## Roads as ecological traps for giant anteaters

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Roads as ecological traps for giant anteaters

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Abstract

Wildlife-vehicle collisions (WVC) represent a serious source of mortality for many species, threatening local populations’ persistence while also carrying high economic and human safety costs. Animals may adapt their behaviour to road-associated threats, but roadside resources can also attract individuals to dangerous roadside habitats, ultimately acting as an ecological trap. Yet, the extent to which individuals modify their behaviour and space use to roads is largely unknown for most taxonomic groups. Using fine-scale movement data from 38 giant anteaters (Myrmecophaga tridactyla) tracked in the Brazilian Cerrado, we aimed to identify facets of movement behaviour that might exhibit plasticity to roads and traffic volume. Specifically, the analysis of daily and instantaneous movement speeds, home range characteristics, and crossing rates/times, allowed us to test for an effect of road proximity, traffic volume and natural linear features on movement behaviour. We found no effect of road proximity or traffic volume on space use or movement behaviour. While individuals tended to reduce their movement speed when approaching roads and crossed roads ~3 times less than would have been expected by random chance, none of the three highways we monitored were impervious. The majority of tracked anteaters living near roads (<2km) crossed them, with higher crossing rates for males than females. Habitat near roads may function as an ecological trap where healthy individuals occupy the territories nearby or bisected by roads but eventually are road-killed given their regular crossings, leaving the territory vacant for subsequent occupation. Crucially, we found no evidence that anteaters actively searched for passage structures to cross the roads. This suggests that crossing structures alone are unlikely to mitigate WVC induced mortality in giant anteaters. Our research reinforces the need to implement fencing, leading to existing passages, and minimising the amount of night-time driving to reduce the number of WVCs.

Keywords: Wildlife-vehicle collisions, Fencing, GPS Tracking, Home range, Movement ecology, Roadkill, Giant anteater, Ecological trap
Introduction

Human development reduces the amount of habitat available to wildlife (Venter et al. 2016). Animals moving through altered landscapes are coming into conflict with humans at rapidly increasing rates (Fahrig 2007; Macdonald 2016; Buchholtz et al. 2020). Of special concern are the impacts of roads on biodiversity (Forman et al. 2003; Van der Ree et al. 2015). In particular, wildlife-vehicle collisions (WVC) that occur while animals try to move across roads, represent a serious source of mortality for many species (D’Amico et al. 2015; González-Suárez et al. 2018; Ascensão et al. 2019a). WVC not only threaten the local population persistence (Desbiez et al. 2020), but also carry high economic and human safety costs (Abra et al. 2019, Ascensão et al. 2021). Beyond the direct impact of WVC, roads can also hinder species’ capacities to disperse and re-distribute (Clark et al. 2010; Long et al. 2010), potentially reducing gene flow and population viability (Riley et al. 2006; Ceia-Hasse et al. 2018).

Whilst roads are important for socioeconomic growth, the detrimental impacts of roads (Fahrig & Rytwinski 2009) are expected to drive individuals living in road-bisected habitats to respond by adapting their behaviour to the requirements of roadside environments (Ascensão et al. 2017). Roadside foraging opportunities can act as attractants for many species (Barrientos & Bolonio 2009; Ascensão et al. 2012), however, providing misleading information about habitat quality. When species perceive these attractants but fail to learn to avoid oncoming vehicles (see Jacobson et al. 2016) and/or fail to search for existing road passages, such as culverts (see e.g. Clevenger et al. 2001) for safe crossings, this can act as an ecological trap (Schlaepfer et al. 2002) that may carry severe consequences. Behavioural plasticity towards roads is especially important for long-lived, $K$-selected species (Sih et al. 2011; Montgomery et al. 2020) that take longer to reach sexual maturity, and have longer interbirth intervals than short-lived species (De...
Magalhaes & Costa 2009). Yet, the extent to which individuals modify their movement
behaviour and space use to roads is largely unknown for most taxa – despite such information
being critical in both the delineation of species and landscape management programs and for the
planning and mitigation of transportation infrastructures (D’Amico et al. 2016).

Here, we address this research gap by identifying facets of animal behaviour that might
exhibit plasticity in response to roads. We base our study on giant anteaters (Myrmecophaga
tridactyla), the largest extant anteater. Giant anteaters reach over two meters and weight up to
50kg (McNab 1984), and are distributed throughout Central and South America (Gardner 2008).

Giant anteater populations have suffered severe reductions with local and regional extirpations
and are currently classified as Vulnerable to Extinction (IUCN 2014). Moreover, WVC are a
major threat to giant anteaters, as they are commonly reported as one of the top mammals
recorded in systematic roadkill surveys, reaching an annual rate of ~17 ind./100km/year in Mato
Grosso do Sul, Brazil (Ascensão et al. 2021). Such high non-natural mortality is thought to
reduce the viability of populations (Desbiez et al. 2020), given their low recruitment (about one
pup per year; Gaudin et al. 2018), and low densities (generally <1ind/km²) (Bertassoni et al. in
press). Consequently, reducing WVC induced mortality is recognised as a conservation priority
for the species (Miranda et al. 2014). Despite this recognition, as for most mammals, there is no
information on whether roadside residents regularly cross highways, or if dispersing individuals
make up the bulk road-killed animals, nor how giant anteaters respond to different types of roads
and traffic volumes. Similarly, giant anteaters are known to use road passage structures (Abra et
al. 2020), but there is no evidence as to whether they search for existing structures to safely cross
roads, or if these are only used opportunistically.
Understanding how the movement of giant anteaters responds to roads and its relationship with roadkill can thus provide valuable information for landscape and road management. Such information is even more pressing given the increasing agribusiness expansion, infrastructure development and low legal protection for this species’ habitat (Strassburg et al. 2017), which may worsen the persistence of local populations in road vicinity areas (Desbiez et al. 2020). Moreover, reducing the number of WVCs also reduces the number of human injuries and material damage, with great benefits for people (Ascensão et al. 2021). We carried out the most extensive telemetry study on giant anteaters to date to fill these critical knowledge gaps. In particular, we aimed to address four over-arching questions: Q₁) Does the movement behaviour of giant anteaters differ with distance to paved roads? Q₂) Does traffic volume influence giant anteater crossing behaviour? Q₃) Do giant anteaters prefer to cross the roads via passage structures? Q₄) Do anteaters respond to roads differently than to natural barriers?

Currently, little is known about the movement ecology of giant anteaters (Medri & Mourão 2005; Giroux, 2021), but because of the high number of giant anteaters found in roadkill surveys (Ascensão et al. 2021) relative to their low population densities (Bertassoni et al. in press), our underlying hypothesis was that roads do not significantly deter giant anteaters. As such, we expected to observe no differences in movement behaviour with road proximity or traffic volumes and similar road crossing rates across the different types of roads and natural linear features, such as streams. Likewise, the use of road passage structures (e.g., culverts, viaducts, etc.) was expected to be opportunistic. Findings are directly applicable to developing road and landscape management plans for giant anteaters, as well as for other medium-large mammals that occupy road-side habitats.
Materials and methods

Study area

The study was conducted at three sites in the state of Mato Grosso do Sul (MS), in the Cerrado biome (savannah) of Brazil (Fig. 1). The climate throughout MS is wet from October to March and dry from April to September (Koppen’s Aw), with mild year-round temperatures (range 21-32°C). Average annual rainfall ranges between 1000-1500mm. The land use bordering all roads was dominated by pasture, with sparse remnants of native forest and savanna, and some areas of eucalyptus plantation. Streams bordered with native riparian vegetation were common throughout the study area, mostly accompanying native savanna vegetation. Three paved, two-lane highways of different ages and traffic volumes cross the study area (Table 1). Speed limits for the highways varied between 80-100 km/h. Traffic volume information for BR262 and BR267 was obtained from official counts (DNIT 2020). MS040 counts were obtained using a similar methodology used by governmental authorities (DNIT 2020), i.e. vehicle counting throughout five consecutive days, 24 h per day. A network of unpaved roads was also present, linking main roads and ranches. These roads had significantly lower traffic volumes (<1 car per hour) in comparison with paved roads (pers. observations when using the roads to access the study areas). Each study area had 9-11 passages (culverts, box-culverts, and viaducts) near the territories of the tracked giant anteaters (Table 1; Appendix S1). This study was performed under License No. 53798 (Chico Mendes Institute for Biodiversity Conservation) that granted permission to capture, immobilize, and manipulate giant anteaters and collect/store biological samples. All procedures followed the Guidelines of the American Society of Mammalogists for the use of wild mammals in research (Sikes et al., 2016).
Giant anteater GPS data collection

Wild giant anteaters were captured between 2017-18, in the vicinity of the three paved highways of the study area, >15km from urban areas, and equipped with GPS tracking collars. The capture team was always comprised of two veterinarians and a biologist, minimum. To capture giant anteaters, we searched open areas for individuals foraging, during colder months (May-August) when individuals are known to exhibit greater diurnal activity (Camilo-Alves & Mourão 2006).

When an adult was spotted, two members of the capture team approached the individual by foot and captured it using two long-handed-dip-nets (handle 1.5m; hoop 0.7m diameter) to restrain it (Kluyber et al. 2021). The veterinarian was then able to safely apply an intramuscular combination anaesthetic injection of butorphanol tartrate (0.1mg/kg), detomidine hydrochloride (0.1mg/kg) and midazolam hydrochloride (0.2mg/kg) into its hind limbs (Kluyber et al. 2021).

After anaesthetic induction, the front claws were first wrapped and completely immobilized using tape. Physical exams were then performed to evaluate health conditions and included measuring weight, pregnancy detection (palpation), general appearance, hydration status, mucous membrane colour, respiratory auscultation, and presence of scars or wounds (Kluyber et al. 2021). Only adult individuals considered in good health by the veterinarians were fitted with the GPS harness (TGW-4570-4 Iridium GPS) and VHF transmitters (MOD 400; Telonics, Mesa, Arizona). For anaesthetic reversal procedures, all individuals received a combination of three antagonists: naloxone hydrochloride (0.02mg/kg), yohimbine hydrochloride (0.125mg/kg), and Flumazenil (0.01mg/kg) (Kluyber et al. 2021). After the procedure, the animal was maintained in a wooden ventilated crate until complete recovery and was then released at its capture location.

Collared giant anteaters were recaptured approximately one year after for harness removal and
data download, but each animal was visually inspected at a distance through binoculars at least once every two weeks for a general health check without disturbing the animals. The trackers took GPS fixes with 20 min intervals.

We deployed collars on 43 individuals out of a total of 45 total captures (2 were deemed too young to collar). These 43 individuals were considered in good health and no signs of infection or diseases were observed during clinical exams performed upon captures and recaptures. Importantly, no health differences were noted between individuals regardless of how far they lived from the highway. Six of the collared giant anteaters were found dead in the course of the study period, four of which were road-killed and two due to unknown causes (see Table S3.1). Two of the collared animals had insufficient data due to collar malfunctions and were excluded from our analyses. Furthermore, 3 of the individuals dispersed over the study period and were therefore excluded from our analyses as we were interested primarily in understanding typical behaviour from range-resident individuals. We therefore present results for 38 range-resident giant anteaters. Trackers operated for a median of 11.2 months across all tagged giant anteaters. The final GPS dataset comprised 847,683 GPS fixes collected over 12,761 individual-days (Appendix S2).

Data analysis

Movement data pre-processing

Before analysis, we performed a data cleaning process in order to calibrate the GPS measurement error and filter outliers using the methods implemented in the R package ‘ctmm’ (Calabrese et al. 2016; Fleming & Calabrese 2020, see Appendix S2). For each location estimate, the GPS trackers recorded a unitless Horizontal Dilution of Precision (HDOP), value
which is a measure of the accuracy of each positional fix. We converted the HDOP values into calibrated error circles by estimating an equivalent range error from 6,948 calibration data points where a tag had been left in a fixed location (Fleming et al. 2020). For each individual dataset, we then removed outliers based on error-informed distance from the median location, and the minimum speed required to explain each location's displacement.

**Movement metrics**

For each of the collared giant anteaters, we quantified key movement metrics and home range related characteristics that allowed us to test for an effect of road proximity, traffic volume and natural linear features on giant anteater movement behaviour. First, using the R package ‘ctmm’, we fitted a series of continuous-time movement models (hereafter ‘CTMM’) to the track data, using perturbative-Hybrid Residual Maximum Likelihood (pHREML; Fleming et al. 2019), and identified the best CTMM via small-sample-sized corrected Akaike’s Information Criterion (AICc).

From each CTMM we estimated both the mean *Daily movement speed* (in km/day) and the *Instantaneous movement speed* (in m/s), using continuous-time speed and distance estimation (Noonan et al. 2019). This approach is insensitive to the sampling schedule, and corrects for GPS measurement error, enabling robust comparisons across individuals.

We next estimated the *Home-range* for each animal, as the polygon delimited by the 95% isopleth of the Utilization Distribution using Autocorrelated Kernel Density Estimation (AKDE) (Fleming et al. 2015). AKDE home-range estimates were conditioned on the autocorrelation structure of the CTMM and we implemented the small-sample-size bias correction of Fleming & Calabrese (2017). For each individual, we quantified the land cover
within their home range polygon to control for possible confounding effects related to habitat quality that could influence movement behaviour. Land cover was obtained from MapBiomas (Souza & Azevedo 2017) for 2018. We compared the proportion of cover of the two main classes occurring within home ranges, namely pasture and native vegetation. Because of a strong negative correlation between the proportion of pasture and native vegetation in an individual’s home range (Pearson correlation = -0.92), only the proportion of pasture cover was included in our analyses. We also calculated the Euclidean distance between each individual’s home-range centroid and the nearest paved road.

We further estimated the total number of crossings across the highways, unpaved roads, and streams for each giant anteater. For this, we used each animal’s tracking data and their CTMM to reconstruct the most likely path that they travelled through the landscape. We identified the total number of intersections (crossings) between the most likely path and the different linear features.

Movement pattern comparisons

We used the information obtained from each animal’s GPS location data to address each of our four core research questions. The R code required to reproduce these analyses, is presented in Appendix S3.

Q1) Does the movement behaviour of giant anteaters differ with distance to paved roads?

In order to answer Q1, we tested for any relationship between the distance individuals lived from roads and i) individual home range areas, ii) daily movement speeds, and iii) instantaneous movement speeds. We also looked at whether there were any differences in these measures
across each of the three paved roads to test for an effect of traffic volume. Home-range areas and
daily movement speeds were analysed using the meta-regression model implemented in the R
package ‘metafor’ (Viechtbauer 2010), which allowed uncertainty in each individual estimate to
be propagated into the population level estimate when making comparisons. Instantaneous
speeds were analysed using a Gaussian mixed effects model that included the quadratic effects of
distance to road and time of day (to control for circadian rhythms), and the identity of the nearest
paved road (to control for traffic volume). We also included a random intercept for each
individual and random slope for the relationship between movement speed and the distance to
the road for each individual giant anteater. Finally, we applied a first order auto-regressive
correction to the residuals to account for autocorrelation in instantaneous movement speeds. The
final model structure was confirmed using likelihood ratio tests and AICc based model selection.
We therefore modelled instantaneous speed as:

\[ Speed_i \sim N(\mu, \sigma^2) \] (1)

\[ \mu = \alpha_{ij} + \beta_{1ij}(\text{Dist}) + \beta_{2ij}(\text{Dist}^2) + \beta_{3i}(\text{hour}) + \beta_{4i}(\text{hour}^2) + \beta_{4j}(\text{Road}) \] (2)

\[
\left(\begin{array}{c}
\alpha_i \\
\beta_{1ij}
\end{array}\right) \sim \left(\begin{array}{c}
\gamma_0^a + \gamma_1^a(\text{Road}_{\text{BR262}}) + \gamma_2^a(\text{Road}_{\text{MS-040}}) \\
\mu_{\beta_{1ij}}
\end{array}\right)\left(\begin{array}{c}
\sigma^2_{\alpha_i} \\
\rho_{\alpha_i\beta_{1ij}}
\end{array}\right), \text{for ID } j = 1, \ldots, J (3)
\]

Where Eq. (1) defines the model’s stochastic component, Eq. (2) the models fixed effects
structure, and Eq. (3) the model’s random effects structure. For the instantaneous speed analyses,
all individuals that lived >2 km from a paved road were excluded. This cut-off was selected as
animals that lived >2 km from a paved road did not interact with roads over the course of the
study period, making it unlikely that they would be modifying their behaviour with respect to
how close/far they were from a road at any given point in time.

Q2) Does traffic volume influence giant anteater crossing behaviour?

To answer Q2 we modelled the relationship between the number of road crossings according to
the nearest highway as a proxy for traffic volume. We also included the variables related to the
home range location (distance of home range centroid to nearest paved road), sampling duration,
sex, and weight. The road crossing data were zero-inflated, where only 26 of the 38 range-
resident individuals (see below) were actually observed to have crossed a road. As a result, we
analysed these data using a hurdle model (Zuur et al. 2009) that modelled individual crossing/not
crossing information according to a logistic regression model, and the individual number of
crossings for those individuals that did cross according to a zero-truncated negative binomial
generalised linear model. This formulation allowed us to distinguish between the factors
governing whether giant anteaters crossed paved roads or not, and the factors driving the
crossing rate for those individuals that did cross, allowing us to capture both ecological processes
in a single model. For both processes, we started with the following global model:

\[ \mu_i = \beta_0 + \beta_1 \text{Road} + \beta_2 \text{Distance to Road} + \beta_3 \text{Sex} + \beta_4 \text{Weight} + \beta_5 \% \text{Pasture} + \beta_6 \text{Sampling Duration}\] (2)

From this global model, we specified a subset of candidate models comprising of all
possible combinations of fixed effects using the R package ‘MuMIn’ (Bartoń 2016), and used the
AICc for model selection to identify the best-fit model for the data. As AICc has been shown to
under/overfit models on small sample sizes (Brewer et al. 2016), we confirmed our selected
model via block cross-validation using the methods implemented in the R package ‘DAAG’ (Maindonald et al. 2015). We also tested if the time of day for each road crossing event was related to the hourly traffic volume variation, using simple linear regression.

Q3) Do giant anteaters prefer to cross the roads via passage structures?

To address Q3, we identified the crossings on each highway that were within 20m (the median GPS measurement error) of a road passage. These were classified as crossings where a giant anteater could potentially have used that structure to move across the road. This allowed us to search for evidence that giant anteaters preferred to cross the roads through existing passages using a chi-square test.

Q4) Do giant anteaters respond to roads differently than to natural barriers?

Finally, to answer Q4, we compared the number of crossings across paved roads to those across unpaved roads and streams using paired t-tests. In a complementary approach, we used simulations to generate a null model of the number of crossings across all linear features that would be expected by chance. For each giant anteater tracked, we used their CTMM to simulate 1000 movement datasets with sampling times that matched the empirical data. We then quantified the number and time of day of road and stream crossings in the simulated movement and averaged the results for each individual. This provided an estimate of the number of road crossings that would be expected by random movement within individuals’ home ranges that we could compare our empirical results against. Observed and expected crossings across paved roads, unpaved roads and streams were compared using paired t-tests.
Results

Movement data summary

The 38 range-resident individuals occupied stable home ranges, with an average 95% area of 6.8km² (4.6–9.0km², 95% CIs reported hereafter). We found that males had significantly larger home range areas than females (8.8km², 5.9–11.6km² versus 4.4km², 1.2–7.6km² respectively; Z = 2.01, p = 0.045). There was no evidence for a relationship between home-range area and body size (Z = -1.95, p = 0.052), however, we did find a negative relationship between home-range area and the proportion of pastureland that it contained (Z = -3.8, p < 0.001). We found partial evidence that high traffic volumes seemed to inhibit some giant anteaters from establishing territories on both sides of the roads, but small sample sizes and substantial inter-individual variation limited the power of these analyses (Appendix S4). Notably, we found no significant differences in habitat composition across the three study sites, nor when comparing habitat on one side of a road versus the other (detailed in Appendix S3).

Q1) Does the movement behaviour of giant anteaters differ with distance to paved roads?

Overall, we found little evidence that giant anteaters modified their home ranging behaviour in response to paved roads. When comparing giant anteaters between the three study sites, there were no differences in home-range sizes (L = 0.38; p = 0.83; Fig 2a), nor did we find a relationship between the distance that individuals lived from a paved road and their home-range sizes (Z = 0.15; p = 0.88; Fig 2b). There were also no differences between their mean daily speeds and the distance that individuals lived from a paved road (Z = -0.08; p = 0.94; Fig 2c) nor...
any evidence that giant anteaters’ mean daily movement speed differed when living near paved
roads with differing traffic volumes ($L = 3.87; p = 0.14$; Fig 2d).

Interestingly, however, we did find evidence that individuals modified their instantaneous
movement speed depending on how far they were from roads (Table 2a). This relationship was
non-linear and, all else being equal, individuals tended to move slowly when close to or on
roads, speed up at intermediate distances, and then slow down again as they moved further away
from roads. The interclass correlation was relatively low (14.5%), suggesting this general pattern
was fairly consistent across all of the giant anteaters we collared, but with some amount of inter-
individual variation in how movement changed with distance to roads (Appendix S3).

Q$_2$) Does traffic volume influence giant anteater crossing behaviour?

We also found little evidence that traffic volume influenced giant anteater crossing behaviour. Of
the 27 giant anteaters with home range centroids <2km from the nearest paved road (i.e., those
individuals with home-ranges bordering or intersecting the nearest paved road), 22 crossed roads,
with a median of 2 crossings per animal per day (range 1–15). Across all individuals, the selected
model (<AICc) predicting whether a giant anteater would cross a road or not (Table 2b) included
the distance an animal lived from the nearest paved road, the animal’s sex, and the road it was
crossing. Using these three terms alone, we found that a logistic regression model could predict
crossings on a hold-out sample with a mean accuracy of 84.0% (83.8–84.3%, 95% CIs).

Unsurprisingly, the closer an animal lived to a road, the more likely it was to cross. Males were
~3.7 times more likely to cross the roads than females, all else being equal. The model further
suggests an overall similarity in crossing events across roads.
The selected model section relating the number of crossings per individual for those giant antelopes that did cross a paved road (Table 2b) included the distance to the nearest paved road, sex, and the amount of pasture contained within their home ranges. Here again, individuals that lived closer to paved roads tended to cross them significantly more often, all else being equal (Fig. 3a). However, males tended to cross the roads more frequently than females (Fig. 3b), and the more pastureland that was in an individual’s home range, the less it crossed paved roads (Fig. 3c).

Giant anteaters tended to cross paved roads more frequently at night, when the traffic volume was lowest, but this also coincided with when they were more active (Fig. 4). We found a significant negative correlation between mean hourly road crossings and traffic volume ($F_{1,22} = -17.0$, $p < 0.001$, adjusted $R^2 = 0.41$). Circadian patterns in traffic volume were also consistent across all three roads (see Appendix S3).

Q3 Do giant anteaters prefer to cross the roads via passage structures?

We found no evidence that giant anteaters searched for road passages (culverts or viaducts) to cross the roads. The median distance of road crossings from the nearest road passage was 1720m (1710–1730m, 95% CIs), and individuals preferred to cross without the use of a structure ($\chi^2_{11} = 1494.9$, $p < 0.0001$). Only 19 crossing events (1.2%) were within 20m of a passage, thus potentially utilizing it, and all of these were from the same animal living near BR267.

Q4 Do giant anteaters respond to roads differently than to natural barriers?

We found significant differences when comparing the number of crossings of giant anteaters across paved roads to that across unpaved roads and streams (i.e., natural linear features).
Individuals crossed paved roads significantly fewer times than they crossed both unpaved roads ($t_{37} = -3.7, p < 0.001$) and streams ($t_{37} = -3.4, p < 0.005$; Fig. 5). This is also supported by the movement simulations results, in which the observed number of paved road crossings was ~3.3 times lower than would have been expected by random chance ($t_{37} = -3.6, p < 0.001$). In contrast, the observed number of unpaved road crossings was only ~2.0 times lower than would have been expected by random chance ($t_{37} = 4.5, p < 0.001$), while the number of stream crossings was not significantly different than would have been expected by random chance ($t_{37} = 0.6, p = 0.57$).

Discussion

A key step in reducing negative effects of roads on wildlife is to understand how individuals behave on and around roads of varying traffic volumes. From detailed tracking of 38 non-dispersing giant anteaters, we found that while individuals did tend to reduce their movement speed when approaching roads, they otherwise showed few signs of adapting their movement when living near paved roads of varying traffic volumes. High traffic volumes seem to inhibit some giant anteaters from establishing territories on both sides of the roads (Fig. 1), and alongside this we found that individuals crossed paved roads less often than would be expected by random chance, whereas there was no difference between the number of observed stream crossings and what would have been expected by chance. In other words, this inhibition was not due to linear features functioning as home range boundaries (Riley et al. 2006), but rather that traffic may occasionally deter giant anteaters from crossing roads. This was also reflected in our finding that giant anteaters reduced their movement speeds as they approached paved roads, suggesting that some level of caution is taken when in the immediate vicinity of high traffic roads. Nevertheless, none of the highways we monitored were impervious to giant anteaters, and
a high proportion (>80%) of tracked giant anteaters living near the paved roads (<2km) did cross them regularly. It is important to note that we detected no significant differences in habitat composition on either side of the roads. As such, it was unlikely that the high rates of crossings we observed were due to giant anteaters needing access to resources contained on one side of the road or the other. Overall, traffic volume and associated noise and light pollution did not appear to significantly affect their behaviour one way or another. In fact, it is possible to observe giant anteaters foraging at the edge of major highways, and one of the individuals tracked in this study even slept regularly in the native vegetation near the road, but he was eventually victim of a collision (Appendix S3). We also found no evidence that giant anteaters actively sought out road passages for safe crossings. Although we regularly find giant anteater footprints inside road passages (e.g. 0.02 crossings per passage per day; Abra et al. 2020), our results suggest that few individuals actually make use of such passages, and those that do probably only do so opportunistically (e.g., when traveling along streams).

Collectively, these results demonstrate that giant anteaters do not change their movement behaviour and space use near paved roads, nor search for safe crossing structures, which is probably the cause of the high roadkill rates (Ascensão et al. 2021). This contradicts previous research suggesting that the barrier to movement and population redistribution was the most important road impact on giant anteaters, and further emphasises the need to obtain sound empirical data on animal movement when planning and managing transportation networks (Ascensão et al. 2019a).
Roads as Ecological Traps

When species fail to recognize and avoid suboptimal sink habitats, the result can be a decrease in population sizes and an increased extinction risk (Pulliam & Danielson 1991). To this end, no differences in clinical exams, clinical signs, or body scores were noted between individuals living near or far from the paved roads, therefore eliminating the alternative hypothesis that territories near roads are suboptimal, and those giant anteaters that occupy such areas were likely to be more debilitated. Indeed, the best model for predicting how far a giant anteater lived from a road was the intercept only model (Appendix S3). Our results suggest that a large proportion of road-killed giant anteaters are roadside residents and not dispersing animal, as six of the individuals monitored in this study eventually died from vehicle collisions (~15%; Appendix S3). The three individuals that dispersed during this study (distances: 35km, 50km and 100km), crossed roads but survived and all established themselves. Because roadside habitats apparently offer good foraging opportunities that allow giant anteaters to remain healthy, the feedback that giant anteaters receive about the quality of roadside habitat may be misguiding. This makes it unlikely that they will learn that roadsides are mortality sinks that should be avoided. Hence, habitat near roads may function as an ecological trap where healthy individuals occupy the territories nearby or bisected by roads but eventually are road-killed given their regular crossings, leaving the territory vacant for subsequent occupation.

This dynamic is a worst-case scenario for this already threatened species that is likely to negatively impact the long-term population viability (Miranda et al. 2014). Moreover, giant anteaters live at low population densities and have a low recruitment (Gaudin et al. 2018; Desbiez et al. 2020; Bertassoni et al. in press), making them particularly vulnerable to WVC (Miranda et al. 2014). Indeed, population viability analysis showed how giant anteaters deaths
due to vehicle collisions decrease the stochastic growth rate of populations by half, making them

416   drastically less resilient to other threats, and slows their recovery time from catastrophic events

417   (Desbiez et al. 2020). The sex ratios of roadkill (Barragán-Ruiz et al. 2021) and our results on

418   road crossing rates are consistent, both suggesting that males are more threatened by roadkill due

419   to their higher crossing rates relatively to females. The fact that males are the most affected by

420   roadkill is less critical than if it were females (Desbiez et al. 2020). This is especially so given

421   that females care for new born pups for at least the first 6-12 months (Jerez & Halloy 2003;

422   Desbiez et al. 2020). Yet, there may be other unforeseen downstream genetic effects resulting

423   from the high mortality of males, which may further imperil population persistence, and further

424   study is clearly warranted.

425

426   Conservation Implications

427   As the transportation networks in South-Central America continue to expand, the impact of road,

428   and most probably railway (Dasoler et al. 2020), induced mortality is likely going to worsen.

429   This may severely limit population persistence throughout the giant anteater’s distribution,

430   calling for immediate road mitigation actions. Because giant anteaters are mostly indifferent to

431   roadside habitat, and do not actively seek out road passages, it is unlikely that establishing a

432   network of crossing structures alone will provide an effective solution. Fencing, leading to

433   existing passages, has been suggested as a cost-effective mitigation measure, for both

434   conservation purposes as well for human safety, as it allows separating giant anteaters and other

435   large animals from traffic, thus significantly reducing the likelihood of collisions (Clevenger et


437   complementary approach is to manage traffic speed in some road sections (via e.g., stop signs,
speeds bumps, speed limits, and/or animal crossing signs) in order to decrease the likelihood of drivers hitting animals.

The application of such management measures throughout the entire road network is unfeasible. One possible approach is to implement mitigation measures in locations with the highest WVC rates (Ascensão et al. 2021) and in road sections that clearly bisect areas of higher landscape connectivity (Grilo et al. 2011). Furthermore, the similarity of crossing events across the three roads suggests that the probability of giant anteaters incurring in collisions is traffic volume dependent. In fact, a systematic roadkill survey in this same study area recorded three times as many cases on high-traffic roads (BR262 and BR267) as on the lower traffic MS040 (Ascensão et al. 2021). Given that we currently lack sound estimates on local giant anteater abundance in the three study sites, we cannot affirm if such differences in mortality rates were due to different population sizes or different probability of being road-killed. Yet, given the similarity in land cover across the three study areas, it is reasonable to assume that the abundance of giant anteaters across them is similar. As such, the mitigation of high traffic roads should be prioritised. Also, given that the giant anteaters' activity peaks at night, similarly as other large mammals recurrently involved in WVC, notably tapirs (*Tapirus terrestris*), reducing the overall amount of night-time driving would most likely result in fewer collisions and, consequently, fewer human injuries (Hobday & Hobday 2010).

**Conclusion**

Coupling detailed movement information with contemporary data from systematic road surveys allowed us to disentangle the main effects of roads on giant anteaters. Roads did not affect the movement behaviour and space use of giant anteaters, nor were substantial barriers for their
displacements. In turn, giant anteaters did not search for passages for safe crossings and readily occupied the areas near the roads. Consequently, roadside areas are sink habitats due to the high roadkill rates, which may threaten the population persistence at the local scale. Such information is critical in the development of road and landscape management strategies, including the planning of future transportation infrastructures.

Acknowledgments

We would like to thank the donors to the Anteaters & Highways Project especially the Foundation Segre as well as North American and European Zoos listed at (http://www.giantanteater.org/). We would also like to thank the owners of all the ranches that allowed us to monitor animals on their property, in particular Nhuveira, Quatro Irmãos and Santa Lourdes ranches. Thank you to M. Alves, D. Kluyber, C. Luba, A. Alves. FA was funded by Fundação para a Ciência e Tecnologia (contract CEECIND/03265/2017). We would like to thank all the volunteers that helped us on carrying out the fieldwork.

References


Giroux, A., Ortega, Z., Bertassoni, A., Desbiez, A.L.J., Kluyster, D., Massocato, G.M., de


### Tables

**Table 1** Age and mean daily traffic volume (MDT) for the three main roads present in the study area.

Traffic volume information for BR262 and BR267 was obtained from official counts (DNIT 2020). MS040 counts were obtained using a similar methodology used by governmental authorities (DNIT 2020), i.e. vehicle counting throughout five consecutive days, 24 h per day. The ‘Passages’ column indicates the type of passage structures in the study areas (numbers in parentheses are the mean width and the mean height of the passages, in m). Full details on the passages are provided in Appendix S1.

<table>
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<tr>
<th>Study area</th>
<th>Road age (years)</th>
<th>MDT</th>
<th>Culvert</th>
<th>Box-Culvert</th>
<th>Viaduct</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS040</td>
<td>6</td>
<td>603</td>
<td>2 (1.0x1.0m)</td>
<td>6 (2.4x2.4m)</td>
<td>1 (30x10m)</td>
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<td>34</td>
<td>3206</td>
<td>3 (2.4x2.4m)</td>
<td>7 (2.0x2.0m)</td>
<td>1 (35x10m)</td>
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<tr>
<td>BR267</td>
<td>34</td>
<td>4285</td>
<td>9 (1.3x1.3m)</td>
<td>-</td>
<td>-</td>
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</table>
Table 2 Summary of models relating A) instantaneous movement speed and B) crossing events with different predictors. A) parameter estimates ($\hat{\beta}$), 95% confidence intervals (CI), t-values, and P-values for the best (<AICc) mixed effects regression model fit to individual instantaneous movement speeds. The model included a first order auto-regressive correlation structure with $\rho = 0.51$. B) parameter estimates ($\hat{\beta}$), 95% confidence intervals (CI), Z values, and P-values for the best (<AICc) zero altered negative binomial model fit to the number of times each individual crossed a paved road. Significant predictors ($p<0.05$) are highlighted in bold.

### A

<table>
<thead>
<tr>
<th></th>
<th>$\hat{\beta}$</th>
<th>Lower 95% CI</th>
<th>Upper 95% CI</th>
<th>t-value</th>
<th>P</th>
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<tr>
<td>Intercept</td>
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<td>$1.00 \times 10^{-1}$</td>
<td>28.06</td>
<td>&lt; 0.001</td>
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<td>Distance to Road</td>
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<td>$3.60 \times 10^{-4}$</td>
<td>$3.31 \times 10^{-3}$</td>
<td>2.44</td>
<td>0.015</td>
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<tr>
<td>Distance to Road$^2$</td>
<td>$-2.28 \times 10^{-4}$</td>
<td>$-3.89 \times 10^{-4}$</td>
<td>$-6.77 \times 10^{-5}$</td>
<td>-2.79</td>
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<td>Time of day</td>
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<td>$-5.13 \times 10^{-3}$</td>
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<td>1.83</td>
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### B

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<td>Sex (male)</td>
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<td>0.38</td>
<td>6.95</td>
<td>2.18</td>
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<tr>
<td>Road (BR262)</td>
<td>17.01</td>
<td>-11339.11</td>
<td>11373.1</td>
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<td>0.998</td>
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<td>Road (MS040)</td>
<td>-1.66</td>
<td>-4.39</td>
<td>1.07</td>
<td>-1.19</td>
<td>0.233</td>
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Count model coefficients (truncated negative binomial with log link)

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<td>Intercept</td>
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<td>Distance to road</td>
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<td>-4.75</td>
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</tr>
<tr>
<td>Sex (male)</td>
<td>1.33</td>
<td>0.26</td>
<td>2.40</td>
<td>2.44</td>
<td>0.015</td>
</tr>
<tr>
<td>Pasture</td>
<td>-0.13</td>
<td>-0.20</td>
<td>-0.06</td>
<td>-3.50</td>
<td>&lt; 0.001</td>
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Figures

**Figure 1** Map showing the location of the three study areas (BR262, MS040 and BR267) in Mato Grosso do Sul, Brazil (top), with state main road network (black lines). In each study area, home ranges are in red for males and green for females (see text for details); the main paved road is depicted in thick black line and other unpaved roads are in thinner black lines, and road passage location are white circles (some circles indicate more than one passage). Blue lines indicate streams. Land cover classes were from MapBiomas (2018 version).
Figure 2 Scatter plots summarizing information for each tracked giant anteater, including the home range area (a), distance of the home range centre to the nearest paved road (b), mean daily movement speed (c) and mean daily movement speed with distance to road (d). Colours and grey shading indicate the three study areas. Circles and bars depict the estimates and the 95% confidence intervals, respectively. Note how there are no clear differences in home-range area or movement speed across sites, nor with distances to roads.
Figure 3 Summary of the crossing results. Panel A) Scatter plots relating the total number of road crossings that each giant anteater performed in relation to the distance of their home range centroid to the nearest paved road. Panel B) Boxplots depicting the number of road crossings for males and females across the three study sites. In panel c), the relationship between the number of road crossings and the proportion of pastureland in each individual’s home range is shown. In panels a) and c), the grey lines depict the fitted negative-binomial regression model and shaded area the 95% confidence intervals.
**Figure 4** Panel A) Relation between the mean number of crossings per hour (dots, left Y-axis) and the hourly mean traffic volume across all roads in total number of cars (bars, right Y-axis). Panel B) mean speed per time of day over the total duration of the study period. The blue lines depict loess smoothed regression curves fit to the hourly means and the shaded area the 95% confidence intervals on hourly means. Note how most road crossings occurred at night when traffic volume was lowest and when giant anteaters are more active.
Figure 5 Scatterplot of the relationship between the number of crossings across barriers, and the distance the individual lived from that barrier. The solid lines depict fitted negative-binomial regression models and shaded areas the 95% confidence intervals.
Appendix S1 – PASSAGE STRUCTURES IN STUDY AREA

1) MS040

<table>
<thead>
<tr>
<th>ID</th>
<th>Coord</th>
<th>Type</th>
<th>Width x Height (m)</th>
<th>Landscape</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS040-A</td>
<td>- 21.03678, -53.96838</td>
<td>Box culvert</td>
<td>2.0 x 2.0</td>
<td>Forestry</td>
<td>Dry passage for cattle.</td>
</tr>
<tr>
<td>MS040-B</td>
<td>- 21.06485, -53.92190</td>
<td>Box culvert</td>
<td>2.0 x 2.5</td>
<td>Forestry, pasture</td>
<td>Dry passage for cattle. Footprints of tapir (<em>Tapirus terrestris</em>), giant anteater, small felid.</td>
</tr>
<tr>
<td>MS040-C</td>
<td>- 21.08494, -53.88859</td>
<td>Double box culvert</td>
<td>2.5 x 2.5</td>
<td>Stream, native vegetation</td>
<td>With water (20 cm deep).</td>
</tr>
<tr>
<td>MS040-D</td>
<td>- 21.09302, -53.87504</td>
<td>Box culvert</td>
<td>3.0 x 3.0</td>
<td>Pasture, native vegetation</td>
<td>Dry passage for cattle.</td>
</tr>
<tr>
<td>MS040-E</td>
<td>- 21.10862, -53.79894</td>
<td>Box culvert</td>
<td>2.5 x 2.5</td>
<td>Pasture, native vegetation</td>
<td>Dry passage for cattle. Footprints of tapir, canids and domestic animals.</td>
</tr>
<tr>
<td>MS040-F</td>
<td>- 21.10718, -53.74151</td>
<td>Double culvert</td>
<td>1.0 x 1.0</td>
<td>Native vegetation</td>
<td>With water (30 cm deep). Footprints of tapir.</td>
</tr>
<tr>
<td>MS040-G</td>
<td>- 21.10575, -53.73802</td>
<td>Viaduct</td>
<td>~30.0 x 10.0</td>
<td>Stream, native vegetation</td>
<td>With water (&gt;1 m deep). Dry area on the sides.</td>
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2) BR262

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<tr>
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<tbody>
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<td>-20.47803, -54.12417</td>
<td>Box culvert</td>
<td>~ 2.0 x 2.0</td>
<td>Pasture</td>
<td>With water (stream).</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------</td>
<td>---------------------</td>
</tr>
<tr>
<td>BR262-B</td>
<td>-20.4666, -54.06498</td>
<td>Double box culvert</td>
<td>~ 2.0 x 2.0</td>
<td>Stream, native vegetation</td>
<td>With water (stream). Capybara feces.</td>
</tr>
<tr>
<td>BR262-C</td>
<td>-20.4321, -53.9831</td>
<td>Box culvert</td>
<td>~ 2.0 x 2.0</td>
<td>Stream, native vegetation, pasture</td>
<td>With water (stream).</td>
</tr>
<tr>
<td>BR262-D</td>
<td>-20.4076, -53.9324</td>
<td>Box culvert</td>
<td>~ 2.0 x 2.0</td>
<td>Stream, native vegetation, pasture</td>
<td>With water (stream).</td>
</tr>
<tr>
<td>BR262-E</td>
<td>-20.4093, -53.8707</td>
<td>Culvert + Double box culvert + Double culvert</td>
<td>~ 2.5 x 2.5 ~ 2.5 x 2.5 1.7 x 1.7</td>
<td>Stream, native vegetation, pasture</td>
<td>Simple culvert: dry passage for cattle. Double box culvert: with water (stream).</td>
</tr>
<tr>
<td>BR262-F</td>
<td>-20.4892, -54.1825</td>
<td>Viaduct</td>
<td>~35.0 x 10.0</td>
<td>Stream, native vegetation, pasture, forestry</td>
<td>With water (&gt;1 m deep).</td>
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### 3) BR267

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<tr>
<th>ID</th>
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<td>BR267-A</td>
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<td>Culvert</td>
<td>0.8 x 0.8</td>
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<td>Without water.</td>
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<td>Double culvert</td>
<td>1.2 x 1.2</td>
<td>Pasture, forestry</td>
<td>Dry passage</td>
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<tr>
<td>BR267-D</td>
<td>-21.61234, -53.73802</td>
<td>Culvert</td>
<td>1.2 x 1.2</td>
<td>Stream, native vegetation</td>
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</tr>
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<td>BR267-E</td>
<td>-21.6091, -53.764</td>
<td>Culvert</td>
<td>1.2 x 1.2</td>
<td>Stream, native vegetation</td>
<td>Dry passage</td>
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IMAGES

1) MS-040

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Appendix S2 - Workflow used to analyse the deployment for this animal and the collar needed replacing. Only the locations from the second deployment were used. In shown here, but the comparison between the raw and filtered data is shown.

Of the 1783 locations collected, 191 were removed due to poor quality, leaving 1592 locations for analysis. The remaining locations had a median horizontal speed of 1.67 m/s (IQR: 0.90 - 2.89 m/s) and a median vertical speed of 1.25 m/s (IQR: 0.55 - 2.15 m/s). The ratio of horizontal to vertical speed was 1.34 (IQR: 0.79 - 2.23).

Road Interaction Metrics

From these analyses we can see that 90% of this animal's home range contains pasture, while 8.2% is comprised of native forest, and the remaining 1.8% belongs to the other land cover types.

Here we see that for this animal the estimated 95% home range area was 11.42 km² (95% CI: 8.41 - 14.88). Visual diagnostics represent the mean speed, which is conditioned off of the data and the fitted model, and is generally more accurate.

To assess whether the animal preferred to cross the road by passage structure or not, we estimated the ratio of home range areas that fell on either side of the sides of a road according to its traffic volume (Q2), we estimated the ratio of home range areas that fell on either side of the road.

We estimated the mean daily movement speed (in km/day) using continuous-time speed and distance (CTSD) estimation. We estimated the mean daily movement speed (in km/day) using continuous-time speed and distance (CTSD) estimation.

Note

The next step after importing and preparing the data was to fit the continuous-time movement models. Following the workflow structure of the best fit model identified above, and we implemented the small-sample-size bias correction of (Fleming and Fleming et al. 2020). From each CTMM, we extracted the positional autocorrelation described in Calabrese et al. (2016), we fit a series of continuous-time movement models to the data using perturbative-Hybrid (pHREML).

Fitting the movement models

Note how there is no longer any indication of clear outliers in the filtered data.

#Return a summary of the fitted model

#Estimate the mean speed

#Estimating the UERE

#Land cover information

```
class.prop$LC_rec[class.prop$Class %in% c("9")]="Forestry"
class.prop$LC_rec[class.prop$Class %in% c("3", "4")]="Native forest"
class.prop$LC_rec[class.prop$Class %in% c("25")]="Others"
```

```
HR_contour <- spTransform(HR_contour,projection(mapbiomas))
mapbiomas <- raster("~/Dropbox (Smithsonian)/Anteater Movement paper/GIS/mapbiomas-matogrosso-dwul-2018.tif")
```
From the track data, we classified crossings on each highway that were within 20 m (the median GPS measurement error) of a passage structure. The number of crossings on each highway was recorded and an estimate of the number of road crossings that would be expected by random movement within individuals’ home ranges that was closest to a passage structure was still 211.3m away.

## 2 Jennifer 262            196               93
## 1 Jennifer 262            264               13

### Stream Crossings

From these calculations, we see that this animal crossed highway BR262 a total of 46 times. In addition to estimating the number of crossings, we quantified the times that each of these crossings occurred.

For this, we used each animal’s tracking data and their CTMM to reconstruct the most likely path that they traveled through the landscape over the course of the study period as above. We identified the total number of intersections (crossings) between the most likely path and local streams.

### Distance of home range center to nearest road

We further estimated the total number of crossings across the highways for each giant anteater. For this, we used each animal’s tracking data and their CTMM to reconstruct the most likely path that they traveled through the landscape over the course of the study period as above. We identified the total number of intersections (crossings) between the most likely path and local streams.

From this we see that the center of this animal’s home range was 0.361 km from the nearest road (BR 262).
Appendix S3 - Descriptive Analyses of Pequi, Ben, Christoffer

1. Does the movement behaviour of giant anteaters differ between the different study sites, and whether there was a relationship between these movement metrics and the distance they travelled?

2. Does traffic volume affect anteaters' movement patterns?

3. Do anteaters prefer to move to paved roads differently than to natural ones when living near paved roads?

As a preliminary check, we inspected the data for any correlations that would result in issues of multi-collinearity when running the meta-regression model. This was done by ensuring that the variables were correctly (e.g., numbers are numbers, factors are factors, etc.), and checking for any correlations among the variables that could affect the model's performance.

In this appendix, we detail the analyses that were carried out on the individual movement metrics to arrive at the results presented in the paper. We also provide code snippets to reproduce the analyses and figures presented in the main text.

# Predicted home range areas of animals living in each of the three sites

```r
predict(Site_HR_res)[c(1, 15, 22),]
```

# Significance of the relationship between home range size and study site

```r
QM(df = 1) = 3.7831, p-val = 0.0518
```

# Results of the meta-regression model testing differences in HR size between the three sites

```r
Model Results:

<table>
<thead>
<tr>
<th>logLik</th>
<th>deviance</th>
<th>AIC</th>
<th>BIC</th>
<th>AICc</th>
</tr>
</thead>
</table>
```

# Test of Moderators (coefficients 2:3):

- tau (square root of estimated tau^2 value):
  - 7.1336

- QM(df = 1) = 3.7831, p-val = 0.0518

- QM(df = 36) = 203699.9539, p-val < .0001

# Code snippets for reproducibility

```r
library(lubridate)
library(MuMIn)

# Convert factor variables to factors
data$Sex <- as.factor(data$Sex)
data <- data[order(data$Road),]

# Run the meta-regression model testing differences in HR size between the three sites
FIT <- gls(Dist_Rd ~ Road + Sex + Weight, data = data, method = "ML")

# Test for Heterogeneity

```r
Test for Heterogeneity:

Random-Effects Model (k = 38; tau^2 estimator: REML)

- intrcpt   34.1590  7.2598   4.7052  <.0001  19.9301  48.3879  ***
- Road 0.23  0.06   0.83 0.38   0.06   0.13   1.82 0.16
- Sex 1.86  0.47   4.00 0.00  1.07   1.63   3.06 0.08
- Weight -0.5826  0.2995  -1.9450  0.0518  -1.1697   0.0045   .

- QM(df = 1) = 3.7831, p-val = 0.0518
- QE(df = 36) = 203699.9539, p-val < .0001

```

# References

- ACV: For review purposes only - please do not distribute

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### References

To test for this, we identified the number of crossings that were within the median error of a road structure. We were also interested in understanding whether giant anteaters preferred crossing roads through existing passage structures or if they chose alternative routes.

Crossing Time Analyses

```r
CROSS_TIMES$Crossing_Times <- as.numeric(CROSS_TIMES$Crossing_Times)
```

Traffic was measured using the Dimensional Road Safety Index (DRSI) at two different points along the roadway:

1. 1.5 km from the western side of the road
2. 4.5 km from the western side of the road

Traffic was defined as the number of vehicles crossing the road per hour. We aimed to correlate traffic with the number of crossings per hour.

```
crossings <- aggregate(ID ~ time, data = CROSS_TIMES, FUN = "length")
crossings_2$crossings <- crossings_2$ID
crossings_2$ID[is.na(crossings_2$ID)] <- 0
```

```
TIMES <- data.frame(time = TIMES, by = "hour")
```

```
CROSS_TIMES$Crossing_Times <- cut(CROSS_TIMES$Crossing_Times, breaks = "hour")
```

```
CROSS_TIMES <- CROSS_TIMES[!is.na(CROSS_TIMES$Crossing_Times),]
```

```
mod1 <- MASS::glm.nb(Rd_Cr ~ Dist_Rd, data = data)
```

```
Selected_Mod <- pscl::hurdle(Rd_Cr ~ Dist_Rd + Sex + Pasture | Road + Dist_Rd + Sex, na.action = na.fail, 
                          control = list(nit = 50, trace = TRUE, maxit = 1000), 
                          verbose = FALSE)
```

```
axis(2)
```

```
labels = row.names(coef(summary(Selected_Mod))$zero), xpd = TRUE, cex = 0.7)
pch = 16,
```

```
Text(x = 1:5, y = par("usr")[3]-0.05, srt = 40, adj = 1,
```

```
## Number of iterations in BFGS optimization: 22
## ---
## Log(theta)  -0.17564    0.38368  -0.458  0.64711
```

```
CIs <- data.frame(x = gg1$data[[1]]$x,
```

```
CROSS_TIMES$time <- cut(CROSS_TIMES$Crossing_Times, breaks = "hour")
```

```
# Add one-hour cut points for aggregating
```

```
plot(Traffic_MS040) +
```

```
plot(Crossings_pannel) +
```

```
plot(Activity_pannel) +
```

```
plot(Crossing Time Analyses) +
```

```
plot(FIGS) +
```

```
plot(gridExtra::grid.arrange(Crossings_pannel, Activity_pannel, ncol = 1))
```
Questions: Do anteaters respond to roads differently than to natural barriers?

```
# New datasets for plotting purposes
# Neg Binomial GLMs for plotting purposes
# sample estimates:
## -52.42163  93.27110
## alternative hypothesis: true difference in means is not equal to 0
t = 0.56811, df = 37, p-value = 0.5734
##  Paired t-test

# Stream crossings vs simulated stream crossings
## sample estimates:
## alternative hypothesis: true difference in means is not equal to 0
data:  data$Rd_Cr and data$Strm_Cr
t = 0.56811, df = 37, p-value = 0.5734

# Dirt road crossings vs simulated dirt road crossings
## mean of the differences
## sample estimates:
t = -134.6216
## 95 percent confidence interval:
## t = -3.6702, df = 36, p-value = 0.0007797
##  Paired t-test

t.test(data$Rd_Cr, data$Num_Crossings, paired = TRUE)
# Paved road crossings vs simulated paved road crossings
```

```
# ACV: For review purposes only - please do not distribute
```

```
# Session info
```

```
```
Figure 9. Home range establishment on roads of various traffic volumes.

Figure 10. Home range establishment on roads with different paved roads (and therefore traffic volume).

Figures depicting these relationships are shown below.

Table 1. Mean daily traffic volume across these roads were: MS-040 - 603 vehicles/day; BR-262 - 3206 vehicles/day; BR-267 - 4285 vehicles/day.

We then modelled the relationship between the ratio of home range areas that fell on either side of the highways across the different paved roads (and therefore traffic volume).

The mean daily traffic volume across these roads were: MS-040 - 603 vehicles/day; BR-262 - 3206 vehicles/day; BR-267 - 4285 vehicles/day.

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Collared anteater for potential journal cover.

1621x1080mm (94 x 94 DPI)