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A Comparison of Driving Versus Walking Roadkill Surveys on a Section of Highway 212 in Baldwin County, Georgia

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A COMPARISON OF DRIVING VERSUS WALKING ROADKILL SURVEYS ON A SECTION OF HIGHWAY 212 IN BALDWIN COUNTY, GEORGIA

by

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PREFACE

This thesis has been written in journal format and conforms to the style appropriate to my discipline. This manuscript will be submitted for publication in the Georgia Journal of Science and will reflect some of the required formatting for this publication. Figures and tables are at the end of the manuscript for ease of reading but will be included within text during publication.

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ABSTRACT

Due to wildlife mortality along roadways, wildlife managers need an efficient and effective way of surveying and identifying roadkill hotspots—locations that have high wildlife mortality rates. The number of roadkill in hotspots is influenced by animal movements in response to seasonal temperature changes, daily activity, surrounding habitat, road topography and physical road features. Due to ease of implementation and time constraints, driving surveys are more common because walking surveys are more labor intensive and time consuming. From February 2018 to February 2019, two survey methods, driving and walking, were used to monitor a 1.16 km section of Highway 212 in Baldwin County, Georgia. Roadkills were identified and monitored from sunrise to noon every Tuesday and Thursday, weather permitting. Twenty-nine roadkills were recorded over the survey period: 48.3% mammals (14/29), 27.6% herpetofauna (8/29), and 24.1% birds (7/29). Forty-eight percent (14/29) of roadkills were missed by the vehicle survey: 43% of herpetofauna, 36% of mammals, and 21% of birds. Of the roadkills missed, 72.7% (8/14) were located in the roadway. Animals smaller than Eastern Gray Squirrel size were more likely missed than those larger than squirrels (χ^2=4.36; p=0.04) in the driving survey. This study demonstrates that driving surveys likely miss a significant portion of roadkill smaller than squirrels and conducting walking surveys separately or in combination with driving surveys is necessary for an accurate estimate of roadkill numbers.

INTRODUCTION

It has been estimated that wildlife-vehicle collisions occur throughout the United States at a rate of one to two million mammals (e.g. White-tailed Deer [*Odocoileus virginianus*], Coyotes [*Canis latrans*], Domestic Dogs [*Canis lupus familiaris*]) per year (Federal Highway Administration 2008). This is likely an underestimate due to underrepresented smaller mammals (e.g. Northern Raccoons [*Procyon lotor*], Eastern Gray Squirrels [*Sciurus carolinensis*], Virginia Opossums [*Didelphis virginiana*]), herpetofauna and birds. These taxa are probably overlooked due to their small size, rapid scavenging, or displacement of carcasses into the verge (grassy strip along the roadway) where they are not seen by motorists (Barthelmess and Brooks 2010). In Georgia alone, it is estimated that as many as 5.4 million mammals (Eastern Gray Squirrel size and larger) are killed along roadways each year (Boitet and Mead 2014). It is estimated that millions of herpetofauna are killed annually on roadways in the southeastern United States (Bailey et al. 2006). In addition, an estimated 80 million birds are killed in the United States each year in wildlife-vehicle collisions (Kociolek et al. 2015).

Driving surveys are the most commonly used method to document the number of wildlife-vehicle collisions. They are used primarily due to their relative safety and the great lengths of road that can be covered in a relatively short period. However, driving surveys likely miss roadkill due to the small size of some animals, dense vegetation in the verge, and limited amount of time a driver has to detect a carcass and make a positive identification at highway speed (Clevenger et al. 2003). Roadkill rates for driving surveys vary from 1.44-3.67/km/yr (Barthelmess and Brooks 2010, Carvalho et al. 2014, Glista and DeVault 2008), however, walking surveys tend to produce higher rates that vary from 139.14-569.06/km/yr (Dutta et al. 2016, Smith and Dodd 2003). Walking surveys have been used separately and in combination with driving surveys resulting in greater roadkill numbers (Langen et al. 2007, Smith and Dodd

2003). Surveying segments of a larger driving route via walking can increase the detection of small roadkill, such as herpetofauna, and give an estimate of what may be missed while driving the entire route (Coleman et al. 2008, Dutta et al. 2016). Because roadkill surveys often observe more mammals (i.e. that are often larger than a squirrel) than other taxa (Cristoffer 1991, Glista and DeVault 2008, Seibert and Conover 1991), changing methodology from driving to walking may help increase detections of herpetofauna and birds.

Roadkill observations are often affected by various factors outside of the observer's control, such as animal size, animal group, surrounding habitat and roadside features, and scavenging and displacement of carcasses. The size of the animal greatly influences whether an observer is able to detect and identify a carcass while conducting a driving survey (Coleman et al. 2008, Langen et al. 2007, Slater 2002). Studies show that it is difficult to notice and/or identify roadkill smaller than a squirrel while driving at posted highway speeds (Barthelmess and Brooks 2010, Glista and DeVault 2008, Langen et al. 2007, Smith-Patten and Patten 2008). In a herpetofaunal methodology survey comparing driving and walking, roadkill observations were 52 times higher while walking than driving (Langen et al. 2007), therefore demonstrating that the detection of small roadkills is enhanced with walking surveys.

Daily and seasonal activities influence the movement of animals and may increase wildlife-vehicle collisions. For example, White-tailed Deer are most active during the early morning and late evening hours (Miller et al. 2003). Additionally, they are observed moving across roadways more frequently during the breeding season in fall and early winter (Clevenger et al. 2003). In smaller mammals, such as Nine-banded Armadillos (*Dasypus novemcinctus*), movements increase in the late afternoon during summer months and correlate with the breeding season and subsequently a seasonal increase in road mortality (Inbar and Mayer 1999, Loughrey and McDonough 1996). Another similar-sized mammal, the Northern Raccoon, encounters roads

more frequently from September-November as they cross roadways searching for mates. Herpetofauna reproductive periods are influenced by seasonal temperatures and coincide with periods of regular rainfall (Glista and DeVault 2008, Coleman et al. 2008). A seasonal increase in daily temperatures may cause an increase in movement because the animals are no longer conserving energy for thermoregulation (Coleman et al. 2008). For example, reptilian movements peak midday as these ectotherms warm their bodies above ambient air temperatures on heated roadways (Beckmann and Shine 2015). Avian movements are typically influenced by daily activity such as foraging, which may increase avian mortalities as birds cross roadways. Most birds are more active throughout the spring and early summer months in North America during periods of reproduction and migration (Husby 2016). Peak bird activity and movement across roadways occurs in early summer as nestlings become fledglings. Daily activity for most birds peaks in the early morning (Slater 2002). Some diurnal species become more active in the evening due to artificial lights on buildings that may mimic natural lighting (Kociolek et al. 2015). For nocturnal species, activity peaks at night.

Roadside habitats influence animal movements and contribute to wildlife-vehicle collisions (Aresco 2005, Boitet and Mead 2014, Glista and DeVault 2008, Lester 2015). Wildlife mortality rates are often higher on roads where wetlands, prairies, and forests are bisected by the roadway (Conard and Gipson 2006, Dutta et al. 2016, Smith and Dodd 2003), leading to spatial clusters of roadkills known as hotspots. Wetlands along roadways often focus wildlife crossings, especially for herpetofauna seeking specific breeding habitats. For example, Coleman et al. (2008) found that most of the herpetofauna found dead on the roadway were observed between borrow pits located on either side of the road. Most rodents tend to cross roadways if forested habitat is present on either side of the roadway (McLaren et al. 2011). Prairie Voles (*Microtus ochrogaster*) and Cotton Rats (*Sigmodon hispidus*) live in the verge along the roadway but have

been found to not cross if the verge is mowed (Swihart and Slade 1984). Other small mammals such as Muskrats (*Ondatra zibethicus*) are known to cross roads as they move between mixed hardwood forests and forested wetlands (Barthelmess and Brooks 2010). Seed- and fruit-eating birds (Carvalho et al. 2014, Clevenger et al. 2003), White-tailed Deer (Forman and Alexander 1998), and rabbits (Slater 2002) have been observed as roadkill more often in areas where vegetation creates cover and food sources close to roadways. Large roadkill, such as White-tailed Deer, may become displaced from the roadway due to the ability to move a short distance after being struck by a vehicle, which may cause the animal to be missed by survey (Main and Allen 2002). Some mammals, such as Eastern Gray Squirrels and Virginia Opossums, experience high roadkill mortalities in urban areas (Kanda et al. 2006, Steele and Koprowski 2001). Virginia Opossums thrive in these areas consuming refuse and available pet food. Eastern Gray Squirrels are found in high densities supported by altered natural habitats with large acorn producing trees (Steele and Koprowski 2001).

Road topography (Aresco 2005, Boitet and Mead 2014, Clevenger et al. 2003, Glista et al. 2007) and physical road features (Clevenger et al. 2001, Collinson et al. 2017, Ogletree et al. 2019) also influence wildlife-vehicle collisions. Wider roads (i.e. more than two lanes, with medians) increase the likelihood of wildlife-vehicle collisions due to increased animal crossing time (Aresco 2005). Four- and five-lane highways have a significantly higher number of wildlife mortalities compared to two-lane roads with the same speed limits (Boitet and Mead 2014). Both avian and mammalian mortalities are more likely to occur on the downside of a hill due to an increase in vehicle speed and inability of drivers cresting the hill top to detect wildlife below (Carvalho et al. 2014, Clevenger et al. 2003, Husby 2016, Kanda et al. 2006). Many animals, especially birds, are found as roadkill around curves due in part to the limited line of sight of motorists (Clevenger et al. 2003, Husby 2016). Though culverts may allow wildlife to follow

streams underneath the roadway, some animals do not utilize culverts while following streams and therefore cross the roadway at higher frequencies in the proximity of culverts (Aresco 2005, Collinson et al. 2017, Ogletree et al. 2019).

Scavengers are often found as roadkill and may affect both driving and walking surveys by removing or displacing carcasses. Mammalian scavengers (e.g. Coyotes, Virginia Opossums, Northern Raccoons) are known to frequent roadways to consume roadkills, increasing the likelihood of wildlife-vehicle collisions (Antworth et al. 2005). Few herpetofaunal species are known to scavenge roadkill; however, in the southeastern United States, Gopher Tortoises (*Gopherus polyphemus*) and Eastern Box Turtles (*Terrapene carolina carolina*) have been observed to consume roadkill as juveniles (Andrews et al. 2008). Turkey Vultures (*Cathartes aura*), Black Vultures (*Coragyps atratus*), and American Crows (*Corvus brachyrhynchos*) are more active near roadways attracted by roadkill in the road and/or verge (Vidal-Vallés et al. 2018). Small roadkills are often removed by scavengers more quickly from roadways than large roadkills, resulting in less small roadkills detected (Main and Allen 2002). Antworth et al. (2005) found that carcasses were more often removed during the day and from the middle of the road, due to scavengers being able to find the animal on the road by sight or smell. The condition of roadkills did not affect scavenging nor did it influence persistence (the length of time a specimen has been on the roadway) on the roadway (Beckmann and Shine 2015, Husby 2016). For example, Beckmann and Shine (2015) found that frog carcasses persisted longer on the roadway during the night or periods of rainfall, possibly due to no scavenger movement during those times. In another study, three trials showed that 60-82% of small carcasses disappeared from the roadway within 36 hours (Antworth et al. 2005). Persistence is often quite variable. Seibert and Conover (1991) could not determine an effective number for mammalian persistence because a

Virginia Opossum persisted in the roadway for one day, and some Groundhogs (*Marmota monax*) persisted on the roadway for almost three months.

Even though driving surveys are useful for identifying the locations of roadkill hotspots (Aresco 2005, Boitet and Mead 2014, Glista and DeVault 2008, Lester 2015), walking surveys may be more useful in monitoring identified hotspots (Langen et al. 2007). Animal size, rate of scavenging, and displacement of carcasses do influence the accuracy of driving roadkill surveys, however no literature is available at this time to demonstrate what roadkills are missed while driving as a simultaneous walking survey is conducted. A better understanding of the difference in roadkill detection rates between driving and walking surveys is needed. The objectives for this study are to compare walking and driving surveys to gain a better understanding of 1) which taxa are most often found as roadkill, 2) what percentage of roadkill is missed in a driving survey, 3) which taxa are most frequently missed in a driving survey, and 4) how long roadkill persists in the roadway or verge.

MATERIALS AND METHODS

Roadkill was surveyed along a 1.16 km section of Highway 212 near the intersection with Highway 22 in Baldwin County, Georgia (Figure 1). The southeast end of the survey section has a residential area (R) on the east side of the road and a small field (O) and two ponds (P) to the west. Moving northwest, the surrounding habitat changes into a small woodland (W) on both sides of the road. The north end of the survey route is surrounded by a few residences and a pond (P) on the east side of the road and a woodland (W) and recreational field (F) to the west. Slight changes in roadway elevation occur between 0.29 km and 0.44 km as well as 0.70 km and 0.95 km. Three small permanent streams flow underneath the road through culverts at 0.53 km, 0.62 km, and 0.79 km.

Driving surveys for roadkill were conducted every Tuesday and Thursday morning (weather permitting) within an hour of sunrise between 1 February 2018 and 31 January 2019. The survey route was driven at an average posted speed limit of 80.5 km/hr from south to north (east side of road) and north to south (west side of road). Immediately following the driving surveys, a walking survey was performed following the same procedure. For each roadkill, species, date, location (roadway or verge), and GPS coordinates (via Google Maps) were recorded during the first observance. Each roadkill was categorized according to size—smaller, larger, or equal to the size of an Eastern Gray Squirrel (300-700 g). Roadkill was monitored for persistence by repeated observations every two hours until noon on the day the roadkill was detected. The minimum amount of time roadkill persisted was based on the last observation. The maximum amount of time roadkill persisted was based on the following time the survey was conducted and the roadkill was not observed. Roadkill rate per year was calculated by dividing the yearly total of roadkill by road length (km). Chi-square tests were used to determine whether size, location (roadway or verge), or taxa influenced the number of roadkills missed by driving surveys.

RESULTS

Between 1 February 2018 and 31 January 2019, 29 roadkills were observed in the walking survey over 98 observation days (Figure 1, Table 1). The roadkill rate was 25.0/km/yr. Roadkill rates were highest for mammals (12.07/km/yr) followed by herpetofauna (6.90/km/yr), and birds (6.03/km/yr). As shown in Figure 2, mammals represented 48.3% (14/29) of total roadkill followed by herpetofauna at 27.6% (8/29) and birds at 24.1% (7/29). Species observed more than once (Table 2) include: Virginia Opossum (4), Northern Raccoon (3), White-tailed Deer (2), Eastern Gray Squirrel (2), and Rat Snake (*Pantherophis obsoletus*, [2]). Eleven

roadkills were smaller than a squirrel and 18 were equal to or larger than a squirrel. During the survey period, no roadkills were documented in February and December 2018 (Figure 3). Mammalian roadkills were documented at least once in 9 of the 12 months (March-October and January), whereas herpetofaunal (April-June, August, and September) and avian (April-May, November, and January) roadkills were detected in less than half of the months. Mammals were found in the months of March, July, and October when herpetofauna and birds were not observed. Birds were found in November with no other taxa recorded for the month.

Forty-eight percent (14/29) of roadkills were missed by the vehicle survey (Table 1, Figure 4). Herpetofauna were most frequently missed (75%, 6/8) followed by birds (43.9%, 3/7) and mammals (35.7%, 5/14), though the difference between taxa was not significantly different (χ^2=3.76; p=0.15). Roadkills smaller than a squirrel were missed (8/11) significantly more often (χ^2=4.36; p=0.04) than those equal to or larger than a squirrel (6/18) (Table 4). For taxa smaller than a squirrel, all mammals (1/1) and herpetofauna (4/4) and some birds (3/6) were missed. Fifty percent of herpetofauna (2/4) and 30.8% (4/13) of mammals equal to or larger than a squirrel were missed by vehicle. The one bird larger than a squirrel was not missed by vehicle. Missed roadkills were located both in the roadway (57.1%, 8/14) and verge (42.9%, 6/14) and did not significantly differ by location (x^2=0.28; p=0.60) (Table 1). All mammalian roadkills (5/5) missed were in the verge and all of the avian roadkills (3/3) missed were in the roadway. More herpetofaunal roadkills missed by vehicle were located in the roadway (83.3%, 5/6) than in the verge (16.7%, 1/6).

On average, mammalian roadkills persisted (hours) longer (min=0, max=384; average=3.11 days) than herpetofaunal (min=4, max=164; average=1.81 days) and avian (min=0, max=116; average=1.07 days) roadkills (Table 3). Small herpetofaunal roadkills (less than squirrel size) persisted longer on average than small avian and mammalian roadkills on

roadways. Of the 11 roadkills persisting more than a day, 27.3% (3/11) were located in the verge and 72.7% (8/11) were located in the roadway (Table 1). For the 18 roadkill persisting for a day or less, 44.4% (8/18) were located in the verge and 55.6% (10/18) were located in the roadway. A White-tailed Deer and Nine-banded Armadillo persisted longer than a week with the White-tailed Deer persisting for two weeks from the observation date until the end of the survey period. One Virginia Opossum was removed by a resident after the driving survey and prior to the walking survey, resulting in zero persistence time.

DISCUSSION

Considering the difficulty of observing and identifying roadkills while conducting a driving survey, it is clear that walking roadways help detect more roadkills. Detection of roadkills in this study were influenced by various factors, such as carcass size and location. As seen in this study and previous studies (Boitet and Mead 2014, Langen et al. 2007, Slater 2002), animals smaller than a squirrel were often missed by driving survey. Beckmann and Shine (2015) described how identification of small carcasses was difficult due to their size and repeated flattening by vehicles. Most small carcasses found in the roadway in this study were flattened. For example, half of the snakes were flattened and had to be removed for identification. However, two birds at the edge of the road were not flattened, possibly due to their location at the edge of the roadway and were probably missed due to vegetation obscuring them from view even though the Pine Warbler (*Setophaga pinus*) was brightly colored. Three other birds, a Northern Cardinal (*Cardinalis cardinalis*), Gray Catbird (*Dumetella carolinensis*), and Carolina Chickadee (*Poecile carolinensis*), were not missed while driving, even though they were smaller than a squirrel. The Northern Cardinal was brightly colored and contrasted with the roadway increasing visibility. The Gray Catbird was probably detected due to the vehicle slowing down at

the end of the survey section. Their locations in the roadway may be due to their low mass inhibiting propulsion into the verge. However, one exception was the Carolina Chickadee that was detected by the driving survey. It was struck by the survey vehicle and thrown into the verge. Detection of roadkill in the verge is difficult because of vegetation height and the presence of ditches (Carvalho et al. 2014, Clevenger et al. 2003). The two additional small roadkills located in the verge, (Eastern Chipmunk [*Tamias striatus*] and Southern Leopard Frog [*Lithobates sphenocephalus*]), were missed by driving survey probably due to the vegetation height. Although roadkill larger than a squirrel should be easily identifiable by vehicle, several were not. Two snakes (Copperhead [*Agkistrodon contortrix*] and Rat Snake [*Pantherophis alleghaniensis*]) located in the roadway were missed by driving survey, probably due to their coloration not contrasting with the roadway and extreme flattening. The four large mammals in the verge were missed most likely due to their locations, suggesting that vegetation height and verge topography were key factors influencing their detection.

The movement of mammals across roadways varies throughout the year in response to daily and seasonal activity including reproductive periods and temperatures. These movements may influence detection rates of mammals in a roadkill survey. Smith-Patten and Patten (2008) found Virginia Opossum roadkills peak from March-May in the southern Great Plains. Additionally, Caro et al. (2000) found Virginia Opossum breeding periods yield high roadkill observations from November-February in California. However, in the current study, Virginia Opossums were recorded only in September and October. An increase in Virginia Opossums at this time of year is not likely related to enhanced movements while searching for mates as their breeding season begins in late December to early January in Georgia (Boitet and Mead 2014, McManus 1974). They may have been on the roadway scavenging roadkill or crossing the roadway to forage elsewhere. For other mammalian roadkills, e.g. White-tailed Deer and

Northern Raccoons, observations coincided with the breeding periods for each taxon, similar to those made by Boitet and Mead (2014).

Herpetofauna movements may also impact observations during roadkill surveys. In the southeast, 61.5% of snakes and 83.3% of anurans observed in a roadkill study were recorded in spring during a single breeding period (Coleman et al. 2008). However, in the current study, herpetofauna were observed in every month from April-September except July. Most amphibians breed during periods of regular rainfall, usually coinciding with late winter and early spring in North America (Glista and DeVault 2008), so it was interesting that no amphibians were found on the roadway during those months in this study. There are three culverts along this section of Highway 212 that amphibians may have used to cross under the roadway. Only one amphibian, the Southern Leopard Frog, was found as roadkill during the survey period in the month of June. However, Southern Leopard Frogs typically breed from December-February (Jensen et al. 2008). Because the majority of herpetofaunal roadkills were reptiles, their occurrence on the roadway may have been due to thermoregulating on warm roadways (Beckmann and Shine 2015).

Typically, birds are mostly found as roadkill during the breeding season because of increased movements for foraging and fledglings leaving the nest in April and May (Husby 2016). Because most birds in this study were found outside of the breeding period, it appears that the breeding period was not influential. Additionally, all avian roadkills observed are considered non-migrating, year-round resident birds in this area (Schneider et al. 2010), so it is not unusual to see these birds throughout the year outside of the breeding period. Although the presence of roadkill usually increases scavenging by Turkey Vultures, Black Vultures, and American Crows and scavengers are often struck by vehicles (Vidal-Vallés et al. 2018), only one American Crow was found as roadkill in this study. Furthermore, the low observed number of birds may be related to the carcasses adhering to the front of a vehicle and falling off when the vehicle slows

down or stops. Although not an avian species, a radio-collared Squirrel Glider (*Petaurus norfolcensis*) was found roadkilled 500 km from the initial study site in Australia (Soanes et al. 2015). This was due to the Squirrel Glider getting stuck on the front of the vehicle and transported. Therefore, it is safe to assume a few avian roadkills may have been transported outside of the survey section.

Scavengers and displacement of carcasses affect roadkill detections due to varying lengths of persistence in the roadway or verge. Herpetofauna smaller than a squirrel persisted longer than mammals and birds smaller than a squirrel. This may be due to the smaller size of herpetofauna and the frequently observed flattening by vehicle. However, Antworth et al. (2005) found that body condition does not affect the persistence of carcasses. Many of the snakes observed as roadkill were flattened and persisted longer than larger mammals even though they were on the roadway. The size of the animal typically influences persistence because scavengers remove small carcasses from the roadway quicker than large carcasses, but in this study small carcasses were left in the roadway longer than large carcasses. Antworth et al. (2005) and Beckmann and Shine (2015) observed that roadkill was scavenged earlier in the day and more quickly if the carcass was small, ultimately decreasing the persistence of smaller roadkills, which coincides with small mammalian and small avian carcass persistence. Because persistence was measured based on the survey days, there is the possibility that removal by person (Georgia Department of Transportation [GDOT] worker or civilian) or scavenger occurred immediately before or after arrival to the location. For example, a Virginia Opossum was recorded while driving but not while walking due to the property owner removing the roadkill prior to the walking survey. The Virginia Opossum was still counted for the walking survey due to its observation during the driving survey. Since the majority of roadkills persisted for a day or less and the survey route was monitored only twice a week, a large percentage of roadkills were

likely missed in the walking survey between Thursday and Tuesday of the next week, perhaps as high as 30%.

A concurrent daily driving survey (prior to sunrise and at late afternoon) of a large portion of Highway 212 recorded an additional 12 roadkills (White-tailed Deer [3], Eastern Gray Squirrels [3], Virginia Opossums [2], Domestic Dog [1], Nine-banded Armadillo [1], hawk [1], and small bird [1]) in the study area that were not included in this survey (Mead, personal comm.). Four of the twelve roadkills (White-tailed Deer, Eastern Gray Squirrel, Domestic Dog, hawk) were observed on days when the survey route was walked, however because the daily survey was driven in the early morning and at dusk, the amount of time between the two surveys may have given scavengers or GDOT workers time to remove the animals from the roadway. Slater (2002) observed that an animal hit in the morning was more likely to be scavenged quickly if the size of the animal was small and an animal hit in the evening was more likely to be scavenged quickly if the size of the animal was large. If the 12 roadkills are added to the current study, a total of 41 roadkills were observed along the roadway during the survey period, increasing the rate to 35.34/km/yr.

The walking roadkill rate was twice as large as the driving roadkill rate. Alternatively, in a walking and driving herpetofaunal survey conducted in New York, Langen et al. (2007) found that walking short segments resulted in a roadkill rate of 175.64/km/yr and driving the entire route resulted in a rate of 0.41/km/yr. Although the difference between the rates in the current study contrasts greatly with Langen et al. (2007) due to the small number of roadkills observed, it still shows that walking survey routes greatly increases roadkill rates compared to just driving the route. In a previous driving survey conducted in Baldwin County, Georgia, Boitet and Mead (2014) observed 6 mammalian roadkills (5.17/km/yr) on the same 1.16 km of Highway 212 as the current survey (12.07/km/yr). Roadkill rates tend to vary per animal group. Other studies in

the United States focusing on mammalian roadkills have found varying rates from: 1.44/km/yr on 206.3 km in New York (Barthelmess and Brooks 2010) to 3.55/km/yr on 158.5 km in the southern Great Plains (Glista and DeVault 2008). Both of these surveys were conducted as driving surveys for approximately one year with no preference for mammalian reproductive periods. The herpetofaunal roadkill rate for the current study is miniscule compared to herpetofaunal rates in other studies. Dutta et al. (2016) observed herpetofaunal roadkill at a rate of 139.14/km/yr on 3.5 km. However, that survey occurred only during peak breeding activity from April-July and the rate is higher than would be expected throughout the year. Smith and Dodd (2003) observed roadkilled mammals, birds, and herpetofauna for an entire year along 3.2 km of roadway and found a higher roadkill rate of 569.06/km/yr. This is likely due to location of the roadway through a preserve and year-round herpetofaunal activity. Both surveys were conducted as walking surveys, so they were able to detect small herpetofauna more accurately than a driving survey. Husby (2016) found an avian roadkill rate of 4.84/km/yr by driving along the same 25 km for almost five years. The current survey had a slightly larger avian roadkill rate, probably due to the use of both walking and driving survey methods.

The current study illustrates the importance of attaining accurate roadkills numbers and rates because of the percentage missed in the driving survey. Because Boitet and Mead (2014) conducted part of a survey on Highway 212 that includes the current survey's section, the percentage missed while driving can be calculated for that section. In the 1.16 km section, the driving survey observed 6 roadkills, and the estimation is calculated as 5 roadkills missed. This percentage could be applied to other surveys, however there are limitations—the same variables must be present in order to achieve an accurate estimation due to various influences. Location, road characteristics, animals, and vegetation must all be similar in order for rates to be calculated

accurately. Nevertheless, walking surveys are still considered to be more accurate in detecting total roadkills than driving surveys.

CONCLUSION

In this survey, a little less than half of the roadkills were missed by the vehicle survey, indicating that roadkill rates are greatly underestimated using this survey method. As many as 75% of herpetofaunal, 44% of avian, and 36% of mammalian roadkills may be missed in a driving survey. Most of the roadkills smaller than an Eastern Gray Squirrel were missed by vehicle. Because of the short persistence time of the observed roadkill, survey routes should be driven every day, maybe multiple times a day, for a more accurate count. Larger driving surveys would benefit by walking shorter segments to increase the likelihood of roadkill observations and to determine the percent of roadkills missed by driving. Furthermore, if the survey route is short, walking instead of driving would improve roadkill detection. This study clearly demonstrates that walking surveys are imperative to achieving accurate roadkill numbers and should be considered when roadkill sampling occurs.

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LITERATURE CITED

Andrews, K.M., J.W. Gibbons, and D.M. Jochimsen. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. Herpetological Conservation 3:121-143.

Antworth, R.L., D.A. Pike, and E.E. Stevens. 2005. Hit and run: effects of scavenging on estimates of roadkilled vertebrates. Southeastern Naturalist 4:647-656. DOI: https://www.jstor.org/stable/3878229.

Aresco, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69:549-560. DOI: https://doi.org/10.2193/0022-541X(2005)069[0549:MMTRHM]2.0.CO;2.

Bailey, M.A., J.N. Holmes, K.A. Buhlmann, and J.C. Mitchell. 2006. Habitat management guidelines for amphibians and reptiles of the southeastern United States. Partners in Amphibian and Reptile Conservation Technical Publication HMG-2, Montgomery, Alabama, 88 pp. DOI: dx.doi.org/10.3996/092015-JFWM-085.S2.

Barthelmess, E.L., and M.S. Brooks. 2010. The influence of body-size and diet on road-kill trends in mammals. Biodiversity Conservation 19:1611-1629. DOI: 10.1007/s10531-010-9791-3.

Beckmann, C., and R. Shine. 2015. Do the numbers and locations of road-killed anuran carcasses accurately reflect impacts of vehicular traffic? The Journal of Wildlife Management 79:92-101. DOI: https://doi.org/10.1002/jwmg.806.

Boitet, E.R., and A.J. Mead. 2014. Application of GIS to a baseline survey of vertebrate roadkills in Baldwin County, Georgia. Southeastern Naturalist 13:176-190. DOI: 10.1656/058.013.0117.

Caro, T.M., J.A. Shargel, and C.J. Stoner. 2000. Frequency of medium-sized mammal road kills in an agricultural landscape in California. The American Midland Naturalist Journal

144:62-69. DOI: https://doi.org/10.1674/0003-0031(2000)144[0362:FOMSMR]2.0.CO;2.

Carvalho, N.C., M.O. Bordignon, and J.T. Shapiro. 2014. Fast and furious: a look at the death of animals on the highway MS-080, Southwestern Brazil. Iheringia Série Zoologia 104:43-49. DOI: http://dx.doi.org/10.1590/1678-4766201410414349.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349. DOI: https://doi.org/10.1046/j.0021-8901.2001.00678.x.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15-26. DOI: https://doi.org/10.1016/S0006-3207(02)00127-1.

Coleman, J.L., N.B. Ford, and K. Herriman. 2008. A road survey of amphibians and reptiles in a bottomland hardwood forest. Southeastern Naturalist 7:339-348. DOI: https://doi.org/10.1656/1528-7092(2008)7[339:ARSOAA]2.0.CO;2.

Collinson W.J., H.T. Davies-Mostert, and W. Davies-Mostert. 2017. Effects of culverts and roadside fencing on the rate of roadkill of small terrestrial vertebrates in northern Limpopo, South Africa. Conservation Evidence 14:39-43.

Conard, J.M., and P.S. Gipson. 2006. Spatial and seasonal variation in wildlife-vehicle collisions. The Prairie Naturalist 38:251-258.

Cristoffer, C. 1991. Road mortalities of northern Florida vertebrates. Florida Scientist 54:65-67. DOI: https://www.jstor.org/stable/24320434.

Dutta, S., H.P. Jana, S. Saha, and S.K. Mukhopadhyay. 2016. The cause and consequences of road mortality of herpetofauna in Durgapur, West Bengal, India. Russian Journal of Ecology 47:88-95. DOI: 10.1134/S1067413616010033.

Federal Highway Administration (FHWA). 2008. Wildlife-Vehicle Collision Reduction Study: Report to Congress. Available online at https://www.fhwa.dot.gov/publications/research/safety/08034/exec.cfm. Accessed 28 October 2017.

Forman, R.T.T., and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology, Evolution, and Systematics 29:207-231. DOI: https://doi.org/10.1146/annurev.ecolsys.29.1.207.

Glista, D.J., and T.L. DeVault. 2008. Road mortality of terrestrial vertebrates in Indiana. Proceedings of the Indiana Academy of Science 117:55-62.

Glista, D.J., T.L. DeVault, and J.A. DeWoody. 2007. Vertebrate road mortality predominantly impacts amphibians. Herpetological Conservation and Biology 3:77-87.

Husby, M. 2016. Factors affecting road mortality in birds. Ornis Fennica 93:212-224.

Inbar, M., and R.T. Mayer. 1999. Spatio-temporal trends in armadillo diurnal activity and road-kills in central Florida. Wildlife Society Bulletin 27:865-872. DOI: https://www.jstor.org/stable/3784110.

Jensen, J.B., C.D. Camp, W. Gibbons, and M.J. Elliott. 2008. Amphibians and Reptiles of Georgia. University of Georgia Press, Athens, GA. 575 pp.

Kanda, L.L., T.K. Fuller, and P.R. Sievert. 2006. Landscape associations of road-killed Virginia Opossums (*Didelphis virginiana*) in Central Massachusetts. The American Midland Naturalist 156:128-134. DOI: 10.1674/0003-0031(2006)156[128:LAORVO]2.0.CO;2.

Kociolek, A., C. Grilo, and S. Jacobson. 2015. Flight doesn't solve everything: mitigation of road impacts on birds. Handbook of Road Ecology. United States Forest Service. 8 pp.

Langen, T.A., A. Machniak, E.K. Crowe, C. Mangan, D.F. Marker, N. Liddle, and B. Roden. 2007. Methodologies for surveying herpetofauna mortality on rural highways. The Journal of Wildlife Management 71:1361-1368. DOI: https://doi.org/10.2193/2006-385.

Lester, D. 2015. Effective wildlife roadkill mitigation. Journal of Traffic and Transportation Engineering 3:42-51. DOI: 10.17265/2328-2142/2015.01.005.

Loughry, W.J., and C.M. McDonough. 1996. Are road kills valid indicators of armadillo population structure? The American Midland Naturalist 135:53-59. DOI: 10.2307/2426871.

Main, M.B. and G.M. Allen. 2002. Landscape and seasonal influences on roadkill of wildlife in southwest Florida. Florida Scientist 65:149-158.

McManus, J.J. 1974. *Didelphis virginiana*. Mammalian Species 40:1-6.

Miller, K.V., L.I. Muller, and K.L. Demarais. 2003. White-tailed deer (*Odocoileus virginianus*). Pp. 906-930 *In* Wild Mammals of North America: Biology, Management, and Conservation, Feldhamer G.A., Thompson B.C. and Chapman J.A. (Eds). The Johns Hopkins University Press, Baltimore, Maryland, USA.

Ogletree, K.A., A.J. Mead, and E.R. Boitet. 2019. Identifying Roadkill Hotspots Using a Running Average. Georgia Journal of Science 77, No. 2, Article 3, 1-6. DOI: https://digitalcommons.gaacademy.org/gjs/vol77/iss2/3/.

Schneider, T.M., G. Beaton, T.S. Keyes, and N.A. Klaus (Eds.). 2010. The Breeding Bird Atlas of Georgia. University of Georgia Press Athens, Georgia. 497 pp.

Seibert, H.C., and J.H. Conover. 1991. Mortality of vertebrates and invertebrates on an Athens County, Ohio, highway. Ohio Journal of Science 91:163-166. DOI: http://hdl.handle.net/1811/23464.

Slater, F.M. 2002. An assessment of wildlife road casualties – the potential discrepancy between numbers counted and numbers killed. Web Ecology 3:33-42. DOI: https://doi.org/10.5194/we-3-33-2002.

Smith, L.L., and C.K. Dodd, Jr. 2003. Wildlife mortality on U.S. Highway 441 across Paynes Prairie, Alachua County, Florida. Florida Scientist 66:128-140. DOI: https://www.jstor.org/stable/24321153.

Smith-Patten, B.D., and M.A. Patten. 2008. Diversity, seasonality, and context of mammalian roadkills in the southern Great Plains. Environmental Management 41:844-852. DOI: 10.1007/s00267-008-9089-3.

Soanes, K., M.C. Lobo, and R. van der Ree. 2015. Radio-collared squirrel glider (*Petaurus norfolcensis*) struck by vehicle and transported 500 km along freeway. Australian Mammalogy 38:1-5. DOI: https://doi.org/10.1071/AM15013.

Steele, M.A., and J.L. Koprowski. 2001. North American Tree Squirrels. Smithsonian Books, Washington, D.C. 201 pp.

Swihart, R.K., and N.A. Slade. 1984. Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster*. Journal of Mammalogy 65:357-360. DOI: https://www.jstor.org/stable/1381184.

Vidal-Vallés, D., A. Rodríguez, and E. Pérez-Collazos. 2018. Bird roadkill occurrences in Aragon, Spain. Animal Biodiversity and Conservation 41:379-388. DOI: https://doi.org/10.32800/abc.2018.41.0379.

FIGURE CAPTION

FIGURE 1. Roadkill observations (white = detected while driving, cyan = detected while walking, red = detected while driving and walking) and culvert locations (white arrows) along the survey section (yellow line) on Highway 212 in Baldwin County, Georgia. Hill bottoms are designated by white arrows. R = residential, P = pond, O = small field, W = woodland, and F = recreational fields. Aerial photo from Google Earth (2018).

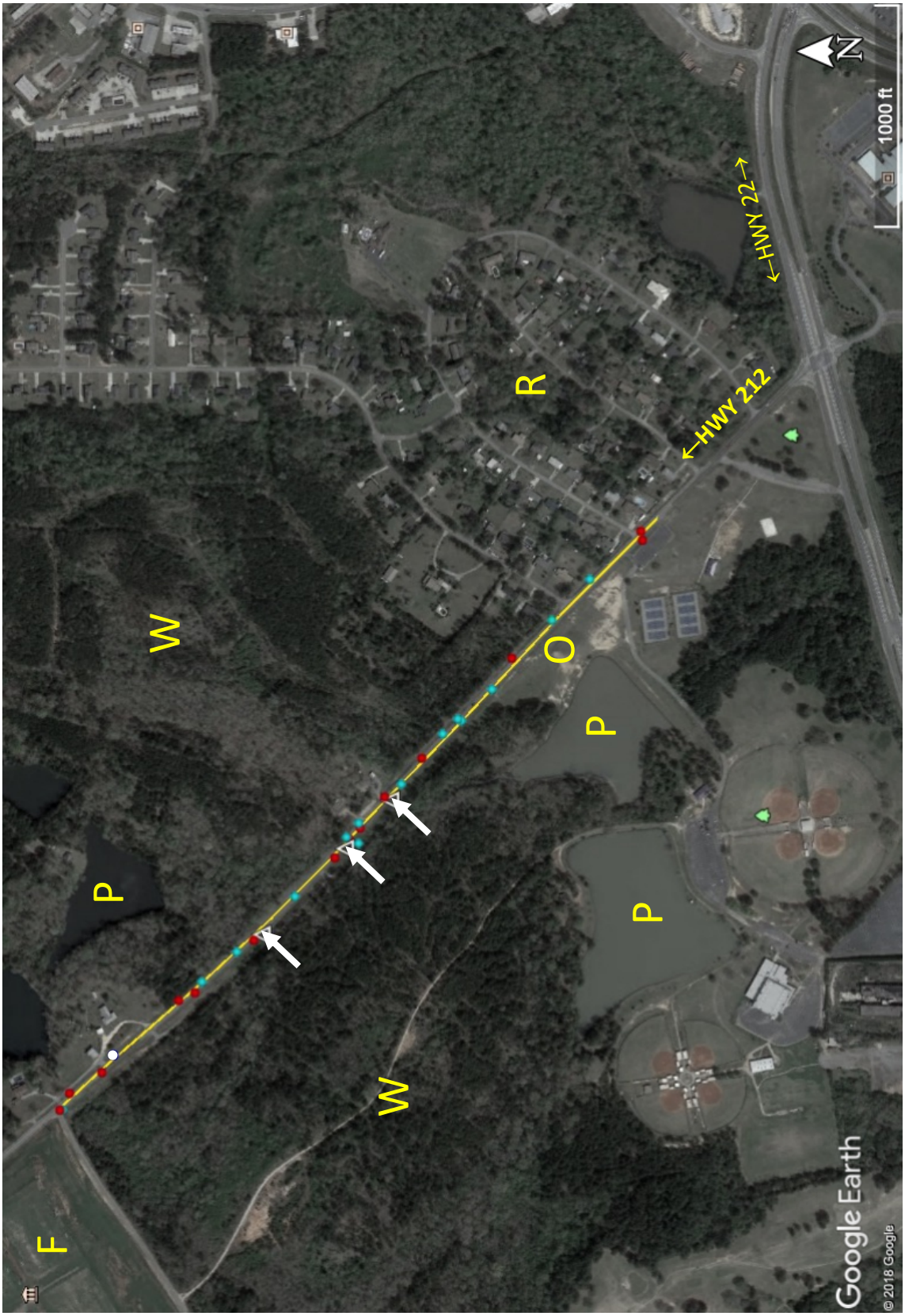

Figure 1.

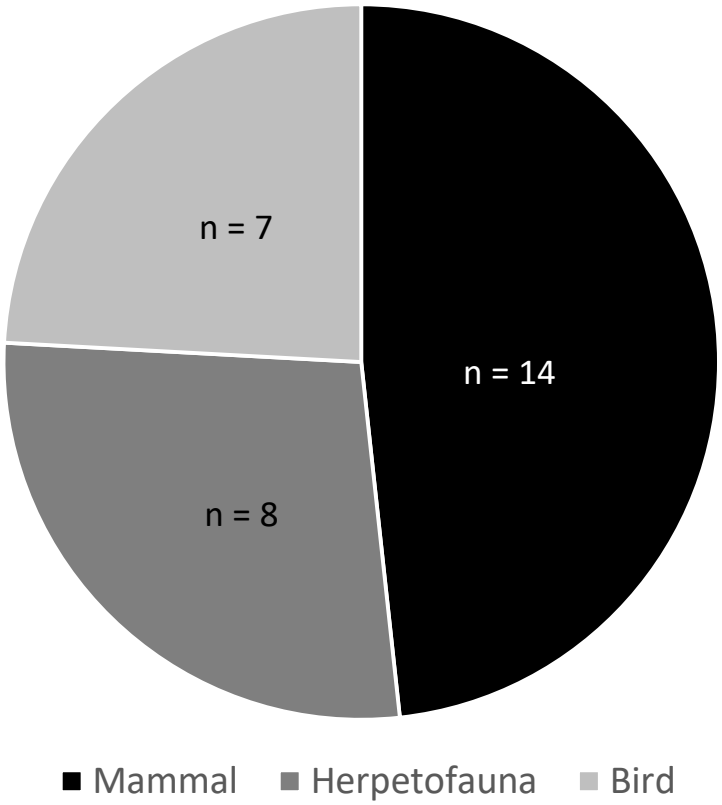

Figure 2. Number of vertebrate roadkill observed by type of animal (mammal, herpetofauna, bird).

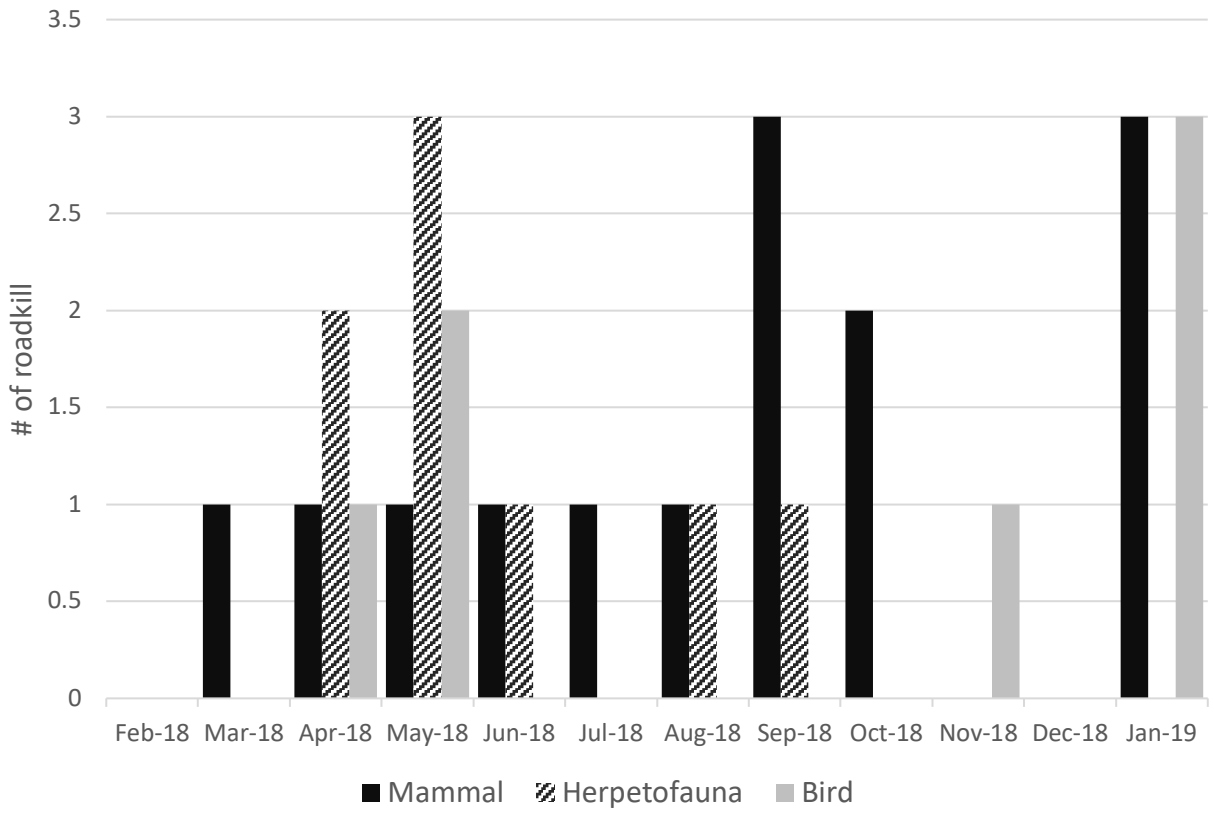

Figure 3. Number of vertebrate roadkills observed along Highway 212 for each month during the survey period according to type of animal.

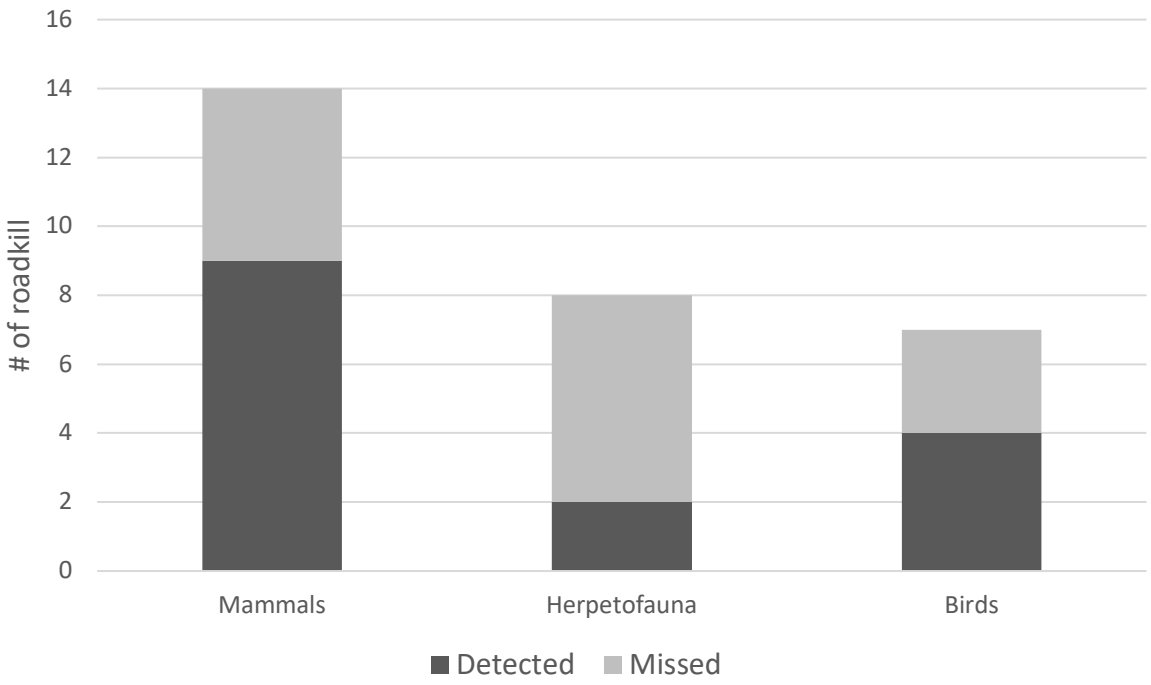

Figure 4. Number of vertebrate roadkill detected and missed by the driving survey according to type of animal.

Date	Common Name	Distance (m)	Missed by vehicle (Y/N)	Persistence (median days)	On road (R) or verge (V)
3-20-2018	Nine-banded armadillo	535.81	N	7.5	R
4-10-2018	White-tailed deer	197.9	N	4.5	R
4-17-2018	Eastern box turtle	1079.11	N	1	R
4-19-2018	Red-bellied water snake	24.3	N	2.5	R
4-26-2018	American crow	31.23	N	0.5	V
5-1-2018	Rat snake	832.23	Y	1	R
5-8-2018	Brown snake*	323.98	Y	1	R
5-8-2018	Rat snake*	894.58	Y	4.5	R
5-10-2018	Northern raccoon	649.59	N	2.5	R
5-10-2018	Chipping sparrow*	1152.69	Y	0.5	R
5-10-2018	Northern cardinal*	455.16	N	2.5	R
6-12-2018	Southern leopard frog*	587.63	Y	1	V
6-14-2018	Eastern gray squirrel	803.55	N	2.5	R
7-31-2018	Eastern gray squirrel	590.17	N	0.5	R
8-14-2018	Domestic cat	126.66	Y	1	V
8-23-2018	Smooth earth snake*	506.01	Y	2.5	R
9-18-2018	Copperhead	384.23	Y	1	R
9-18-2018	Virginia opossum	611.43	N	1	R
9-18-2018	Virginia opossum	910.87	N	1	R
9-18-2018	Virginia opossum	1051.34	N	0	V
10-2-2018	Virginia opossum	935.43	N	1	V
10-30-2018	Eastern chipmunk*	197.9	Y	0.5	V
11-22-2018	Gray catbird*	1133.06	N	2.5	V
1-15-2019	Northern raccoon	386.98	Y	1	V
1-15-2019	Northern raccoon	416.49	Y	4.5	V
1-15-2019	White-tailed deer	606.43	Y	16	V
1-15-2019	Pine warbler*	613.02	Y	0.5	R
1-15-2019	Unidentifiable bird*	722.33	Y	0.5	R
1-22-2019	Carolina chickadee*	276.93	N	0.5	V

Table 1. Vertebrate roadkill observed on Highway 212 in Baldwin County, Georgia. * = animals smaller than an Eastern Gray Squirrel.

Species	Common Name	Number Observed
Didelphis virginiana	Virginia opossum	4
Procyon lotor	Northern raccoon	3
Odocoileus virginianus	White-tailed deer	2
Pantherophis obsoletus	Rat snake	2
Sciurus carolinensis	Eastern gray squirrel	2
Unidentifiable bird	Unidentifiable bird	1
Agkistrodon contortrix	Copperhead	1
Cardinalis cardinalis	Northern cardinal	1
Corvus brachyrhynchos	American crow	1
Dasypus novemcinctus	Nine-banded armadillo	1
Dumetella carolinensis	Gray catbird	1
Felis catus	Domestic cat	1
Lithobates sphenocephalus	Southern leopard frog	1
Nerodia erythrogaster	Red-bellied water snake	1
Poecile carolinensis	Carolina chickadee	1
Setophaga pinus	Pine warbler	1
Spizella passerina	Chipping sparrow	1
Storeria dekayi	Brown snake	1
Tamias striatus	Eastern chipmunk	1
Terrapene carolina	Eastern box turtle	1
Virginia valeriae	Smooth earth snake	1
Total		**29**

Table 2. Number of species observed in vertebrate roadkill study.

Common Name	Persistence Min (hours)	Persistence Max (hours)	Median (hours)
White-tailed deer	384	384	384
Nine-banded armadillo	172	188	180
White-tailed deer	52	164	108
Northern raccoon	52	164	108
Northern raccoon	4	116	60
Eastern gray squirrel	4	116	60
Domestic cat	4	44	24
Virginia opossum	4	44	24
Virginia opossum	4	44	24
Virginia opossum	4	44	24
Northern raccoon	4	44	24
Eastern chipmunk	2	4	3
Eastern gray squirrel	2	4	3
Virginia opossum	0	0	0
Rat snake	52	164	108
Red-bellied water snake	4	116	60
Smooth earth snake	4	116	60
Rat snake	4	44	24
Eastern box turtle	4	44	24
Copperhead	4	44	24
Southern leopard frog	4	44	24
Snake	4	44	24
Northern cardinal	4	116	60
Gray catbird	4	116	60
Carolina chickadee	2	4	3
American crow	2	4	3
Bird	2	4	3
Chipping sparrow	0	2	1
Pine Warbler	0	2	1

Table 3. Minimum, maximum, and median number of hours vertebrate roadkill persisted on the roadway.

	Mammal		Herpetofauna		Birds	
	Small	Large	Small	Large	Small	Large
Detected while driving	0 (0%)	9 (64%)	0 (0%)	2 (25%)	3 (43%)	1 (14%)
Missed while driving	1 (7%)	4 (29%)	4 (50%)	2 (25%)	3 (43%)	0 (0%)

Table 4. Number of vertebrate roadkill detected and missed according to size (less than squirrel size [Small] versus equal to or larger than a squirrel [Large]) and type of animal.