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Reptile populations are declining worldwide, and anthropogenic habitat loss and fragmentation are frequently cited causes. As road networks continue to expand globally, indirect impacts to adjacent wildlife populations remain largely unknown. In addition, quantifying direct effects, such as road mortality, can be difficult because scavengers can rapidly remove carcasses from the road and cause underestimation of mortality counts. Therefore, we had two objectives for this project: 1) to evaluate the relative influence of three different road characteristics (surface treatment, width and traffic volume) and habitat features on populations of northern sagebrush lizards (*Sceloporus graciosus graciosus*), plateau fence lizards (*S. tristichus*) and greater short-horned lizards (*Phrynosoma hernandesi)* in mixed arid shrubland habitats in southwest Wyoming, and 2) to determine the effect that scavengers might have had on our ability to accurately detect reptile road mortality during extensive driving surveys in 2009 using unique simulated snake carcasses made out of Burbot (*Lota lota*), a locally invasive fish species. With regards to the first objective, we found that neither lizard presence, nor relative abundance was significantly related to any of the assessed road characteristics, although there was a trend for higher *Sceloporus* spp. abundance adjacent to paved roads. *Sceloporus* spp. relative abundance did not vary systematically with distance to the nearest road. Rather, both *Sceloporus* spp. and greater short-horned lizards were strongly associated with particular habitat characteristics adjacent to roads. These results suggest that characteristics of roads do not significantly influence adjacent lizard populations, at least in our system. With regards to the second objective, we found that removal of simulated carcasses was higher than expected on paved roads in all study areas, with an average of 74% of the carcasses missing within 60 h. Carcass removal was lower than expected on dirt and two-track roads in all study areas, with an average of 33% and 31% missing on dirt and two-track roads, respectively, after 60 h. Carcass size was not a significant predictor of time of removal. Scavengers may therefore negatively impact the ability of researchers to accurately detect herpetofaunal road mortality, especially on paved roads where road mortality is likely the most prevalent.

THE RELATIVE INFLUENCE OF ADJACENT ROAD CHARACTERISTICS AND HABITAT ON LIZARD POPULATIONS IN ARID SHRUBLANDS

By

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GENERAL INTRODUCTION

Wyoming has gained national recognition as a major producer of oil, natural gas and wind energy. The state contains some of the oldest and largest energy development sites in the country, and these continue to grow and expand. By 2003 there were over 40,000 producing oil and gas wells in the state of Wyoming (BLM, 2005). Southwest Wyoming, in particular, has some of the largest and most-productive energy fields in the state (BLM, 2005), and development of these energy fields has already led to the loss and fragmentation of surrounding habitat (Weller et al., 2002).

There have been several studies examining the effects of energy development on local game mammals and high profile bird species, such as Mule deer (*Odocoileus hemionus*; Sawyer et al., 2006) and the Greater sage-grouse **(***Centrocercus urophasianus*; Doherty et al., 2008; Holloran, 2010), and increasing interest in the effects of energy development on less recognized species, such as songbirds (Gilbert and Chalfoun, 2011). However, prior to this research there had yet to be any studies on the impact of energy development, and associated road networks, on herpetofauna. This study originated from both a concern over observed reptile mortality on existing roads associated with the Moxa Arch Area natural gas field, and the possibility of future energy development in the Flaming Gorge National Recreational Area.

The following two chapters summarize the major finding and conclusion from this two-year study. Each chapter will be published in a separate peer-reviewed journal, and is written in the manuscript format of its intended journal (e.g., *Journal of Biological*

Conservation for chapter one and *Herpetological Conservation and Biology* for chapter two). Below, I briefly discuss four additional aspects of the project that were not discussed in either chapter, but may still provide valuable insight to future researchers.

Driving survey methodology

The complexity of the road networks in the study areas prevented the creation of easily repeatable survey routes. Therefore, each study area was divided into approximately four sections (e.g., NE, NW, SE, SW Flaming Gorge) and road survey crews were rotated between these areas over the course of the summer. Two technicians conducted each road survey from a single vehicle, with one person driving and one person acting as a spotter. Driver/spotter teams were rotated throughout the summer to minimize potential observer bias. We recorded the exact driving routes of each road survey using Garmin GPS units. In addition, spotters hand-recorded the driven mileage from the vehicle odometers during each survey in order to track the total number of miles surveyed on each road type, as well as the number of miles repeated for each road type due to back-tracking.

At the start and end of each road survey, we recorded the time and ambient temperature. For each animal encountered, we recorded the species, time of day, condition (alive, dead or injured), GPS location, road type, road width, adjacent habitat type, and distance to nearest rocky outcrop, water body, and/or energy development feature (if applicable). If the animal was alive, the road surface temperature, ambient temperature, and % cloud cover was also recorded. If necessary, we moved all animals, regardless of condition, to the side of the road following completion of data collection. This spared live animals from potential collisions with cars, and ensured that mortality events were not counted twice over the course of the survey.

Due to low detections of both living (n = 20) and dead (n = 2) animals during the 2009 driving surveys, we decided to discontinue this aspect of the project in 2010. Doing so enabled us to more-than-double the number of visual encounter surveys, thus increasing site replication across both study areas and significantly increasing reptile detections.

Animal captures

In 2009, we initially intended to hand-capture all herpetofauna detected during visual encounter surveys so we could record snout-vent lengths and examine potential age class partitioning with distance from roads. We were able to capture all observed greater short-horned lizards by hand, but other lizard species proved more difficult. Per the recommendations of collaborators, we fashioned nooses from fishing line and affixed them to expandable fishing poles. However, despite our best efforts we were not able to capture a single lizard this way, and decided to abandon all attempts in an effort to focus on other objectives. Total detections of greater short-horned lizards in 2009 were too low (n = 17) for age partitioning analysis. We did not attempt to capture any animals detected during the 2010 field season.

Coverboards

In 2009, we used coverboards with the hope that they would increase detection of rare and cryptic species which might otherwise go undetected during the visual encounter surveys. We installed three ¾", untreated, 2 x 2 ft plywood coverboards in each site. For consistency, coverboards were placed in a row down the center of each site, lengthwise along the 50 m line. The first was placed approximately 5 m from the road, to avoid areas of disturbance and/or road features (e.g., drainage ditches, dirt shoulders), the second at the plot center at approximately 125 m from the road, and the last approximately 5 m from the end of the site (i.e., 245 m from the road edge). We checked coverboards as they were encountered during the visual encounter surveys, and took extreme care to avoid startling potentially poisonous species. When a species was detected under a coverboard, we recorded its species name and the GPS location of the coverboard under which it was discovered. Only two northern sagebrush lizards, the most common species in both study area, were found under coverboards during the 2009 field season. All coverboards were collected at the end of the 2009 field season, and we decided not to use them in 2010. Coverboard sampling, while effective in other systems such as hardwood forests, may not be as useful in arid shrubland systems or may need longer time in the field for attractive microsites to develop for herpetofauna.

Detection probability

Compared to other taxonomic groups, herpetofauna can be notoriously difficult to detect in the wild (Mazerolle et al. 2007). Many reptile species are cryptic, non-vocal, nocturnal, seasonally inactive or any combination of these, and this can affect the accuracy of abundance measurements (Mazerolle et al. 2007). Therefore, during the 2010 field season we attempted to quantify the detection probability of reptiles in the study area. In mid-summer, each field technician surveyed a separate 100 x 125 m plot in eastern Flaming Gorge containing a random number of artificial herpetofauna (e.g., plastic lizards and snakes) planted by another crew member. We chose an area with “intermediate” habitat conditions (e.g., moderate shrub cover), but the exact placement of the plots was selected randomly. The artificial lizards (n = 24) and snakes (n = 4) resembled real animals in general size and body structure, and we spray-painted all of them a neutral brown color. We planted the artificial animals across varying levels of detectability (e.g., out in the open, under shrubs, within the shrub foliage), and recorded the GPS location of each. No one knew exactly how many animals were present in their plot.

We searched for artificial animals using the same methods employed during actual visual encounter surveys. However, only two artificial animals were detected (one snake and one lizard), both by me. In fact, the artificial animals were so hard to detect, that it took us well over an hour to collect them all, even with the GPS locations. Several times I found myself closely scanning the ground for an artificial lizard that I knew should be nearby, only to discover minutes later that it had been in plain sight directly between by feet the whole time. The spray paint color we used may have too closely matched the soil color in that particular part of Flaming Gorge. However, this exercise also emphasized the important role that movement plays in our ability to detect reptiles during actual visual encounter surveys.

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CHAPTER ONE

THE RELATIVE INFLUENCE OF ADJACENT ROAD CHARACTERISTICS AND HABITAT ON LIZARD POPULATIONS IN ARID SHRUBLANDS

Abstract

As road networks continue to expand globally, indirect impacts to adjacent wildlife populations remain largely unknown. Simultaneously, reptile populations are declining worldwide, and anthropogenic habitat loss and fragmentation are frequently cited causes. We evaluated the relative influence of three different road characteristics (surface treatment, width and traffic volume) and habitat features on populations of northern sagebrush lizards (*Sceloporus graciosus graciosus*), plateau fence lizards (*S. tristichus*) and greater short-horned lizards (*Phrynosoma hernandesi)* in mixed arid shrubland habitats in southwest Wyoming. Neither lizard presence nor relative abundance was significantly related to any of the assessed road characteristics, although there was a trend for higher *Sceloporus* spp. abundance adjacent to paved roads. *Sceloporus* spp. relative abundance did not vary systematically with distance to the nearest road. Rather, both *Sceloporus* spp. and greater short-horned lizards were strongly associated with particular habitat characteristics adjacent to roads. *Sceloporus* spp. presence and relative abundance increased with rockiness, while abundance increased with shrub cover and presence decreased with grass cover. Greater short-horned lizard presence increased with bare ground and decreased marginally with shrub cover. Our study is one of few to simultaneously examine the potential impacts of multiple

road characteristics on adjacent wildlife. Our results suggest that characteristics of roads do not significantly influence adjacent lizard populations, at least in our system. Therefore, an effective conservation approach for these species may be to consider the landscape through which new roads, and their associated development, would traverse, and the impact that placement could have on critical habitats.

1. Introduction

1.1. Global herpetofaunal declines

Herpetofauna are some of the most imperiled vertebrates in the world (Blaustein and Wake, 1990; Stuart et al., 2004). Significant population declines and extinctions have been recorded for thousands of amphibian and reptile species since the 1970s (Gibbons et al., 2000; Stuart et al., 2004; Wake, 2007). Nearly all continents have experienced losses to herpetofaunal assemblages at a rate that far exceeds those of natural fluctuations (Blaustein and Wake, 1990; Stuart et al., 2004). Numerous mechanisms have been proposed, including pollution, climate change, disease, overexploitation, and habitat loss and fragmentation (Collins and Storfer, 2003; Daszak et al., 2003; Beebee and Griffiths, 2005). A combination of factors is likely responsible for herpetofaunal declines and extinctions; however, habitat loss and fragmentation due to anthropogenic activity represent two of the most obvious and widespread drivers (Alford and Richards, 1999; Gibbons et al., 2000; Driscoll, 2004; Cushman, 2006).

1.2. Habitat fragmentation

Habitat fragmentation occurs naturally in most ecosystems, but is increasingly a product of anthropogenic activities (Saunders et al., 1991; Vitousek et al., 1997; Leu et al., 2008). Fragmentation of habitat can lead to population and community level changes through isolation, reduced patch size and physical alteration of remaining habitat, which can lead to altered resource availability and species interactions (Saunders et al., 1991; Fahrig, 2003; Fletcher et al., 2007). Although some species (e.g., generalists, invasive species) benefit from the novel biotic and abiotic environmental conditions associated with edge habitat (Collins and Barrett, 1997; Sakai et al., 2001; Chalfoun et al., 2002), many species are negatively impacted, either directly or indirectly, by fragmentation (Gibbs, 1998; Chalfoun et al., 2002; Lehtinen, 2003; Dobkin and Sauder, 2004; Driscoll, 2004). Moreover, relatively little is known about the effects of fragmentation on herpetofauna compared to other taxonomic groups (McGarigal and Cushman, 2002; Cushman, 2006).

1.3. Road impacts

Road networks are an inevitable product of human development and a widespread cause of habitat fragmentation worldwide (Forman and Alexander, 1998; Balkenhol and Waits, 2009). Over 19% of the United States total land area is directly impacted by roads (Forman, 2000) and this value has likely increased significantly since originally calculated. The most obvious threat to wildlife is the potential for collisions with vehicles. Almost all taxa are directly impacted by road mortality (Forman and Alexander, 1998), which in some cases can potentially threaten population viability (Fahrig et al., 1995). However, roads also fragment large, contiguous patches of habitat, act as physical and or behavioral barriers to movement and dispersal, and facilitate the movement of invasive species with detrimental effects to native populations (Forman and Alexander, 1998; Trombulak and Frissell, 2000; Brown et al., 2006). Moreover, indirect road-related disturbance (e.g., pollution, runoff, noise) often extends into adjacent habitat, thereby increasing the area negatively impacted by the road itself (Forman and Alexander, 1998; Forman and Deblinger, 2000), and potentially causing a shift in species composition and distribution (Ingelfinger and Anderson, 2004; Fuentes-Montemayor et al., 2009).

1.4. Herpetofauna and roads

Reptiles and amphibians have been the two least studied taxa in road-related wildlife studies worldwide (Taylor and Goldingay, 2010). Existing studies of herpetofauna and roads have focused primarily on mortality (Rosen and Lowe, 1994; Fahrig et al., 1995; Ashley and Robinson, 1996; Bonnet et al., 1999; Hels and Buchwald, 2001; Mazerolle, 2004; Shepard et al., 2008; Langen et al., 2009; Gerow et al., 2010). When roads are closely associated with areas of mass breeding or dispersal, such as wetlands or hibernacula, mortality rates can be especially rapid and severe (Langen et al., 2007). Other studies have focused on the behavioral responses of herpetofauna to roads and vehicles (Shine et al., 2004; Andrews and Gibbons, 2005; Mazerolle et al., 2005; Bouchard et al., 2009), impacts to movement and dispersal (Gibbs, 1998; Cushman, 2006), and the effects of roads on adjacent populations (Vega et al., 2000; Sanzo and Hecnar, 2006; Marsh, 2007; Tanner and Perry, 2007). Whether road effects vary with road attributes, however, is relatively unknown.

Although correlated, different road characteristics could potentially impact adjacent herpetofaunal populations in very different ways. Certain artificial road surface treatments (e.g., pavement) can be appealing to herpetofauna for thermoregulation (Sullivan, 1981; Rosen and Lowe, 1994). In such cases we would predict higher abundance adjacent to roads with artificial surface treatments. Alternatively, roads can act as physical and/or behavioral barriers to herpetofaunal movement (Klingenbock et al., 2000; Shine et al., 2004; Andrews and Gibbons, 2005). In terms of road width, where roads function as barriers we would expect increased abundances adjacent to wider roads as individuals prevented from crossing "stack up" against the road edge. Finally, traffic volume can have both direct and indirect effects on adjacent populations (Forman and Alexander, 1998; Forman and Deblinger, 2000). High traffic volumes can increase herpetofaunal road mortality (Rosen and Lowe, 1994; Fahrig et al., 1995; Mazerolle, 2004), while indirect effects, such as noise, movement and pollution (e.g., dust, chemical runoff, litter), can alter adjacent habitat and lead to active avoidance of roads and road-side areas (Forman and Alexander, 1998; Forman, 2000). In both cases, we would predict lower abundance adjacent to roads with high traffic volumes.

Despite the potential for road characteristics to be important determinants of wildlife behavior and distribution, few studies have addressed how specific road characteristics influence adjacent populations. Road studies that focus on reptiles, particularly lizard species, are especially rare (Taylor and Goldingay, 2010). Our study is the first, to our knowledge, to assess how three distinct road characteristics impact the presence, relative abundance and distribution of adjacent lizard populations.

1.5. Study objectives

Our objective was to examine the potential effects of three road characteristics on adjacent reptile communities, while simultaneously accounting for important habitat attributes. Specifically, we examined lizard presence and relative abundance (hereafter: abundance) across gradients of road surface treatment, width and traffic volume, and shrubland habitat structure and composition. We also tested for potential road avoidance or attractance by examining whether reptiles were non-randomly distributed with respect to distance from the nearest road.

1.6. Study area

Our study was conducted during 2009–2010 within two areas of diverse arid shrubland habitat and road composition in the Green River Basin, southwest Wyoming, USA: the Moxa Arch Area natural gas field and the Flaming Gorge National Recreation Area. The Moxa Arch Area natural gas field is located northwest of Green River, WY in Lincoln, Uinta, and Sweetwater counties and has been heavily dissected with roads used mostly for natural gas extraction. As of 2007, there were approximately 1400 completed natural gas wells in Moxa Arch, with a proposed action to add 1861 wells and 1498 km of associated new road in the next ten years (BLM, 2007). Elevations in this area range from 1890 to 2195 m and primary habitat consists of sagebrush steppe (primarily *Artemisia tridentata* spp.), alkali scrub, and vegetated sand dunes (BLM, 2007). The Flaming Gorge National Recreation Area is located south of Green River, WY in Sweetwater County. This popular recreation site has also been designated as a critical habitat area by the Wyoming Game and Fish Department, but is facing increasing pressure from energy development (WGFD, 2009). Elevations range from 1829 to 2743 m and habitats include sagebrush steppe, salt desert shrub, mountain shrub, and juniper woodlands blended with a diverse topography of rock outcrops, talus slopes, red-rock canyons and steep valleys (WGFD, 2009). Average annual precipitation for both study areas is 20.6 cm (Western Regional Climate Center, 2011). Notably, Flaming Gorge was not selected as a control site to test for impacts associated with energy development at Moxa Arch due to extensive differences in elevation, topography and vegetation between these two areas. Rather, these two study areas allowed us to examine potential road effects across a wide range of habitats.

Based on known and predicted species ranges, the following reptile species occur in one or both of the study areas: Great Basin gopher snake (*Pituophis catenifer deserticola*), greater short-horned lizard (*Phrynosoma hernandesi*), midget faded rattlesnake (*Crotalus oreganus concolor*), plateau fence lizard (*Sceloporus tristichus*), northern sagebrush lizard (*Sceloporus graciosus graciosus*), northern tree lizard (*Urosaurus ornatus wrighti*), striped whipsnake (*Coluber taeniatus*) and the wandering gartersnake (*Thamnophis elegans vagrans*; WGFD, 2005; WGFD, 2010; Hubbard, 2011).

2. Materials and methods

2.1. Site selection

In 2009, we used aerial imagery and a geographic information system (GIS) to randomly select sampling sites stratified by one of three adjacent road types: paved (asphalt, cement, or chip sealing), dirt (dirt or gravel), or two-track (delineated tire tracks with vegetation between). Sites were restricted to shrubland habitat, classified from LANDFIRE 1.1.0 data, and were ≥ 1 km apart. Sites measured 100 x 250 m and were positioned with the 100 m edge flush with the adjacent road edge and the 250 m edge extending away from the road at a right angle. We surveyed six sites per road type per study area (n = 30), with the exception of two-track sites in Moxa Arch, which were rare.

All sites surveyed in 2009 were surveyed again in 2010 to examine potential year effects and the consistency of patterns. We added an additional six sites per road type in 2010, again with the exception of two-track sites in Moxa Arch, to increase replication, sample sizes, and habitat diversity. We also added a new category of sites with no road associations (≥ 500 m from road edge) to compare herpetofaunal presence and abundance in habitats that were far removed from roads and any potential road-zone effects (Forman, 2000; Forman and Deblinger, 2000) with those that were close to roads. A total of 54 new sites were surveyed in 2010, including the 24 sites with no road association.

2.2. Reptile abundance and species richness

We quantified reptile detections and species richness using visual encounter surveys. Visual encounter surveys are a widely accepted method of detecting herpetofauna in a variety of environments (Heyer et al., 1994; Ford and Hampton, 2005) and enabled the sampling of a large area while preserving the in-situ microhabitat associations of detected animals. To account for potential seasonal effects, we surveyed each site twice each year; once in early summer (late-May to late-June) and once in late summer (mid-July to mid-August). Surveys were conducted between approximately 0800 and 1800 hours and each site was surveyed once prior to 1200 hours and once after 1200 hours to account for potential time-of-day effects. Sites were not surveyed on very cold or rainy days to standardize weather conditions.

Two people surveyed half of each site simultaneously, starting side-by-side at the midpoint of one of the 250 m edges. Both surveyors walked the width of the site, scanning approximately 2 m to each side of their path in search of herpetofauna. Surveyors also checked potential cover sites (e.g., logs, outcrops, shrubs) for concealed animals. Upon reaching the opposite 250 m edge, surveyors moved approximately 4 m away from the center and each other, and begin surveying a new transect in the opposite direction. This procedure was repeated until each surveyor reached the end of their half of the site. We used GPS units and compasses to maintain straight transects and avoid spatial overlap. For each animal encountered, we recorded the species and GPS location. To minimize potential observer bias, sites were visited by four different observers within a year.

2.3. Road characteristics

We defined road width as the exposed distance between roadside vegetation at a randomly selected point along the 100 m length of the adjacent study site. Average daily traffic volume was measured in 2010 using Diamond Apollo Traffic Counters. We installed counters on most paved and dirt roads adjacent to at least one site. Safety concerns prevented the installation of counters on multi-lane roads, or roads with especially high traffic volumes. Counters were installed for a full week to account for daily variation in traffic. For roads known to experience wide seasonal fluctuations in traffic (e.g., recreational access roads to Flaming Gorge Reservoir), we installed counters in both the early and late summer and averaged traffic counts.

2.4. Habitat characteristics

To account for habitat while evaluating road effects, we measured relevant habitat attributes within each site. We collected all habitat data within a three week period beginning in late-June to minimize temporal variation in plant phenology. To promote even sampling, we divided each site into ten 50 x 50 m subsections and surveyed a randomly placed 10 m line transect in each. We determined the starting location of each transect by choosing a random distance (between zero and 15 m using a random number table) and random orientation (via spinning a compass) from the center point of each subsection.

We measured shrub cover along each transect using the line intercept method (Canfield, 1941; Bonham, 1989). Shrubs serve as important refugia and thermoregulatory sites for reptiles by providing shelter and shade, especially in exposed habitats (Burrow et al., 2001; Kerr and Bull, 2004). Extremely high densities of shrubs, however, can limit sun exposure and basking sites. Rocks and rock outcrops also provide herpetofauna with basking sites and protection from predators, so we used the line intercept method to measure rock cover along each transect for all rocks with a diameter ≥ 10 cm. Finally, we recorded basal ground cover (shrub, forb, grass, cactus, bare soil, rock, litter) every 0.25 m using the point intercept method (Bonham, 1989). High grass density in particular can have negative impacts to lizard thermoregulation by preventing direct sunlight from reaching the ground. Cheatgrass (*Bromus tectorum*), an invasive grass species plaguing many sagebrush habitats in the western United States (Mack, 1981), has been shown to impair the movement of several lizard species, including the desert horned lizard (*Phrynosoma platyrhinos*; Newbold, 2005; Rieder et al., 2010). In addition, desert horned lizard presence was lower in areas of high cheatgrass cover (Newbold, 2005). Although we did not identify grass by species, we still expected grass cover to be inversely related to both lizard presence and abundance. All habitat data were averaged across transects to create one value for each habitat metric per site.

2.5. Distance from road

We measured the distance of each reptile from the road using the GPS location of the animal recorded during the visual encounter surveys and the distance measuring tool in MapSource 5.00 (Garmin International, Inc., Olathe, KS).

2.6. Statistical analysis

We used the maximum detections per visit at a site as a comparative index of lizard abundance. This metric has been used in previous reptile habitat studies to examine patterns in relative abundance across habitat gradients, with the understanding that it is not necessarily an accurate representation of true population density (Diaz and Carrascal, 1991; Monasterio et al., 2010). In addition, maximum detections per visit and average detections within a year were highly correlated (Pearson $r = 0.98$, df = 82, $P < 0.001$) for the species (*Sceloporus* spp.) included in our abundance analysis.

Repeated measures general linear mixed models in SPSS 18 (SPSS Inc., Chicago, IL), using the 30 sites sampled in both 2009 and 2010, did not show a significant year effect ($F_{1,27} = 2.68$, $P = 0.11$) or year by road treatment interaction ($F_{2,27} = 0.47$, $P = 0.63$) for *Sceloporus* spp. abundance. We focused on the full dataset of 84 sites from 2010 for all subsequent analyses, which were conducted in Minitab 16 (Minitab Inc., State College, PA).

As is often the case with biological abundance data for species that are patchily distributed, our *Sceloporus* spp. abundance data were skewed and contained many zeros (Fletcher et al., 2005). To address this issue, we used a two-stage regression approach (Fletcher et al., 2005). First, we used binary logistic regression to examine relationships between road (surface treatment, width, average daily traffic volume) and habitat variables in determining *Sceloporus* spp. presence. Second, we used linear regression to model the logarithm of abundance for those sites containing *Sceloporus* spp., thus examining road and habitat effects on *Sceloporus* spp. abundance given presence. Due to low numbers of detections, we only analyzed potential road and habitat effects on greater short-horned lizard presence using binary logistic regression. To account for habitat, models included a single habitat covariate for each species (percent rockiness for *Sceloporus* spp. and percent bare ground for greater short-horned lizards), which we selected from biologically relevant habitat variables using best subsets regression (Ramsey and Schafer, 2002). We also used logistic and linear regression to analyze habitat variables separately (rockiness, shrub cover and grass cover for *Sceloporus* spp., and bare ground, shrub cover and grass cover for greater short-horned lizards) to better understand independent habitat effects on greater short-horned lizards presence and *Sceloporus* spp. presence and abundance given presence.

Sceloporus spp. distribution with respect to distance from roads was tested using linear regression, with the logarithm of *Sceloporus* spp. abundance for those sites containing *Sceloporus* spp. as the response variable. We divided all road-associated sites into five 100 x 50 m subsections of increasing distance from the road and calculated the total number of *Sceloporus* spp. detections for each subsection from the two visits. We used total detections per subsection instead of average detections because lizards are mobile and site visits were over a month apart. In that time, a lizard could move freely between subsections (closer to or further from the road), or remain in the subsection where it was first sighted. Therefore, each site visit represented an independent record of lizard distribution and habitat use in relation to the closest road.

We initially intended to include all road-associated sites in the distribution analysis, while including rockiness as a habitat covariate. However, rockiness is a highly significant predictor of both *Sceloporus* spp. presence and abundance given presence, and because rocky habitat in the study area is patchily distributed, it can strongly influence *Sceloporus* spp. distribution. Indeed, we identified a significant interaction between rockiness and distance from road in the original model. Therefore, for this analysis we only included sites with $\leq 1\%$ measured rockiness in each of their five subsections. This kept sites with incidental amounts of rockiness in the analysis, and enabled us to examine *Sceloporus* spp. distribution independent of the influence of large areas of highly desirable rocky habitat. We analyzed all road types together and separately in different models, with site included as a fixed factor.

All logistic regression models contained at least one continuous predictor variable, so we verified goodness-of-fit using the Hosmer-Lemeshow test (Hosmer and Lemeshow, 2000). All linear regression model residuals displayed equal scatter and approximately normal distribution, and we verified that all models were free of significant outliers and interactions between road characteristic variables and habitat covariates. We set statistical significance at alpha ≤ 0.05 for all tests.

3. Results

3.1. Species

In 2010, we detected five herpetofaunal species during 168 visual encounter surveys: northern sagebrush lizard, plateau fence lizard, greater short-horned lizard, midget faded rattlesnake, and wandering gartersnake. Due to similarities in appearance, we could not reliably differentiate between the northern sagebrush lizard and plateau fence lizard in the field. Therefore, we grouped these two species in all analyses, and refer to them hereafter as *Sceloporus* spp. The northern tree lizard is also similar in appearance to the *Sceloporus* spp. and may have occasionally been mistakenly identified and included in this group. However, unlike either *Sceloporus* spp., the northern tree lizard is rare enough in the state to be included in the 2010 Wyoming State Wildlife Action Plan list of Species of Greatest Conservation Need (WGFD, 2010). Likewise, previous reptile surveys in Flaming Gorge have documented very few encounters with this species (WGFD, 2010). Observations of northern tree lizards were therefore likely rare during our study. *Sceloporus* spp. and greater short-horned lizards accounted for 94% (n = 797) and 5% (n = 45) of total detections, respectively. Only *Sceloporus* spp. and greater short-horned lizards were present in sufficient numbers to include in presence and abundance analyses. Species richness was too low for statistical analysis, with only one site having greater than two species present.

3.2. Effect of road and habitat characteristics on presence and abundance

Road widths ranged from 6.8–15.5 m (mean = 11.1 m) for paved, 3.0–14.7 m (mean = 7.7 m) for dirt and 2.3–3.4 m (mean = 2.8 m) for two-track roads. Average daily traffic volumes for paved roads ranged from 79–796 cars per day (mean = 457 cars per day) and from 2–145 cars per day (mean = 29 cars per day) for dirt roads.

Road surface treatment, width, and traffic volume did not affect *Sceloporus* spp. presence while accounting for habitat (Table 1). Although areas next to paved roads tended to have higher *Sceloporus* spp. abundance than the other three surface treatments (Fig. 1), abundance did not vary significantly with road surface treatment, width, or traffic volume (Table 1). Percent rockiness was a significant or marginally significant predictor in all six *Sceloporus* spp. road models (Table 1). Both *Sceloporus* spp. presence ($Z = 2.04$, df = 1, $P = 0.04$) and abundance ($F_{1,57} = 21.75$, $P < 0.001$; Fig. 2) increased with rockiness. The estimated probability of *Sceloporus* spp. presence increased from 60% at sites with no rockiness to 100% at sites with ≥ 8% rockiness. At sites where *Sceloporus* spp. were present, a 10% increase in rockiness was associated with a 381% increase in the median of *Sceloporus* spp. abundance. *Sceloporus* spp. presence was not significantly associated with shrub cover ($Z = 1.41$, df = 1, $P = 0.16$); however, shrub cover was a significant positive predictor of abundance given presence ($F_{1,57} = 6.70$, $P = 0.01$; Fig. 3). A 10% increase in shrub cover was associated with a 51% increase in the median of *Sceloporus* spp. abundance. The opposite was true of grass cover, which was a significant negative predictor of *Sceloporus* spp. presence ($Z = -2.30$, df = 1, $P = 0.02$; Fig. 4), but not of abundance ($F_{1,57} = 0.62$, $P = 0.44$).

For every 10% increase in grass cover, the odds of *Sceloporus* spp. presence decreased by 52%.

Greater short-horned lizard presence showed a similar lack of road effects while accounting for habitat. There were no significant effect of road surface treatment, width, or traffic volume on short-horned lizard presence; however, percent bare ground was a significant or marginally significant predictor in all road models (Table 2). Separate regression analysis on relevant habitat variables confirmed that bare ground was a significant positive predictor of greater short-horned lizard presence ($Z = 1.96$, df = 1, $P = 0.05$; Fig. 5). For every 10% increase in bare ground, the odds of presence increased by 33%. Shrub cover was a marginally significant negative predictor of short-horned lizard presence ($Z = -1.90$, df = 1, $P = 0.06$; Fig. 5); for every 10% increase in shrub cover, the odds of presence decreased by 43%. Short-horned lizard presence was not associated with grass cover ($Z = -0.43$, df = 1, $P = 0.67$; Fig. 5).

3.3. Effect of roads on reptile distribution

Sceloporus spp. detections did not vary with distance to the nearest road for any road type while accounting for site (Table 3).

4. Discussion and conclusions

Few studies have quantified road effects on lizards (Taylor and Goldingay, 2010), and none to our knowledge has focused on how multiple road characteristics may influence adjacent populations. Decreased fitness (using tail loss as a proxy) and abundance closer to a paved road was shown for Galapagos lava lizards (*Microlophus albermarlensis*), the latter of which was attributed to high rates of road mortality (Tanner and Perry, 2007). If lizards in our study area were being significantly impacted by specific road characteristics, patterns of *Sceloporus* spp. and greater short-horned lizard presence, abundance and spatial distribution should have varied with respect to road attributes and distance to the nearest road.

Neither the *Sceloporus* spp. nor greater short-horned lizard showed significant associations with roads in our study area or the specific characteristics of roads. There were no effects of road treatment, road width or traffic volume on *Sceloporus* spp. presence, abundance or distribution with respect to distance to the nearest road. Likewise, there were no significant effects of roads or road features on greater short-horned lizard presence. Roads were therefore not likely acting as barriers to lizard movement or thermoregulatory attractants, because detections were not higher closer to the road edge or at road-associated sites compared to no-road sites. However, the trend of increased *Sceloporus* spp. abundance adjacent to paved roads may indicate that paved roads can act as minor barriers or attractants in some contexts. Regardless, roads were likely not repelling lizards or leading to significant mortality since *Sceloporus* spp. abundance did not decrease closer to road edges, and the presence and relative abundance of *Sceloporus* spp. and greater short-horned lizards were not significantly lower at any of the road-associated sites compared to no-road sites. However, we did not measure landscape-level road density in our study, which may be a more important determinant of lizard presence and abundance than the specific characteristics of adjacent roads.

There are several potential explanations for why *Sceloporus* spp. and greater short-horned lizards might not be as susceptible to road effects compared to other herpetofaunal species (e.g., snakes, amphibians, turtles). Unlike some herpetofauna (e.g., snakes), many *Sceloporus* spp. lizards have small home ranges (Turner et al., 1969; Ferner, 1974; Smith, 1995; Sheldahl and Martins, 2000) and are not known to migrate or disperse great distances (Stebbins, 1944; Stebbins, 1948). For example, the average maximum distance moved between summer observations for northern sagebrush lizards was only 25 m for males and 18 m for females (Stebbins, 1944). Although the estimated home ranges for many *Phrynosoma* spp. are considerably larger than those of *Sceloporus* spp. (Munger, 1984; Fair and Henke, 1999; Wone and Beauchamp, 2003), they are still small compared to other herpetofauna (Macartney et al., 1988; Diemer, 1992). Having a small home range might significantly decrease the number of incidental encounters that lizards have with roads, thus reducing the opportunity for collisions with vehicles.

Though some herpetofaunal species regularly utilize road surfaces for thermoregulation, small-bodied lizard species may be less likely to do so. *Sceloporus* spp. (snout vent length 4.8–8.9 cm) and greater short-horned lizards (snout vent length 4.4–12.4 cm) can easily utilize smaller or less accessible basking sites on the landscape (e.g., gaps between shrubs; Stebbins, 2003). In addition, *Sceloporus* spp. are extremely agile, which enables them to frequently exploit vertical basking sites such as steep rock outcrops and tree trunks (Rose, 1976; Stebbins, 2003). Finally, small lizard species might actively avoid basking in roads because of exposure to aerial predators, some of which are known to actively scavenge along road networks (Antworth et al., 2005; Dean and Milton, 2003).

Although we did not find any significant road effects for either species, we identified specific habitat associations for lizard populations adjacent to roads. These relationships are critical because herpetofaunal road mortality tends to coincide with particular habitat characteristics. For example, the highest mortality of Galapagos lava lizards occurred along stretches of road flanked by dense vegetation and limited basking sites (Tanner and Perry, 2007). We did not quantify mortality in this study; however, placing roads next to critical habitat areas (e.g., rocky outcrops) is likely to increase the risk of mortality for lizards and other species (Tanner and Perry, 2007). Delineating the habitat features that influence lizard presence and abundance in areas adjacent to roads is therefore important for minimizing herpetofaunal-vehicle collisions.

Rock outcrops simultaneously provide lizards with basking locations as well as refugia from predators, so it is not surprising that *Sceloporus* spp. abundance increased with rocky habitat. Rockiness was a strong predictor of both *Sceloporus* spp. presence and abundance given presence; however, it was not essential to either. We had several sites with little to no rockiness that still supported large *Sceloporus* spp. populations. This suggests that there may be other resources essential to *Sceloporus* spp. fitness that we did not directly measure (e.g., food availability).

Shrub cover was not associated with *Sceloporus* spp. presence; however, we found a significant positive association between shrub cover and *Sceloporus* spp. abundance given presence. *Sceloporus* spp. use shrubs as refugia and thermoregulatory sites (Kerr and Bull, 2004), which may explain the positive association between shrub cover and abundance. However, the highest measured shrub cover at a site was 39%, which is low enough to provide plenty of available open areas for basking between shrubs. Areas with much higher shrub cover may limit *Sceloporus* spp. abundance due to decreased availability and size of open basking locations.

Grass cover was negatively associated with *Sceloporus* spp. presence, but not abundance given presence. At high enough densities, grass physically hinders lizard movement and fills potential basking areas between shrubs, which is worrisome from a conservation standpoint. Cheatgrass was present in many of the study sites, at various densities. As this grass continues to spread through shrubland communities in the western United States, *Sceloporus* spp. could be completely excluded from otherwise suitable habitat.

Unlike the more physically agile *Sceloporus* spp., greater short-horned lizards are restricted to low-lying basking sites because of their physical morphology, so it is not surprising that greater short-horned lizard presence increased with bare ground. Accordingly, shrub cover was a marginally negative predictor of greater short-horned presence, though horned lizards do utilize shrubs for refugia and thermoregulation (Burrow et al., 2001).

Contrary to our prediction, grass cover did not significantly negatively influence short-horned lizard presence. High cheatgrass cover has been associated with reduced abundance of desert horned lizards while using scat as a proxy (Newbold, 2005). However, greater short-horned lizards were not abundant in our study area and were only present at 34 out of 84 sites. Likewise, only 25 sites had ≥ 10 % measured grass cover. Therefore, we may have lacked the necessary statistical power to identify a relationship between short-horned lizard habitat use and grass cover.

In conclusion, our data suggest that habitat is the primary driver behind lizard presence and abundance in landscapes bisected by roads, at least in our system. The characteristics of the adjacent habitat may be mitigating minor road impacts, or road effects may be too small to translate into observable impacts.

4.1. Management Implications

Our study identified significant habitat associations for several lizard species and emphasizes the important role of specific habitat characteristics in determining the presence and abundance of lizards, especially within fragmented landscapes. From a management perspective, it is crucial to identify and protect these habitat "hot-spots" from anthropogenic disturbance. As existing road networks continue to expand, the placement of new roads and other anthropogenic developments will become increasingly important. By identifying critical habitat attributes for local species prior to road placement, we can avoid the direct loss of important habitat areas. Our results indicate that lizard species can exist adjacent to roads, even a paved road with considerable traffic, as long as certain habitat features are available. Thoughtful road planning and design will help prevent the permanent conversion or degradation of critical habitat areas, which is particularly important for rare or endangered species and those with specialized habitat requirements.

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Table 1. Test statistics and *P*-values for tests of road effects on *Sceloporus* spp. presence (logistic regression) and abundance given presence (linear regression) while accounting for percent rockiness, an important habitat feature. Road surface treatment types were paved, dirt, two-track and no road. ADT is average daily traffic volume.

	Logistic regression		Linear regression	
	Test statistic	*P*	Test statistic	*P*
Surface treatment	$G = 3.57$	0.69	$F_{3,54} = 1.12$	0.35
Rockiness	$Z = 1.97$	0.05	$F_{1,54} = 23.07$	<0.001
Width	$Z = -1.22$	0.22	$T_{56} = 1.17$	0.25
Rockiness	$Z = 1.88$	0.06	$T_{56} = 4.74$	<0.001
ADT	$Z = -0.65$	0.52	$T_{45} = -0.61$	0.55
Rockiness	$Z = 1.76$	0.08	$T_{45} = 3.60$	<0.01

Table 2. Test statistics and *P*-values for tests of road effects on greater short-horned lizard presence (logistic regression) while accounting for percent bare ground, an important habitat feature. Road surface treatment types were paved, dirt, two-track and no road. ADT is average daily traffic volume.

	Test statistic	*P*
Surface treatment	$G = 4.40$	0.78
Bare ground	$Z = 1.70$	0.09
Width	$Z = 0.60$	0.55
Bare ground	$Z = 2.02$	0.04
ADT	$Z = -0.27$	0.79
Bare ground	$Z = 1.67$	0.10

Table 3. Linear regression test statistics and *P*-values for tests of distance-from-road effects on *Sceloporus* spp. abundance given presence in all road-associated sites with ≤ 1% measured rockiness in all five 100 x 50 m site subsections. N is the number of sites included in analyses.

	Test statistic	*P*	N
Distance from road	$F_{1,47} = 1.91$	0.17	22
Site	$F_{21,47} = 2.67$	<0.01	
Distance from paved	$F_{1,17} = 2.57$	0.13	9
Site	$F_{8,17} = 9.05$	<0.001	
Distance from dirt	$F_{1,23} = 1.68$	0.21	10
Site	$F_{9,23} = 0.95$	0.51	
Distance from 2-track	$F_{1,5} = 0.56$	0.49	3
Site	$F_{2,5} = 2.46$	0.18	

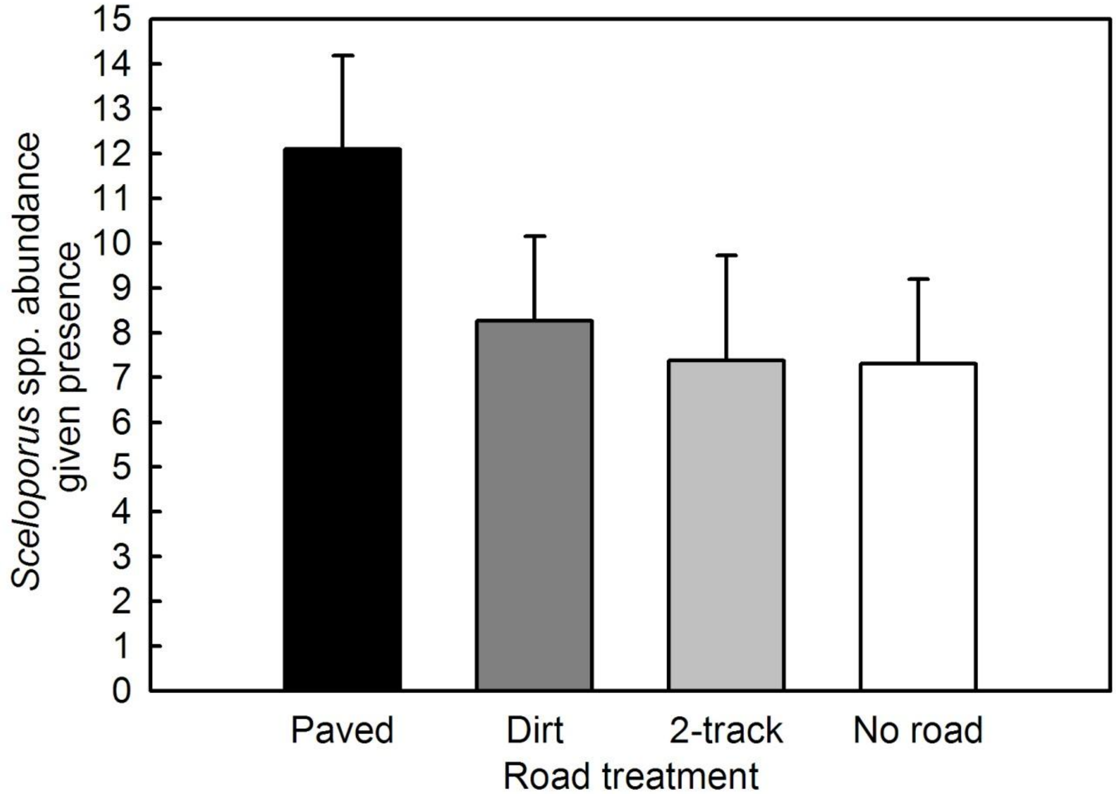

Fig. 1. Marginal means (± 1 SE) of *Sceloporus* spp. relative abundance pooled across sites where present, while accounting for percent rockiness, for the four road surface treatments.

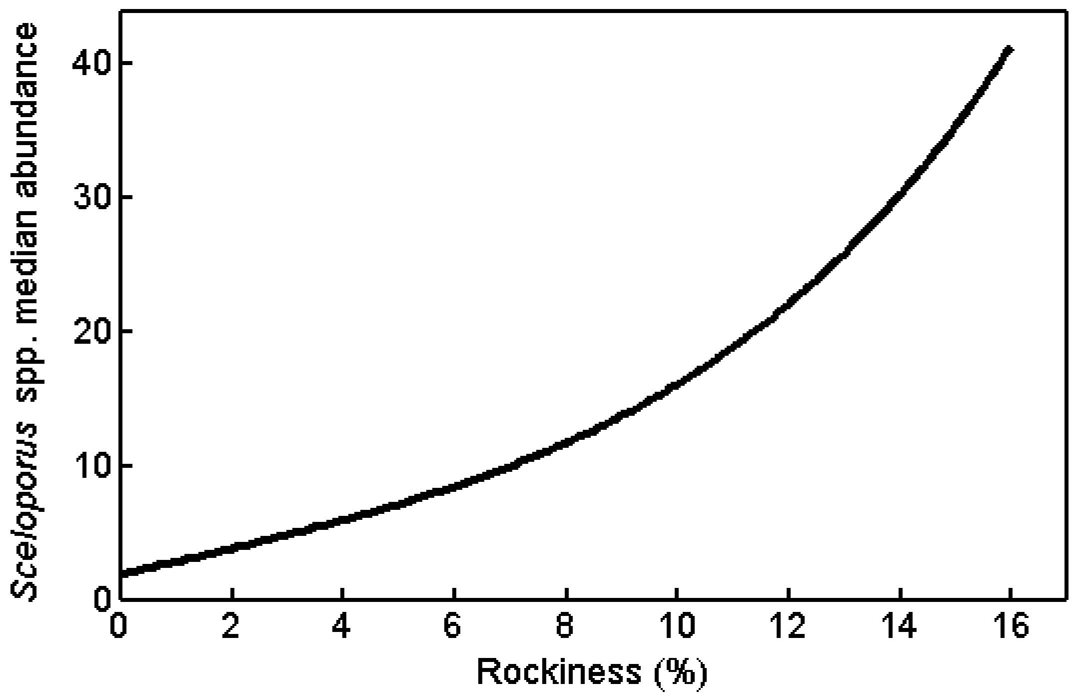

Fig. 2. Combined results from the significant *Sceloporus* spp. presence (logistic regression) and *Sceloporus* spp. abundance given presence (linear regression) rockiness models, which gives the expected median abundance of *Sceloporus* spp., plotted against observed rockiness and pooled across sites and road types.

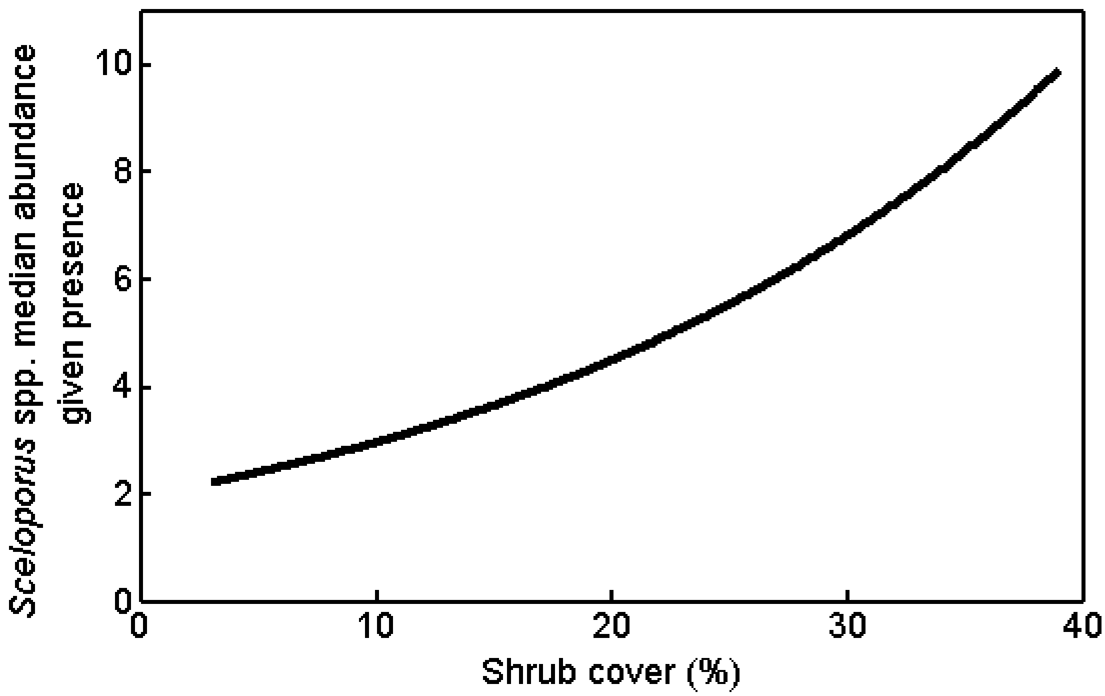

Fig. 3. Estimate of expected median abundance given presence of *Sceloporus* spp. plotted against observed percent shrub cover pooled across sites and road types.

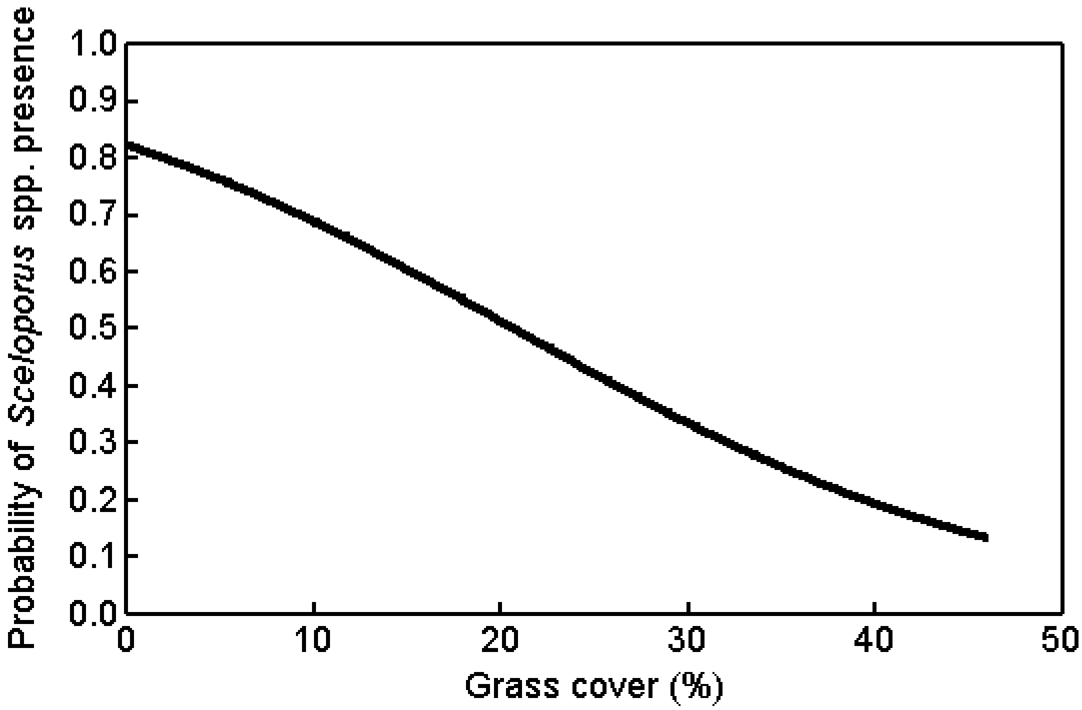

Fig. 4. Estimate of the probability of presence for *Sceloporus* spp. plotted against observed percent grass cover pooled across sites and road types.

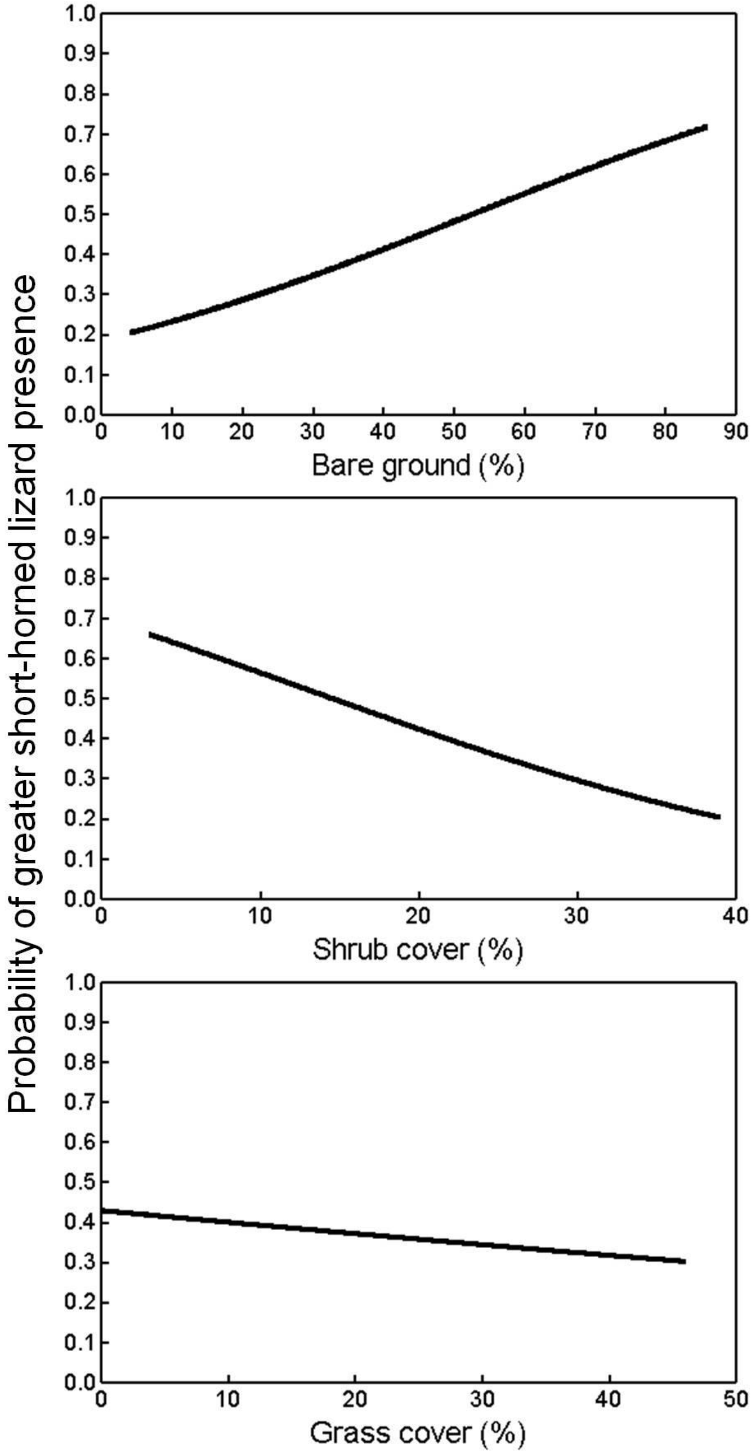

Fig. 5. Habitat associations for greater short-horned lizards pooled across sites and road types. From top to bottom: estimate of probability of presence plotted against observed percent bare ground, observed percent shrub cover, and observed percent grass cover.

CHAPTER TWO

AN EXPERIMENTAL EVALUATION OF POTENTIAL SCAVENGER EFFECTS ON SNAKE ROAD MORTALITY DETECTIONS

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 counts. 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 in three study areas. Carcass size was not a significant predictor of time of removal. Removal of simulated carcasses was higher than expected on paved roads in all study areas, with an average of 74% of the carcasses missing within 60 h. Carcass removal was lower than expected on dirt and two-track roads in all study areas, with an average of 33% and 31% missing on dirt and two-track roads, respectively, after 60 h. Scavengers may therefore negatively impact the ability of researchers to accurately detect

herpetofaunal road mortality, especially on paved roads where road mortality is likely the most prevalent.

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 Gibbon 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 (Andrew 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 (Bonnet et al. 1999).

Herpetofaunal road mortality is frequently quantified through the use of road surveys; however, the ability to accurately quantify road mortality varies depending on the survey method used (e.g. driving or walking) and road and traffic conditions (Enge and Wood 2002;

Langen et al. 2007; Coleman et al. 2008; Gerow et al. 2010). In addition, scavengers often remove roadkill from the road, eliminating evidence of mortality events prior to detection and potentially impacting the accuracy of road mortality estimates (Dean and Milton 2003; Antworth et al. 2005). Approximately 97% of snake carcasses were removed from the 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).

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), dirt (dirt or gravel surface) and two-track (delineated tire tracks with vegetation between). We surveyed 1,368 km of paved roads, 1,920 km of dirt roads and 762 km of two-track roads (not counting back-tracked mileage) over 158 h. However, we only recorded two mortality events, both on paved roads: one Great Basin Gopher Snake (*Pituophis catenifer deserticola*) and one Midget Faded Rattlesnake (*Crotalus oreganus oreganus*), a species of conservation need in Wyoming. One explanation for the low number of mortality detections despite extensive effort was high numbers of scavengers, especially Common Ravens (*Corvus corax*), in the study area (Wyoming Game and Fish Department, pers. comm.).

Although scavengers can significantly reduce the accuracy of wildlife road mortality counts, little is known about the actual extent of carcass removal in most systems. In addition, previous studies have required the procurement of real carcasses for experimentation. Our objective was to better understand the potential influence of scavengers on the accuracy of snake road mortality counts. Specifically, 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, dirt and two-track). To support the null hypothesis of no scavenging of simulated carcasses, we predicted negligible disappearance rates in all study areas 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 during the summer of 2010 in three areas of southwest Wyoming, USA: the Moxa Arch Area natural gas field, and the western and eastern sides of the Flaming Gorge National Recreation Area. Located northwest of Green River, WY in Lincoln, Uinta, and Sweetwater counties, the Moxa Arch Area is a well-established natural gas field with an extensive network of access roads. The Flaming Gorge National Recreation Area is located south of Green River, WY in Sweetwater County, and contains a diverse assemblage of roads that provide access to the Flaming Gorge Reservoir and surrounding area. All sites were separated by ≥ 10 km. Moreover, the three sites differed in elevation, topography and habitat characteristics, which allowed examination of scavenger effects across three different ecological contexts.

Site selection.—We stratified all experimental road sections under the same three road classifications (paved, dirt and two-track) used during the previous driving surveys, and starting points were randomly selected using a geographic information system (GIS). All road sections were 4–5 km in length 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 areas with regards to width (e.g., all sections of paved road were two lanes wide) and daily traffic volume.

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 species in parts of Wyoming. Each carcass was fashioned from 1–2 strips of Burbot, which were hand-processed and frozen until use in the experiment. Simulated carcasses were measured prior to placement, and ranged in size from 36–62 cm in total length, and 3.0–7.7 cm at the point of maximum width.

We conducted our experiment twice on the same road sections in Moxa Arch, once in late-June and once in early-August, to assess potential seasonal effects. We conducted the experiment in each of the Flaming Gorge study areas once to increase our spatial replication; western Flaming Gorge in late-June and eastern Flaming Gorge in early-August. All carcasses (n = 9 per road type per study area) were placed approximately 0.5 km apart to limit spatial autocorrelation by potential scavengers. We placed all carcasses on the edge of the road to minimize driver distraction, risks to scavengers and the potential for carcasses to be run over by passing vehicles. Each carcass was marked with GIS and an orange pin flag, located approximately 5 m from the road edge, to preserve its location after removal. We ran the experiment for a total of 60 h, and checked carcasses every 6 h until sunset (i.e., 0900, 1500 and 2100). One carcass in the western Flaming Gorge study area that was completely destroyed after being run over by a passing vehicle was removed from the experiment. All remaining carcasses and marker flags were collected at 2100 on the third day of the experiment.

Statistical analysis.—We analyzed each of the three study areas independently, with all analyses conducted 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 trial. We conducted a paired *t*-test to examine potential seasonal effects in the Moxa Arch study area, with the percent of carcasses missing at 60 h for each road type per trial as the response variable. We used chi-square analysis with equal expected proportions to compare the percentage of simulated carcasses missing at 60 h for each road type within each study area. Finally, to examine potential effects of carcass size on time of disappearance, we used multiple linear regression with carcass length and maximum width as continuous predictor variables. We verified that all linear regression model residuals displayed approximately normal distribution and equal scatter, and defined statistical significance as $\alpha < 0.05$ for all tests.

RESULTS

The percentage of carcasses missing after 60 h did not vary seasonally in Moxa Arch ($t_2 = 2.00$; $P = 0.18$), so we averaged results from the two trials for this study area. For carcasses removed from the road, neither carcass length nor maximum width were significant predictors of time of disappearance at any site (Table 1).

Paved roads had higher than expected removal of simulated carcasses at all three study areas, while carcass removals on dirt and two-track roads were lower than expected (Fig. 2). In the Moxa Arch study area, 78% of carcasses were missing from the paved roads after 60 h, while an average of 34% were missing from the dirt and two-track roads ($\chi^2 = 28.63$, df = 2, $P < 0.001$; Fig. 2). There was a similar pattern after 60 h in the western Flaming Gorge ($\chi^2 =$

14.44, df = 2, $P < 0.01$; Fig. 2) and eastern Flaming Gorge ($\chi^2 = 38.97$, df = 2, $P < 0.001$; Fig. 2) study areas, with 67% and 78% of carcasses missing, respectively, from paved roads, and an average of 36% and 28% removed, respectively, from the dirt and two-track roads.

DISCUSSION

As road networks continue to expand, the ability to quantify wildlife road mortality, particularly for species that are most vulnerable and/or rare, will be an increasingly important component of successful management. However, the accuracy of mortality counts may often be compromised by scavengers that remove carcasses from roads prior to observation. Scavengers have been associated with the rapid and extensive removal of carcasses of a wide variety of taxa from paved roads at other locations (Dean and Milton 2003; Antworth et al. 2005). Corvids and raptors are known to scavenge along artificial corridors such as roads and power lines, as are some terrestrial scavengers (May and Norton 1996; Dean and Milton 2003).

We predicted that carcass removal would be low across road types and study areas 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 areas 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, in all three study areas, with an average of 74% of the simulated carcasses missing after 60 h. Therefore, scavengers might have negatively impacted our ability to accurately detect road mortality on paved roads in 2009, where only two snake mortality events were recorded over 1,368 km of road surveys. Simulated carcasses were probably more visible, especially from the air, against the dark asphalt of the paved roads, which is likely also true of roadkilled snakes. Dirt and two-track roads had lower than expected removal rates in all three study areas, with 33% of simulated carcasses missing from dirt roads and 31% missing from two-track roads after 60 h. Simulated carcasses were likely less visible to potential scavengers on roads with these more natural surface treatments (gravel, dirt, sand). In addition, scavengers may not utilize these road types as frequently due to reduced human use (e.g., less discarded garbage) and reduced access to artificial perches for avian scavengers, such as power lines and telephone poles.

Finally, 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 that used real snake carcasses found a similar lack of significant size effects (Antworth et al. 2005), which could indicate that scavenger impacts to detections of snake mortality are likely comparable across species and age classes.

Future considerations.—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 roadkilled snake carcasses are subjected to similar conditions; however, they likely retain moisture for considerably longer because of their enclosed tough skin. However, in more humid environments desiccation of the simulated carcasses should 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. Even simulated carcasses placed to the right of the shoulder line and rumble strip were occasionally hit. 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 replace the carcasses in their original location. For these reasons, however, we were careful to refer to percent "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.

Acknowledgements.—This project was generously funded by the Wyoming Game and Fish Department. We thank Jeffrey Beck, Kevin Gelwicks, Wayne Hubert, Robert Keith, Charlotte Matthews, Zack Walker, David Zafft and Mark Zornes for their valuable ideas and involvement. The Green River Fisheries Management crew provided the Burbot used in this experiment. We thank the Green River office of the Wyoming Game and Fish Department for use of their facilities in processing and storing the simulated carcasses. Amanda Larson and Alison Shaver of the Wyoming Cooperative Fish and Wildlife Research Unit provided essential logistical support. We also thank our 2010 field technicians for their involvement and hard work in all stages of the experiment. Any use of trade or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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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 in each of the three study areas.

	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

FIGURE 1. From top to bottom: a Burbot carcass prior to processing; using a filet knife to cut the Burbot into strips; a simulated carcass placed on a road (Photographed by Kaylan A. Hubbard).

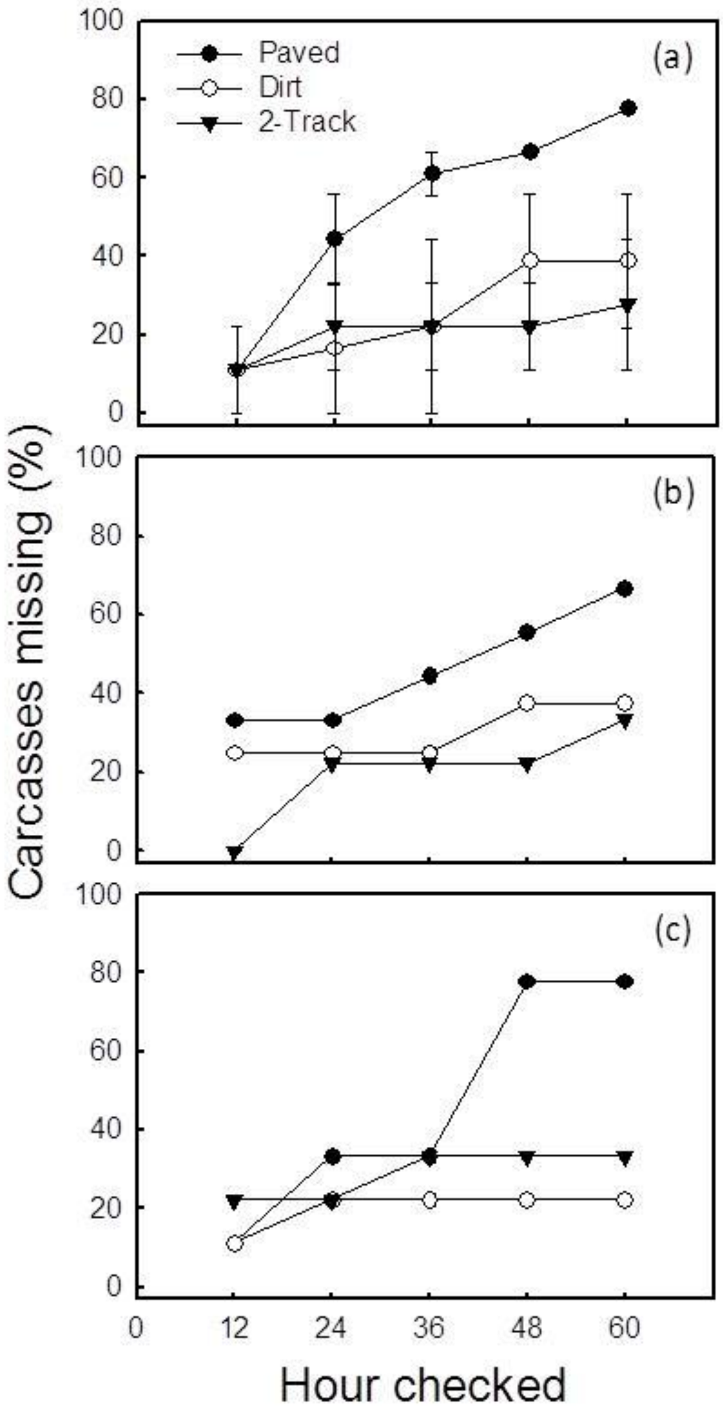

FIGURE 2. The percentage of simulated carcasses missing after 60 h for each of the three road surface treatments in the (a) Moxa Arch (mean ± 1 SE of the early and late trials), (b) western Flaming Gorge and (c) eastern Flaming Gorge study areas.

FUTURE RESEARCH SUGGESTIONS

In summary, the visual encounter survey methodology described in chapter one illustrates an effective, easily repeatable and cost-effective means of surveying lizard species in shrubland habitat. However, alternative survey methods would need to be employed in order to conduct a similar study for more cryptic reptiles, such as snakes. Other possible survey techniques could include pitfall trapping and/or drift fence arrays, although these methods are more labor intensive and would add to overall costs. In addition, coverboards should not be completely ruled out as a possible survey tool. While it is true that other researchers have also had limited success with the use of coverboards in Wyoming (Zack Walker, pers. comm.), it is possible that different sizes, materials or lengths of deployment could improve the appeal to reptiles.

I believe our study sites were of a sufficient size to accurately examine lizard distribution on the landscape. Likewise, I believe our habitat sampling methods generally provided an accurate way to quantify habitat for between-site comparisons. However, I would be interested in exploring alternative methods (e.g., aerial imagery) for quantifying percent rockiness at the site level, as I do feel that the line intercept method often underestimated this habitat metric.

Possible future research should include repeating this study in other parts of the state to examine whether road impacts to lizard populations vary across habitats or ecosystems. In addition, it would be interesting to quantify and examine the potential threshold effects of landscape-level road density. It is possible that road density is a stronger predictor of reptile presence, relative abundance and distribution on the landscape than the individual characteristics of the roads themselves. Finally, it would be valuable to conduct a similar study that is specifically tailored to snake populations adjacent to roads. Snakes are especially vulnerable to direct road effects, such as road mortality, which likely impact adjacent populations on some level. Therefore, it would be valuable from a conservation standpoint to quantify these effects, especially for species of greatest conservation concern such as the midget faded rattlesnake in Wyoming.

APPENDIX

Table A1. Summary of study sites. The listed UTM coordinates are for the two site corners closest to the road edge. All coordinates are in datum NAD83 Zone 12 North.

Plot code	Study area	Year(s) surveyed	Road Type	UTM coordinates			
				Easting	Northing	Easting	Northing
F37	Flaming	2009/2010	Paved	651492	4556744	651575	4556801
F38	Flaming	2009/2010	Paved	650021	4569086	650048	4568990
F39	Flaming	2009/2010	Paved	614883	4570927	614940	4570850
F42	Flaming	2009/2010	Paved	614665	4562625	614652	4562725
F43	Flaming	2009/2010	Paved	639587	4546776	639688	4546774
F44	Flaming	2009/2010	Paved	617452	4550985	617469	4551084
F65	Flaming	2010	Paved	640127	4580454	640106	4580552
F66	Flaming	2010	Paved	639465	4579364	639539	4579431
F80	Flaming	2010	Paved	610367	4572525	610288	4572462
F81	Flaming	2010	Paved	608214	4570218	608269	4570300
F84	Flaming	2010	Paved	616991	4567738	616899	4567776
F91	Flaming	2010	Paved	613443	4575816	613500	4575898
F04	Flaming	2009/2010	Dirt	631178	4564172	631182	4564268
F05	Flaming	2009/2010	Dirt	616121	4566717	616212	4566678
F13	Flaming	2009/2010	Dirt	651685	4557321	651784	4557333
F28	Flaming	2009/2010	Dirt	620088	4556205	620166	4556144
F29	Flaming	2009/2010	Dirt	629484	4546300	629562	4546241
F31	Flaming	2009/2010	Dirt	616087	4560397	616186	4560415
F01	Flaming	2010	Dirt	629979	4543731	630043	4543654
F12	Flaming	2010	Dirt	634636	4540676	634735	4540667
F17	Flaming	2010	Dirt	629619	4541429	629719	4541429
F61	Flaming	2010	Dirt	641102	4593535	641144	4593625
F63	Flaming	2010	Dirt	637351	4585426	637408	4585346
F74	Flaming	2010	Dirt	648167	4567919	648245	4567857
F10	Flaming	2009/2010	2-Track	649242	4555166	649337	4555200
F11	Flaming	2009/2010	2-Track	606248	4571776	606348	4571776
F14	Flaming	2009/2010	2-Track	628421	4555543	628422	4555443
F21	Flaming	2009/2010	2-Track	614678	4542359	614666	4542458
F22	Flaming	2009/2010	2-Track	614030	4567224	614123	4567259
F30	Flaming	2009/2010	2-Track	610989	4545030	611037	4544944
F70	Flaming	2010	2-Track	628659	4559677	628645	4559579
F72	Flaming	2010	2-Track	628388	4547566	628359	4547659
F86	Flaming	2010	2-Track	612941	4544466	612936	4544566
F90	Flaming	2010	2-Track	615660	4571302	615761	4571297
F111	Flaming	2010	2-Track	641934	4580798	641834	4580799
F112	Flaming	2010	2-Track	630673	4578116	630762	4578073
F100	Flaming	2010	No Road	610614	4572082	610686	4572148
F101	Flaming	2010	No Road	616977	4551173	616959	4551074
F102	Flaming	2010	No Road	606249	4572276	606349	4572275
F103	Flaming	2010	No Road	637839	4585667	637935	4585637

Plot code	Study area	Year(s) surveyed	Road Type	UTM coordinates			
				Easting	Northing	Easting	Northing
F104	Flaming	2010	No Road	651696	4557832	651596	4557819
F105	Flaming	2010	No Road	640619	4580539	640598	4580641
F106	Flaming	2010	No Road	639217	4579811	639141	4579747
F107	Flaming	2010	No Road	616295	4559931	616199	4559904
F108	Flaming	2010	No Road	608627	4569936	608684	4570018
F109	Flaming	2010	No Road	610604	4544707	610553	4544788
F110	Flaming	2010	No Road	629716	4540931	629816	4540929
F113	Flaming	2010	No Road	623052	4582558	623069	4582464
M01	Moxa	2009/2010	Paved	573815	4621863	573887	4621794
M03	Moxa	2009/2010	Paved	563612	4627163	563712	4627157
M04	Moxa	2009/2010	Paved	587717	4640884	587795	4640827
M11	Moxa	2009/2010	Paved	587882	4602634	587975	4602591
M12	Moxa	2009/2010	Paved	588983	4639962	589066	4639898
M14	Moxa	2009/2010	Paved	578577	4645772	578671	4645732
M02	Moxa	2010	Paved	567710	4625579	567805	4625545
M61	Moxa	2010	Paved	575081	4646382	575001	4646323
M63	Moxa	2010	Paved	569464	4646139	569363	4646141
M64	Moxa	2010	Paved	564132	4645698	564212	4645758
M68	Moxa	2010	Paved	580796	4642453	580895	4642468
M69	Moxa	2010	Paved	583769	4642622	583868	4642606
M28	Moxa	2009/2010	Dirt	579404	4607007	579477	4606944
M31	Moxa	2009/2010	Dirt	579414	4585302	579505	4585334
M32	Moxa	2009/2010	Dirt	577978	4623168	578055	4623102
M36	Moxa	2009/2010	Dirt	588640	4639295	588733	4639338
M49	Moxa	2009/2010	Dirt	577357	4595998	577408	4595912
M53	Moxa	2009/2010	Dirt	586892	4615033	586964	4614957
M72	Moxa	2010	Dirt	579272	4627199	579247	4627295
M77	Moxa	2010	Dirt	579909	4615260	579934	4615164
M79	Moxa	2010	Dirt	584108	4607883	584023	4607933
M82	Moxa	2010	Dirt	570711	4593189	570666	4593099
M85	Moxa	2010	Dirt	574093	4588354	574108	4588255
M87	Moxa	2010	Dirt	576082	4582679	576062	4582581
M88	Moxa	2010	No Road	589278	4640366	589367	4640296
M89	Moxa	2010	No Road	583679	4642133	583778	4642117
M90	Moxa	2010	No Road	578772	4646233	578867	4646191
M92	Moxa	2010	No Road	567902	4626045	567992	4626004
M93	Moxa	2010	No Road	588080	4641238	588013	4641286
M94	Moxa	2010	No Road	580972	4641975	580872	4641969
M95	Moxa	2010	No Road	587658	4602191	587743	4602141
M97	Moxa	2010	No Road	589856	4637266	589764	4637226
M98	Moxa	2010	No Road	570108	4650019	570148	4649923
M101	Moxa	2010	No Road	569357	4645644	569460	4645641
M105	Moxa	2010	No Road	586092	4613722	585992	4613716
M110	Moxa	2010	No Road	561805	4634748	561702	4634728

Table A2. Summary of total reptile detections (from two visits) at each study site in 2009 and 2010. Highlighted cells indicate presence in one or both years of surveys. Species codes are: SG = *Sceloporus* spp., PH = greater short-horned lizard (*Phrynosoma hernandesi*), CO = midget faded rattlesnake (*Crotalus oreganus concolor*), T = wandering gartersnake (*Thamnophis elegans vagrans*).

Plot code	Year(s) surveyed	Road Type	Total detections			
			SG	PH	CO	T
F37	2009/2010	Paved	0/0	1/0	0/0	0/0
F38	2009/2010	Paved	0/0	0/0	0/0	0/0
F39	2009/2010	Paved	0/1	1/0	0/0	0/0
F42	2009/2010	Paved	10/4	2/1	0/0	0/0
F43	2009/2010	Paved	0/1	0/0	0/0	0/0
F44	2009/2010	Paved	0/0	2/2	0/0	0/0
F65	2010	Paved	93	0	0	0
F66	2010	Paved	66	0	1	1
F80	2010	Paved	8	0	0	0
F81	2010	Paved	5	1	0	0
F84	2010	Paved	8	0	0	0
F91	2010	Paved	0	0	0	0
F04	2009/2010	Dirt	0/0	0/0	0/0	0/0
F05	2009/2010	Dirt	7/23	0/0	0/0	0/0
F13	2009/2010	Dirt	0/0	0/0	0/0	0/0
F28	2009/2010	Dirt	41/26	1/1	1/0	0/0
F29	2009/2010	Dirt	9/17	0/1	0/0	0/0
F31	2009/2010	Dirt	1/3	0/0	0/0	0/0
F01	2010	Dirt	22	0	0	0
F12	2010	Dirt	0	0	0	0
F17	2010	Dirt	0	0	0	0
F61	2010	Dirt	14	0	0	0
F63	2010	Dirt	19	0	0	0
F74	2010	Dirt	30	0	0	0
F10	2009/2010	2-Track	0/0	0/0	0/0	0/0
F11	2009/2010	2-Track	5/25	0/0	0/0	0/0
F14	2009/2010	2-Track	0/1	1/0	0/0	0/0
F21	2009/2010	2-Track	2/1	0/0	0/0	0/0
F22	2009/2010	2-Track	1/4	0/0	0/0	0/0
F30	2009/2010	2-Track	3/2	1/1	0/0	0/0
F70	2010	2-Track	7	0	0	0
F72	2010	2-Track	18	0	0	0
F86	2010	2-Track	6	0	0	0
F90	2010	2-Track	5	0	0	0
F111	2010	2-Track	36	0	0	0
F112	2010	2-Track	1	1	0	0
F100	2010	No Road	21	0	0	0
F101	2010	No Road	1	0	0	0
F102	2010	No Road	8	3	0	0
F103	2010	No Road	34	0	1	0
F104	2010	No Road	0	0	0	0

Plot code	Year(s) surveyed	Road Type	Total detections			
			SG	PH	CO	T
F105	2010	No Road	66	0	0	1
F106	2010	No Road	19	0	0	0
F107	2010	No Road	12	0	1	0
F108	2010	No Road	1	0	0	0
F109	2010	No Road	7	1	0	0
F110	2010	No Road	2	1	0	0
F113	2010	No Road	1	0	0	0
M01	2009/2010	Paved	0/0	0/0	0/0	0/0
M03	2009/2010	Paved	0/0	1/1	0/0	0/0
M04	2009/2010	Paved	9/10	1/1	0/0	0/0
M11	2009/2010	Paved	0/3	0/0	0/0	0/0
M12	2009/2010	Paved	2/0	0/0	0/0	0/0
M14	2009/2010	Paved	37/39	0/1	0/0	0/0
M02	2010	Paved	0	3	0	0
M61	2010	Paved	5	1	0	0
M63	2010	Paved	0	1	0	0
M64	2010	Paved	0	2	0	0
M68	2010	Paved	9	1	0	0
M69	2010	Paved	3	1	0	0
M28	2009/2010	Dirt	10/7	2/1	0/0	0/0
M31	2009/2010	Dirt	0/0	2/0	0/0	0/0
M32	2009/2010	Dirt	0/0	0/0	0/0	0/0
M36	2009/2010	Dirt	4/6	1/0	0/0	0/0
M49	2009/2010	Dirt	4/7	0/0	0/0	0/0
M53	2009/2010	Dirt	3/2	1/1	0/0	0/0
M72	2010	Dirt	5	1	0	0
M77	2010	Dirt	1	0	0	0
M79	2010	Dirt	17	0	0	0
M82	2010	Dirt	5	1	0	0
M85	2010	Dirt	8	1	0	0
M87	2010	Dirt	0	1	0	0
M88	2010	No Road	0	1	0	0
M89	2010	No Road	0	0	0	0
M90	2010	No Road	25	1	0	0
M92	2010	No Road	0	2	0	0
M93	2010	No Road	14	0	0	0
M94	2010	No Road	6	3	0	0
M95	2010	No Road	0	1	0	0
M97	2010	No Road	1	1	0	0
M98	2010	No Road	4	0	0	0
M101	2010	No Road	0	2	0	0
M105	2010	No Road	2	2	0	0
M110	2010	No Road	0	1	0	0

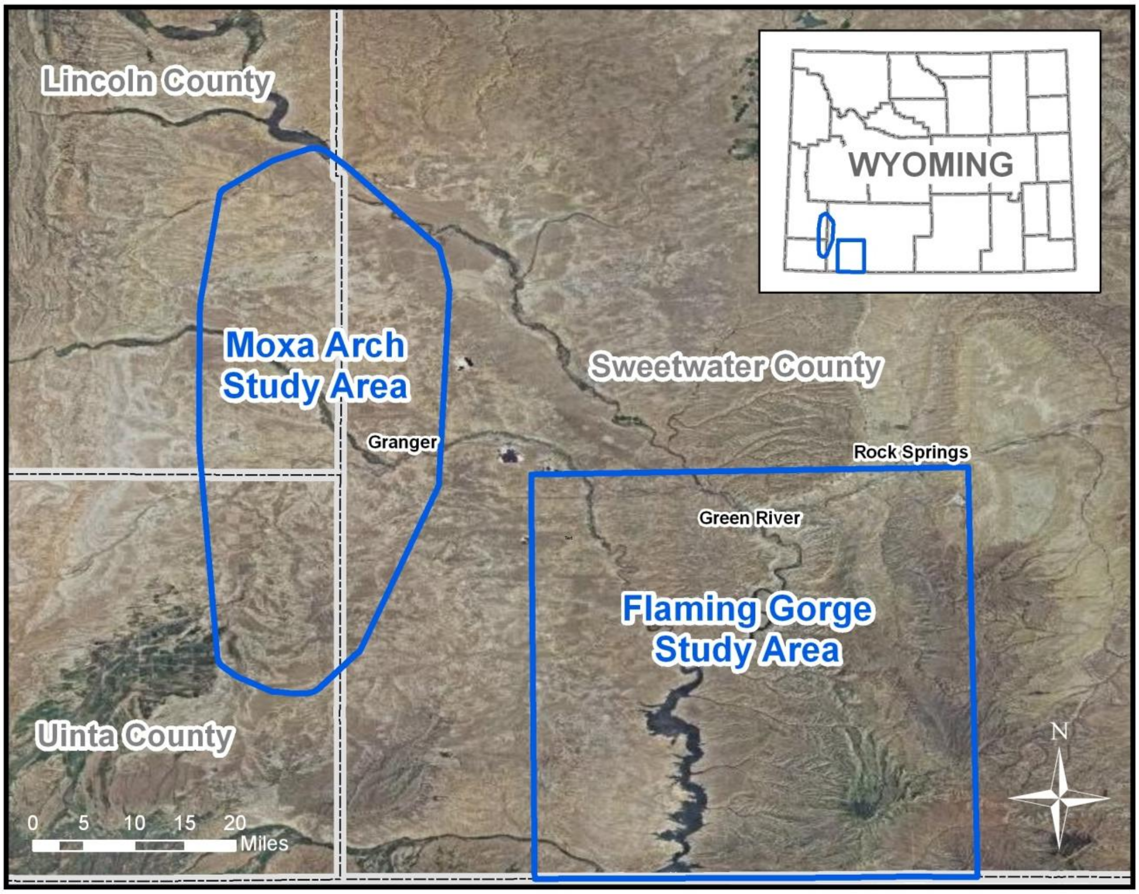

Figure A1. Map showing the location of the two study areas in southwest Wyoming, USA.

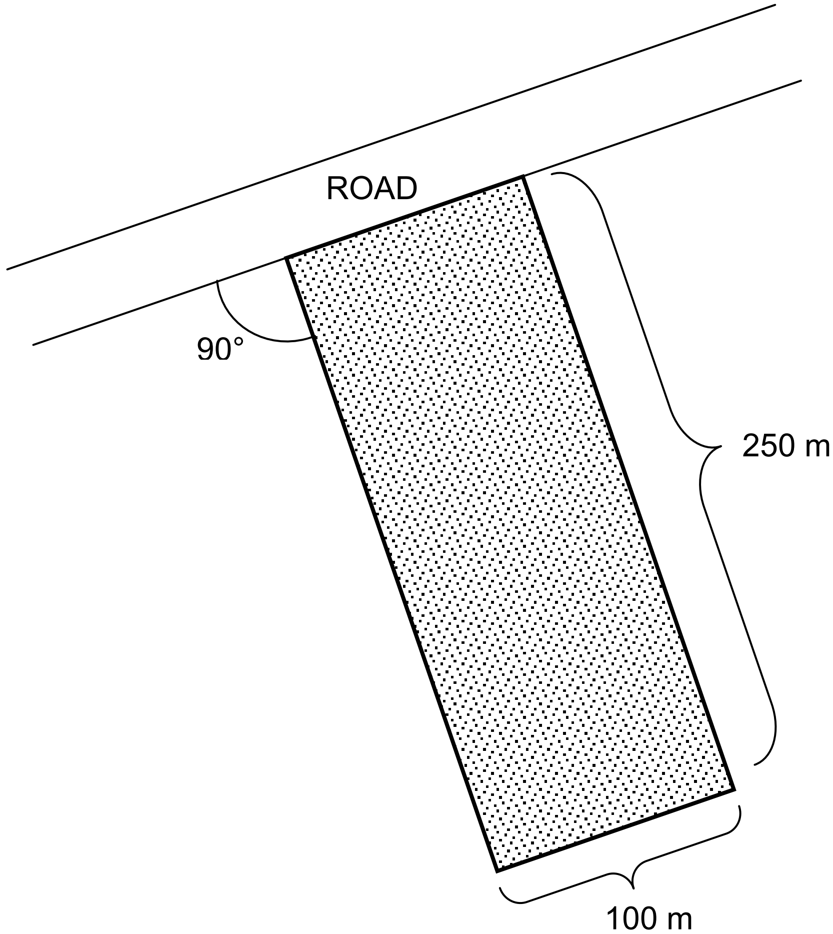

Figure A2. Sample study site showing dimensions and orientation in relation to the road. Figure not drawn to scale.

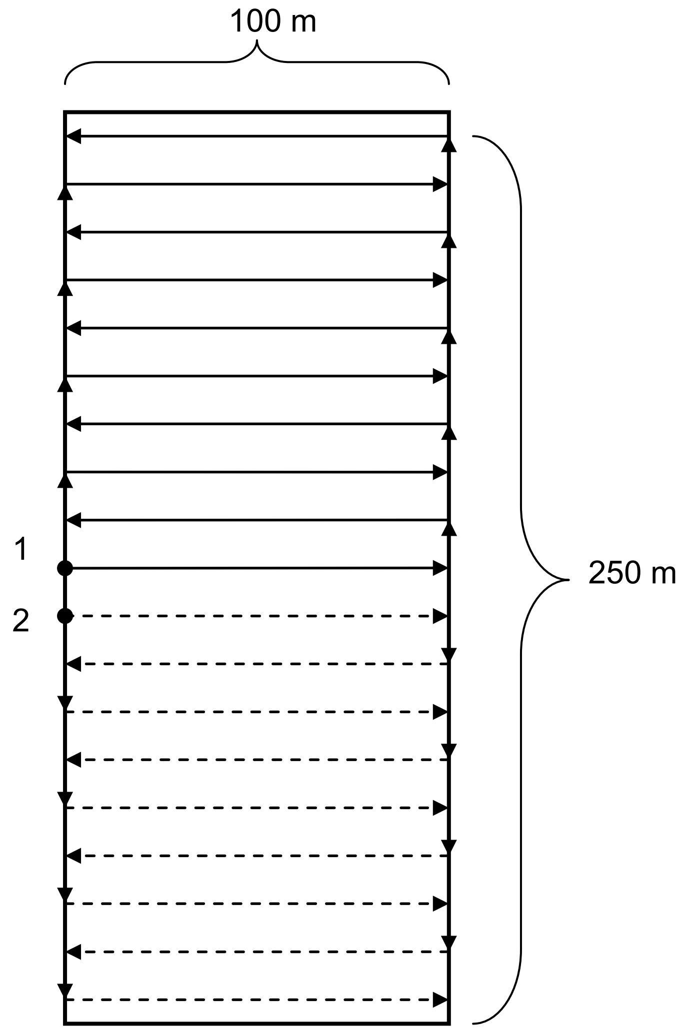

Figure A3. Walking pattern of visual encounter surveys. The numbers represent the approximate starting locations of the two technicians (starting edge chosen randomly). Figure not drawn to scale.

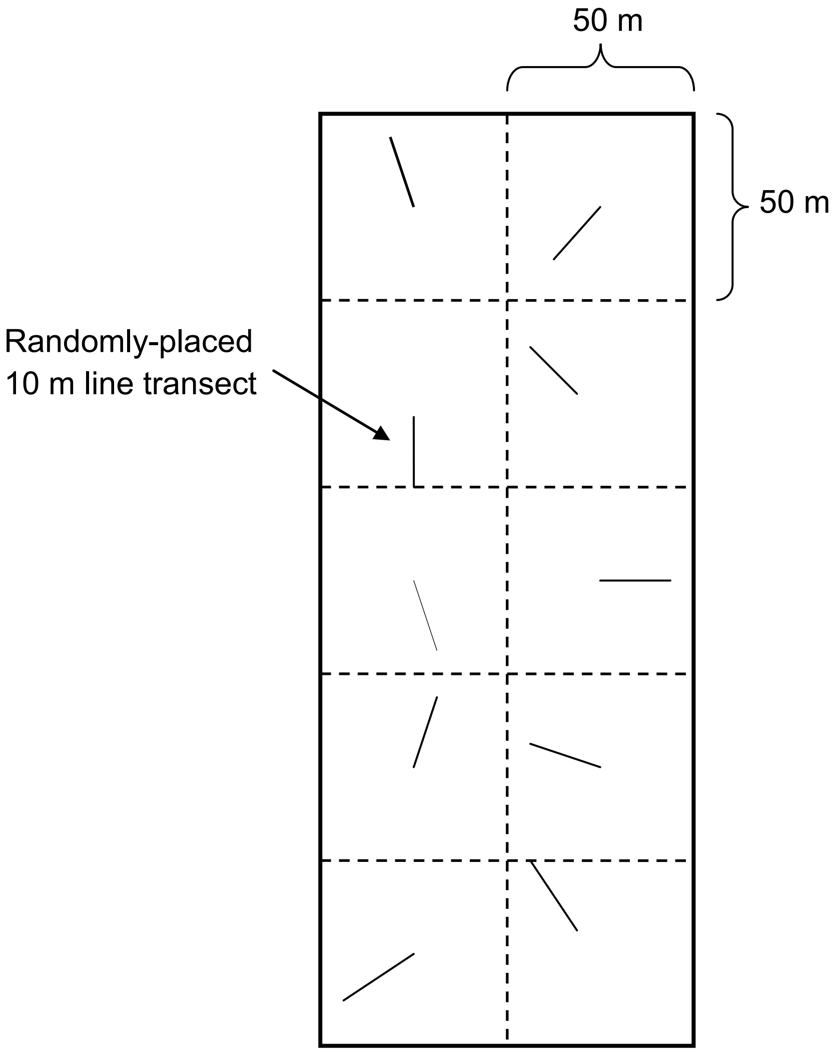

Figure A4. Pattern for vegetation/habitat transect sampling in a study site. Figure not drawn to scale.

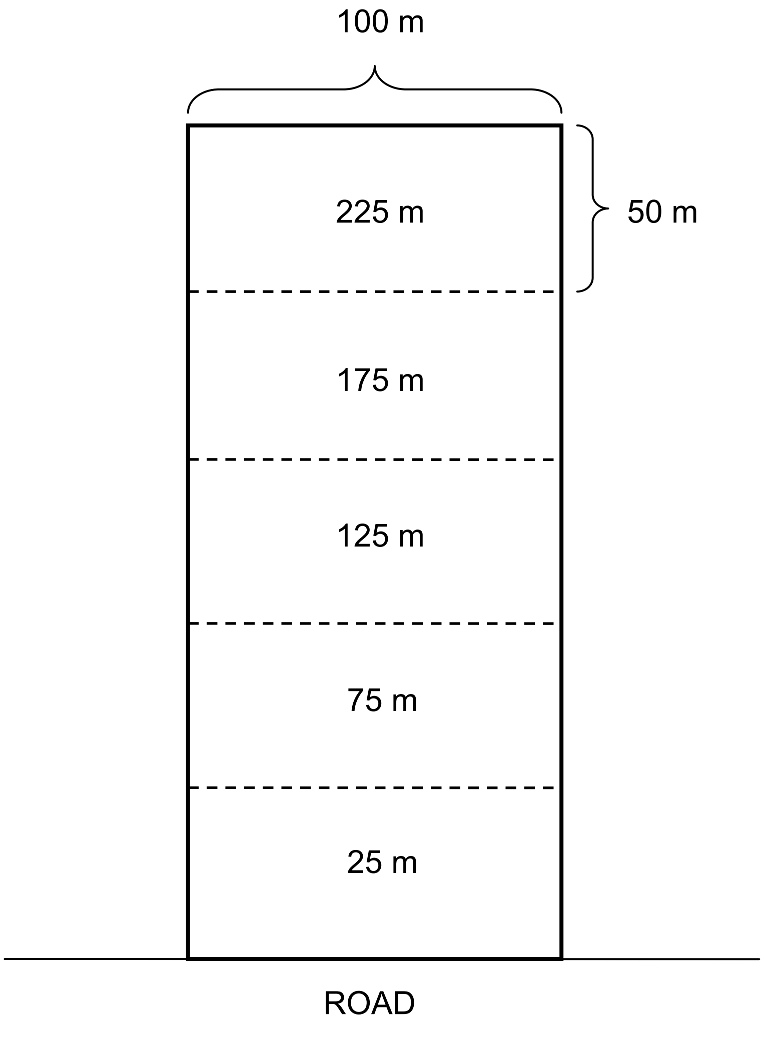

Figure A5. Sample study site showing the position and distance classification of sub-divisions used in the distance to road analysis. Figure not drawn to scale.