Movement ecology of vulnerable lowland tapirs across a gradient of human disturbance

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**Running head:** Lowland tapir space use

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**Statement on human or animal subjects:** NEED PATI HERE

# 1 Abstract

**Keywords:**

# 2 Introduction

While agriculture, urbanisation, and transportation infrastructure are critical to human socio-economic improvement (Esfahani and Ramı́rez 2003), the associated habitat transformations represent a major threat to species survival (Fahrig 1997; Venter et al. 2006; Powers and Jetz 2019). Of particular concern is the impact of human activities on animal movement and space use (Allen and Singh 2016; Tucker et al. 2018; Doherty, Hays, and Driscoll 2021). Animal movement governs how individuals, populations, and species interact with each other and the environment (Schick et al. 2008) and mediates key ecological processes (Bauer and Hoye 2014). The capacity for individuals to move unhindered across complex landscapes is therefore critical for species survival and ecosystem function. Problematically, human development has been reducing the amount of habitat available to wildlife (Brooks et al. 2002; Cardinale et al. 2012; Hooper et al. 2012). This has spurred dramatic changes in animal movement behaviour across the globe (Fahrig 2007; Tucker et al. 2018; Doherty, Hays, and Driscoll 2021). The consequences of human induced changes in movement are not insubstantial, and can include lower fitness and survival, altered predator-prey dynamics, reduced seed dispersal, genetic isolation and local extinction (Fahrig 2007; Dickie et al. 2017; Cosgrove, McWhorter, and Maron 2018; Tucker et al. 2021).

BECAUSE OF THE EFFECTS OF ANTHROPOGENIC CHANGE ON HABITATS, SPECIES ARE EXPECTED TO SHOW SOME ADAPTIVE BEHAVIOUR. Importantly, human disturbance has been shown to have differential effects across species (Toews, Juanes, and Burton 2018; Doherty, Hays, and Driscoll 2021), even for closely related taxa occupying the same habitat (Thatte et al. 2020), and response to human activities are thus largely taxa and context specific (Doherty, Hays, and Driscoll 2021). There are therefore no clear *a priori* expectations as to how any given species might be expected to respond to human disturbance. For instance, although Wall et al. (2021) found a tendency for African elephants (*Loxodonta spp.*) to have reduced movement in human modified landscapes, Morato et al. (2016) noted that jaguars (*Panthera onca*) living in regions with high human population densities occupied home ranges that were orders of magnitude larger than those of jaguars living in more pristine habitats. As human disturbance is only expected to worsen over the next decade it is critical to understand how species respond to human disturbance in order to develop effective conservation strategies.

The capacity for behavioural plasticity in response to human disturbance is especially important for long-lived, K-selected species (Sih, Ferrari, and Harris 2011; Montgomery, Macdonald, and Hayward 2020) that take longer to reach sexual maturity, and have longer interbirth intervals than short-lived species (De Magalhaes and Costa 2009).

Here we focus on lowland tapirs (*Tapirus terrestris*).

# 3 Methods

## 3.1 Study area and data collection

The data was collected in three different ecosystems in southern Brazil (Fig. 3.1): south-western Cerrado (savannah, control environment), Pantanal (wetland, agricultural environment), and western Mata Atlântica (forest, degraded environment).

*Add details on climate and land use?*

Animals were tracked using VHF tracking (all three regions) and GPS tracking (Pantanal and Cerrado). *Add details on capturing and tracking devices*

A total of 74 tapirs were tracked starting in July of 1997 until October of 2019, with the majority of the data being in the Pantanal (46), while 17 and 11 were from the Cerrado and Mata Atlântica regions, respectively.

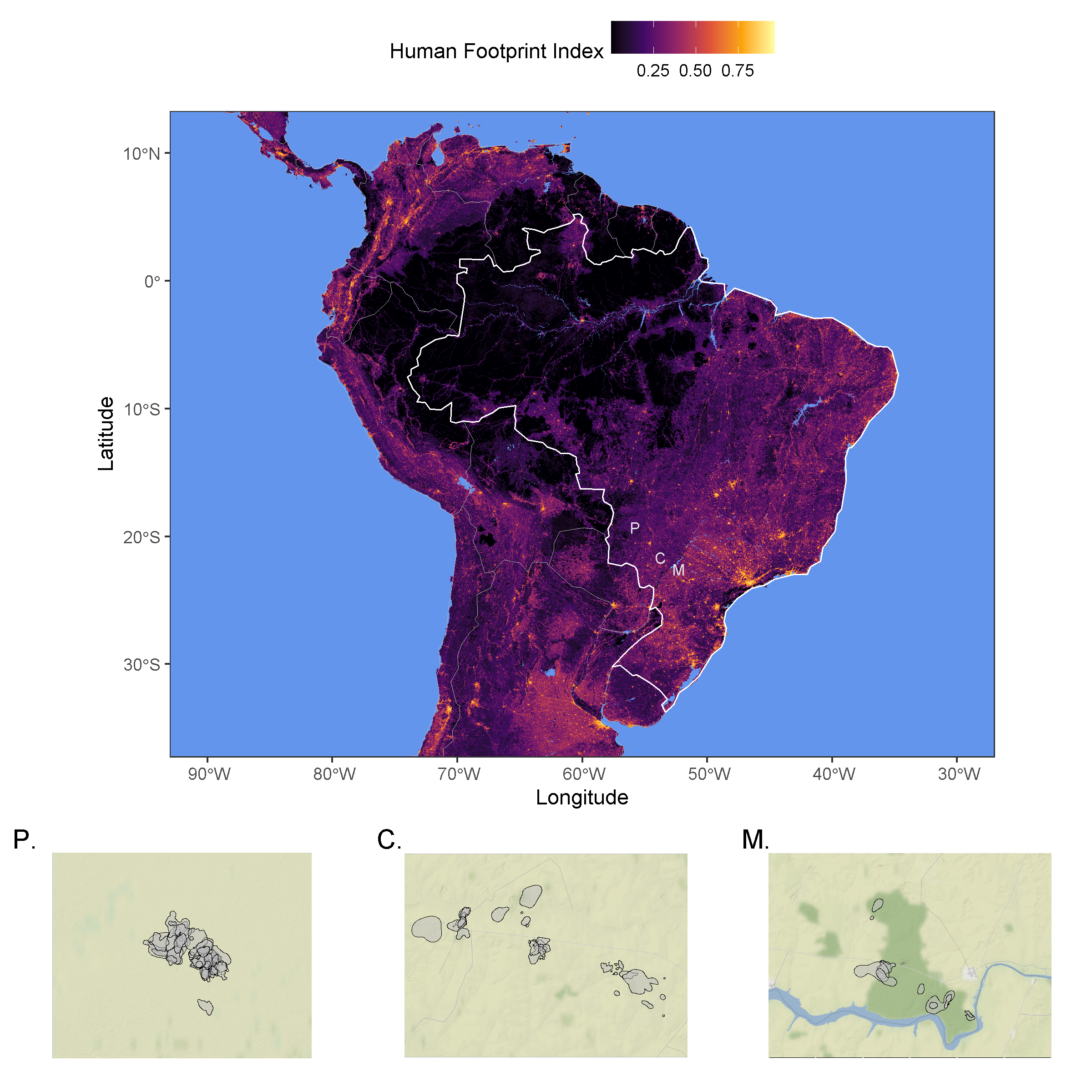


Figure 3.1: Location of the tree study sites (Pantanal, Cerrado, Mata Atlântica) over a raster of Human Footprint Index, which is a measure of anthropogenic alteration of an ecosystem.

## 3.2 Data analysis

All statistical analysis and plotting were performed using R (version 4.0.5, R Core Team 2021) using packages ctmm (version 0.6.1, “Ctmm: Continuous-Time Movement Modeling,” n.d.), mgcv (version 1.8-36, Wood 2017), ggplot2 (version , Wickham 2016) ggmap (version , Kahle and Wickham 2013). The furrr package (version 0.2.2, Vaughan and Dancho 2021) was used for parallel computation on Windows machines. All R code can be found in the GitHub repository at <https://github.com/StefanoMezzini/tapirs>.

Before analysis, outliers were removed if they appeared to be unreliable due to large measurement errors after accounting for measurement uncertainty and following the methods detailed in the ctmm package (“Ctmm: Continuous-Time Movement Modeling,” n.d.). Location estimates from GPS tracking were calibrated using a unitless Horizontal Dilution of Precision (HDOP), which estimated the accuracy of each positional fix. We then estimated an equivalent range error with the HDOP values from 883 and 174 measurements from tags in fixed locations in the Pantanal and Cerrado, respectively (C. H. Fleming et al. 2020). Data points were then considered as outliers (and removed) if they had a large (error-informed) distance from the median location and the minimum speed required to explain the displacement was unusually high (m/s). The Mata Atlântica dataset contained a total of 4 082 observations, 8 of which were removed as outliers; and the Pantanal dataset contained 139 138 observations, 914 of which were removed; while the Cerrado dataset contained 90 402 observations, 193 of which were removed. *(no speed outliers found when I (Stefano) was cleaning the datasets, but 1105 outliers had already been removed)*

The best Continuous-Time Movement Model (CTMM) for each animal was then chosen using the ctmm.select function from the ctmm package, which fits a series of CTMMs using perturbative Hybrid Residual Maximum Likelihood (pHREML, Christen H. Fleming et al. (2019)) and chooses the best model using small-sample-sized corrected Akaike’s Information Criterion (AICc).

Using each of the best models, we then estimated each animal’s home range (HR) area, range crossing time, directional persistence, and average daily speed. The models used here are insensitive to sampling frequency (Noonan et al. (2019)) and they account for spatio-temporal autocorrelation in the data (when possible), so they are robust to irregular or frequent sampling frequency, HR underestimation, and significance inflation.

The HR of each tapir was estimated as the area within the 95% isopleth of the Utilization Distribution using Autocorrelated Kernel Density Estimation (AKDE) obtained from the CTMM (C. H. Fleming et al. (2015)).

To test whether environmental modification significantly altered the animals’ behavior, the HR sizes and average daily speeds were regressed against their HR’s average human footprint index using Generalized Linear Models (GLMs) with a Gamma distribution and a log link for the response. The Gamma distribution allows for more accurate significance testing, while the log link scale allows HFI to have a multiplicative effect on the response. The GLMs were fit using the mgcv package (Wood 2017), and Restricted Maximum Likelihood (REML).

# 4 Results

## 4.1 Individual variation in movement and space use

*change values to more appropriate estimates; currently using mean +/- 1.96 sd/sqrt(n)*

The mean home range size across all monitored tapirs was 5.82 km (95% CI: 4.71 - 7.12), ranging between 1 km and 29.7 km (Fig. 4.1a). Tapirs had HR crossing times of 0.72 days on average (95% CI: 0.35 - 1.10), ranging from 0.05 to 12.8 days (Fig. 4.1b), and a mean velocity autocorrelation timescale of 0.44 hours (95% CI: 0.39 - 0.49), ranging from 0.17 to 1.88 hours (Fig. 4.1c). We estimated that tapirs had mean movement speeds of 11.2 km/day (95% CI: 10.2 - 12.1), ranging from 1.51 to 25.96 km/day (Fig. 4.1d). There was no evidence that average daily speed differed between sexes (females: 10.5 km/day, 95% CI: 9.19 - 12.0; males: 11.9 km/day; 95% CI: 10.3 - 13.7, ), and there was little to no evidence of it differing between age groups (adults: 11.8 km/day, 95% CI: 10.6 - 13.2; sub-adults: 9.52 km/day, 95% CI: 7.94 - 11.4; ).

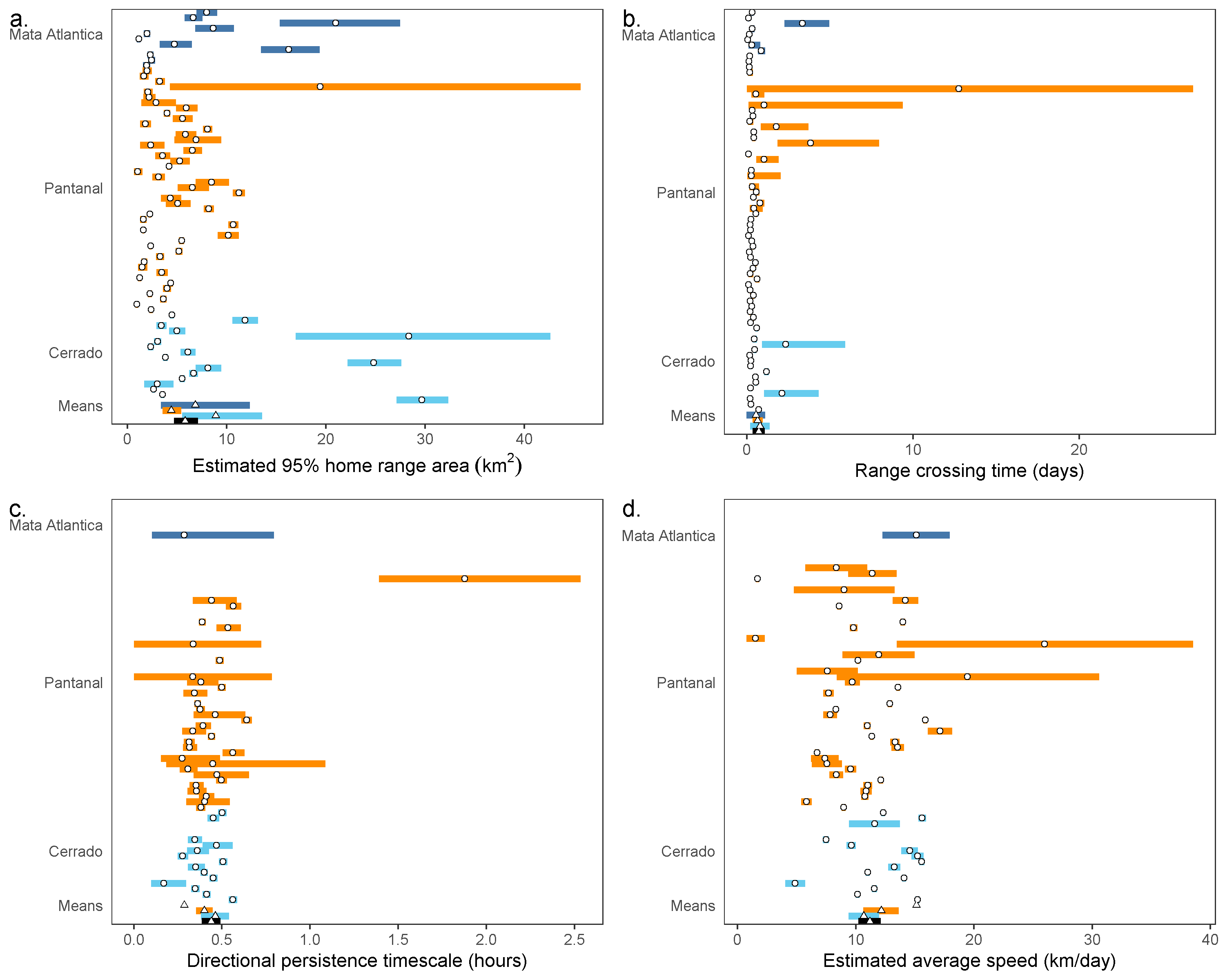


Figure 4.1: Parameter estimates from each tapir’s movement model (circles) and group means (triangles), with 95% confidence intervals. Individuals with a movement model that does not allow for inferences in movement speed are left blank.

There was no evidence that home ranges sizes differed between sexes (males: 5.43 km, 95% CI: 3.84 - 7.68; females: 6.27 km, 95% CI: 4.64 - 8.48; ) nor between age groups (adults: 5.47 km, 95% CI: 4.21 - 7.1; sub-adults: 7.01 km, 95% CI: 4.63 - 10.6; ).

## 4.2 Variation in movement across biomes and gradients of human disturbance

The Atlantic Forest, Cerrado, and Pantanal varied substantially in habitat composition, levels of human disturbance, and tapir population densities (*PATI, IS THERE A SOURCE TO SUPPORT THIS STATEMENT?*). Despite this, we found that lowland tapir movement behaviour and space use were consistent across all three biomes (Fig. 4.1.

We also found [no] relationship between home range area and HABITAT LAYER RESULTS (Fig. XXX). Similar trends were observed across all other movement parameters (Fig. XXX).  
HFI had no significant effect on either lowland tapir home range size (p-value = 0.90; Fig. XXXXa), nor average daily movement speed (p-value = 0.53; Fig. XXXb). A tapir living in a near pristine environment (HFI = 0.004) was estimated to have a home range of 7.79 km and an average speed of 13.19 km/day, while a tapir from the most altered habitat we monitored tapirs in (HFI = 0.31) had an estimated home range area of 6.93 km and an average speed of 10.43 km/day. [WE’LL NEED CIs ON THESE PREDICTIONS]

# 5 Discussion

# 6 Acknowledgments

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