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Roadkill rate of snakes in a disturbed landscape of Central Andes of Colombia

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Abstract. Animal causalities are among the more generalized and conspicuous ecological effects of roads. We estimated vertebrate mortality during July-August 2006 and January-March 2007 in a 6.4 km stretch of road located in Central Andes of Colombia. We recorded 117 vertebrates dead on the road (105 snakes, 4 birds, 7 amphibians, and one mammal). Snake roadkill rate was 78,8 individuals/km/year which, is higher than estimates in other studies. The species that exhibited greater mortality was *Atractus cf melanogaster* (72 individuals) followed by *Liophis epinephelus* (12 individuals). Recording roadkill rates in Colombia Andes can offer baseline data to increase the general knowledge of the variability of road effects in tropical landscapes, and eventually optimize management strategies.

Keywords. reptiles, road ecology, vehicular traffic, ecological impact, Andes of Colombia.

Introduction.

Roads are an integral part of human society due to the multiple benefits they offer to the society, for example for health, education, and recreation. Nevertheless, roads impose ecological effects such as high mortality of fauna by vehicular collisions or crushing, access to habitat invasion by alien species, acoustic and chemical contamination, alteration of natural hydrologic flow of ecosystems, and increase of ground erosion rate (Seiler, 2001; Forman et al., 2003). In addition, roads can promote the colonization and establishment of human communities with subsequent habitat fragmentation and landscape transformation (Young, 1992). Ecological effects of roads have been widely studied in temperate ecosystems in North America and Europe (see reviews in Spellerberg, 1998; Forman et al., 2003; Beckmann et al., 2010), and on few occasions in tropical ecosystems (e.g. Goosem, 2001, 2002; Pohlman et al., 2007; Kaiser and Hammers, 2009). The geographic bias of studies about road ecology is worrying because the severity of ecological effects varies among places due to differences in topography, variation in ecosystem, community and population dynamics, and the life traits of the species (Forman and Lauren, 1998; Seiler, 2001; Forman et al., 2003).

Animal causalities are among the more generalized and conspicuous ecological effects of roads (Spellerberg, 1998; Beckmann et al., 2010). Wildlife mortality on roads has been estimated in thousands to millions individuals per year; for instance, in United States of America (USA), a million vertebrates per day are reportedly affected by roadkill; in Bulgaria five million birds; and in Australia, approximately five million frogs and reptiles die every year due to vehicular collisions (Forman and Lauren, 1998; Hels and Buchwald, 2001). In Latin America a relatively small number of studies about roadkills have been developed (e.g. Rodda, 1990; Fisher, 2002; Pinowski, 2005; Vargas-Salinas et al., 2011; Hartmann et al., 2011), but available information suggests that vertebrate mortality on roads is also high. For instance, censuses during 18 months on a 50 Km road segment on the Atlantic coast of Colombia, documented roadkills of 216 vertebrates of 41 species: 41.7% mammals, 26.8% birds, 26.4% reptiles and 5.1% amphibians (Argotte and Monsalvo, 2002).

Reptiles can be one of the vertebrate groups most affected by roads (Andrews et al., 2008). Specifically,

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snakes can be highly susceptible to mortality by vehicular causalities (Dodd et al., 1989; Rosen and Lowe, 1994; Andrews and Gibbons, 2008). Apparently, this is because snakes are relatively slow-moving animals that need medium to large home ranges for finding food, refuges, and mates (Green, 1997; Zug et al., 2007) hence, they frequently cross roads (Shine et al., 2004). Here, we estimated the roadkill rate of vertebrates, snakes in particular, to assess susceptibility to this mortality factor on a road in Central Andes of Colombia. This information would offer baseline data of the variability of the road effects in the tropics, and would facilitate the implementation of biodiversity conservation plans when necessary. For instance, the implementation of linear forest corridors has been proposed in the study area in order to connect located woodland fragments on opposite sides of the monitored road, but the continuity of those forest corridors is interrupted by the road without safe passages for animals (Mendoza et al., 2007). Therefore, roadkills might increase if animals living in woodland fragments use corridors and cross the unsafe road to reach the forest corridor in the opposite margin of the road.

Material and Methods

Study area

We conducted this study on a 6.4 km road segment located between the municipality of Filandia in the department of Quindío and the Coffee highway (Autopista del Café), on the western slope of the Central Andes of Colombia (4º 40’48”N, 75º 45’32”W; Fig. 1). Personal observation allowed us to estimate an average vehicular traffic of around 47 cars, 20 motorcycles, and 15 heavy (e.g. trucks) vehicles per hour. The studied road is located between 1700 and 2100 m asl in a natural Wet Forest Lower Montane life zone (Holdridge, 1987) with a mean precipitation of 2515 mm/year and a mean temperature of 17ºC (Mendoza et al., 2007). Currently, the landscape in the study area is largely comprised of a matrix of grassland due to the cattle exploitation (Fig. 1).

Methods

The observations were made by two people who walked along the road, one on each side, looking for carcasses. We conducted samples twice per month (every two weeks) in July-August 2006 and January-March 2007 during the summer and rainy seasons. Our time sampling period was 152 days (62 days in 2006, plus 90 days in 2007). We recorded and collected the carcasses found on the road in order to avoid recounting. Also, we used carcasses for identifying the specimens; this was possible due to previous experience with herpetofauna in the study area (Osorio-Domínguez 2007; Quintero-Ángel, 2008), and literature (Peters and Orejas-Miranda, 1970; Pérez-Santos and Moreno, 1988; Passos and Lynch, 2010). We assumed that all the specimens found dead on the road were killed by vehicular traffic. We georeferenced the location where each carcass was found with a Garmin eTrex GPS. Vouchers were deposited in the Vertebrates collection of the Universidad del Valle (UV) and in the Departmental Museum of Natural Sciences (INCIVA for its abbreviation in Spanish) from Valle del Cauca, Cali, Colombia.

Our roadkill rate estimate is conservative because we assume that carcasses endure for 7 days on the road, i.e. our calculations point out a lower number of dead snakes than if we perform calculations assuming previous estimates of carcass duration on roads (2-3 days, Forman et al., 2003). We do not have estimates of carcass duration in the study area or in the Colombian Andes, hence, we prefer to be conservative until more information is available about that aspect and about eventual temporal fluctuations in roadkill. Because we argued that carcasses endure for 7 days and that counts were conducted every two weeks, our snake roadkill estimate is doubled, that is: [(number of carcasses/longitude stretch of road)(days of year/number of days monitored)]*2. We subdivided the road segment into 32 sections of 200 m length each (Fig. 1). We compared the frequencies of roadkills among road sections using Chi-square tests (Zar, 1998). In addition, we conducted a nearest neighbor analysis (NNA) which allowed us to test whether there was a distribution pattern of snake carcasses on the road (random, regular, or grouped). We used equation: $R=2\check{D}\sqrt{(n/a)}$, where $\check{D}$ is the mean distance between neighbor carcasses, n is the number of carcasses, and a is the sampling area (calculated using 8 meter as the road width). If $R<1$ carcasses were grouped, if $R=1$ carcasses were distributed randomly, and if $R>1$ then distribution of carcasses was regular. The NNA was performed using the extension “Animal Movement” for the software ArcView 3.3.

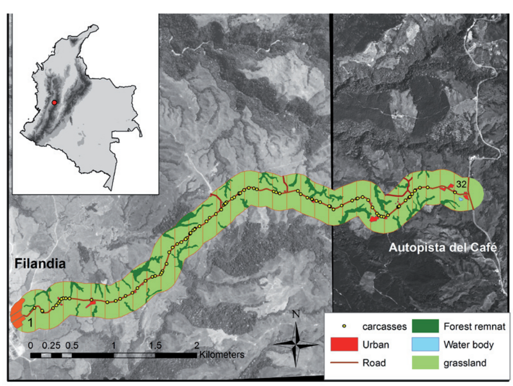

Figure 1. Aerial picture showing the 6.4 Km segment road in the study area (Department of Quindío, Central Andes of Colombia, South America). Numbers (1, 32) indicate start and final sections on the road (200 m each) for analysis of carcasses distribution. The town Filandia (left) and predominant habitats alongside the road are shown (Photos by Instituto Geográfico Agustín Codazzi, Colombia; IGAC: R1193-239-308, 1991; C2256-91, 1986; C1257-30-29-331, 1969).

Table 1. Number of snake carcasses per species found in 6.4 km of road segment in the study area (Department of Quindío, Central Andes of Colombia, South America). Some snakes are unidentified because carcasses were so degraded.

Taxa	2006		2007			Total
	July	August	January	February	March	
COLUBRIDAE						
Atractus cf *melanogaster* Werner 1916	9	22	25	15	1	72
Dipsas sanctijoanis Boulenger 1911	0	0	0	2	0	2
Geophis sp.	0	1	2	0	0	3
Lampropeltis triangulum Lacépede 1789	0	0	1	0	0	1
Liophis epinephelus Cope 1862	3	1	3	4	1	12
Tantilla longifrontalis Boulenger 1896	1	1	0	0	0	2
Urotheca decipiens Günter 1893	2	0	1	0	0	3
Unidentified colubrids	0	0	1	3	1	5
LEPTOTYPHLOPIDAE						
Leptotyphlops sp.	1	2	0	0	1	4
VIPERIDAE						
Bothriechis schlegelii Berthold 1846	1	0	0	0	0	1
Total	**17**	**27**	**33**	**24**	**4**	**105**

Table 2. Model of linear regression testing the relationship between number of snake carcasses and habitat kind alongside the road (grassland, forest remnant, and human houses).

Predictor	Coefficient	SE Coefficient	T	P
Constant	-5.314	2.153	-2.47	0.020
Grassland	0.00010796	0.00002830	3.82	0.001
Forest remnant	0.00008092	0.00005814	1.39	0.175
Human houses	-0.0001027	0.0002487	-0.41	0.683

To test whether there is a relationship between the number of snake carcasses and kind of habitat alongside the road monitored, we performed a multiple regression analysis. For this analysis, we used digitalized aerial photographs (Instituto Geografico Agustin Codazzi, Colombia; IGAC: R1193-239-308, 1991; C2256-91, 1986; C1257-30-29-331, 1969) and classified habitats as grassland, forest remnant, human houses, and bodies of water (Fig. 1). The latter habitat was excluded from our analysis because there were few representatives in the study area.

Results

We found a total of 117 carcasses: 105 carcasses (89.74 %) represented ten snake species (Table 1; Fig. 1). The other 12 carcasses (10.26 %) corresponded to three caecilians (Amphibia: Caecilidae), four frogs (Amphibia: Anura: Brachycephalidae), a wild hare (Mammalia: Lagomorpha: Leporidae: *Sylvilagus brasilensis* Linnaeus 1758) and four birds (Birds: Passeriformes: Tyraniidae). The species that exhibited greatest mortality was the snake *Atractus* cf *melanogaster* Werner 1916 (Colubridae) with 72 registered carcasses (Fig.2a), followed by *Liophis epinephelus* Cope 1862 (Colubridae) with 12 carcasses (Fig. 2d). One of the snake carcasses corresponds to *Urotheca decipiens* Günter 1893 (Colubridae), an unreported species for the department of Quindío (Castro and Vargas-Salinas, 2007; Fig. 2b). The vertebrate roadkill rate in our study was 87.8 individuals/km/year, and the snake roadkill rate was 78.8 individual/km/year.

There were no significant differences in frequency of carcasses (i.e. frequency of mortality) among road sections ($\chi^2 = 28.4$, $P = 0.54$). Accordingly, the NNA indicate that snake carcasses exhibit a regular pattern of distribution on the road ($Z = 41.63$, $R = 3.39$). The multiple regression analysis indicates that the grassland habitat is mostly correlated to the presence of snake carcasses ($S = 1.70848$, $R^2 = 38.5\%$, $P = 0.001$; Table 2).

Discussion

The snake mortality by roadkill in the study area was higher than the roadkill of other vertebrates. Previous observations on the same road also indicates a higher snake mortality rate compared to amphibians, reptiles, mammals or birds (June 2006, we recorded carcasses of three frogs, two *Anolis* lizards, and 31 snakes). Further, a similar pattern has been reported in a forest remnant on the Western Andes of Colombia (Vargas-Salinas et al., 2011). Although we cannot establish conclusive patterns until we obtain more evidence, we hypothesized that snakes can be especially susceptible to mortality on roads in the Andes of Colombia, due to several nonexclusive reasons. First, snakes cross roads at ground level whereas birds or some mammals (e.g. bats, monkeys) do it several meters above the ground and/or could do it at a greater speed (Goosem, 2007). Second, snakes are thigmotherms that apparently use the warm surface of roads as substrates for thermo-regulation and/or basking (Sullivan, 1981; Gibbons and Semlitsch, 1987; Bernardino and Dalrymple, 1992; Ashley and Robinson, 1996; Pinowsky, 2005). In relatively cold climates as it occurs in the Andean forests of Colombia, thermoregulation hypothesis would have support, but it needs to be demonstrated. Third, some species of snakes adopt a stationary 'freezing' behavior when a vehicle is approaching them (Andrews and Gibbons, 2005), and people sometimes intentionally run over snakes on roads (Langley et al., 1989; F. Vargas-Salinas, personal observations). Regardless of the cause promoting it, testing those hypotheses is important because roadkills can result in a reduction in snake abundance and diversity in contiguous areas (Fahrig et al., 2009, Row et al. 2007) and even might be a factor contributing to global decline of those reptiles (Reading et al., 2010), as well as for amphibians (Fahrig et al., 1995; Glista et al., 2008).

Our estimate of snake roadkill mortality (78.8 individuals/km/year) is higher than obtained in another locality of Colombian Andes (17.55 snakes/km/year; Vargas-Salinas et al. 2011). A similar tendency arises when we compare our results with those obtained in other studies, our estimate is higher than 8.6 snakes/km/year by Hartmann et al. (2011), 12.8 snakes/km/year recorded by Enge and Wood (2002); 22.5 snakes/km/year by Rosen and Lowe (1994), and 48.6 snakes/km/year by Borczyk (2004). Differences in snake roadkill between studies could be due to differences in sampling methodologies, sampling periods and multiple biotic and abiotic factors among study areas (Bernardino and

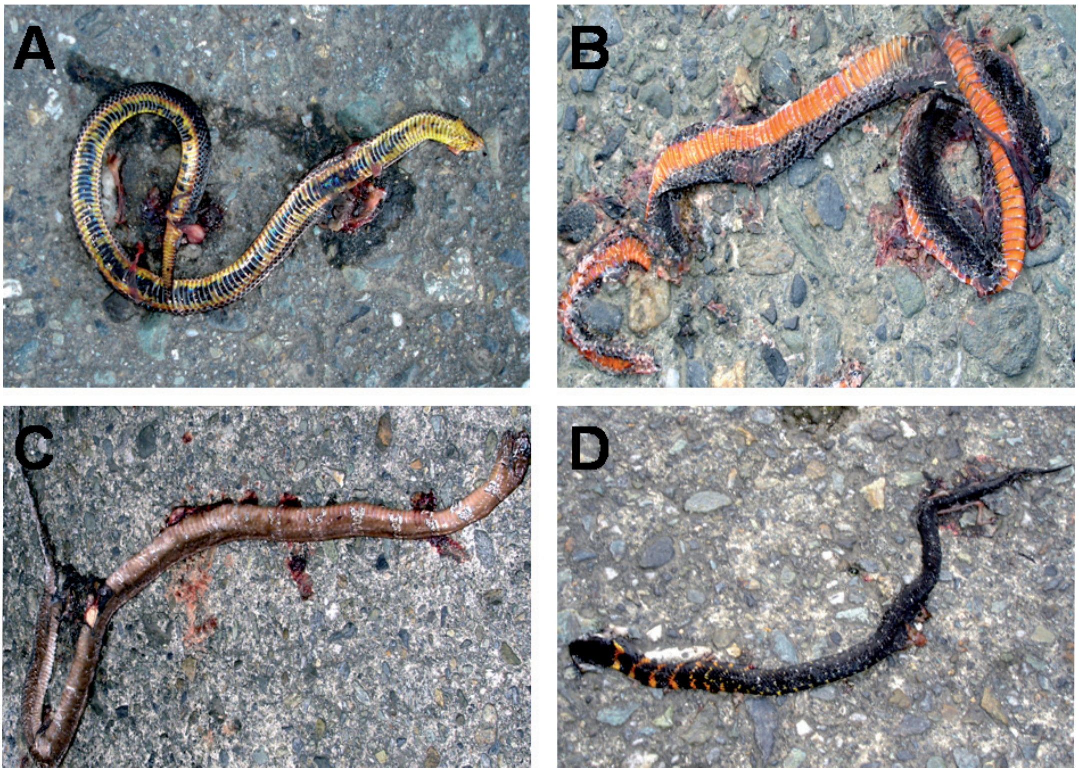

Figure 2. Image of some snakes carcasses found on the study area: Department of Quindío, Central Andes of Colombia, South America. A: *Atractus cf melanogaster*, B: *Urotheca decipiens* (geographical extension for central Andes of Colombia, see Castro & Vargas-Salinas 2007), C: *Dipsas sanctijoanis*, D: *Liophis epinephelus*. Photos by A. Quintero-Angel.

Dalrymple, 1992; Mendelson III and Jennings, 1992; Jochimsen, 2006). For instance, the road in our study area is surrounded by open areas for farming activities, whereas in another study in the Andes of Colombia (Vargas-Salinas et al., 2011) the road bisects forested areas. Also, differences in temporal patterns of activity and environment could explain differences in roadkill rate found among studies (Hartmann et al. 2011).

The absence of a spatial pattern of mortality in our data is not surprising because the totality of the observation period might include activities of reproduction, feeding, and the search for refuge by snakes (Hartmann et al., 2011). Also, since open areas (grasslands) predominate along the roads and the recorded species can inhabit wooded areas and/or open areas, the species could be active in any section of the road monitored. Regarding the difference of abundance between the species, this may be a reflection of the relative abundances of the community of snakes in the region. However, we cannot discard alternatives, for example, some individuals or species may be more susceptible to die on the road than others (Andrews and Gibbons, 2008). In any case, a small number of roadkill individuals does not necessarily mean that the negative effect on the natural populations of a given species is low (Seiler, 2001; Forman et al., 2003; Fahrig and Rytwinski, 2009). There is no information about demography for snake populations in Colombia, but since 70% of the Colombian Andean forest has been modified or deforested (Cavalier and Etter, 1995), and many snakes die due to human aversion, it is important to study whether it is necessary to formulate and implement management strategies to diminish roadkill rates. At present we do not know whether snakes or other animals are using underground passages (culverts) constructed for rain water-drainage as a safe way for crossing the road (Clevenger et al., 2001; Shine and Bonnet, 2009; Taylor and Goldingay, 2003).

The study area is located in Andes of Colombia, recognized for its high biodiversity (Kattan et al., 2004) and high levels of fragmentation and deforestation (Cavalier and Etter, 1995; Etter and Wyngaarden, 2000). The Colombian Andes has the highest concentration of the country's population, and a complex network of roads (see www.invias.gov.co). The ecological effects of fragmentation and the loss of habitat by deforestation and agricultural activities have been evaluated in several studies (e.g. Kattan et al., 1994; Renjifo, 1999), but road effects remain unknown. In this respect, recording specimens killed on roads is crucial for understanding the potential role of roads as anthropogenic elements increasing mortality of vertebrates (and invertebrates) in Colombian Andes. Road ecology has been studied more thoroughly in temperate countries, but requires further exploration in Neotropical regions.

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