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Foto de Portada: Roadkilled *Alouatta palliata* in Chepo, Panamá Este (foto © Sergio Bermúdez C.).

Wild animal roadkill in Panama (2007-2020)

Josué Ortega[1], Roberto Miranda[2], Juan J. Lezcano[2] & Sergio E. Bermúdez C.[2]

RESUMEN

Los atropellos se encuentran entre las principales causas de mortalidad no natural de la vida silvestre. En este trabajo se describen las especies de vertebrados silvestres atropellados en Panamá durante 2007-2020, a partir de observaciones no sistemáticas. Cada vía o carretera se caracterizó según el número de carriles, la presencia o ausencia de aceras y calzadas, el tipo de vía (camino de terracería, de un solo sentido, de dos y tres sentidos, asfaltado) y de la proximidad a una zona boscosa (p.e. bosque primario, bosque secundario, bosque de galería) en uno o ambos lados de la carretera, o paisaje antropogénico (p. ej. rural, urbano y suburbano). Las identificaciones de animales se realizaron mediante observación directa de los cadáveres o fotografías de identificación proporcionadas por investigadores y observadores. Se calculó el porcentaje de animales según el grupo taxonómico. Se contaron un total de 230 vertebrados silvestres, que representan 63 especies: cuatro especies de anfibios, 27 especies de reptiles, nueve especies de aves y 27 especies de mamíferos. Estas especies mantienen estatus de protección en Panamá o la región Neotropical: destacadas aves marinas, rapaces nocturnas, vertebrados arbóreos y carnívoros de tamaño mediano. El mayor número de accidentes ocurrió en vías pavimentadas de un solo sentido en cada dirección (n=167), seguidas de vías de doble sentido (n=44), carreteras de tres sentidos (n=4) y caminos de tierra (n=9), entre otros. En cuanto a la cobertura forestal que rodea las áreas de atropellos, 149 eventos ocurrieron en áreas con bosques a ambos lados del camino, 68 ocurrieron en áreas con bosques solo en un lado. En general, estos accidentes ocurrieron principalmente en zonas rurales y boscosas. Los datos muestran que la mortalidad de los vertebrados silvestres en las carreteras debe considerarse una de las preocupaciones más críticas de Panamá para la conservación de la biodiversidad. Establecer medidas de mitigación que reduzcan este impacto es un desafío que tenemos que afrontar en el corto, mediano y largo plazo en Panamá y otros países de la región.

Palabras clave: Impacto antropogénico, ecología vial, amenazas, mamíferos, aves rapaces, herpetofauna.

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ABSTRACT

Roadkill is among the leading causes of non-natural mortality of wildlife. To describe roadkilled wild vertebrates during 2007-2020 in Panamá, from non-systematic observations. Each road or highway was characterized according to the number of lanes, the presence or absence of sidewalksly and carriageway, the type of road (dirt road, one-way, two-way and three-way asphalt), and proximity to a wooded area (e.g. primary forest, secondary forest, gallery forest) in one or both side of the road, or anthropogenic landscape (e.g. rural, urban and suburban). Wild animal identifications were made by directly observing the carcasses or identifying photographs provided by researchers and observers. We calculated the percentage of animals for the taxonomic group. A total of 230 wild vertebrates were counted, representing 63 species: four amphibian species, 27 reptile species, nine bird species, and 27 species of mammals. These species maintain protected status in Panamá or the Neotropical region: outstanding seabirds, nocturnal birds of prey, arboreal vertebrates, and medium-sized carnivores. The highest number of accidents occurred on one-way paved roads in each direction (n=167), followed by two-way roads (n=44), three-way highways (n=4), and dirt roads (n=9), among others. Regarding the forest cover surrounding the roadkill areas, 149 events occurred in areas with forests on both sides of the way, 68 occurred in areas with forests only on one side. In general, these accidents occurred mainly in rural and forested areas. The data show that the mortality of wild vertebrates on the roads must be considered one of Panama most critical concerns for conserving biodiversity. Establishing mitigation measures that reduce this impact is a challenge that we have to face in the short, medium and long term in Panamá and other countries in the region.

Keywords: Anthropogenic impact, road ecology, threats, mammals, avian raptors, herpetofauna.

INTRODUCTION

Wildlife, vertebrates and invertebrates, is exposed to multiple threats related to the expansion of the human population, and roadkill is among the leading causes of non-natural mortality of wildlife (Sánchez-Soto *et al*. 2016, Sánchez-Soto 2017, Grilo *et al*. 2020, Pinto *et al*. 2020). Nevertheless, road-mortality is one of the least evaluated causes (Canal *et al*. 2018). Globally, it is estimated that millions of wild animals are killed by vehicular traffic each year, which impacts animal populations in various ways; it can be detrimental to endangered species.

Additionally, roadkill's cause significant human or economic losses (Mendoza and Palomares 2016, Ceia-Hasse *et al*. 2017, Canal *et al*. 2018, Grilo *et al*. 2020).

This relevance has encouraged some nations to emphasize the need to establish monitoring protocols that provide information allowing effective long-term prevention policies (Lester 2015, Schwartz *et al*. 2020). Moreover, in contrast to poaching and illegal wildlife trade, the impact of the roads can go unnoticed to authorities in some countries, because the events that caused the accident were not investigated and the number of species of dead animals was not monitored (Mendoza & Palomares 2016, Abra *et al*. 2019, Ibarra *et al*. 2022). On the other hand, from a legal point of view, roadkills in many countries are not sanctioned in the same ways that mistreatment of pets, even if they are species at risk of extinction.

Despite being a regrettable event from a conservation and economic point of view (Bissonette *et al*. 2008, Morelle *et al*. 2013), roadkill's can be useful and exploited for scientific purposes (Gottdenker *et al*. 2001, Borda-de-Água *et al*. 2014, Bermúdez *et al*. 2023). In this sense, monitoring the events provides valuable information to allow management measures that prevent or minimize accidents (Borda-de-Água *et al*. 2014, Ceia-Hasse *et al*. 2017, Ibarra-Portillo *et al*. 2022). Roadkill studies can give general information about what species inhabit an area, their movements, and new distribution data, establish the presence of rare species, provide information from prays and diet, and even describe new species (Gottdenker *et al*. 2001, Sánchez Soto *et al*. 2016, Sánchez Soto 2017, Schwarz *et al*. 2020; Rödel *et al*. 2023). In addition, carcasses may provide information on pathogens circulating in wild animals or the presence of parasites, which can be used as sentinels in studies of potential zoonoses (Gottdenker *et al*. 2001, Aguilar-Vargas *et al*. 2022, Bermúdez *et al*. 2023). In summary, the systematic use of roadkill carcasses could be helpful to extract ecological information about the species involved in the environment where the events occur (Ceia-Hasse *et al*. 2017, Pinto *et al*. 2020, Schwartz *et al*. 2020).

In Panama, road-killed mammals have provided new distribution records, e.g. the first data of crab-eating fox (*Cerdocyon thous* L., 1766) in that country (Tejera *et al*. 1999) and its presence on the western side of the Panamá Canal (Hody *et al*. 2019); the first observation of coyotes (*Canis latrans* Say, 1823) in the east side of the Panama Canal (Bermúdez *et al*. 2013); the increased distribution of the woody opossum, *Caluromys derbianus* (Waterhouse, 1841) (Ortega *et al*. 2021); information about tick-host relationships and detection of bacterial in ticks (Bermúdez *et al*. 2013, 2015, 2021, García *et al*. 2014, Bermúdez *et al*. 2015, 2021). Nonetheless, there are few systematic works on run-over wild animals. In this sense, Contreras and González (2018) reported the first checklist of roadkill animals, including 82 vertebrates of eight species (two domestic and six wild mammals), over three months of observation on a highway; and a study conducted near City of Panamá found 79 run-over animals belonging to 20 species in three years (Galvez 2021).

In this paper, we show data from 15 years of non-systematic observations of roadkill on several roads in Panamá. These data include species and were collected from different habitat types around the roads.

MATERIALS AND METHODS

Study sites and types of roads. The information was opportunistically extracted in highways and roads along Panama during 2007-2020. This data was provided to the authors by other people (see acknowledgements). Each road or highway was characterized according to the number of lanes, presence or absence of sidewalks and carriageways, and type of environment (e.g., crossing forests, pastures, rural towns, or urban towns).

Additional and particular observations were made in the Omar Torrijos Road (OTR), which crosses a stretch of 32 km from the City of Panamá to Gamboa. The last 11 km of OTR crosses Soberania National Park (SNP) and Summit Municipal Park (SMP), two important protected areas on the west bank of the Panama Canal basin. On this road, fortuitous observations were made monthly from 2007 to 2020. Moreover, a special consideration was discussed in the observations on the Corredor Sur highway and the presence of aquatic birds road-killed.

Taxonomy of the Species. Authors identified species by directly observing carcasses or thoroughly examining photographs provided by fellow researchers and observers. In order to maintain data accuracy, we relocate animals away from the road or respectfully collect and donate carcasses to museums. Subsequently, the identified species were classified based on their conservation status, particularly concerning whether they were listed as endangered or not.

Location data. In each observation, the type of road (dirt road, one-way, two-way, and three-way asphalt) was identified. We determined if the point of collision was in or near a wooded area (1 km radius, 2 km radius and 3 km radius) and whether the wooded area was on one side or both sides of the road. The type of habitat where the accident occurred (e.g., primary forest, secondary forest, gallery forest, rural, urban and suburban) was also classified.

Data summarization and visualization. We calculated the percentage of animals for the taxonomic group. All the roadkill records were georeferenced and a map was created with the points to determine the most vulnerable areas for accidents during these observations.

RESULTS

We registered 230 wildlife roadkill records across the country, belonging to 63 species (33 families) of the four Class of terrestrial vertebrates. Mammals were the most affected group, accounting for 77.4% of all roadkill, followed of reptiles

(15.7%), birds (5.2%) and amphibians (1.7%) (Figs. 1, 2). Considering the Orders, the most affected are Carnivora (Mammalia), Squamata (Reptilia), Didelphimorphia and Pilosa (Mammalia), with 171 wildlife animal roadkill events. Table 1 reflects the characteristics of the events documented.
Descriptions related to the behaviour and conservation status of each species are treated in tables 2-4 for mammals, reptiles, amphibians, and birds, respectively.

Table 1. General characteristics of the wildlife roadkill in Panama (2007-2020) [N=230]

Animal Group		Individuals	(%)
	Mammals	178	77.4
	Reptiles	36	15.7
	Birds	12	5.2
	Amphibians	4	1.7
Activity			
	Diurnal	36	15.7
	Nocturnal	134	58.3
	Diurnal/Nocturnal	60	26
Habits			
	Predator	94	40.9
	Herbivorous	36	15.7
	Insectivorous	24	10.4
	Scavenger	3	1.3
	Omnivore	73	31.7
Orden			
	Carnivora	91	39.6
	Pilosa	24	10.4
	Rodentia	16	7.0
	Primates	13	5.7
	Didelphimorphia	25	10.9
	Cingulata	4	1.7
	Artiodactyla	5	2.2
	Crocodilia	4	1.7
	Testudines	1	0.4
	Squamata	31	13.5
	Accipitriformes	2	0.9
	Coraciformes	1	0.4
	Falconiformes	1	0.4
	Pelecaniformes	1	0.4
	Strigiformes	7	3.0
	Anura	4	1.7

Table 2. List of mammal roadkills recorded for activity, habits, and conservation status from Panama, 2007-2020

Order/Families	Scientific name	Roadkills	Activity	Habits	Conservation status
Carnivora					
Canidae	*Canis latrans*	14	Diurnal/Nocturnal	O	LC
Canidae	*Cerdocyon thous*	11	Nocturnal	O	LC
Canidae	*Urocyon cinereoargenteus*	7	Nocturnal	O	LC
Felidae	*Leopardus pardalis*	19	Nocturnal	P	LC
Felidae	*Leopardus wiedii*	2	Nocturnal	P	NT
Felidae	*Herpailurus yagouaroundi*	20	Nocturnal	P	LC
Mephitidae	*Conepatus semistriatus*	5	Nocturnal	P	LC
Mustelidae	*Galictis vittata*	3	Diurnal/Nocturnal	P	LC
Mustelidae	*Lontra longicaudis*	2	Diurnal/Nocturnal	P	NT
Procyonidae	*Nasua narica*	1	Diurnal/Nocturnal	O	LC
Procyonidae	*Potos flavus*	2	Nocturnal	O	LC
Procyonidae	*Procyon lotor*	5	Diurnal/Nocturnal	O	LC
Artiodactyla					
Cervidae	*Odocoileus virginianus*	5	Diurnal	H	LC
Cingulata					
Dasypodidae	*Dasypus novemcintus*	4	Nocturnal	I	LC
Didelphimorphia					
Didelphidae	*Caluromys derbianus*	9	Nocturnal	O	LC
Didelphidae	*Didelphis marsupialis*	16	Diurnal/Nocturnal	O	LC
Pilosa					
Bradypodidae	*Bradypus variegatus*	3	Diurnal/Nocturnal	H	LC
Megalonychidae	*Choloepus hoffmanni*	4	Diurnal/Nocturnal	H	LC
Cyclopedidae	*Cyclopes dorsalis*	1	Nocturnal	I	LC
Myrmecophagidae	*Tamandua mexicana*	16	Nocturnal	I	LC
Primates					
Atelidae	*Alouatta palliata trabeata*	4	Diurnal	H	VU
Atelidae	*Alouatta palliata palliata*	2	Diurnal	H	VU
Atelidae	*Alouatta p. aequatorialis*	1	Diurnal	H	VU
Cebidae	*Saimiri oerstedii*	3	Diurnal	O	EN
Cebidae	*Cebus capucinus*	1	Diurnal	O	VU
Callitrichidae	*Saguinus geoffroyi*	2	Diurnal	O	NT

Order/Families	Scientific name	Roadkills	Activity	Habits	Conservation status
Rodentia					
Caviidae	*Hydrochoerus isthmius*	11	Nocturnal	H	DD
Dasyproctidae	*Dasyprocta punctata*	2	Diurnal	H	LC
Erethizontidae	*Coendou rotschildii*	3	Nocturnal	H	LC

Legend: Habits: Predators (P), Herbivorous (H), Insectivorous (I), Omnivore (O); Conservation status: Endangered (EN), Vulnerable (VU), Near threatened (NT), Least concern (LC), and Data deficient (DD) according by International Union for Conservation of Nature (IUCN).

Table 3. List of Bird roadkills recorded for activity, habits, and conservation status from Panama, 2007-2020

Order/Families	Scientific name	Roadkills	Activity	Habits	Conservation status
Accipitriformes					
Cathartidae	*Coragyps atratus*	2	Diurnal	S	LC
Coraciformes					
Momotidae	*Momotus momota*	1	Diurnal	I	LC
Falconiformes					
Falconidae	*Milvago chimachima*	1	Diurnal	S	LC
Pelecaniformes					
Ardeidae	*Ardea alba*	1	Diurnal	P	LC
Strigiformes					
Strigidae	*Asio clamator*	2	Nocturnal	P	LC
Strigidae	*Glaucidium brasilianum*	1	Nocturnal	P	LC
Strigidae	*Megascops choliba*	1	Nocturnal	P	LC
Strigidae	*Ciccaba virgata*	1	Nocturnal	P	LC
Tytonidae	*Tyto alba*	2	Nocturnal	P	LC

Legend: Habits: Predators (P), Insectivorous (I), Scavenger (S); Conservation status: Least concern (LC) according by International Union for Conservation of Nature (IUCN).

Table 4. List of Amphibian and Reptile roadkills recorded for activity, habits, and conservation status from Panama, 2007-2020.

Order/Families	Scientific name	Roadkills	Activity	Habits	Conservation status
Anura					
Bufonidae	*Incilius signifer*	1	Nocturnal	I	LC
Bufonidae	*Rhinella centralis*	1	Nocturnal	O	LC
Bufonidae	*Rhinella horribilis*	1	Nocturnal	O	
Leptodactylidae	*Leptodactylus bolivianus*	1	Nocturnal	P	LC
Crocodilia					
Alligatoridae	*Caiman crocodilus*	4	Diurnal/Nocturnal	P	LC
Testudines					
Kinosternidae	*Kinosternon* sp.	1	Nocturnal	I	*
Squamata					
Iguanidae	*Iguana iguana*	1	Diurnal	H	LC
Boidae	*Boa imperator*	3	Diurnal/Nocturnal	P	LC
Boidae	*Corallus ruschenbergerii*	1	Diurnal/Nocturnal	P	LC
Boidae	*Epicrates maurus*	1	Diurnal/Nocturnal	P	LC
Colubridae	*Chironius grandisquamis*	1	Diurnal/Nocturnal	P	LC
Colubridae	*Enulius flavitorques*	1	Nocturnal	P	LC
Colubridae	*Erythrolamprus* sp.	1	Diurnal/Nocturnal	P	*
Colubridae	*Lampropeltis polyzona*	1	Diurnal/Nocturnal	P	LC
Colubridae	*Leptodeira rhombifera*	3	Nocturnal	P	LC
Colubridae	*Mastigodryas melanolomus*	1	Diurnal	P	LC
Colubridae	*Mastigodryas alternatus*	1	Diurnal	P	LC
Colubridae	*Ninia maculata*	1	Nocturnal	P	LC
Colubridae	*Phimophis guianensis*	1	Nocturnal	P	LC
Colubridae	*Phrynonax poecilonotus*	1	Diurnal	P	LC
Colubridae	*Pseudoboa neuwiedii*	1	Nocturnal	P	LC
Colubridae	*Spilotes pullatus*	1	Diurnal	P	LC
Elapidae	*Micrurus dissoleucus*	1	Diurnal	P	LC
Elapidae	*Micrurus nigrocinctus*	5	Diurnal	P	LC
Viperidae	*Bothriechis lateralis*	1	Nocturnal	P	LC
Viperidae	*Bothriechis nigroadspersus*	1	Nocturnal	P	LC
Viperidae	*Lachesis stenophrys*	3	Nocturnal	P	NT

Legend: Habits: Predators (P), Herbivorous (**H**), Insectivorous (I), Omnivore (O); Conservation status: Near threatened (NT), Least concern (LC) according by International Union for Conservation of Nature (IUCN). (*) Data no available.

Regarding accident sites, the highest number of accidents occurred on one-way paved roads in each direction (74.6%, n=167), followed by two-way roads (19.6%, n=44), three-way highways (1.8%, n=4), and dirt roads (4.0%, n=9). In general, these types of roads have a limit of speed of 40 km/h, 80 km/h, 110 km/h, and 30 km/h, respectively. Regarding the forest cover surrounding the road kill areas, 66.5% (n=149) occurred in areas with forests on both sides and within a radius of less than 1 km; 30.3% (n=68) occurred in areas with forest only on one side and with a radius of less than 1 km; 2.2% (n=5) in areas with forests on one side of the road and with a radius of less than 2 km; 0.5% (n=1) occurred in wooded areas on both sides and with a radius of less than 2 km; and 0.5% (n=1) occurred in areas with forest on only one side and with a radius of less than 3 km.

For the land use types in the surrounding areas, 36.1% (n=88) of the roadkill occurred in rural areas, 18% (n=46) in secondary forests, 18.9% (n=46) in suburban areas, 9.8% (n=24) in primary forests, 9.8% (n=24) in gallery forests and only 6.5% (n=16) in urban areas (Tables 1-4). With the exception of two individuals, all animals were identified to species level, which represents four amphibian species, 23 reptile species, nine bird species, and 27 species of mammals. In general, nocturnal animals seem more susceptible to being run over than diurnal ones (Fig. 3).

One hundred and seventy-eight roadkill mammals of 27 species, belonging to terrestrial and arboreal habitats, were found during this study (Table 2). In general, the most commonly found species was the jaguarundi, *Herpailurus yagouaroundi* (E. Geoffroy Saint-Hilaire, 1803) (8.9%, n=20), followed by the anteater ocelot (*Leopardus pardalis* L., 1758) (8.5%, n=19) and (*Tamandua mexicana* Saussure, 1860) (6.7%, n=15). The largest species road-killed was the white-tailed deer (*Odocoileus virginianus* Zimmermann, 1780) (2.2%, n=5), and there was evidence of roadkilled ponchos, *Hydrochoerus isthmius* (Goldman, 1912), and porcupines *Coendou rotschildii* (Thomas, 1902), which are the largest rodents in Panama. Order Carnivora presented the highest number of reports with 39.5% (n=91), corresponding to Felidae (17.8%, n=41), Canidae (13.9%, n=32), Procyonidae (3.5%, n=8), Mustelidae and Mephitidae (2.2%, n=5). Other groups that were strongly affected were Didelphimorphia (10.9%, n=25), and Pilosa with 10.4% (n=24) (Table 2).

Some mammals notables for their rarity or for be inconspicuous included: crab-eating fox, gray fox (*Urocyon cinereoargenteus* Schreber, 1775), margay (*Leopardus wiedii* Schinz, 1821), skunks *Conepatus semistriatus* (Boddaert, 1785), grisons (*Galictis vittata* Schreber, 1775), and otters *Lontra longicaudis* (Olfers, 1818). Moreover, collisions of arboreal animals were counted: porcopines, sloths (*Bradypus variegatus* Schinz, 1825 and *Choloepus hoffmanni* Peters, 1858), silky anteater, *Cyclopes dorsalis* (J. E. Gray, 1865), and kinkajous (*Potos flavus* Schreber, 1774). Primates represent 5.8% (n=13), including three subspecies of howler monkey *Alouatta palliata palliata* (Gray, 1849) (*Alouatta p. trabeata, Alouatta p. aequatorialis*) that are in danger of extinction, white-faced capuchin *Cebus capucinus* (L., 1758), and the Chiriqui squirrel monkey (*Saimiri oerstedii*

citrinellus Reinhardt, 1872), which is in critical danger of extinction. Of these all mammals are under international protection categories (IUCN), and 21 are on the list of threatened species in Panama (Anonymous 2016).

Regarding birds, we observed seven individuals of roadkill nocturnal birds of prey, belonging to the families Strigidae [*Ciccaba virgata* Cassin, 1849, *Glaucidium brasilianum* (Gmelin, 1788), *Megascops choliba* (Vieillot, 1817), *Ansio clamator* (Vieillot, 1807)], and Tytonidae (*Tyto alba* Scopoli, 1769). Dozens of cormorants, pelicans, and other unidentified water birds were found killed each year, during October-April along Corredor Sur Highway (not tabled). Sporadic observations included two black vultures *Coragyps atratus* (Bechstein, 1793), and one observation each of yellow-headed caracara, *Milvago chimachima* (Vieillot, 1816), the great egret (*Ardea alba* L., 1758), and motmot (*Momotus lessonii* Lesson, 1842) (Table 3).

Finally, 40 ectothermic terrestrial vertebrates, included four individuals of amphibians corresponding to the families Leptodactylidae and Bufonidae, were listed during our observation. Of these stand out the toad *Rhinella centralis* (Narvaes and Rodrigues, 2009), because is an amphibian endemic to Panama. Twenty-seven species of reptiles belonging to the Orders Squamata (lizards, and arboreal and snakes), Crocodilia (caimans), and Testudines (turtles) were found killed on roads (Table 4). Among ectothermic vertebrates, Squamata was the most affected (13.5%, n=31). Among the outstanding species, either for being rare or poisonous, were the pygmy coral snake *Micrurus dissoleucus* (Cope, 1860), Central America coral snake (*Micrurus nigrocinctus* Girard, 1854), arboreal vipers [*Bothriechis lateralis* Peters, 1862, and *Bothriechis nigroadspersus* (Berthold, 1846)], and Central American bushmaster (*Lachesis stenophrys* Cope, 1875). Of these, *M. dissoleucus* and *B. lateralis* are considered at risk of extinction, and *L. stenophrys* is considered vulnerable in Panamá (Anonymous 2016).

DISCUSSION

Various factors influence road collision with fauna, especially those related to the characteristics of the roads (e.g. presence of sideways, carriageways, forests), or the hour that the event occurred (Coffin 2007, Attademo *et al*. 2011, Bueno *et al*. 2015; Mendoza and Palomares 2016). Considering the animals, they themselves represent a diversity of factors to consider (e.g. age, behavior), whether they are healthy or whether a disease affects their normal behavior; in the latter, injured animals would be more likely to be road-killed, compared to elusive or uninjured animals. Moreover, car lights may confuse or dazzle animals at twilight hours or at night (Borda-de-Agua *et al*. 2014, Grilo *et al*. 2020).

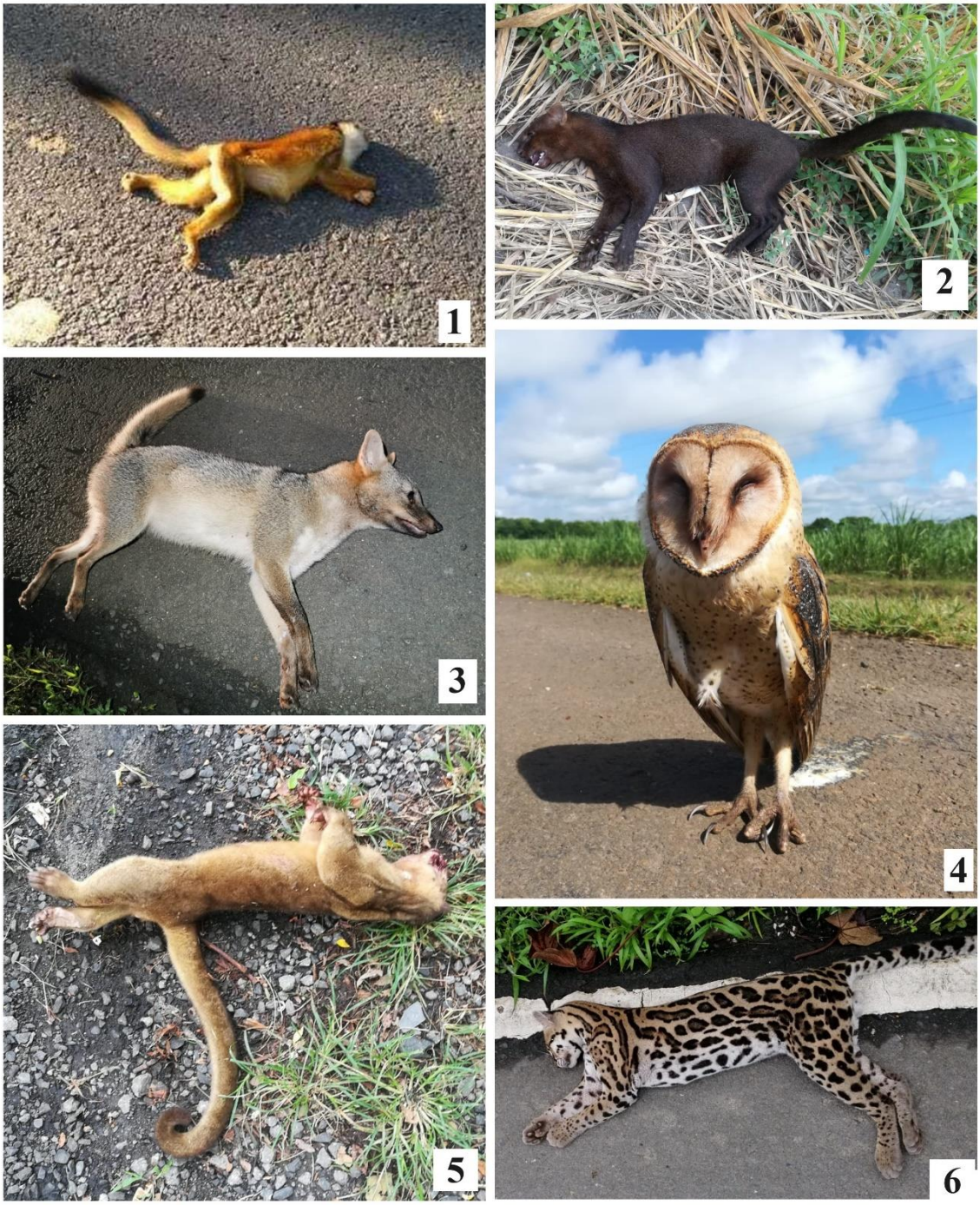

Figure 1. Some wild animals roadkill during our observations. 1. *Saimiri oerstedii*. 2. *Herpailurus yagouaroundi*. 3. *Cerdocyon thous*. 4. *Tyto alba*. 5. *Potos flavus*. 6. *Leopardus pardalis*..

Figure 2. Some wild animals roadkill during our observations. 1. *Conepatus semistriatus*. 2. *Cerdocyon thous*. 3. *Coendou rotschildii*. 4. *Urocyon cinereoargenteus*. 5. *Hydrochoerus isthmius*. 6. *Canis latrans*.

On the other hand, factors intrinsic to drivers also play a decisive role when an accident occurs. (Mendoza and Palomares 2016). In this sense, accidents can be produced by many factors such as recklessness, drunkenness, inexperience, or bad condition of the vehicle. Together, all these factors mean that the study of these events involves realistic observations that avoid erroneous interpretations, especially when it is intended to apply analyzes or statistics that do not include all these variables.

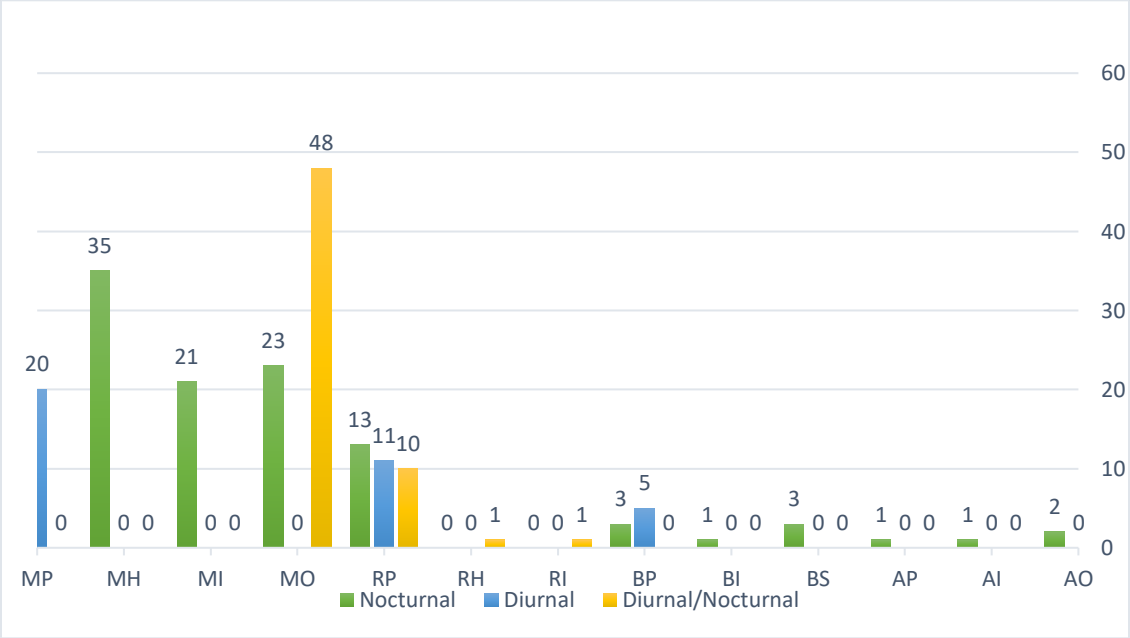

Figure 3. Count wildlife roadkill's separate by class and activity period, 2007-2020.

Legend: Mammal predators (MP), M. herbivorous (MH), M. insectivorous (MI), M. omnivores (MO), Reptile predators (RP), R. herbivorous (RH), R. insectivorous (RI), Bird predators (BP), B. insectivorous (BI), B. scavenger (B.S), Amphibian predators (AP), A. insectivorous (AI), A. omnivore (AO).

There are some biases when it comes to collecting and correctly interpreting our information. For example, our data shows a high percentage of traffic accidents on one-way roads with forests on both sides; however, these types of roads, especially OTR, received the most attention. Even so, our observations on this road, and similar ones, are consistent in pointing out that the interruption of forested areas affects the movement of wildlife. In the case of the OTR, the section that crosses the SNP and the SMP, maintained a high amount of roadkill despite the speed limit being 60 km/h.

Around these sites there is one of the most diverse forested areas in Panama (Meyer *et al*. 2015), which is why it should be considered one of the highest risk areas for the country's wildlife.

Furthermore, the observation sources themselves are a biasing factor because many observations were made by different people. In this way, these observations could be more directed at certain groups of animals, which is evident in the number of individuals run over by some species. For example, more ocelots were observed than anteaters or sloths, which could be because wild cats stand out more than these mammals. On the other hand, large animals may not die immediately after being hit and could run off the road, preventing counting. In the case of the carcasses of small animals killed on the road (for example, rodents, birds or ectothermic vertebrates), these can be consumed by scavengers and destroyed by vehicles, making them impossible to find or unrecognizable (Forman *et al*. 2003, Arévalo *et al*. 2017).

Considerations such as those described above could explain our few observations of amphibians or reptiles, compared to other studies in the Latin-American region. In this sense, our data only includes four terrestrial amphibians and 36 reptiles, while Arevalo *et al*. (2017) reported 4402 amphibians and 160 reptiles in a road close to Carara National Park in Costa Rica. Furthermore, Quintero *et al*. (2012), reported 105 snakes of 117 vertebrates, in a study focused on this group of reptiles. This shows that focused studies can provide more information on these groups, by increasing the effort to survey and identify individuals.

The finding of toads and terrestrial frogs could be related to their size and ease of noticing them from the road, in compared to tree frogs which may be less obvious. Moreover, their phenology and requirements for water along the road makes them more likely to be run over if they breed or stay near pools of water on the side of roads. In fact, some roadside sites are optimal breeding sites for amphibians, both for terrestrial and arboreal frogs (Arevalo *et al*. 2017). In the case of reptiles as such caimans, road-killed animals were sub-adults or juveniles, which is similar to the findings of Pinowski (2005) in Venezuela. According to this author, caimans do not respond to motor vehicles, which would make them more susceptible to be killed on the road, especially at night. This factor could be similar for other reptiles, especially those with less mobility or slower reaction times, such as turtles or certain snakes. On the other hand, the proximity to bodies of water or roads that cross swamps or ponds makes turtles and semi-aquatic snakes particularly vulnerable.

Of 20 species of snakes, two species of coral snakes and three species of vipers stand out as species of importance for public health; of these, *L. stenophrys* is considered as one of the largest vipers in America. This species is a terrestrial snake rarely reported in Panama, and all individuals were found on a one-way road in the Santa Fe National Park (Veraguas province) at elevations of 700-800 meters above sea level. Moreover, the arboreal viper *B. nigroadspersus* was also found on this road. Encountering these arboreal vipers, such as *B. nigroadspersus* and *B. lateralis*, is unusual because these animals are rarely seen on the ground.

In our study few individuals and species of birds were reported. Birds may be under-represented in this work for the same reasons explained above, and it is possible that more focused research will reveal more roadkills in these animals. A large number of water birds were found along Corredor Sur highway, in particular on bridges and during north-south winter migration (November-April). The car accidents with these birds are likely since birds tend to fly quickly along rivers and when crossing a bridge, they do not take flight and are hit by cars. It is important to note this highway has sections where the maximum speed is 110 km/h, which means that drivers have less time to avoid killing the animals. An alternative solution to lowering the speed limit is to install "birdscares", or shiny objects that discourage birds from landing on bridges; these have already been successfully implemented in Panama (Anonymous 2018).

Another finding of interest were birds of prey and scavengers, which can be observed frequently feeding on the carcasses of other animals. This behavior could make them susceptible to being run over, especially on highways where the speed of the cars is high enough to prevent the birds from avoiding the collision. In the case of owls and barn owls, glare from cars may prevent them from escaping from vehicles, a fact that would explain roadkills to other groups of nocturnal or crepuscular animals (Grilo *et al*. 2020, Silva *et al*. 2020). These birds have been reported in several studies, and of these, the barn owl is one of the most affected species (Borda-de-Água *et al*. 2014, Grilo *et al*. 2015). In fact, according to Grilo *et al*. (2012) and Hindmarch *et al*. (2017), collisions with vehicles are one of the main threats faced by this species. Likewise, their great adaptability to thrive in rural-urban environments by feeding on fresh roadkill or animals injured on the road in turn increases the probability of being run over (Grilo *et al*. 2012, 2015, Hindmarch *et al*. 2017, Allen *et al*. 2019).

It is possible that mammals make up most of the cases of roadkills, both because of the greater visibility in largest species, as well their diversity and abundance. During our study, both arboreal and terrestrial mammals were noticed on different types of roads. White-tailed deer was the largest species reported in this study. These animals were run over in suburban areas within City of Panama, and on roads where the speed limit does not exceed 40-60 km/h. There were no deer road-killed near wooded environments. This could be because animals used to humans lose their fear of cars.

In this work, mid-sized mammals as such anteaters, armadillos (*Dasypus novencinctus* L., 1758), and the common opossum (*Didelphis marsupialis* L., 1758), occurred more in rural and suburban areas than on roads with forests on both sides. These animals generally top the lists of roadkill in different regions along the Neotropics (Pinowski 2005, Carvajal-Alfaro and Díaz-Quesada 2016). In the case of anteaters and armadillos, their erratic movements and poor vision makes prone to road deaths, in fact, anteaters are considered one of the most road-killed animals throughout their distribution (Artavia *et al*. 2015). *Didelphis marsupialis* it is a synanthropic mammal frequently found in urban, rural and wild environments (Adler *et al*. 2012, Aranda 2012).

Two species of terrestrial rodents were found during this work: ponchos (*H. isthmius*), and ñeques (*Dasyprocta punctata* Gray, 1842) in OTR. Both rodents are common along this road and in the vicinity of Gamboa and other sites around the Panama Canal basin. Ponchos are the largest rodents in Panama and exhibit semi-aquatic and crepuscular behavior (Moreira *et al*. 2022); therefore, it is possible that these animals are more likely to be killed on roads at night or at dawn. Unlike this rodent species, ñeques are diurnal and are often seen in towns, where speed limits are less than 40 km/h, which would make it easier to avoid running them over.

On the other hand, carnivores were the most conspicuous species found in this work. Of these, coyotes and ocelots were largest carnivores found during this work, and the finding of both species in rural areas and perturbed forests, confirms their adaptability to inhabit in anthropogenic environments of Panama (Haines *et al*. 2005, Bermúdez *et al*. 2017, Hody and Kays 2018). This it is like the presence of other carnivores as such jaguarondis, crab-eating foxes, raccoons, or coatis, which were road-killed close to perturbed forests or rural towns (Artavia *et al*. 2015, Sánchez Soto 2019). On the other hand, less common were the findings of skunks, grisons or otters, which are considered rare or inconspicuous mammals (Artavia *et al*. 2015). We recorded two run-overs otters on the same stretch of road near a hydroelectric plant, and with an extensive gallery forest on both sides. Otters are semiaquatic mammals with clumsy movements on land, so are very vulnerable to being run over when trying to cross streets to move between different water sources (Quintela *et al*. 2012).

Regarding arboreal mammals, the finding of two of the three species of sloths of Panama (*B. variegatus* and *C. hoffmanni*), in addition to other species such as *C. dorsalis, C. rotschildii, P. flavus*, and monkeys (*A. palliata S. oerstedii*, and *Saguinus geofroyi*), reiterates the necessity of canopy bridges that allow animals to pass over roads (Teixeira *et al*. 2013). Moreover, this could also benefit scansorial mammals as *L. wiedii*, *U. cinereoargenteus*, or the opossum *C. derbianus*. Like other prevention measures, the location of these bridges should be considered after population censuses of susceptible species; therefore, the mitigation of vehicular collisions should be part of broader conservation programs (Hamer *et al*. 2015).

Finally, recognizing the areas at risk to the species, and in which regions there are more vulnerable species, makes it possible to identify conservation areas where mitigation measures can be prioritized (Attademo *et al*. 2011, Mendoza and Palomares 2016, Ceia-Hasse *et al*. 2017, Ibarra Portillo *et al*. 2022). To mitigate the negative effects of roads and highways on wildlife, constructions of canopy bridges, tunnels, or the location of birds-scares, must be based on studies of population dynamics or fluctuation, and according to the behavior of the species involved, as well as the areas most affected (Teixeira *et al*. 2013, Hamer *et al*. 2015).

Road-killed wild animals are a valuable source of scientific data, which can provide useful information on ecology, distribution, potential pathogens, or vectors; their use could facilitate this type of research, in addition to providing information that helps to reduce road kills of wildlife (Gottdenker *et al*. 2001, Borda-de-Água *et al*. 2014, Schwarz *et al*. 2020, Bermúdez *et al*. 2023).

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