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Population decline of an endangered primate resulting from the impact of a road in the Catazajá wetlands, Chiapas, México

Reducción poblacional de un primate en peligro por el impacto de una carretera en los humedales de Catazajá, Chiapas, México

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The construction of large infrastructures such as roads poses a major threat to biodiversity due to wildlife roadkills. Some of the underlying threats are easy access for hunters, habitat degradation around the road caused by agricultural activities, oil and gas extraction, and mining. Altogether, these result in serious risk for primates as 55 % of the total species are endangered and 75 % have declining populations. This study is the first in the Americas addressing the population decline of an endangered arboreal primate resulting from the impact of road expansion in Chiapas, México. In the study area, the population of *Alouatta pigra* underwent a 56 % decline from 2012 to 2017, with 37 roadkills. The most affected age group was immature animals (both sexes), with an age:sex ratio that changed from 1.2 immature individuals per adult female in 2012 to 0.5 in 2017. This work highlights the dramatic population decline resulting from the poor conduct of Environmental Impact Studies combined with an inadequate application of mitigation measures on the road studied.

Key words: Arboreal primates; environmental impact; howler monkeys; mitigation; road ecology.

El desarrollo de grandes infraestructuras como las carreteras han colocado en grave amenaza a la biodiversidad debido a la mortalidad por atropellamiento de fauna silvestre. Una de las amenazas subyacentes es el fácil acceso para los cazadores; degradación del hábitat alrededor de la carretera por actividades agropecuarias, extracción de petróleo, gas y la minería. Lo anterior coloca en grave riesgo a los primates, con 55 % del total de sus especies en peligro de extinción y disminución de sus poblaciones en un 75 % de sus especies. Este trabajo es el primer estudio en América con un primate arborícola en peligro de extinción y que examina la reducción poblacional sufrida por el impacto de una ampliación de carretera existente en Chiapas, México. La población de *Alouatta pigra* se redujo en el área de estudio en un 56 % entre el periodo 2012-2017 con 37 atropellamientos. La proporción sexo-edad más afectada es la de inmaduros (de ambos sexos) pasando de 1.2 en 2012 a 0.5 inmaduros por cada hembra adulta en el 2017. Este estudio resalta la disminución poblacional drástica provocada por no realizarse de manera adecuada los estudios de impacto ambiental y las medidas de mitigación en la carretera de estudio.

Palabras clave: Ecología de carreteras; impacto ambiental; mitigación; monos aulladores; primates arborícolas.

In México, road construction underwent accelerated growth over 21 years, reporting 817,966 km in 2021. The longest roads run through the states of Chihuahua, Sonora, Veracruz, Jalisco, Chiapas, Oaxaca, Durango, Michoacán, Tamaulipas, and Guerrero (RNC 2022). México is habitat to only 3 species of arboreal primates (*Alouatta pigra, A. palliata,* and *Ateles geoffroyi*). The southeastern region of México (Veracruz, Oaxaca, Chiapas. Tabasco, Campeche, Yucatán, and Quintana Roo), within the distribution range of primates, has 20,000 km of roads (2.8 % of the total road infrastructure in México), and 98 % lacks mitigation structures to protect these primates (own data). Additionally, the Maya Train (a government megaproject consisting of the construction of freight and tourism railroads in the Yucatán Peninsula, eastern Tabasco, and northern Chiapas) started construction works in 2020 and will comprise approximately 1,600 km; thus, a primate protection program should be a priority to prevent roadkills.

The most recent global review, limited to reports in English and social networks, recorded 46 species of wild primates affected in 368 roadkills and 16 species from South America with 72 roadkill records (Hetman *et al.* 2019). Most of these reports inform less than 10 primate roadkills, a figure below death by predation or natural causes (Hetman *et al.* 2019). However, in Southern Asia, a higher number of deaths by vehicle collision have been reported for 4 species (*Nycticebus bengalensis, Macaca leonina, Trachypithecus phayrei,* and *Macaca mulatta*), with 17 events in 2 National Parks in Bangladesh (Al-Razi *et al.* 2019). These reports suggest that roads are one of the main causes of mortality of primates in tropical forests.

An 18-year study of primate species (*Colobus angolensis palliatus, Cercopithecus mitis albogularis, Chlorocebus pygerythrus hilgerti,* and *Papio cynocephalus cynocephalus*) along a 10 km stretch of road on the outskirts

of Diani, Kenya, recorded 705 roadkills and 1,896 reports of conflicts between humans and monkeys (Cunneyworth and Duke 2020). There were 3 primate-vehicle collisions per month on average (range 0–10), and 83 % resulted in primate deaths.

Finally, another recent study reported 29 roadkills of *Piliocolobus kirkii* on Zanzibar Island off the coast of East Africa (Olgun *et al.* 2021). This study describes that while natural predators select young, old, or sick animals, vehicles kill individuals from populations irrespective of their health condition or age. In addition, even non-lethal collisions cause adverse effects on animals through an increase in glucocorticoid production, leading to physiological stress.

In Latin America, 4 roadkills of *Sapajus cay* were recorded in Brazil (Brum *et al.* 2018) and 4 of *A. palliata* in Costa Rica (Artavia *et al.* 2015). In Panamá, howler monkeys (*A. coibensis trabeata*) have been killed by vehicle collisions in the Azuero Peninsula (Méndez-Carvajal *et al.* 2013; Méndez- Carvajal 2020). In México, 8 road-killed individuals of *Alouatta pigra* have been reported in the Usumacinta region in Tabasco (Pozo-Montuy *et al.* 2008; Candelero-Rueda and Pozo-Montuy 2011).

However, research on road ecology in Tabasco is at a very early stage despite recent contributions addressing road impacts (Pacheco-Figueroa *et al.* 2014; Pacheco-Figueroa *et al.* 2021). There is an urgent need for information on primate roadkills to support mitigation measures in the construction of new roads and the modernization of the existing ones.

This study represents the first effort in America to assess the impact of road expansion work on the population of black howler monkeys, *Alouatta pigra*, inhabiting patches of vegetation at both sides of the road. The present report outlines behavioral observations, a population census, and recommendations to mitigate primate roadkills in southeastern México.

We monitored and followed up a population of black howler monkeys inhabiting a tropical forest crossed by a stretch of road at the Emiliano Zapata Tabasco–Usumacinta bridge within the Catazajá Lagoon System, a Protected Natural Area in the state of Chiapas comprising 47,058.77 ha. The Villahermosa–Escárcega road was originally C-type (6 m wide, no shoulder lanes), built before an additional 6 m-wide protected area was declared. In 2012, it was upgraded to an A2 superhighway measuring 12 m in width with 2 m of shoulder lane and a 60 m right-of-way, due to increased traffic volume, particularly of heavy trucks traveling to and from the Yucatán Península. The C-type road ran across secondary vegetation with trees reaching 30 m in height and natural tunnels formed by the canopy used as corridors by animals (Figure 1).

The study area is a 10 km stretch between km 135 + 660 to km 145 + 800 (17° 46′ 24.89″ N, 91° 49′ 41.96″ W) running from the Emiliano Zapata junction to the toll booth of the Usumacinta bridge (17° 51′ 15.73″ N, 91° 47′ 12.53″ W). In this stretch, an 800 m wide polygon was drawn in Google Earth, 400 m on each side of the road, where complete population censuses of howler monkeys were carried out (total count of individuals identified by body marks within an area), considering the daily movements of individuals of this species (Pozo-Montuy *et al.* 2013; Figure 2).

A complete population census was performed in February 2012 (Pozo-Montuy *et al.* 2021), during the first stages of the road expansion work, when land clearing, deforestation, and slope construction operations were carried out. During the study, each patch of vegetation at both sides of the road was traveled along a 10 km stretch by 5 persons over 6 hours, between 7:00 and 13:00 hr. The data collected included the geographic coordinates and sex and age of the individuals observed. Sex and age:sex ratios were calculated as the number of adult females divided by the number of adult males and the number of immature organisms (infants and juveniles of both sexes) divided by the number of adult females, respectively. Also, average group sizes were computed.

In July 2014, 2 years after the start of the road expansion work but before completing it, a second population census was performed in the same area and with the same methodology. Finally, in August 2017, a third population census was conducted after the road expansion work was completed, when the stretch was released and wildlife overpasses expressly made for these primates were installed.

Roadkill monitoring was performed continuously from 2012 to 2017. Roadkills were recorded and reported by the Saraguato Wildlife Management Unit staff, who perform daily tours along this stretch at different times, mainly in the morning (7:00–11:00 hr) and afternoon (15:00–18:00 hr). Additionally, residents and taxi drivers of Villa Chablé reported howler roadkills to the study team. At the collision sites, the data gathered included the geographic coordinates and sex, age, and photographs of roadkilled specimens; afterward, carcasses were removed from the road.

During population censuses and site visits at 2-month intervals since 2012, *ad libitum* observations were made to collect information on the behavior of *A. pigra* along the road. Data on responses to environmental noise, foraging, and activity patterns were recorded. A roadkill event witnessed by our team was also described.

Finally, as part of the primate roadkill mitigation measures following a Conservation Plan submitted to the General Direction for Environmental Impact and Risk of the Secretariat of the Environment and Natural Resources (SEMARNAT, in Spanish) one year after the start of the expansion, the Secretariat of Communications and Transportation (SCT, in Spanish) installed 4 wildlife bridges including galvanized steel cables, concrete poles, and green plasticized cyclone wire. The effectiveness of each of these bridges was assessed once per month by a camera trap (Bushnell Trophy Cam HD) from August to December 2016.

Figure 1. Stretch of the Villahermosa-Escárcega highway from km 135 + 660 to km 145 + 800 in Playas de Catazajá, Chiapas, México. a-b) before road expansion (2010); c-d) after road expansion (2012)

The initial 2012 census revealed a total population of 57 howler monkeys in the study area in 12 social groups plus 5 solitary males living in the roadside forest (5 groups on one side of the road and 7 on the other). The average group size was 4.3 individuals (Table 1). The adult female:male ratio was 1.9:1, and the immature:adult female ratio was 1.2:1.

The 2014 census (during the road construction) revealed a population reduction to 35 individuals in 9 social groups plus 5 solitary adult males inhabiting the roadside forest, representing a 39 % reduction from 2012 to 2014. The average group size was 3.3 individuals (Table 1). The adult female:male ratio was 0.9:1 and the immature:adult female ratio was 0.8:1.

The 2017 census, once the road expansion work was completed, showed that the population of howler monkeys was further reduced to 25 individuals in 5 social groups plus 2 solitary adult males living in the roadside forest. Five specimens in 2017 showed evidence of bruises and wounds, likely being survivors of non-fatal vehicle collisions. The population was reduced by 56 % versus the initial one. The average group size was 4 individuals (Table 1). The adult female:male ratio was 0.8:1 and the immature:adult female ratio was 0.5:1.

During the 2012–2017 monitoring, 37 roadkill events were recorded; most of them involved immature individuals ($n = 20$), although the number of adults was also noticeable ($n = 17$). There were no significant differences ($P > 0.05$) between sexes in the number of roadkills, with 19 males and 18 females hit (Figure 3). However, the immature:adult female ratio showed that immature monkeys are the most affected age group as the ratio decreased from 1.2:1 at the start of the road expansion work to 0.5:1 after completion.

The overall roadkill rate was 37 individuals per 10 km. At the start of the road expansion work (2012), there were 12 roadkills; subsequently, the number dropped to 10 in 2013 and remained around 5 from 2014 to 2016; finally, only one roadkill was recorded in 2017. With a sampling effort of 480 camera trap days, we confirmed that only 2 of the 4 bridges were used by black howler monkeys (Figure 3).

The *ad libitum* observations confirmed that howler monkeys display the normal pattern of daily activities reported for the species (Pozo-Montuy and Serio-Silva 2007), *i. e.*, a long resting time (70 %) followed by foraging (20 %) and moving around (10 %). In the study area, black howler monkeys feed on guácimo (*Guazuma ulmifolia*), ceiba (*Ceiba pentandra*), pichi (*Enterolobium cyclocarpum*), caracolillo

(*Albizia guachapele*), cantemó (*Albizia niopoides)*, macuili (*Tabebuia rosea*), jobo (*Spondias mombin*), and a variety of unidentified vines. In addition to arboreal locomotion and road crossings from 6:00 to 9:00 hr and from 16:00 to 19:00 hr, black howler monkeys descend to the ground to move between patches, feed on seedlings, and drink water from pools between road bridges.

Of the total visits (n = 24), play behavior was rarely observed; this is typical of the species since social interactions are rare. However, there was a considerable number of intergroup vocalizations (2 per day) from 7:00 to 9:00 hr and from 17:00 to 18:00 hr to keep the distance between groups. At the start of the road expansion work, the groups showed behavioral signs of stress, moving more than the usual rhythm reported for the species (*i. e*., moving in resting hours between 11:00 and 16:00 hr) and exchanging vocalizations between groups (vocalizations at any time). During a roadkill event observed by the team, behavioral stress was recorded: a juvenile male that was hit remained lying on the road; this caused distress in the rest of the group, mainly in the alpha male, which emitted vocalizations and attempted to descend to approach the lying corpse. The first author removed the body from the road and carried it close to a tree trunk near the group of monkeys, which remained in the tree until the next day.

This is the first study in America reporting the impact of roadkill events on the population size and structure of howler monkeys. Immature individuals (infants and juveniles) were most affected, reducing the immature:adult female ratio from 1.2:1 to 0.5:1, thus affecting reproductive success (Días *et al.* 2020). One of the implications of the higher mortality of immature individuals is the lesser adequacy of the species associated with the loss of genes inherited during reproduction. The most recent studies on primate roadkills in Africa and Asia reported collisions by species without estimating the remaining population in the road-effect zone (Al-Razi *et al.* 2019; Cunneyworth and Duke 2020; Olgun *et al.* 2021).

A study on primate roadkills in Asia and Africa estimated that the road-effect zone varies in extent, depending on the size or body mass of the primate species, from 1 km to as much as 7 km for large primates (Perumal *et al.* 2021). In a detailed analysis by Andrasi *et al.* (2021) on chimpanzees (*Pan troglodytes verus*) in east Africa, these authors calculated the road-effect zones, estimating a range of 4.9 to 5.8 km for secondary roads (6 m wide) and 15.8 to 18.6 km for highways, with the species and type of road as key attributes. In the case of the black howler monkey, an arboreal species, the effect zone may be smaller, depending on landscape connectivity and the ability of this species to move across the ground, which has been reported as 350 m in the Usumacinta region (Pozo-Montuy *et al.* 2013). However, food availability and tree cover on roadsides (within the right of way) may be acting as an ecological trap for individuals who colonize these zones, sometimes increasing roadkill rates by including between 15 and 25 species of plants as sources of food (road attraction effect; Benitez *et al.* 2021a). In the road stretch studied, 37 howler monkeys were road-killed, but the annual roadkill rate decreased due to the deterrent effect of the road, which induces animals to avoid it, and the behavior of the species.

Behavior is another aspect that has been poorly investigated. This work confirmed that animals maintained their daily activity patterns with long resting periods. They also moved on the ground, as reported to occur in disturbed sites (Pozo-Montuy *et al.* 2013). Besides, this report describes for the first time the reaction of a group of howler monkeys to the roadkill of one of its members. An evaluation of the movement and home range of gibbons (*Hylobates lar* and *H. pileatus*) estimated a probability of road crossing of 35 % by tracking them over 90 full days and recording their movements every minute (Asensio *et al.* 2021). These authors state that although roads divide the home range of these primates, these were not impassable, and gibbons had crossing points on the road. It is necessary to continue performing detailed studies analyzing the

Table 1. Complete censuses and percent population reduction of the black howler monkey, *Alouatta pigra*, at the start, during, and after the road expansion work of the Villahermosa-Escárcega highway in Chiapas, México. AM, adult male; AF, adult female; JM, juvenile male; JF, juvenile female; IM, infant male; IF, infant female; ind, individuals.

Class sex age	Initial census In 2012	Census during road expansion work in 2013	Census after road expansion work in 2017
AM	16	13	11
AF	19	12	9
JM	7	4	2
JF	8	3	2
IM	4	2	1
IF	3	1	0
Total	57 ind	35 ind	25 ind
Social groups	12	9	5
Solitary individuals	5 males	5 males	2 males
Average size	4.3	3.3	4
% Population reduction	0.00	39 %	56 %

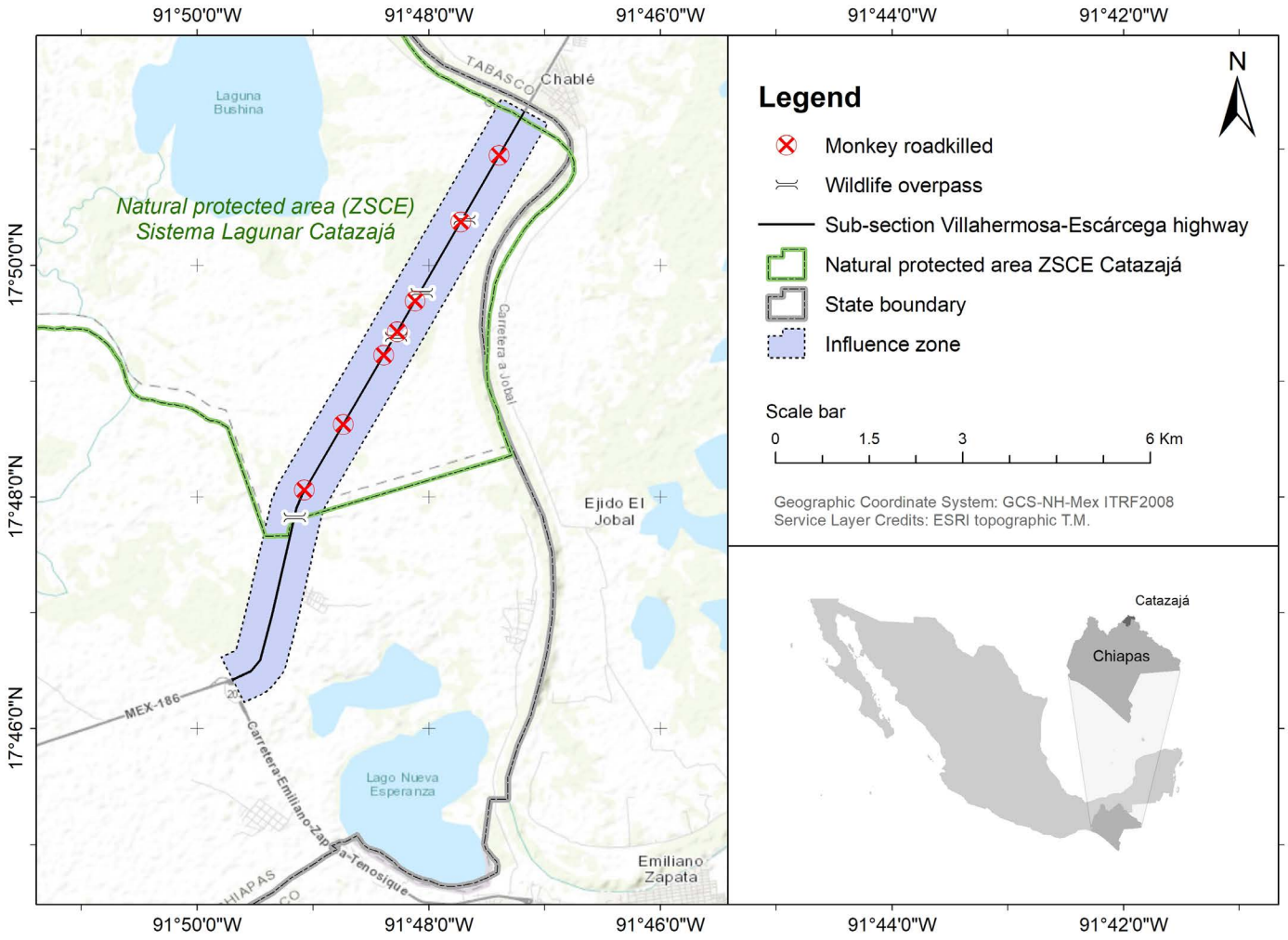

Figure 2. Roadkill area of black howler monkeys, *Alouatta pigra*, on the Villahermosa-Escárcega highway (blue stripe), state of Chiapas, México. The sites of *A. pigra* roadkills (2012-2017) are marked with red crosses. The Catazajá Lagoon System Protected Natural Area is demarcated with a green polygon. Drafted by I. Castañeda Guerrero.

behavior and movements of howler monkeys, addressing the sink and ecological-trap effects, in addition to studies on the physiological effects of vehicle collisions impacting howler monkeys, and estimate the main crossing points for the construction of arboreal wildlife overpasses.

First, it is recommended that environmentalists and environmental authorities be particularly careful when performing and reviewing Environmental Impact Assessments to avoid overlooking species at risk, as this may have major consequences; this is the case of the black howler monkey, an endangered species, which has undergone a 56 % population reduction (Estrada 2017; IUCN 2021). Although there is literature reporting the presence of black howler monkeys in the area (Bonilla-Sánchez *et al.* 2010) and it is a species listed as endangered in NOM-059-SEMARNAT-2010 (SEMARNAT 2010), consultants and environmentalists failed to report their presence. Despite this omission, the environmental authorities approved the road expansion project. It should be noted that in the road stretch studied, other protected species are also affected by roadkills, which were not considered in mitigation actions (wildlife overpasses), including the anteater (*Tamandua mexicana*), otter (*Lontra longicaudis*), common green iguana (*Iguana iguana*), black iguana (*Ctenosaura similis*), and freshwater turtles such as the narrow-bridged musk turtle (*Staurotypus triporcatus*) listed as a threatened species (NOM-059-SEMARNAT-010; SEMARNAT 2010; GBIF 2021).

Finally, the mitigation measures were implemented by SCT after the local population of howler monkeys was reduced by half (which could have been avoided). Bridges may have worked better if a formal study on the movements of howler monkeys had been performed and, mainly, if overpasses had been installed in sites with trees growing on both sides of the road or with the presence of these primates (Benitez *et al.* 2021b). During our assessment, we confirmed that half of the bridges were built in sites devoid of vegetation on one side. In addition, the Federal Electricity Commission (CFE, in Spanish) installed high-voltage lines close to bridges, which pose an additional risk for primates and hamper the functionality of these bridges. This can be addressed with reforestation programs to reconnect the vegetation on the treeless side of the road, and by isolating the CFE cables. Bridges work as linear corridors that restore the connectivity between forest patches (Teixeira *et al.* 2013). However, assessing the effectiveness of bridges requires investigating whether barrier effects and mortality

Figure 3. Roadkills of black howler monkeys, *Alouatta pigra*, of different sex and age, and wildlife overpasses on the Villahermosa-Escárcega highway in the Emiliano Zapata-Chable stretch, Chiapas, México. a) Adult female with a male infant; b) juvenile female; c) proper placement of a bridge connecting two wooded roadsides; d) the use of the bridges by howler monkeys is confirmed when these are placed and built correctly.

are reduced and whether the population remains stable. A review paper confirmed that most studies on wildlife passages have documented that mitigation can be deemed successful for individual animals, but the implications on persistence at the population level should also be monitored (van der Ree *et al.* 2015).

In this sense, it is recommended that the impact of roads on biodiversity be legislated, including mandatory guidelines on good construction practices of linear communication infrastructure and mitigation measures. These actions should be addressed with proper planning, approved budgets, and considering subsequent maintenance and monitoring.

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