First national assessment of wildlife mortality in Ecuador: an effort from citizens and academia to collect roadkill data at country scale.

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Abstract

Ecuador has both high richness and high endemism of species which are increasingly threatened by anthropic pressures, including roads. However, research evaluating the effects of roads remains scarce, making it difficult to develop mitigation plans. Here we present the first national assessment of wildlife mortality that allow us to 1) identify species and areas where mortality occurs due to collision with vehicles and 2) reveal knowledge gaps. We bring together data from systematic surveys and citizen science efforts in Ecuador to present a dataset with >5000 wildlife roadkill records from 454 species. Systematic surveys were reported by ten studies conducted in five out of the 24 Ecuadorian provinces. Collectively they revealed 282 species with mortality rates ranging from 0.008 to 95.56 ind./km/year. The highest rates were for the yellow warbler Setophaga petechia in Galápagos (95.56 ind./km/year), the cane toad Rhinella marina in Napo (16.91 ind./km/year), and the small ground-finch Geospiza fuliginosa in Galápagos (14.11 ind./km/year). Citizen science and other no systematic monitoring provided 1705 roadkill records representing all the 24 provinces of Ecuador and 299 species. The common opossum Didelphis marsupialis, the Andean white-eared opossum Didelphis pernigra, and the yellow warbler Setophaga petechia were more commonly reported (250, 104, and 81 individuals respectively). Across all sources, we found 15 species listed as Threatened and six as Data Deficient by the IUCN. We suggest stronger research efforts on areas where mortality of endemic or threatened species could be critical for populations, such as in Galápagos. This first assessment of wildlife mortality on Ecuadorian roads represents contributions from several sectors including academia, members of the public, and government underlining the value of wider engagement and collaboration. We hope these findings and the compiled dataset will guide sustainable planning of infrastructure in Ecuador and ultimately, contribute to reduce wildlife mortality on roads.

Introduction

Ecuador is a small (283,561 km^2) but highly biodiverse country hosting two biodiversity hotspots: Choco/Darien/Western Ecuador and Tropical Andes (considered to have the highest richness and endemism of vertebrates species of the planet; Myers et al., 2000). Approximately 659 species of amphibians species (Ron *et al.* , 2021), 500 reptiles (Torres-Carvajal *et al.* , 2022), 1699 birds (Freile & Poveda, 2019), and 466 mammals (Brito *et al.* , 2021) have been described in Ecuador. Likely, these numbers are highly underestimated as new species are still regularly identified (e.g., Leonan et al., 2022; Guayasamin et al., 2022; Brito et al., 2022) and cryptic species are probably common (Funk *et al.* , 2012). Ecuador is also a highly anthropized country transected by more than 16,647 km of primary and secondary roads (Meijer *et al.* , 2018) and a recent studied estimated 420,861 birds and 119,599 mammals are roadkilled in Ecuador each year (Medrano-Vizcaíno *et al.* , 2022). Additionally, with a further 1,555 km of new roads planned by 2030 (MTOP, 2016), roadkill numbers are predicted to increase by 9.3% (Medrano-Vizcaíno *et al.* , 2022). High road mortality, high biodiversity, and limited information have contributed to propose this territory as a priority for road ecology research (Medrano-Vizcaíno et al. in rev.). Indeed, systematic research (i.e., theses, and scientific papers) focused on wildlife mortality on roads is rare in this country. To our knowledge, the first study of this type was conducted in 2007, in the Galápagos Islands, but focused on a single species, the Galápagos lava lizard (*Microlophus albemarlensis*) (Tanner & Perry, 2007). The first study in continental Ecuador was conducted in 2014 (covering all tetrapods) (Medrano-Vizcaíno, 2015). Although a few additional studies have been published since then (González, 2018; Aguilar *et al.* , 2019; Filius *et al.* , 2020; García-Carrasco *et al.* , 2020; Zavala, 2020; Gaón & Valdez, 2021; Armendáriz, 2022), research is still limited. This paucity of road impact assessments is common to all Latin America (Pinto *et al.* , 2020), and poses a great challenge to assess potential threats for biodiversity.

Understanding the effects of roads on wildlife populations is key for conservation plans that include mitigation of current impacts, and to assess risk and inform the planning of future roads. However, conducting systematic roadkill surveys is costly and requires funding for fieldwork, which can be scarce or unavailable in developing countries. The continuous advancement of technology and internet access has provided the opportunity for new ways to gather data with citizens being involved in science projects as active collaborators. Citizen science is a valuable approach that engages diverse people, and offer a way to obtain field data without high costs (e.g., Mueller et al., 2019; Medrano-Vizcaíno et al., 2020). Data on road impacts obtained from citizen science projects can complement systematic surveys. Indeed, several citizen science projects have collected roadkill data and contributed to inform about the magnitude of road impacts on wildlife in different parts of the world (see Chyn et al., 2019; Périquet et al., 2018; Raymond et al., 2021; Swinnen et al., 2022; Valerio et al., 2021). Moreover, involving the public with the collection of roadkill data offers an opportunity to provide environmental education and awareness in local communities (Vercayie & Herremans, 2015), which could significantly contribute to reduce wildlife mortality on roads.

The scarce and disperse information on road impacts in Ecuador has limited the potential to identify the areas and species most affected and likely has prevented the development of environmental policies to require consideration of road impacts during the planning of new infrastructures. As a first step to address the knowledge gap, we present a national database consisting of >5000 roadkill records from systematic studies and non-systematic methods representing 454 wild species. Analysing this database, we identify species with high mortality that may require protection measures, and reveal unstudied areas (research gaps) where citizen and scientific efforts are needed to best understand the impacts of roads on Ecuadorian wildlife. Compiling this data required collaboration among citizens and academics. We hope to raise awareness of the issue of road impacts on wildlife in Ecuador and encourage policy makers and researchers to work together to collect needed data to guide conservation plans and sustainable roads.

Methods

Data from systematic studies control and report sampling effort allowing to estimate standardized roadkill rates (number of individuals killed per area and time span) for different species and areas. However, these studies, and thus their data, are often limited to particular road sections and periods of time. On the other hand, citizen science data can cover wider spatial and temporal windows, but sampling is often not regulated or quantified making the definition of standardized estimates complicated. To avoid methodological issues, data obtained from these two approaches are presented separately.

Records from systematic studies

We searched for roadkill survey conducted in Ecuador and described in peer-reviewed publications and theses. This search was performed in English and Spanish (official language of Ecuador) using the keywords “roadkill Ecuador”, “wildlife mortality Ecuador”, “amphibians roadkills Ecuador”, “birds roadkills Ecuador”, “mammals roadkills Ecuador”, “reptiles roadkills Ecuador”, “snakes roadkills Ecuador”, “frogs roadkills Ecuador”, “atropellamiento fauna Ecuador”, “atropellamiento anfibios Ecuador”, “atropellamiento aves Ecuador”, “atropellamiento mamíferos Ecuador”, “atropellamiento reptiles Ecuador”, “atropellamiento serpientes Ecuador”, “atropellamiento sapos Ecuador”, “atropellamiento ranas Ecuador”. When a study was located, but the roadkill records were not available, we contacted authors asking to provide their data.

From each identified study we collected: taxonomic information of roadkilled organisms, number of roadkills per species or lowest identified taxonomic group, length of road surveyed, survey method (car, motorcycle, bicycle, or walking), time interval between surveys, total sampling period, and geographic coordinates of each roadkill record if available. As original records could include synonyms or obsolete species names, we additionally provide taxonomic information standardized using the IUCN nomenclature. We removed any records of domestic and farm animals. For each study we then calculated roadkill rates per species (only specimens identified to species were considered) by dividing the total number of records by the total length in kilometers of the surveyed road(s) and the total sampling period (days) (number of days between the first day until the last day of fieldwork). This value was converted to number of individuals per km per year (ind./km/year) multiplying by 365. Standardized rates allow comparison of road mortality among species and areas where systematic studies have been conducted.

Citizen science and other records

Our main source of data was our citizen science project: Red Ecuatoriana para el Monitoreo de Fauna Atropellada (hereafter REMFA). This project started in September 2020 and is ongoing, for this study we capture records reported in the first 24 months (September 2020-2022). REMFA is an initiative that in addition to capture roadkill data seeks to promote environmental education on road ecology to citizens. Using word of mouth, traditional and social media we invited people to share photos and geographic location of roadkill events in Ecuador. Communications included emails, social networks (Facebook, Instagram and Twitter), messaging platforms (Whatsapp), and the mobile App Epicollect5 (dedicated project “Animales atropellados Ecuador”). We also compiled roadkill records from iNaturalist (https://www.inaturalist.org/), an open global online system where naturalists and citizen scientists share observations of biodiversity. Additionally, we included sporadic roadkill records found in the scientific literature but that had not been gathered via systematic surveys.

All records were checked (confirming species identification when photographs were available and location when GPS data were provided) and combined into a standardized electronic database. Without standardized methodologies and no information on monitoring effort, estimating roadkill rates, as done for systematic studies, was not possible. Instead, we summarize these data by reporting total number of records for identified taxonomic classes and species (when identified), and total for each Ecuadorian province.

For systematic and non-systematic data, when geographical coordinates of roadkill events were not available, we defined coordinates as the central point of the geographical reference provided by citizens or the published source. For these cases, we included an uncertainty value to reflect the potential error in the estimated coordinates based on the described area or road. This was given in km when we had information on the location of the road where the roadkill was found, or in km^2 when the road was not described but had information on the administrative area.

Results

In total we compiled 5010 roadkill events from both systematic surveys and non-systematic studies (citizen science and other studies). Most of these (4244) had accurate geographic information with GPS coordinates taken at the site where roadkill was found. In total, roadkill records represented at least 454 wildlife species. Most were non-threatened fauna, but two are listed as Critically Endangered, four as Endangered, nine as Vulnerable, and six as Data Deficient by the IUCN (IUCN, 2022). Nearly all records were tetrapods with relatively similar proportions of records in the four classes but marked differences in the diversity of species identified. Birds had the highest number of roadkills: 1428 (28.50% of the total) representing 200 species, followed by reptiles with 1356 records (27.06%) from 123 species, 1326 records (26.47%) for 94 mammalian species, and 895 records (17.86%) for 36 amphibian species. We obtained five records via citizen science (0.1%) for two invertebrates classes, Malacostraca and Clitellata. This vertebrate bias does not reflect lack of roadkill among invertebrates but detectability and the most common target groups of systematic surveys and citizen science efforts.

Although amphibians had the lowest number of records, the cane toad*Rhinella marina* was the most road-killed species with 532 records (more than half of the records for amphibians). The second and third most recorded species were two marsupials: the common opossum*Didelphis marsupialis* (n=454) and the Andean white-eared opossum*Didelphis pernigra* (n=336). A bird, the yellow warbler*Setophaga petechia* (n=193), and a reptile, the common green iguana *Iguana iguana* (n=126) were the fourth and fifth most roadkilled species.

Systematic studies

We compiled 3305 wildlife roadkill records from ten systematic surveys conducted on Ecuadorian roads. These corresponded to five published papers, four theses, and one unpublished dataset (Medrano-Vizcaíno et al. in review). Georeferenced data were available for eight of these studies and comprised 2744 roadkill records.

Systematic survey studies were not only rare, but also geographically biased (Figure 1), with three studies conducted in Napo province (Filius et al., 2020; Medrano-Vizcaíno & Espinosa, 2021; Medrano-Vizcaíno et al. in review), two in Galápagos (Tanner & Perry, 2007; García-Carrasco*et al.* , 2020), two in Guayas (González, 2018; Armendáriz, 2022), two in Manabí (Zavala, 2020; Gaón & Valdez, 2021) and one in Azuay (Aguilar *et al.* , 2019).

Collectively systematic studies surveyed only 2.7 % (454.5 km) of the 16,647.65 km of primary and secondary roads in Ecuador (Meijer *et al.* , 2018) and yet reported roadkill events for at least 282 species (i.e., not all individuals had been identified). Seven out of the ten studies reported data for all tetrapods, while two studies focused on birds, and one on a single species: the lava lizard *Microlophus albemarlensis.* Most records were for reptiles (965 from 76 species; 80 unidentified individuals) and birds (943 from 130 species; 224 unidentified individuals), followed by amphibians (717 from 24 species; 71 unidentified individuals), and mammals (680 from 52 species; 86 unidentified individuals). Roads were monitored using different methods: driving a car, a bicycle, a motorcycle and walking. Survey intervals varied between 1.4 and 7 days with the total survey period ranging from 27 to 425 days (Table 1).

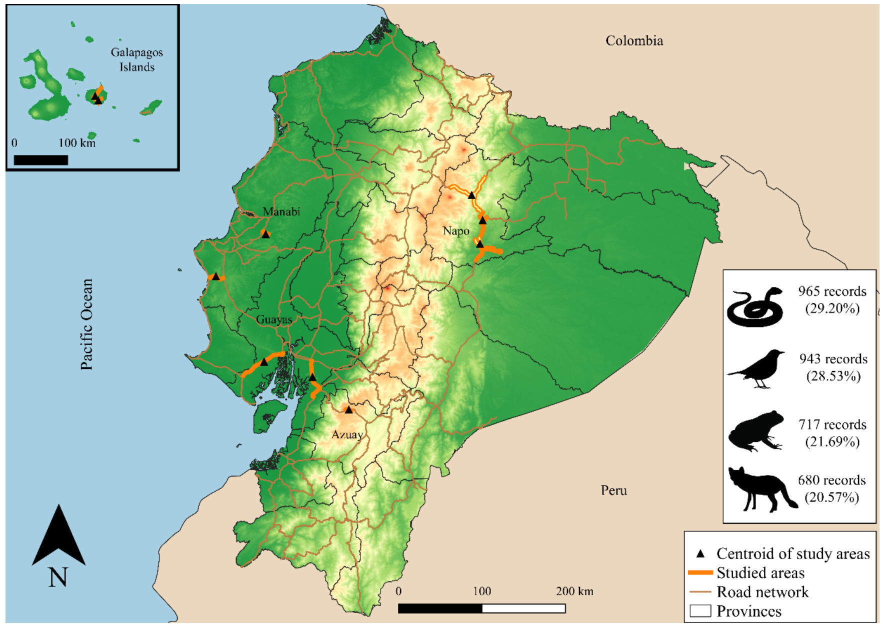

Figure 1. Ecuadorian road network (primary and secondary roads) highlighting the sites and roads where systematic studies were conducted and the total number of roadkill records per taxonomic class across all studies. For Napo province Medrano-Vizcaíno *et al* . (in review) study area covers almost the whole province of Napo overlapping with the areas studied by Filius et al., (2020) and Medrano-Vizcaíno & Espinosa, (2021), both shown in a clearer color.

Table 1 . Systematic roadkill surveys conducted in Ecuador. For each study we list: the province where data were collected, citation, studied taxonomic group, total number of roadkill records, length of road surveyed, survey period, survey interval, and survey method.

Province	**Study**	**Studied taxa**	**Roadkills (n)**	**Road length (km)**	**Su**
Azuay	Aguilar et al., 2019	Birds	60	15	36
Galápagos	Tanner and Perry, 2007	*Microlophus albemarlensis*	71	40	27
Galápagos	García-Carrasco et al., 2020	Birds	168	13.8	30
Guayas	González, 2018	Tetrapods	224	51	42
Guayas	Armendáriz, 2022	Tetrapods	246	58.1	27
Manabí	Zavala, 2020	Tetrapods	52	26.6	11
Manabí	Gaón and Valdez, 2021	Tetrapods	321	10	91
Napo	Filius et al., 2020	Tetrapods	590	15.88	12
Napo	Medrano-Vizcaíno & Espinosa, 2021	Tetrapods	445	99	16
Napo	Medrano-Vizcaíno *et al.* (in prep.)	Tetrapods	1125	240	18

Estimates of roadkill rates varied greatly across species (median=0.05 ind./km/year, SD=5.89 ind./km/year), with several taxa, particularly birds and reptiles, estimated to suffer high mortality rates in Galápagos and Napo (Table 2; Appendix 1). Although most roadkilled species were categorized as Least Concern by the IUCN Red List (IUCN, 2022), six species were found in a category of conservation concern, and two as Data Deficient (Table 3). While roadkill rates for these threatened species are not very high, due to their vulnerability, road mortality could pose a threat to their persistence. Although the tapeti (*Sylvilagus brasiliensis*), considered as Endangered, was reported in four studies with a median roadkill rate of 0.028 ind./km/year (range=0.008-0.79), it is possible that these records correspond to other *Sylvilagus* species, as the IUCN restricts the distribution of *S. brasiliensis* to Pernambuco-Brazil (IUCN, 2022).

Table 2 . Top ten most roadkilled wildlife in Ecuador as reported in systematic surveys. We report taxonomic information (class, order and species name), IUCN Red List status, the number of studies in which that species was recorded, the estimated standardized roadkill rate (if a species was detected in more than one study, we report its highest rate), and the province for the reported roadkill rate.

Class	Order	Species	IUCN status	No. studies	Roadkill rate (ind./km/y)
Aves	Passeriformes	*Setophaga petechia*	LC	1	95.56
Amphibia	Anura	*Rhinella marina*	LC	5	63.88
Reptilia	Squamata	*Microlophus albemarlensis*	LC	1	24.00
Aves	Passeriformes	*Geospiza fuliginosa*	LC	1	13.65
Reptilia	Squamata	*Amphisbaena fuliginosa*	LC	2	11.68
Reptilia	Squamata	*Atractus collaris*	LC	1	8.67
Aves	Cuculiformes	*Crotophaga ani*	LC	6	6.83
Aves	Passeriformes	*Mimus parvulus*	LC	2	6.83
Reptilia	Squamata	*Atractus elaps*	LC	2	6.78
Reptilia	Squamata	*Atractus major*	LC	2	6.41

Table 3 . Species listed as Threatened or Data Deficient by the IUCN Red List or not yet unassessed that were reported as roadkill by systematic surveys in Ecuador. We provide taxonomic information (class, order and species name), IUCN Red List status, the number of studies in which that species was recorded, the estimated roadkill rate (if a species was detected in more than one study, we report its highest rate), and the province for the reported roadkill.

Class	Order	Species	IUCN status	No. studies	Roadkill rate (ind./km/y)
Aves	Apodiformes	*Metallura baroni*	EN	1	0.13
Mammalia	Lagomorpha	*Sylvilagus brasiliensis*	EN	3	0.79
Reptilia	Squamata	*Coniophanes dromiciformis*	VU	1	1.19
Mammalia	Carnivora	*Leopardus tigrinus*	VU	1	0.02
Mammalia	Cingulata	*Priodontes maximus*	VU	1	0.008
Mammalia	Squamata	*Trilepida anthracina*	VU	1	0.008
Mammalia	Rodentia	*Ichthyomys tweedii*	DD	1	3.17
Reptilia	Squamata	*Atractus touzeti*	DD	1	0.02
Mammalia	Lagomorpha	*Sylvilagus andinus*	DD	1	0.008
Reptilia	Squamata	*Dipsas georgejetti*	NE	1	0.02

Citizen science and other records

Citizen science and other non-systematic records provided a smaller sample of 1705 roadkill records but offered a much wider geographical coverage than the systematic data with records from all 24 provinces of Ecuador (Figure 2). Most records were from Manabí province (362), Napo (302), and Pichincha (186). Records were mainly obtained from the REMFA citizen science project (698 records), iNaturalist (556 records), and from 7 scientific studies that reported 154 roadkill records collected sporadically, not in a systematic survey. Our initiative REMFA offers different ways to report roadkill and we found difference in frequency of use, with most data reported via Whatsapp (457 records), followed by the Epicollect App (165 records), Social networks (Facebook, Twitter, and Instagram; 73 records), and Email (3 records).

Among all non-systematic records, mammals were the most registered group (646 records, 63 species), followed by birds (485 records, 127 species), reptiles (391 records, 86 species) and amphibians (178 records, 22 species). Two marsupial mammals (*D. marsupialis and D. pernigra*) and the yellow warbler (*S. petechia*) were the most frequently reported species (250, 104, and 81 respectively. Table 4). Several species were reported from multiple locations and provinces, with*D. marsupialis* roadkill reports from 16 provinces, *D. pernigra* from eleven, *Tamandua mexicana* and *Conepatus semistriatus* from nine, and *Coragyps atratus* from eight provinces.

As with the systematic data, most records represented species classified as Least Concern by the IUCN Red List (IUCN, 2022) but there were twelve species of conservation concern, four currently listed as Data Deficient, and one not yet assessed by the IUCN (Table 5).

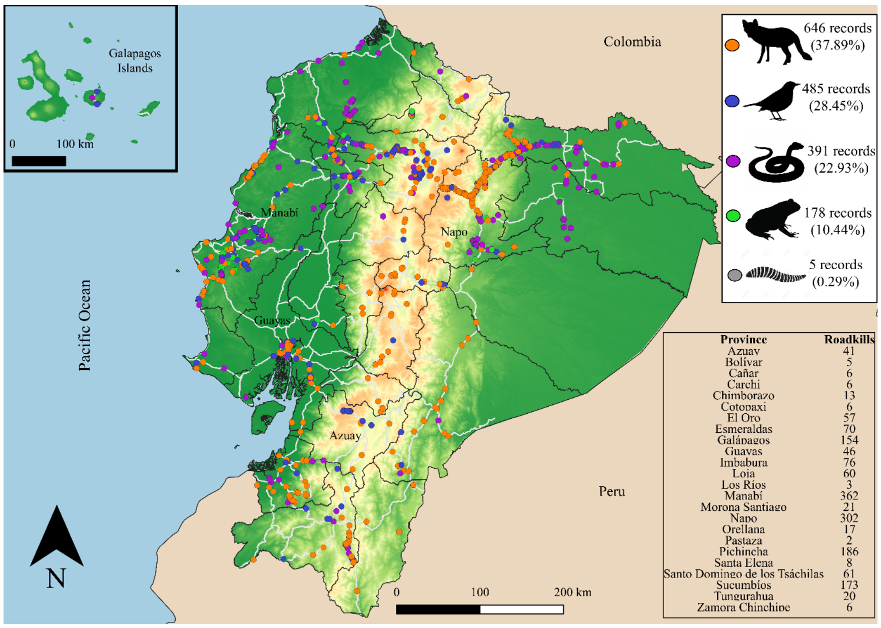

Figure 2. Location of all roadkill records compiled from citizen science and other sources and total number of records for each taxonomic Class and province.

Table 4 . Top ten roadkilled wildlife in Ecuador based on citizen science and other sources (non-systematic studies). We report taxonomic information (Class, Order and Species names), IUCN Red List status, and the total number of roadkill records.

Class	Order	Species	IUCN status	N roadkills
Mammalia	Didelphimorphia	*Didelphis marsupialis*	LC	250
Mammalia	Didelphimorphia	*Didelphis pernigra*	LC	104
Aves	Passeriformes	*Setophaga petechia*	LC	81
Amphibia	Anura	*Rhinella marina*	LC	53
Reptilia	Squamata	*Atractus dunni*	NT	37
Aves	Cathartiformes	*Coragyps atratus*	LC	37
Mammalia	Carnivora	*Conepatus semistriatus*	LC	25
Reptilia	Squamata	*Iguana iguana*	LC	23
Reptilia	Squamata	*Boa imperator*	LC	23
Reptilia	Squamata	*Epicrates cenchria*	LC	20

Table 5 . Species listed as Threatened or Data Deficient by the IUCN Red List or not yet unassessed that

were reported as roadkill by citizen scientists and in non-systematic studies in Ecuador. We provide species name, IUCN Red List status, and the number of roadkill records.

Species	**IUCN status**	**No. roadkills**
Chelonoidis porteri	CR	1
Pterodroma phaeopygia	CR	1
Porthidium arcosae	EN	3
Metallura baroni	EN	1
Tapirus pinchaque	EN	1
Ceratophrys stolzmanni	VU	7
Coniophanes dromiciformis	VU	4
Dipsas elegans	VU	2
Leopardus tigrinus	VU	2
Mazama rufina	VU	2
Alouatta palliata	VU	2
Chelonoidis denticulata	VU	1
Sylvilagus andinus	DD	7
Chironius flavopictus	DD	4
Coendou quichua	DD	2
Synophis calamitus	DD	1
Dipsas georgejetti	NE	13

Discussion

We compiled a large dataset that describes mortality due to wildlife-vehicle collision in Ecuador based on both systematic surveys and non-systematic records that came from citizen science and opportunistic observations reported in the scientific literature. Collectively, these data reveal that 13.66% of described vertebrate species from Ecuador are susceptible to die on roads, a number that likely underestimates the true impact of roads as not all areas are well sampled and smaller and cryptic species may be underreported. We see a need for additional systematic surveys, which can provide more comparable estimates, and have been few and limited to some areas. Likewise, citizen science reports are overrepresenting certain areas, with gaps in other regions.

We found that marsupials (*D. marsupialis* , and *D. pernigra*) represented more than a half of mammalian records (systematic and non-systematic) reported in 21 out of the 24 provinces. Their generalist habits (diet and habitat), together with increased abundance and intermediate body masses could be important factors for their high mortality (Medrano-Vizcaíno *et al.* , 2022). Likewise, species with a scavenger or omnivorous diet such as the American black vulture*Coragyps atratus,* the smooth-billed ani *Crotophaga ani* and the groove-billed ani *Crotophaga sulcirostris* comprised a great part of the avian records. The common green iguana *Iguana iguana*was the most common roadkilled reptile. While this is mainly a herbivore, iguanas have been recorded feeding on carcasses of deer and opossums (Anderson & Enge, 2012). Roadkilled animals and invertebrates that get attracted to these carcasses can be a food source for scavengers, which attracted to road then have a higher probability of being hit by a car.

Among the systematic studies we estimated particularly high standardized mortality rates in some cases. Studies in Galápagos (García-Carrasco*et al.* , 2020), Napo (Filius *et al.* , 2020), and Manabí (Gaón & Valdez, 2021) where roadkill rates were disproportionally high in comparison with other studies were all conducted in small areas (13.8, 15.8, and 10 km, respectively). These areas could be hotspots of mortality that do not represent rates across wider areas (overestimate risk). On the other hand, roads in these studies were surveyed by bicycle. Slower survey methods like bicycle or walking can result in higher detectability, 8.4 times higher than using a car (Wang *et al.* , 2022). Therefore, these studies may be better capturing the true mortality, at least for those smaller areas.

How road impacts wildlife in areas of biological importance should be further studied. For example high road mortality for endemics of the Galápagos Islands could threaten population persistence (Wiedenfeld, 2006; Tejera *et al.* , 2018). In this territory, threatened species comprise 20 out of 43 birds species, 18 out of 42 reptiles species, and 6 out of 9 non-cetacean mammals species (IUCN, 2022), for which the impacts of roads on their populations remain unexplored. But also non-threatened species may be impacted. For example, the yellow warbler*Setophaga petechia* , that was commonly reported as roadkill, has experienced a dramatic population decline, and although low insect abundance due to intense use of herbicides has been associated with this decline (Dvorak *et al.* , 2012), road mortality could contribute to further declines (or already be a factor). While there have been two systematic studies in Galápagos these offer limited insight as one focused on a single species focus (Tanner & Perry, 2007) and the other represented a single one-month survey (García-Carrasco *et al.* , 2020). The real impact of roads on wildlife populations in Galápagos remains unknown and considering the high endemism and quantity of threatened species, we think that this area deserves special attention for research.

We found roadkill records for 15 Threatened and six Data Deficient species, with some of them showing repeatedly in different regions of Ecuador. The Peters' running snake *Coniophanes dromiciformis* , is a Vulnerable and little known species recorded in only nine locations of Ecuador (Cisneros-Heredia, 2021). This range-restricted species showed a roadkill rate of 1.19 ind./km/year in Manabí, with an additional four non-systematic records. Another worrying case is the Violet-throated Metaltail *Metallura baroni* . This bird, catalogued as Endangered and endemic to Azuay and Cañar provinces, is known from five locations (BirdLife International, 2016), and we estimated roadkill mortality of 0.13 ind./km/year in Azuay, with an additional non-systematic record. In addition, we gathered seven non-systematic records of the pacific horned frog *Ceratophrys stolzmanni* in Manabí*,* a Vulnerable and rare species whose entire population is distributed in less than eight subpopulations (IUCN SSC Amphibian Specialist Group, 2018). Directing research efforts on roads within the distribution areas of these range-restricted species could be important to determine the impact of roads on their populations.

Additionally, poorly studied organisms such as Caecilians and*Atractus* sp. snakes were also regularly reported as roadkill. These animals are among the least known vertebrates, with several taxonomic uncertainties and unknown conservation status for many of them (Cisneros-Heredia, 2005; Wilkinson, 2012; IUCN, 2022). Both groups were frequently detected across three studies in Napo (Filius et al., 2020; Medrano-Vizcaíno & Espinosa, 2021; Medrano-Vizcaíno et al. in prep), and non-systematic data included 41 records of *Atractus* sp. snakes. In a survey conducted in 2014, Medrano-Vizcaíno & Espinosa (2021), found two roadkilled individuals attributed to the genus*Atractus* in Napo that were latter described as new species (described by Melo-Sampaio et al., 2021; Arteaga et al., 2022). Road ecology research in areas with poorly-known and undescribed species would be valuable, both to quantify impacts but also to potential expand our understanding of these species.

Our study offers an overview of wildlife mortality on Ecuadorian roads, but likely underestimates the impact. We obtained roadkill records from all the 24 provinces in Ecuador, but systematic studies were only available for five, and non-systematic data was disproportionally distributed in provinces like Manabí, and Napo (more than 300 records for each province). While in Bolívar, Cañar, Carchi, Cotopaxi, Galápagos, Los Ríos, Pastaza, Santa Elena, and Zamora Chinchipe, we gathered less than ten records per province. Our results also show that citizen science data can complement systematic studies and identify top roadkill species (like *D. marsupialis, D. pernigra, S. petechia* , and *R. marina*) that were both commonly reported in non-systematic and systematic data from Galápagos, Manabí, Guayas and Napo (González, 2018; Filius *et al.* , 2020; García-Carrasco *et al.* , 2020; Zavala, 2020; Gaón & Valdez, 2021; Medrano-Vizcaíno & Espinosa, 2021). We hope by expanding our network of citizen scientists in REMFA we will be able to fill geographical gaps of information, and gain insights into wildlife mortality in areas where systematic studies are lacking.

A limitation in out compiled dataset is the assumption of correct taxonomic identification in systematic studies (and our own correct identification in non-systematic records). For example, some species were reported outside their known distribution ranges in Ecuador:*Neacomys amoneus, Mesoclemmys heliostemma,* *Myrmochanes hemileucus, Pseudocolopteryx acutipennis, Rhogeessa io, Scinax ruber,* and*Xenoxybelis argenteus,* and even one species not distributed in Ecuador was reported (*Rhinella arenarum*). These may be misidentifications (likely for *R. arenarum*), but previous roadkilled specimens have revealed new distribution areas for certain species (Medrano-Vizcaíno & Brito-Zapata, 2021). Roadkill records can provide valuable information about the biology and ecology of species and with correct taxonomic identification contribute to our understanding of biodiversity.

Road ecology research in Ecuador is gaining interest, but is still relatively limited. Promoting and guiding additional research and public engagement is important. Through our citizen science project REMFA we have given a special relevance to science communication, which has been vital to reach citizens to join our work, and we are now engaging with policy makers. The active involvement of government ministries such as the Ministry of Environment, Water and Ecological Transition, together with the Ministry of Public Works is necessary for the inclusion of adequate policies to reduce wildlife mortality across existing roads, and to plan sustainable roads for the future. We hope that this work can be an initial step towards these national aims for wildlife conservation.

Data availability

We provide 439 roadkill rates calculated for 282 species found in systematic studies as Appendix 1, and a database of 5010 roadkill records (4244 with accurate geographic coordinates taken at the roadkill site) from 454 species as Appendix 2. Data is available at: https://figshare.com/s/8e12f0cde86e654674c2

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REFERENCES

Aguilar, J.M., Nieto, A., Espinoza, N., Loja, G. & Tinoco, B. (2019) Assessing patterns of bird roadkills in a high Andean Ecuadorian national park. *Studies on Neotropical Fauna and Environment* ,**54** , 149–156.

Anderson, C. & Enge, K.M. (2012) Ctenosaura similis (Gray's spiny-tailed iguana) and Iguana iguana (green iguana). Carrion feeding.*Herpetological Review* , **43** .

Armendáriz, A. (2022) Mortalidad de vertebrados silvestres por atropellamiento en la ruta E40 (Guayaquil-Guayas).

Arteaga, A., Quezada, A., Vieira, J. & Guayasamin, J.M. (2022) Leaving no stone unturned: three additional new species of Atractus ground snakes (Serpentes, Colubridae) from Ecuador discovered using a biogeographical approach. *ZooKeys 1121: 175-210* , **1121** , 175–210.

BirdLife International (2016) Violet-throated Metaltail Metallura baroni. *The IUCN Red List of Threatened Species* .

Brito, J., Camacho, M., Romero, V. & Vallejo, A. (2021) Mamíferos del Ecuador. Versión 2021.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador.

Brito, J., Tinoco, N., Pinto, C.M., García, R., Koch, C., Fernandez, V., Burneo, S. & Pardiñas, U.F.J. (2022) Unlocking Andean sigmodontine diversity: five new species of Chilomys (Rodentia: Cricetidae) from the montane forests of Ecuador. *PeerJ* , **10** , e13211.

Chyn, K., Lin, T.-E., Chen, Y.-K., Chen, C.-Y. & Fitzgerald, L.A. (2019) The magnitude of roadkill in Taiwan: Patterns and consequences revealed by citizen science. *Biological Conservation* ,**237** , 317–326.

Cisneros-Heredia, D. (2021) Coniophanes dromiciformis. *The IUCN Red List of Threatened Species* .

Cisneros-Heredia, D. (2005) Rediscovery of the Ecuadorian snake Atractus dunni Savage, 1955 (Serpentes: Colubridae). *Časopis Národního muzea, Řada přírodovědná* , **174** , 87–114.

Dvorak, M., Fessl, B., Nemeth, E., Kleindorfer, S. & Tebbich, S. (2012) Distribution and abundance of Darwin's finches and other land birds on Santa Cruz Island, Galápagos: evidence for declining populations. *Oryx* , **46** , 78–86.

Filius, J., Hoek, Y., Jarrín-V, P. & Hooft, P. (2020) Wildlife roadkill patterns in a fragmented landscape of the Western Amazon. *Ecology and Evolution* , **10** , 6623–6635.

Freile, J. & Poveda, C. (2019) Aves del Ecuador. Version 2019.0. Museo de Zoologia, Pontificia Universidad Catolica del Ecuador.

Funk, W., Caminer, M. & Ron, S.R. (2012) High levels of cryptic species diversity uncovered in Amazonian frogs. *Proceedings of the Royal Society B: Biological Sciences* , **279** , 1806–1814.

Gaon, J. & Valdez, G. (2021) Mortalidad de la fauna silvestre por efecto vehicular en la carretera Calceta-Quiroga.

Garcia-Carrasco, J.M., Tapia, W. & Munoz, A.R. (2020) Roadkill of birds in Galapagos islands: A growing need for solutions. *Avian Conservation and Ecology* , **15** , 1–8.

Gonzalez, M. (2018) Mortalidad de fauna silvestre por efecto vehicular en el area de influencia de la Reserva Ecologica Manglares de Churute durante la epoca seca y humeda.

Guayasamin, J.M., Brunner, R.M., Valencia-Aguilar, A., Franco-Mena, D., Ringler, E., Armijos, A.M., Morochz, C., Bustamante, L., Maynard, R.J. & Culebras, J. (2022) Two new glassfrogs (Centrolenidae: Hyalinobatrachium) from Ecuador, with comments on the endangered biodiversity of the Andes. *PeerJ* , **10** , e13109.

IUCN (2022) The IUCN Red List of Threatened Species. Version 2022-1.

IUCN SSC Amphibian Specialist Group (2018) Ceratophrys stolzmanni. The IUCN Red List of Threatened Species 2018: e.T56341A89204905.

Leonan, R., Novaes, M., Claudio, V.C., Carrion-Bonilla, C., Abreu, E.F., Wilson, D.E., Maldonado, J.E. & Weksler, M. (2022) Variation in the Myotis keaysi complex (Chiroptera, Vespertilionidae), with description of a new species from Ecuador. *Journal of Mammalogy* ,**103** , 540–559.

Medrano-Vizcaino, P. (2015) Efecto de las carreteras en la mortalidad de vertebrados en un area megadiversa: Los Andes Tropicales del Ecuador.

Medrano-Vizcaino, P., Bedoya, J. & Cadena-Ortiz, H. (2020) Dynamics of the distribution and hosts of molothrus bonariensis (Passeriformes: Icteridae) in Ecuador. *Caldasia* , **42** , 38–49.

Medrano-Vizcaino, P. & Brito-Zapata, D. (2021) Filling biogeographical gaps through wildlife roadkills: New distribution records for six snake species from Ecuador (Anilius scytale, Drymarchon corais, Erythrolamprus breviceps, Micrurus lemniscatus, Oxyrhopus vanidicus, Trilepida anthracina). *Neotropical Biodiversity* , **7** , 554–559.

Medrano-Vizcaino, P. & Espinosa, S. (2021) Geography of roadkills within the Tropical Andes Biodiversity Hotspot: Poorly known vertebrates are part of the toll. *Biotropica* , **53** , 820–830.

Medrano-Vizcaino, P., Grilo, C., Silva Pinto, F.A., Carvalho, W.D., Melinski, R.D., Schultz, E.D. & Gonzalez-Suarez, M. (2022) Roadkill patterns in Latin American birds and mammals. *Global Ecology and*

Biogeography , **31** , 1756–1783.

Meijer, J.R., Huijbregts, M.A.J., Schotten, K.C.G.J. & Schipper, A.M. (2018) Global patterns of current and future road infrastructure.*Environmental Research Letters* , **13** .

Melo-Sampaio, P.R., Passos, P., Prudente, A.L.C., Venegas, P.J. & Torres-Carvajal, O. (2021) Systematic review of the polychromatic ground snakes Atractus snethlageae complex reveals four new species from threatened environments. *Journal of Zoological Systematics and Evolutionary Research* , **59** , 718–747.

MTOP (2016) *Plan estrategico de movilidad 2013 - 2037* , Ministerio de Transporte y Obras Publicas, Ecuador.

Mueller, M.A., Drake, D. & Allen, M.L. (2019) Using citizen science to inform urban canid management.

Myers, N., Mittermeler, R.A., Mittermeler, C.G., Da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities.*Nature* , **403** , 853–858.

Periquet, S., Roxburgh, L., le Roux, A. & Collinson, W.J. (2018) Testing the value of citizen science for roadkill studies: A case study from South Africa. *Frontiers in Ecology and Evolution* ,**6** , 15.

Pinto, F.A.S., Clevenger, A.P. & Grilo, C. (2020) Effects of roads on terrestrial vertebrate species in Latin America. *Environmental Impact Assessment Review* , **81** , 106337.

Raymond, S., Schwartz, A.L.W., Thomas, R.J., Chadwick, E. & Perkins, S.E. (2021) Temporal patterns of wildlife roadkill in the UK. *PLoS ONE* , **16** .

Ron, S., Merino-Viteri, A. & Ortiz, D. (2021) Anfibios del Ecuador. Version 2021.0. Museo de Zoologia, Pontificia Universidad Catolica del Ecuador.

Swinnen, K.R.R., Jacobs, A., Claus, K., Ruyts, S., Vercayie, D., Lambrechts, J. & Herremans, M. (2022) "Animals under wheels": Wildlife roadkill data collection by citizen scientists as a part of their nature recording activities. *Nature Conservation* ,**47** , 121–153.

Tanner, D. & Perry, J. (2007) Road effects on abundance and fitness of Galapagos lava lizards (Microlophus albemarlensis). *Journal of Environmental Management* , **85** , 270–278.

Tejera, G., Rodriguez, B., Armas, C. & Rodriguez, A. (2018) Wildlife-vehicle collisions in lanzarote biosphere reserve, Canary Islands. *PLoS ONE* , **13** , e0192731.

Torres-Carvajal, O., Pazmino-Otamendi, G., Ayala-Varela, F. & Salazar-Valenzuela, D. (2022) Reptiles del Ecuador. Version 2022.1. Museo de Zoologia, Pontificia Universidad Catolica del Ecuador.

Valerio, F., Basile, M. & Balestrieri, R. (2021) The identification of wildlife-vehicle collision hotspots: Citizen science reveals spatial and temporal patterns. *Ecological Processes* , **10** , 1–13.

Vercayie, D. & Herremans, M. (2015) Citizen science and smartphones take roadkill monitoring to the next level. *Nature Conservation* ,**11** , 29–40.

Wang, Y., Yang, Y., Han, Y., Shi, G., Zhang, L., Wang, Z., Cao, G., Zhou, H., Kong, Y., Piao, Z. & Merrow, J. (2022) Temporal patterns and factors influencing vertebrate roadkill in China. *Transportation Research Interdisciplinary Perspectives* , **15** .

Wiedenfeld, D.A. (2006) Aves, The Galapagos Islands, Ecuador.*Check list* , **2** , 1–27.

Wilkinson, M. (2012) Caecilians. *Current Biology* , **22** , R668–R669.

Zavala, J. (2020) Mortalidad de fauna silvestre en la carretera 483 tramo Jipijapa-Puerto Cayo.