road mortality on paved roads in 2009.

Unpaved and two-track roads had lower than expected removal rates, with 34% of simulated carcasses missing from unpaved roads and 31% missing from two-track roads after 60 h. Simulated carcasses were often more camouflaged, and therefore less visible to potential scavengers, against the natural surfaces (e.g., gravel, dirt, sand) of unpaved and two-track roads. In addition, scavengers may not use these road types as frequently due to reduced human presence (e.g., less discarded garbage) and reduced access to artificial perches for avian scavengers, such as power lines and telephone poles. Telephone poles and associated power lines paralleled all experimental sections of paved road used in this study, and the availability of these anthropogenic perches may partially explain the higher carcass removal rates on paved roads.

The variation in carcass removal rates between different road types has implications for future road mortality studies. Although simulated carcasses were removed from all road types, removal was highest on paved roads, which is where most snake mortality events likely occur and where many road-related scavenger experiments are conducted. Future road mortality studies, especially those on paved roads, should account for the potential removal of carcasses by scavengers to avoid underestimation of snake mortality.

Our carcass removal rates for paved roads were lower than those recorded during previous studies using snake carcasses (Antworth et al. 2005; DeGregorio et al. 2011). However, our study differed from previous investigations in terms of climatic conditions, habitat types, and the

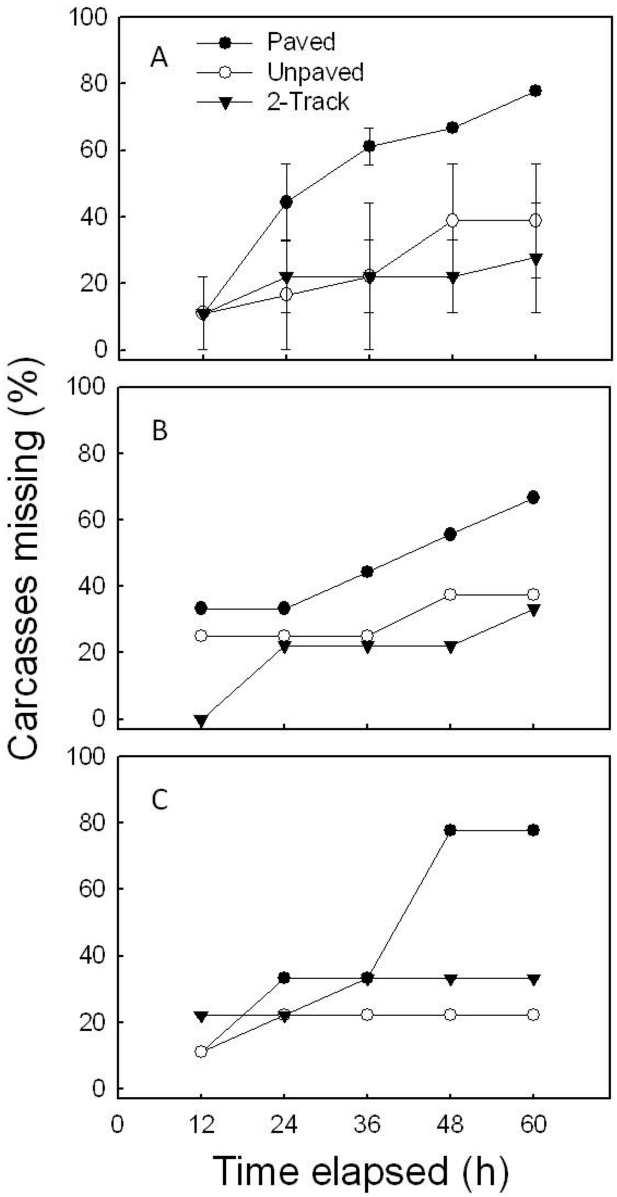

FIGURE 2. The percentage of simulated carcasses missing after 60 h for each of the three road surface treatments in the (A) Moxa Arch (mean ± 1 SE of the early and late trials), (B) western Flaming Gorge, and (C) eastern Flaming Gorge study sites in southwest Wyoming.

ambient assemblages and densities of aerial and terrestrial scavengers. Likewise, our simulated carcasses differed from real snake carcasses in both appearance and smell, and it is possible that both visual and olfactory-dependent scavengers reacted to them differently than they would actual snake carcasses. Therefore, we recognize that there are limitations to the conclusions that we can make about potential scavenging effects on snake road mortality detections in our study areas. However, most scavengers are, by definition, opportunistic feeders of carrion. We believe that fish, although novel to many terrestrial scavengers, would still have appealed to those that depend primarily on smell to locate potential food items. Likewise, the simulated carcasses closely resembled real snake carcasses in their general appearance (Fig. 1C), especially from a distance. We feel it is unlikely that a scavenger, upon closer examination of a simulated carcass, would turn down a potential meal.

Carcass removal during the daytime and nighttime hours was comparable at all three study sites. Time of carcass removal varied extensively in studies that used real snake carcasses, from those that recorded higher daytime removal (Antworth et al. 2005) to those that only recorded removal of carcasses during the nighttime (DeGregorio et al. 2011). Time of carcass removal, and extent of removal in general, is likely a function of local scavenger community composition, foraging behavior, and availability of alternative prey resources. Likewise, weather, road conditions (e.g., traffic volume), and scavenger behavior (e.g., learned association of roads with carcasses, use of roadside perches, avoidance of cars) could also influence daytime and nighttime removal rates.

Simulated carcass size was not a significant predictor of time of removal. Longer or wider carcasses were no more likely to be removed faster from the road surface than shorter or thinner carcasses. Previous scavenger studies targeting a variety of taxa in a diverse range of habitats have also found a lack of significant size effects (Antworth et al. 2005; Ponce et al. 2010; DeGregorio et al. 2011), which could indicate that scavenger impacts to detections of snake mortality are likely comparable across snake size classes in our study areas.

We suggest consideration of several issues that should be addressed by those interested in conducting a similar study. First, we found that the simulated carcasses experienced rapid desiccation in the hot and arid summer environment where our experiment was conducted. Within 24 h of being placed on the road, most carcasses had lost all moisture, which left them with the consistency of jerky for the remainder of the experiment. Of course, real road-killed snake carcasses are subjected to similar conditions, but they likely retain moisture for considerably longer because of their enclosed tough skin. However, in more humid environments desiccation of the simulated carcasses may not be an issue.

Another potential caveat of the experiment was unintentional contact between the simulated carcasses and passing vehicles. We quickly learned that the Burbot did not hold up well when run over, especially during the early stages of the experiment. Carcasses that were run over by vehicles within the first 24 h were often completely wiped from the road surface to the point of having to be replaced or discounted. Therefore, in studies conducted on open, public roads, it is important to carefully consider the placement of simulated carcasses to minimize potential loss due to contact with vehicles.

We did not attempt to identify the mechanisms by which the simulated carcasses were removed from the road, and there were occasions where strips were simply blown off the road surface, a problem that became more common after desiccation had occurred. Therefore, we were always very careful to thoroughly search surrounding areas before declaring that a carcass was missing. In addition, because our experiment was not conducted on closed or controlled roads, we once had an entire section of simulated carcasses swept off the road by a street sweeper. Luckily, we were there to witness this event and immediately returned the carcasses to their original location. For these reasons, however, we were careful to refer to percentage "missing" and "removal rates" instead of "scavenging rates" when discussing the results of our experiment.

Future studies should aim to expand the scope and experimental replication of the experiment, which will increase statistical power and analytical options. However, we believe that the use of simulated carcasses holds promise for quantifying scavenger impacts to the accuracy of road mortality counts, and could be adopted by those interested in conducting similar scavenger experiments. Specifically, the experiment presented herein could be conducted concurrently with road mortality surveys to adjust estimates of mortality to account for scavenger removal rates. The generation of more accurate mortality counts would subsequently aid wildlife managers in assessing risks to populations of numerous snake and other wildlife species.

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