THERYA NOTES 2023, Vol. 4 : 219-225 DOI: 10.12933/therya_notes-23-132 ISSN 2954-3614

Mastofauna associated with culverts along a road within the Yasuní National Park, Ecuador

Mastofauna asociada a estructuras de drenaje en un acceso vial dentro del Parque Nacional Yasuní, Ecuador

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Road construction is one of the main boosters of biodiversity loss. Fortunately, culverts can function as passes for certain wildlife species. This study recorded the mammal species that may use these structures to move from one side of a road to the other. The mammals visiting 11 culverts on a road within the Yasuní National Park were recorded over a month using camera traps. The capture rate (TC) and the visitation rate (TV) were calculated to quantify the most visited site and the most frequent visitor species. A sampling effort of 365 camera-trap days yielded 7,110 records with 264 independent events corresponding to 10 mammal species. The highest visitation rates corresponded to *Cuniculus paca* (52.05) and *Mazama americana* (9.86); the other species had a visit rate lower than 3. *Cuniculus paca* was recorded in 10 culverts. *Cuniculus paca* was the only species recorded inside a culvert; however, we cannot conclude that it crossed from one side to the other. The rest of the species approached the culverts, but there was no evidence of their entry. The use of culverts likely depends on the construction characteristics and the required conditions. However, implementing culverts can mitigate adverse impacts to the fauna, so future research is necessary.

Key words: Barrier effect; mammals; phototrapping; protected area; road; underground passages; wildlife crossing.

La construcción de carreteras es una de las principales razones que acelera la pérdida de biodiversidad. Afortunadamente, las estructuras de drenaje pueden actuar como pasos para ciertas especies de fauna silvestre. Nos propusimos registrar las especies de mamíferos que podrían utilizar estas estructuras para movilizarse de un lado al otro de una carretera. En una carretera dentro del Parque Nacional Yasuní, mediante trampas fotográficas, se registró durante un mes los mamíferos que frecuentaron 11 estructuras de drenaje. Se calculó la tasa de captura (TC) y la tasa de visita (TV), permitiéndonos cuantificar que sitio fue más visitado y que especies realizaron más visitas. Con un esfuerzo de muestreo de 365 trampas-día, se obtuvieron 7,110 registros con 264 eventos independientes que corresponden a 10 especies de mamíferos. Las mayores tasas de visita fueron de *Cuniculus paca* (52.05) y *Mazama americana* (9.86), el resto de las especies presentaron una tasa de visita menor a 3. *Cuniculus paca* fue registrada en 10 estructuras de drenaje. *Cuniculus paca* fue la única especie registrada dentro de un drenaje; sin embargo, no podemos concluir que cruzó de un lado al otro. El resto de las especies se acercaron a los drenajes, pero no se evidencia su ingreso. Consideramos que el uso de los drenajes depende de las características constructivas y una serie de condiciones requeridas; sin embargo, su implementación puede mitigar impactos negativos a la fauna, por lo que futuras investigaciones son necesarias.

Palabras clave: Área protegida; carretera; cruce de fauna; efecto barrera; fototrampeo; mamíferos; pasos subterráneos.

Road construction causes landscape fragmentation, loss of habitats, and ecosystem degradation (Ochoa 2008; Ministerio de Medio Ambiente y Medio Rural y Marino 2010; Ibisch *et al.* 2016; Pulsford *et al.* 2019; Benítez *et al.* 2021). It leads to changes in the original forest composition and structure, affecting the mobility patterns and behavior of species and disrupting dispersal, migration, and genetic exchange processes (López-Barrera 2004; Peña-Becerril *et al.* 2005; Mata *et al.* 2006; Arroyo-Rodríguez and Mandujano 2007; de la Torre *et al.* 2012; Garzón-Santomaro *et al.* 2019; Benítez *et al.* 2021; Pozo-Montuy and Bonilla-Sánchez 2022; Ruíz-Ramírez *et al.* 2022). Roads transform the habitat, generating pollution, noise, and artificial light, thus exacerbating the deterioration of ecosystems (Benítez *et al.* 2021; Pozo-Montuy and Bonilla-Sánchez 2022; Ruíz-Ramírez *et al.* 2022). All these adverse impacts may reduce population abundance and increase the species extinction risk (Jaeger and Fahrig 2004; Morera et al. 2008; Ochoa 2008; Rubio-Rocha *et al.* 2022).

The construction of wildlife crossings has been one of the measures to mitigate the adverse impacts of roads (Wang *et al.* 2017; Delborgo *et al.* 2020). These crossings or passes are permanent structures designed exclusively for a certain species or group of species (specific fauna crossings) or built for a different purpose (*i.e.*, connect water bodies, canals, sewers, culverts) not designed for wildlife crossing but that can be used for that purpose (non-specific wildlife crossings; Torres 2011).

Road construction near or within protected areas in the Ecuadorian Amazon directly threatens biodiversity (Espinosa *et al.* 2018). The Yasuní National Park (PNY, in Spanish) is the largest protected area in mainland Ecuador and is considered one of the most biodiverse zones worldwide (Bass *et al.* 2010). Despite this, oil companies have built roads for oil extraction activities that modify the original landscape (Espinosa *et al.* 2014). Culverts are built along these roads to mitigate impacts on water bodies (Envirotec 2011; Abad *et al.* 2014).

In this context, the mammal species that may use culverts to move from one side of the road to the other, *i.e.*, for which culverts function as non-specific animal passes, were recorded through photo trapping.

The study was conducted within the oil facility (Block) 31 at the Tiputini-Apaika road within the Yasuní National Park, located at Cononaco parish, Aguarico canton, Orellana province (Figure 1a). The road runs from the southern bank of the Tiputini River, on the PNY border, to the Apaika oil platform (Envirotec 2011). The dominant vegetation type along the road is the flood forest of the Amazonian alluvial plain; there are also patches of flood forest where the palm *Mauritia flexuosa* predominates (Ministerio del Ambiente de Ecuador 2013).

The Tiputini-Apaika road comprises sections of unpaved compacted soil alternating with sections covered with syn-

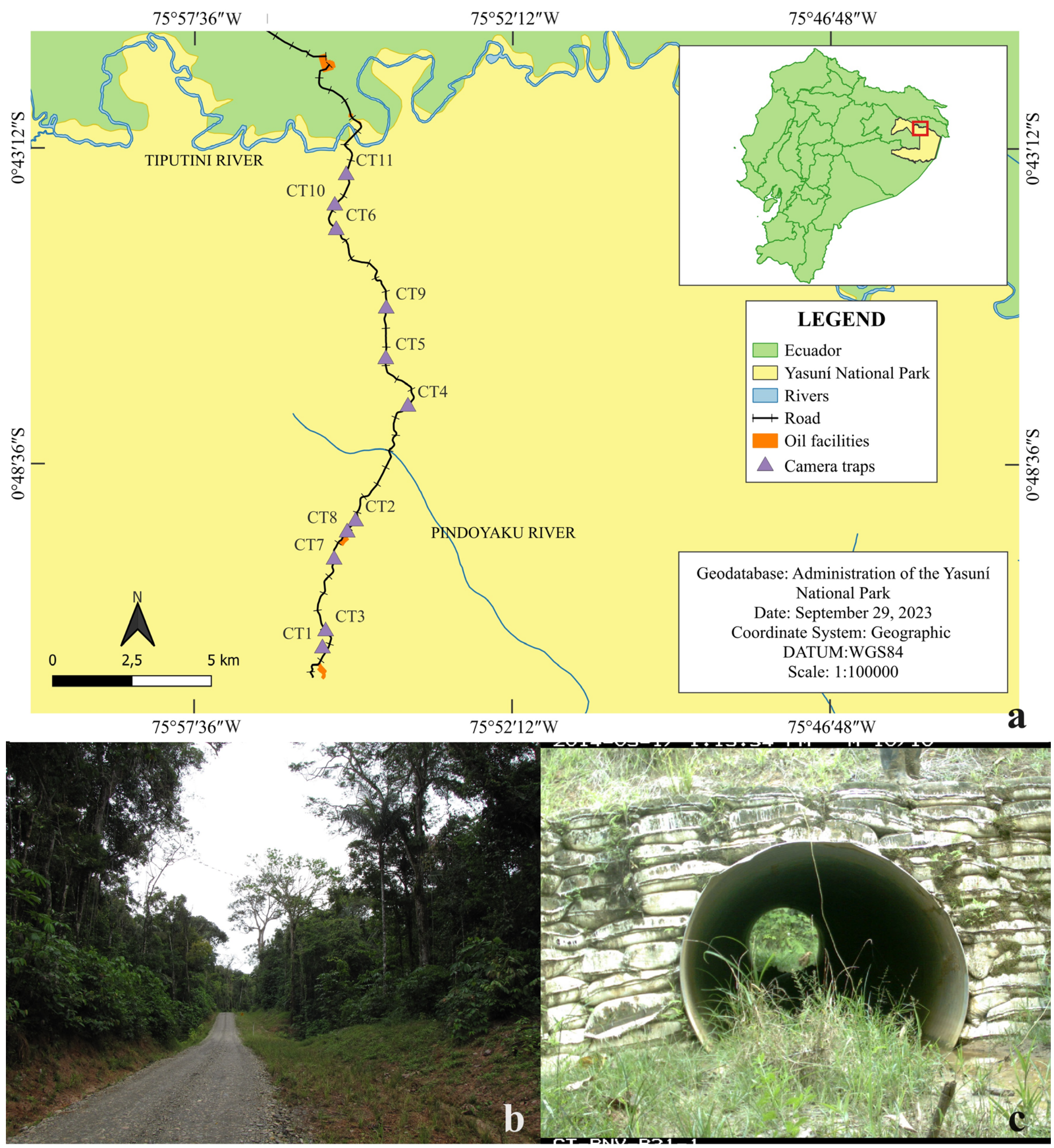

Figure 1. a) Map of the study area. Tiputini-Apaika road and location of the phototrapping stations in the Yasuní National Park, Ecuador; b) Tiputini-Apaika road within the Yasuní National Park; c) Culverts (drainage structures installed in water bodies).

thetic materials called Geoterra and MegaDeck/Durabase, which are placed on the compacted soil (Envirotec 2011). It measures 20 km long by 10 m wide, and its access is restricted to oil company vehicles that circulate at a maximum allowed speed of 35 km/h (Envirotec 2011).

In the low-rainfall months of September and October 2014 (Bass *et al.* 2010; Envirotec 2011), 11 of 82 drainage structures (culverts) were selected along the Tiputini-Apaika road (Figure 1; Table 1). Culverts were selected based on the presence of mammal footprints at the inlets-outlets and considering that they were easily accessible to install camera traps. Culverts are galvanized structures measuring 12 m long and approximately 1.5 m in diameter, with soil-cement heads installed at both ends (Envirotec 2011). All culverts had very small water flows that grew and flooded these structures during heavy rains (Figure 1c).

Camera traps were installed facing one of the culvert inlets. One RECONYX H600 HyperFire camera trap was used per culvert, set to capture 10 consecutive photographs with no waiting time between detections. These cameras were installed considering the criteria of Tobler *et al.* (2008) and Díaz-Pulido and Payán (2012), such as the position of the camera trap relative to the target and the ground, fixing the equipment in firm and stable places, and with an unobstructed field of view.

For the data analysis, records were considered independent when more than 30 min passed between consecutive photographs of the same species at a given photo trapping station. Consecutive photographs of different species were also considered independent records regardless of the time elapsed (Blake *et al.* 2011).

The capture rate (TC, for its acronym in Spanish) by site was calculated by dividing the number of independent captures by the number of sampling days and multiplied by 100 (correction coefficient). This allowed quantifying the visits to each site over 100 days. Similarly, the visitation rate (TV, for its acronym in Spanish) for each species was calculated by dividing the number of independent records by the number of days of total sampling and multiplied by 100 (correction coefficient). This allowed quantifying independent events by species for 100 days (Rovero *et al.* 2014; Mandujano and Pérez-Solano 2019; Table 2).

A sampling effort of 365 camera-trap days resulted in 7,110 photographic records, of which 259 are independent records of 10 mammal species, with 1 unidentified rodent species. In addition, an individual of the Neotropical otter (*Lontra longicaudis*) was recorded by direct observation. Of these species, 6 are included in Ecuador's Red List (Tirira 2021), the International Union for the Conservation of Nature Red List (IUCN 2023), and the appendices to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2023; Table 2).

The site with the highest number of independent visitations was CT5, with 24 % of the records (TC = 16.99, *n* = 62), followed by CT6 and CT2, with 15% each (TC = 10.96, *n* = 40, and TC = 10.68, *n* = 39, respectively). The other sites recorded a TC of less than 10 (Table 1).

The species with the highest number of independent captures was *Cuniculus paca,* with 72 % of the records (TV = 52.05, *n* = 190), followed by *Mazama americana,* with 13.6 % of independent records (TV = 9.86, *n* = 36). The rest of the species had a TV lower than 3: *Coendou* sp. (TV = 1.64, *n* = 6), *Dasyprocta fuliginosa* (TV = 1.37, *n* = 5), *Procyon cancrivorus* and *Leopardus pardalis* (TV = 1.09, *n* = 4), *Dicotyles tajacu* (TV = 1.75, *n* = 7)*, Panthera onca* and *Pecari tajacu* (TV = 0.27, *n* = 1; Table 2).

Cuniculus paca was recorded in 10 of the 11 sites studied and appears within a culvert (Figure 2a). *Mazama americana* (Figure 2b) and *D. fuliginosa* were recorded in 4 sites. *Procyon cancrivorus* and *T. terrestris* (Figure 2c) were recorded in 3 sites and *L. pardalis* in 2. The remaining species were recorded only in a single site each (Table 2), including *P. onca* (Figure 2d).

The lowland paca (*C. paca*) had the highest visitation rate, recorded in 10 of the 11 sites sampled. These findings are similar to those obtained by Monge-Velázquez and Sáenz

Table 1. Data from camera traps (CT) installed in culverts along the Tiputini-Apaika road within the Yasuní National Park, Ecuador.

Camera	Traps/ day	South Latitude	West Longitude	Photographs Captured	N° of independent records	Capture rate	N° of species
CT1	36	0° 51´ 45´´	75° 55´ 25´´	260	20	5.48	3
CT2	36	0° 49´ 34´´	75° 54´ 51´´	1,410	39	10.68	4
CT3	10	0° 51´ 27´´	75° 55´22´´	70	2	0.55	2
CT4	36	0° 47´ 36´´	75° 53´58´´	350	18	4.93	7
CT5	36	0° 46´ 48´´	75° 54´21´´	1,640	62	16.99	5
CT6	36	0° 44´ 35´´	75° 55´11´´	1,140	40	10.96	1
CT7	35	0° 50´ 13´´	75° 55´13´´	610	22	6.03	2
CT8	35	0° 49´ 46´´	75° 55´ 0,2´´	10	1	0.27	1
CT9	35	0° 45´ 56´´	75° 54´ 20´´	60	6	1.64	4
CT10	35	0° 44´ 10´´	75° 55´ 13´´	1,030	35	9.59	1
CT11	35	0° 43´ 39´´	75° 55´ 1,6´´	530	19	5.21	4

Figure 2. a) Lowland paca (*Cuniculus paca*) was the only species recorded within the culvert and had the highest visitation rate; b) red deer (*Mazama americana*) attained the second-highest visitation rate; c) the Amazon tapir (*Tapirus terrestris*) was recorded in three culverts; d) a jaguar (*Panthera onca*) was recorded in a single photo trapping station in the Yasuní National Park, Ecuador.

(2022) in a coastal zone of Costa Rica, where culverts have also been installed. Similarly, *C. paca* is one of the species with the highest crossing frequency in the study by Torres (2011).

On the other hand, the direct observation of a culvert used as a crossing by the Neotropical otter, *L. longicaudis*, suggests that this species may be using these sites. However, considering that the otter was in a flooded culvert and that it moved away using the culvert as an escape route upon noticing the presence of the observer, the observation could be a fortuitous event explained by the aquatic and elusive habits of the species (Vallejo and Pozo 2022).

Due to its size, the jaguar (*Panthera onca*) is unlikely to use culverts as crossings; these structures measure 1.5 m in diameter, and large species such as the jaguar prefer large, open structures (Torres 2011; Kintsch *et al.* 2015). González-Gallina *et al.* (2018) recorded at least 6 individuals of *P. onca* using animal passes measuring 3 m wide and 4.5 m high; this same study recorded no jaguar approaching culverts 1.8 m in diameter, similar to those included in the present study. Along the Tiputini-Apaika road, oil company and PNY workers have repeatedly observed jaguars crossing the road throughout the oil plant operation.

The presence of carnivores in culverts suggests that these sites, visited by potential prey (*e.g.*, small and medium-sized rodents), represent hunting opportunities for predators. Although culverts may not be used as crossings, they may be sites of potential food availability. For instance, the ocelot, *Leopardus pardalis,* is an opportunistic predator that feeds on a wide range of prey (Moreno *et al.* 2006), including birds and mammals, mainly rodents such as the agouti (*Dasyprocta fuliginosa*) and the lowland paca (*C. paca*) recorded in this study, as well as amphibians and reptiles that may use these sites as shelters and that the ocelot can visit in search of prey (Macas-Pogo *et al.* 2023). However, a long-term study conducted in the Banff National Park, Canadá, reported only 5 predation events over 13 years; the authors concluded that there is no association between crossing structures and predation events (Clevenger and Ford 2010).

As for the ungulates captured, none used culverts as crossings, consistent with the reports by Torres (2011) and González-Gallina *et al.* (2018). However, these same studies did report crossing events of white-tailed deer, *Odocoileus virginianus*, using fauna crossing structures, *i.e.*, structures designed for this purpose. As with the jaguar and large mammal species, the size of these structures is crucial for their use (Kintsch *et al.* 2015).

The culverts installed along the Tiputini-Apaika road were not built for use as fauna crossings; however, this study recorded two crossing events by *C. paca* and *L. longicaudis*. It could be stated that most of the recorded fauna does not use culverts to move across and that the records of the present work were incidental since, according to Fernández-Buces *et al.* (2022) and Monge-Velázquez and Sáenz (2022), culverts are attractive sites to wildlife.

As the sites where these structures were installed are flooded, it can be expected that species of terrestrial habits do not use them to cross the road (Jochimsen *et al.* 2004). Most of the recorded fauna likely use them only as watering holes and food-seeking sites, as is the case with the crab-eating raccoon (*Procyon cancrivorous*), an omnivorous species that feeds on fish, amphibians, reptiles, and aquatic crustaceans (Phillips 2005).

On the other hand, the recording of threatened species such as the Neotropical otter, the Amazonian tapir, and the jaguar (Table 2) highlights the need to install different types of fauna crossings (*i.e.*, specific fauna crossings) in sensitive sites such as the PNY. The size and behavior of the species expected to use the crossings must be taken into account to construct them accordingly, taking into account the design, type of material used, dimensions, inlets and outlets, as well as the traffic and noise level of the road (Monge-Velázquez and Sáenz 2022). Ruediger and DiGiorgio (2007) indicate that the building material of crossings is irrelevant for some species but is very important for others, while Corlatti *et al.* (2009) describe the particular characteristics of crossings for some wildlife groups.

Culverts can serve as non-specific wildlife crossings. However, a long-term monitoring plan should be implemented to gather conclusive information contributing to the effective management of the protected area.

Acknowledgements

The authors wish to thank the Ministerio del Ambiente, Agua y Transición Ecológica (Ministry of Environment, Water and Ecological Transition) of Ecuador, specifically the Environmental and Social Repair Program (PRAS, in Spanish)

Table 2. List of species, visitation rate, and threat categories recorded along the Tiputini-Apaika road within the Yasuní National Park. [1]Ecuador's Red Book. [2]International Union for the Conservation of Nature. [3]Convention on International Trade in Endangered Species of Flora and Fauna. DD: Data deficient. LC: Least concern. NT: Near threatened. VU: Vulnerable. EN: Endangered. CR: Critically endangered. I and II: Appendices 1 and 2.

Taxonomy	N° of captures	N° of independent records	Visitation rate	[1]LRE	[2]IUCN	[3]CITES
ARTIODACTYLA						
Cervidae						
Mazama americana	1,350	36	9.86	NT	DD	--
Tayassuidae						
Dicotyles tajacu	10	1	0.27	NT	LC	II
CARNIVORA						
Felidae						
Leopardus pardalis	50	4	1.10	NT	LC	I
Panthera onca	20	1	0.27	EN	NT	I
Procyonidae						
Procyon cancrivorus	90	4	1.10	LC	LC	--
Mustelidae						
Lontra longicaudis		Direct observation		VU	NT	I
PERISSODACTYLA						
Tapiridae						
Tapirus terrestris	370	9	2.47	EN	VU	II
RODENTIA						
Cuniculidae						
Cuniculus paca	4,940	190	52.05	NT	LC	III
Dasyproctidae						
Dasyprocta fuliginosa	70	5	1.37	LC	LC	--
Erethizontidae						
Coendou sp.	80	6	1.64	--	--	--
Incertae sedis	30	3	0.82	--	--	--

for having provided the technical and economic resources for conducting the present work, as well as the authorization for using the data collected. Thanks also to the Head of the Yasuní National Park, its technicians and park rangers for their support. To PetroAmazonas EP for having provided logistics support within Block 31. Two anonymous reviewers provided comments that contributed improve this note. M. E. Sánchez-Salazar translated the manuscript into English.

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Associated editor: Coral Pacheco Figueroa.
Submitted: June 12, 2023; Reviewed: September 16, 2023.
Accepted: October 1, 2023; Published on line: October 10, 2023.