Title: Beyond deforestation: the impact of agricultural intensification on a flagship mammal species

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Abstract

Research on the impact of landscape change primarily focuses on the loss of natural areas, particularly native forests, while the destruction of non-forest biomes, also rich in biodiversity, is often neglected. Moreover, little attention has been given to the effects of agricultural intensification on wildlife. We investigated the impact of converting pastures to soybean plantations on the movement patterns of giant anteaters (*Myrmecophaga tridactyla*, Pilosa: Mammalia), a species of conservation concern. To this end, we employed long-term telemetry tracking data within a before-after control-impact design. We tracked the same individuals before and after the conversion from pasture to soybean, while also monitoring anteaters in an adjacent, unchanged pasture as the control. In addition, we analyzed whether isolated trees within pastures serve as shelters for the species. We found that transitioning from low- to high-intensity agriculture led anteaters to move home ranges away from soy plantations and increase displacement. These results might be partially explained by the removal of isolated trees. Indeed, we found that giant anteaters often return to isolated trees in pastures, suggesting that these trees are essential resources, potentially offering shelter and protection. Our study suggests that converting pastures to soybean plantations, often considered an alternative to deforestation, has hidden ecological impacts on wildlife, potentially affecting their fitness and population dynamics. We underscore the importance of addressing not only deforestation but also the implications of agricultural intensification for wildlife in regions like the Brazilian Savanna, a biodiversity hotspot that currently lacks adequate legal protection.

Keywords: BACI design; conservation; GPS telemetry; isolated trees; landscape change; movement ecology; savanna

1 Introduction

Decades of research have demonstrated that the conversion of natural areas to cash-crop agriculture has detrimental ecological impacts, ranging from declines in biodiversity to altered population dynamics and interspecific interactions (Soterroni et al., 2019; Tilman et al., 2017). However, research often overlooks the destruction of non-forest biomes. For example, savannas and grasslands have largely been converted into agricultural lands, yet this transformation receives less attention in the literature (Bispo et al., 2024). Importantly, far less understood are the ecological consequences of transitioning from one form of agricultural land use to another, such as converting pastures to cash crop cultivation. This is especially true when the conversion leads to agricultural intensification involving the use of farming machinery, intensified input of fertilizers and pesticides, and the establishment of monocultures (Emmerson et al., 2016; Maeda et al., 2023). This intensification can simplify and homogenize landscapes, potentially creating an even more hostile environment for wildlife (Tscharntke et al., 2005).

Anthropogenic habitat alterations can influence the movement and behavior of wildlife (Doherty et al., 2021; Gaynor et al., 2018), and it is likely that the same is true for agricultural intensification. For example, areas under agricultural intensification can create barriers impermeable to animal movement, constraining their space and altering their movement patterns (Doherty et al., 2021; Tucker et al., 2018). These habitat changes may require animals to change their movement patterns, increasing displacement from their initial location, and shifting their home ranges to maintain access to essential resources (Doherty et al., 2021). Animals establish home ranges for their normal activities, such as food gathering, mating, and caring for their young (Burt, 1943). Importantly, some species exhibit site fidelity, regularly returning to specific locations that provide critical resources such as shelter, nesting, and foraging (Bracis et al., 2018; Morrison et al., 2021). However, under changing environmental conditions, site fidelity behavior can become disadvantageous when previously suitable areas now pose a threat to the animal's survival (e.g., ecological traps) (Merkle et al., 2022). In addition to compromising individual fitness, these changes could ultimately drive local extinctions and changes in community composition (Doherty et al., 2021; Gaynor et al., 2018). Therefore, understanding how and why animal movement is influenced during agricultural intensification provides ecologists and conservation practitioners with essential evidence for developing effective management and conservation plans.

While there have been significant advances in movement ecology, most work to date continues to rely on the analyses of observational data. This has led to calls for movement ecology to integrate experimental approaches to shift from hypothesis-generating to hypothesis-testing frameworks (Hansen et al., 2025). However, movement ecology experiments can be challenging, impractical, or even impossible due to issues such as scale complexity (e.g., experiments across large landscapes), limited replication, and ethical constraints (Wiersma, 2022) (but see Laurence & Gomez, 2005). In these situations, a powerful alternative is the Before-After Control-Impact (BACI) design, which couples the strategic collection of observational data with statistical frameworks to assess how animal behavior responds to temporal changes in landscape structure (Conner et al., 2016; Thiault et al., 2017). This approach provides clear results for ecologists, managers, and interested parties, making it valuable for management and conservation applications (Conner et al., 2016).

We employed a BACI analysis to assess how agricultural intensification alters the movement of the giant anteater (*Myrmecophaga tridactyla*, Mammalia: Pilosa) – an iconic and vulnerable species (IUCN, 2024). This species is also relevant to identifying conservation priorities in Brazil's highly threatened savanna woodlands, known as the Cerrado. The Cerrado is a biodiversity hotspot that is poorly protected and often excluded from national sustainability policies (Bispo et al., 2024; Myers et al., 2000). Over half of its native vegetation has been lost, initially due to pasture for cattle ranching, and, more recently, these pastures have been converted into soybean plantations (Bispo et al., 2024; Nepstad et al., 2019; Rabeschini et al., 2025). Soybean cultivation raises concerns as it creates hostile environments for wildlife through landscape homogenization (Machado et al., 2023; Newbold et al., 2015). For example, shrubs and isolated trees that remain in pastures used for extensive cattle ranching can provide additional shelter and food resources for some species (Harvey et al., 2004), but soybean plantations usually eliminate all isolated trees and shrubs. The giant anteater is an ideal model for studying the ecological consequences of agricultural intensification since its low metabolic rate and specialized diet give it a limited physiological capacity to regulate body temperature (McNab, 1984). As a result of these characteristics, giant anteaters strategically use forested areas to rest and seek thermal refuge while foraging in open habitats (Camilo-Alves & Mourão, 2006; Giroux et al., 2023; Meiga et al., 2026). Importantly, giant anteaters were found to expand their home ranges as the proportion of forest within their ranges decreased, likely traveling in search of more forested areas (Giroux et al., 2021). Finally, while studies have investigated the effects of human-modified and agricultural landscapes

on giant anteater abundance and space use (Barreto et al., 2012; Bertassoni et al., 2020; dos Reis et al., 2025; Meiga et al., 2026), none address the impact of agricultural intensification.

Our primary goal was to assess how converting cattle ranching pasture to soybean plantations impacts giant anteater movement patterns. We tracked the same individuals both before and after the conversion of pasture to soybean plantation, while simultaneously monitoring anteaters in an adjacent pasture that remained unchanged. This allowed us to assess individual home ranges and net squared displacement before and after the establishment of crop plantations and then test two predictions: (1) giant anteaters shift their home ranges and exhibit greater displacement (i.e., dispersal behavior) after the establishment of crop plantations. These two complementary strategies allow animals to move away from crop plantations while searching for suitable thermal shelters, which are absent in soybean fields (Dobhal et al., 2024); (2) Because of anteaters' physiological thermoregulatory needs, isolated trees in pastures are a key resource providing shelter. Anteaters will therefore return more often to isolated trees, particularly after soybean planting, and anteaters will select areas with trees over areas with no trees within pastures.

2 Methods

2.1 Study Site

The Brazilian savanna has a tropical seasonal climate, with dry winters from April to September and wet summers from October to March (Alvares et al., 2013). Annual rainfall averages 1,000 to 1,500 mm (Alvares et al., 2013), and temperatures typically range from 21ºC to 32ºC, sometimes exceeding 40ºC or dropping to -3ºC (Correia Filho et al., 2023; Nascimento & Novais, 2020). Our study site encompasses two areas in Mato Grosso do Sul state: a "control" area, where land use remained unchanged during the study duration (consisting of a mosaic of uses primarily with pasture for extensive cattle ranching), and an "impact" area, originally comprised of a mosaic of uses, similar to the control area, but subsequently converted to soybean cultivation. Animal monitoring began between 2018 and 2021. Soil preparation for soybean cultivation began in April 2021 for polygons A and B, and in December 2021 for polygon C (Figure 1). We evaluated the impact of soybean cultivation on animal movement at the local scale across three distinct periods: (1) "before-impact" period, defined as the time preceding soil clearing activities; (2) "immediate after-impact" period, considering six months after soybean establishment; and (3) "long-term after-impact" period,

encompassing the remaining six months after soybean establishment. For details regarding each individual and their respective monitoring timeframe, see the supplementary table (Appendix 1).

Figure 1. Map of the study region highlighting control (blue) and impact areas (red). (1) Map shows circles representing the centroid of the GPS locations of each individual giant anteater and their names. Land cover type is shown on the map and soybean plantation polygons in the impact area are identified by letters A, B and C; (2) Satellite image of the impact area where yellow dots indicate isolated trees prior to removal; (3) Satellite image of the impact area after tree removal and soy establishment, indicated by letters and red polygon; (4) Pile of trees removed and cleared soil; (5) Giant anteater in the pasture with cleared soil on the background; (6) Giant anteater with GPS harness resting under isolated tree in the control area; (7) Drone photo of the control area.

2.2 Capturing and Processing Movement and Environmental Data

Giant anteaters in the control (n = 7) and impact (n = 7) areas were captured and equipped with GPS harnesses (GPS TGW-4570-4 Iridium), with locations recorded every 80 minutes, except for one individual, which was monitored only every 8 hours. Individual information on sex, treatment area, total GPS locations, monitoring dates, and tracking time interval is provided in Appendix 2. All the methods followed the Guidelines of the American Society of Mammalogists for use of wild mammals in research (Sikes, 2016) and were authorized by the Brazilian Ministry of the Environment (MMA) and the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio).

We pre-processed movement data, removing outliers derived from GPS errors using the continuous-time movement modeling (‘ctmm’) package (Calabrese et al., 2016) in R (R Core Team, 2023). We removed outliers that indicated unrealistic distances or speeds between consecutive locations. Considering realistic speeds for giant anteaters, we removed locations that implied displacement greater than 3 km between consecutive 80-minute fixes (Calabrese et al., 2016; Noonan et al., 2022). The resulting dataset consisted of 120,515 GPS locations. Data from two individuals required specific handling due to sampling inconsistencies. Individual 'Annie' had a reduced sampling frequency (8-hour intervals) during the post-soy period, while ‘Houston’ presented a data gap during the before-and-after period due to collar detachment. The details of which animals were dropped are provided in the data analysis section.

Accurately mapping land use and land cover was crucial for understanding the effect of soybean plantations on giant anteater’s movement. We mapped soybean polygons using field measurements, satellite imagery, and data from farmers to accurately reflect real-time changes in land use. For the isolated trees in the pasture, we visually identified these trees in the impact area. This was accomplished by selecting the imagery of the year of interest (before soy plantation) on Google Earth Pro (Google, n.d.), and using QGIS (QGIS, n.d.) drawing tools to manually delineate tree polygons. Finally, we added a 6-meter buffer around each tree polygon to account for shade variations from the sun. This buffer size was determined after visually assessing the average size of tree shade in the high-resolution imagery from Google Earth Pro. After classifying LULC before and after the impact, we retained only GPS locations in the pasture and soybean plantation. Finally, we extracted the land use information at each pair of consecutive GPS points (hereafter referred to as a step) of the giant anteater's individual tracks and calculated the proportion of each land use within a 30 m buffer (to account for GPS location error) around each step (Valle et al., 2024a).

2.3 Data Analysis

The movement metrics used in this study include home range size and home range overlap (Calabrese et al., 2016), net squared displacement (NSD) (Bastille-Rousseau et al., 2016), revisitation index (Bracis et al., 2018), and time-explicit habitat selection (TEHS) (Valle et al., 2024a). The analyses were conducted using R (R Core Team, 2023). The individual Annie was used only for the home-range estimations because the analysis from the ‘ctmm’ package tends to be less sensitive to sampling frequency

(Calabrese et al., 2016). Houston was only kept for the home range and the TEHS analyses because these analyses are not influenced by the data gap in the monitoring of this individual.

Prediction 1: Anteaters shift home ranges and exhibit dispersal behavior to avoid soybean fields

To analyze movement patterns, we employed a Progressive-Change BACIPS (Before-After Control-Impact Paired Series, hereafter BACIPS) approach (Thiault et al., 2017). The BACIPS is especially suited for ecological systems because it accounts for gradual, time-varying changes rather than assuming impacts are immediate or constant (Thiault et al., 2017). More specifically, we analyze three distinct periods: (1) "before-impact," (2) "immediate after-impact," and (3) "long-term after-impact". Animals in both the control and impact areas were monitored during equivalent timeframes using the three-period design.

To estimate home range, we used the ‘ctmm’ package in R (Calabrese et al., 2016). We fitted multiple movement models to the individuals’ movement data and selected the best model based on Akaike Information Criterion (AIC) values for each individual. We analyzed data from resident giant anteaters (i.e., those not dispersing) using their movement parameters (Calabrese et al., 2016). To verify residency within the range, we examined the variograms of position across time for each individual’s tracking period. Individual giant anteater home ranges were estimated using the 95% area-corrected autocorrelated kernel density estimator (AKDEc 95%), which accounted for each animal's best-fit movement model to determine home range sizes and associated confidence limits. We estimated home ranges for all individuals simultaneously using the ‘meta’ function from the ‘ctmm’ package, which incorporates uncertainty from individual home range estimates into our population-level analysis (Fleming et al., 2022). Finally, we estimated the overlap of the home range between the same individual at different time periods (before and after the impact) using the Bhattacharyya coefficient (Winner et al., 2018). The Bhattacharyya coefficient measures the similarity between two distributions on a scale of 0 to 1, where 1 indicates they are identical, whereas 0 indicates no overlap (Bhattacharyya, 1946). To standardize the comparison between the control and impact areas, we estimated home ranges for each individual using the same dates to define each time period (before, immediate-after, and long-term after the soy) for data from both areas.

We estimated giant anteaters’ net squared displacement (NSD) over the entire time in both control and impact areas. NSD is a metric that measures the squared Euclidean distance between an animal's starting point and each subsequent location along its movement path. This metric has been used to identify

movement strategies, such as migration, dispersal, nomadism, and sedentarism (Börger & Fryxell, 2012; Singh et al., 2012). In our study, we aimed to compare the movement of giant anteaters in areas undergoing agricultural intensification (impact areas) versus those experiencing no change (control areas) to determine if animals in the impact area would disperse to other areas in search of better resources. We used the mean monthly NSD for individuals in the impact and control areas and applied the Progressive-Change BACIPS based on the assumption that the difference between the impact and control sites was stable before the soybean plantation, whereas this difference in animal movement patterns increased after soy was planted (Thiault et al., 2017).

Prediction 2: Anteaters return more often to isolated trees, selecting areas with trees over areas with no trees within pastures

To determine whether isolated trees in pastures are seen as a resource by giant anteaters, we verified if individuals revisited these trees significantly more than areas with no trees. Animal revisitation can help identify frequently used sites and can help characterize the importance of specific locations to species survival and conservation (Bracis et al., 2018). We calculated the revisitation index and residence time using the 'recurse' R package (Bracis et al., 2018). This approach was developed to help identify revisitations along the individual's trajectory and provide metrics such as the revisitation index and duration of the visit (hereafter residence time), considering both spatial and temporal patterns of revisitation (Bracis et al., 2018). We defined a radius of 15 meters to calculate revisitation, as it is small enough to effectively encompass the area of isolated trees and their shade, while also accounting for typical GPS errors (Bracis et al., 2018). To evaluate how isolated trees influence revisitation movement patterns, we identified the intersection of the areas occupied by the isolated trees and the areas identified by the revisitation analyses and analyzed residence time as a function of distance to the nearest tree. We conducted a Mann-Whitney non-parametric test to determine whether areas with isolated trees had different revisitation rates compared to areas without trees. Additionally, we examined temporal patterns by analyzing how the mean revisitation frequency and mean residence time varied throughout the months. We used the revisitation analysis in the impact area because, despite soybean plantations removing all isolated trees where they are implemented, animals can still access isolated trees in other adjacent areas.

To determine whether giant anteaters select isolated trees over soybean plantations, we used the time-explicit habitat selection (TEHS) model (Valle et al., 2024a). By combining the habitat selection submodel and the time submodel, the TEHS provides additional information on the time the animal spends in selected or avoided habitats. This enables us to gain a more nuanced understanding of animal behavior and their interactions with their environment. For example, the TEHS model helps determine if an animal is selecting a habitat for resource use (slow movement in selected habitat), displacement (fast movement in selected habitat), or avoiding it due to risk (fast movement in avoided habitat) or difficulty (slow movement in avoided habitat) (Valle et al., 2024a). Since we were interested in comparing the selection between isolated trees and soybean plantations, we conducted the TEHS analysis after soybeans were established in the impact area. Given that the time submodel requires distances greater than zero, we pre-processed the data to replace all GPS fixes with zero distances with one meter, representing the shortest step length present in our dataset. Our time submodel incorporates isolated trees and soybean as covariates, while pasture serves as the baseline since pasture is the predominant LULC in our study site. Because pasture was the baseline, it was excluded from our set of LULC covariates (Valle et al., 2024b). The time submodel only includes linear terms for LULC covariates (i.e., no interactions or non-linear effects were included). When fitting the TEHS habitat selection submodel, we established potential paths for the animal to characterize habitat availability by delineating four alternative steps identical in length to the observed step. These steps had four directions (east, west, north, and south) from the initial point of the step, as described in Valle et al. (2024a). We estimated the proportion of isolated trees and soybean categories within a 30-meter buffer surrounding the straight line of each step (Valle et al., 2024a). As with the time submodel, we used pasture as a baseline in our habitat selection submodel analysis because pasture was the predominant LULC in our study sites, and isolated trees and soybeans were set as covariates. We fitted the time submodel and habitat selection submodel within a Bayesian framework using JAGS (Plummer, 2003; Valle et al., 2024a). Separate models were fit for each animal.

3 Results

Prediction 1: Anteaters shift home ranges and exhibit dispersal behavior to avoid soybean fields

The seven range-resident giant anteaters in the control area showed a relatively stable home range over their monitoring periods. In contrast, we found that the seven animals in the impact area displaced their

home ranges after the establishment of the soybean plantation, particularly in the long-term period following the impact of soybean establishment (Figure 2).

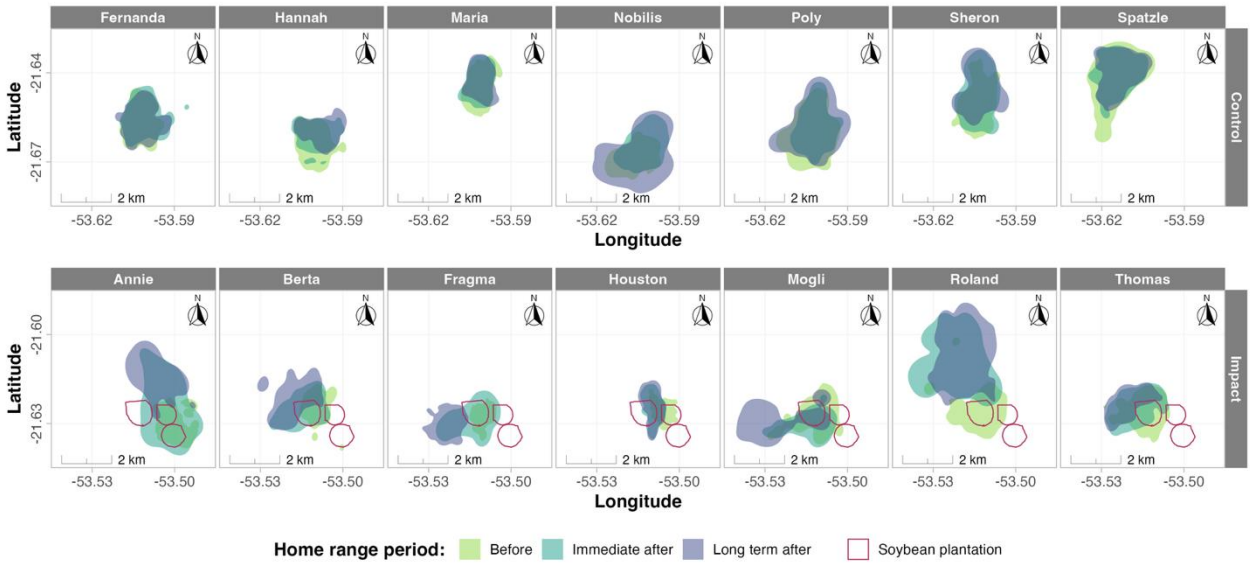

Figure 2. Home range of giant anteaters changes substantially in the impact area, but not in the control area. Panels show individual home range estimates in the control and impact areas across three different periods: before soy, immediate after, and long-term after. Red polygons represent the soybean plantations established in the impact area.

Most individuals in the control area exhibited high overlap of the home ranges estimated for the different time periods, with a mean overlap of 0.90 (range: 0.87–0.93). In contrast, individuals in the impact area occupied different areas over time, showing a considerably lower overlap in the after-soy periods, averaging 0.66 (range: 0.62–0.70) (Figure 3).

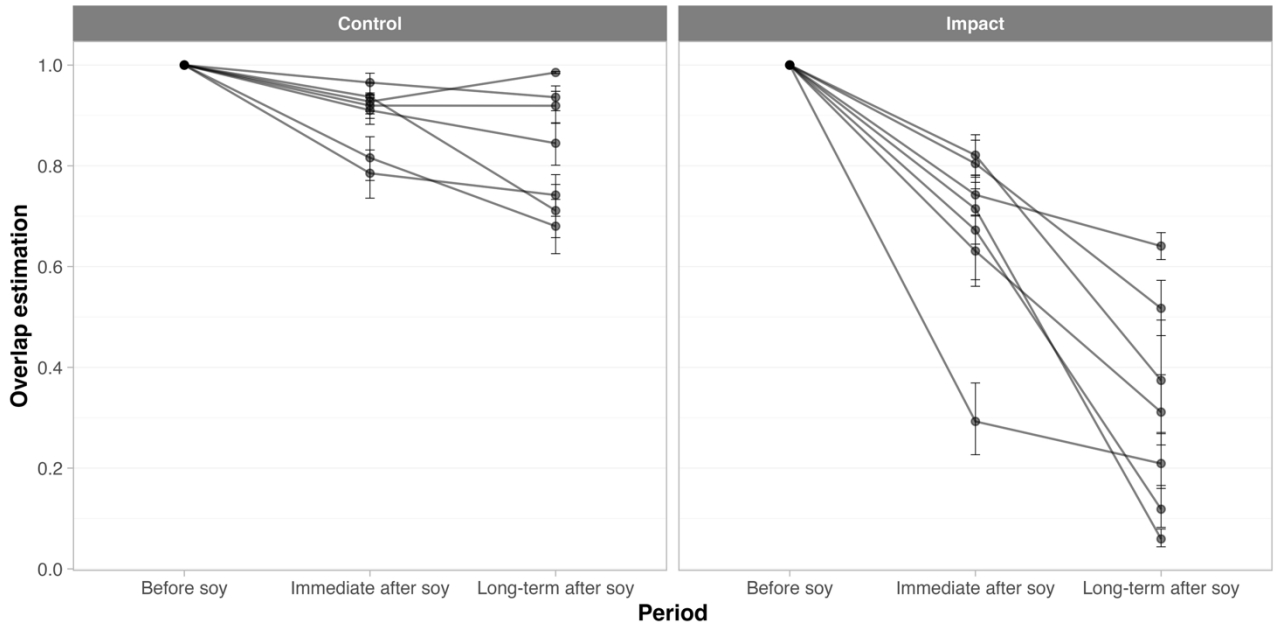

Figure 3. Giant anteaters' overlap estimates are markedly different in the impact area, while remaining largely consistent in the control area. Left and right panels show results for control and impact areas, respectively. Lines connect home range overlap estimates for the same individuals. Vertical bars represent the 95% confidence intervals on the individual overlap estimates.

Based on the NSD, we observed that giant anteaters' movement patterns changed after the soybean plantation (Figure 4a). The best model result from BACIPS indicated a 98% likelihood that a sigmoid model describes the data, suggesting a slow initial change in the NSD after the soybean plantation, followed by rapid acceleration over time (indicating dispersing animals), leading to stabilization (indicating stationary movement in a new area) (Figure 4b).

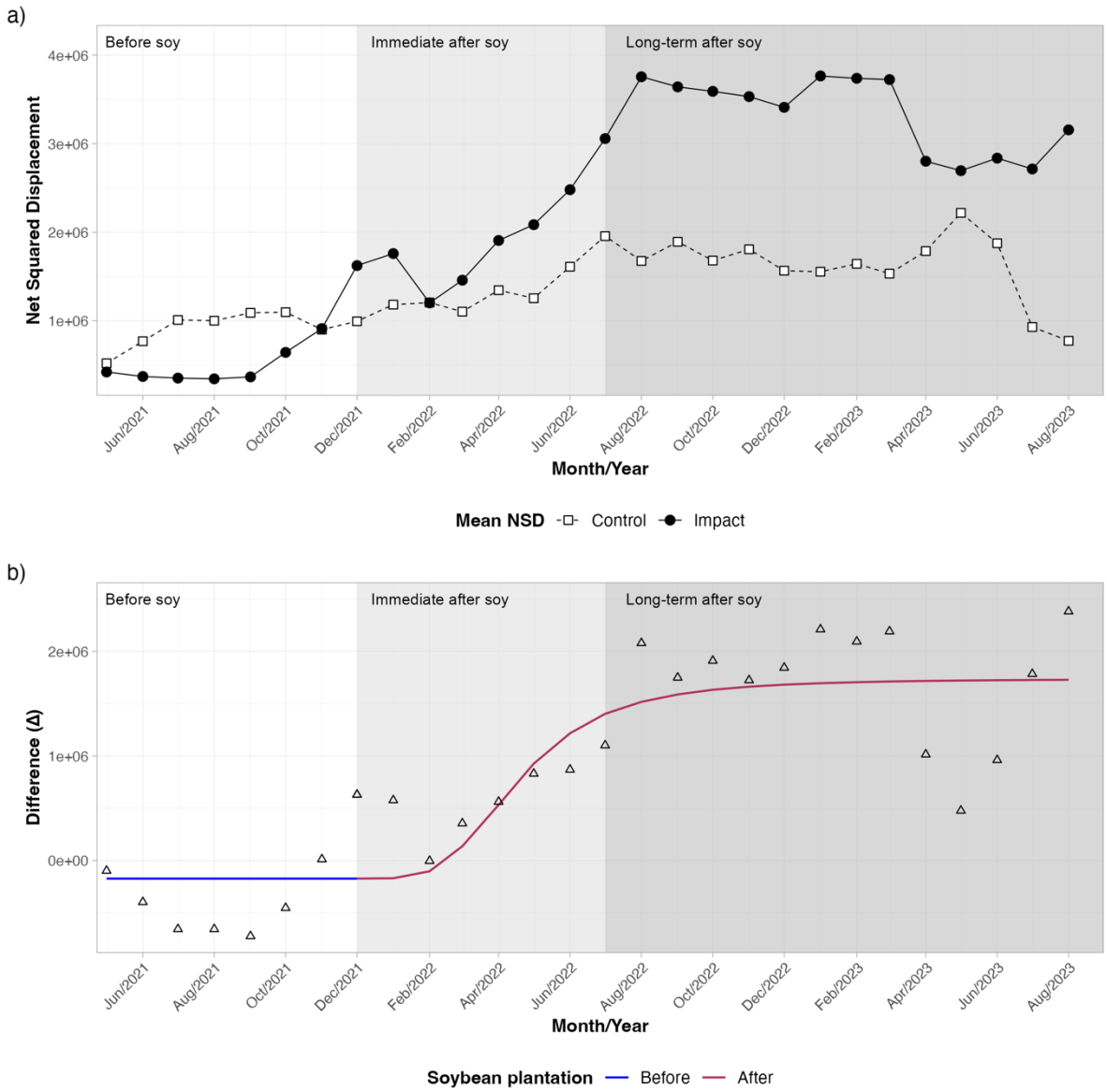

Figure 4. Changes in animal movement pattern before and after the soybean plantation. (a) Mean net squared displacement (NSD) simultaneously measured at impact (black dots) and control (white squares) areas before and after the soybean plantation; (b) Best fitted model showing the differences (Δ) between impact and control areas as a Sigmoid effect of the soybean on animal movement patterns. Note that we only used animals in the impact area that were impacted by soy plantation established in December 2021 (i.e., polygon C, Fig. 1)

Prediction 2: Anteaters return more often to isolated trees, selecting areas with trees over areas without trees within pastures:

As expected, giant anteaters spend more time (referred to as residence time) closer to isolated trees (Figure 5a). Additionally, giant anteaters revisited areas with isolated trees more often than areas with no trees, particularly during the winter months (Figure 5b). Moreover, the residence time also increases during these winter periods (Figure 5c). Interestingly, before the soybean plantation, three out of five animals

revisited areas with isolated trees more frequently than areas without trees (non-parametric Mann-Whitney, $p < 0.05$). On the other hand, after the soybean plantation was established, all individuals consistently revisited adjacent areas with isolated trees more frequently (non-parametric Mann-Whitney, $p < 0.05$), indicating that these trees represent an even more important resource for these animals once the soybean plantation was established. In short, once all isolated trees were removed for the soybean plantation, our results indicate that animals had to search for new areas with isolated trees for revisitation.

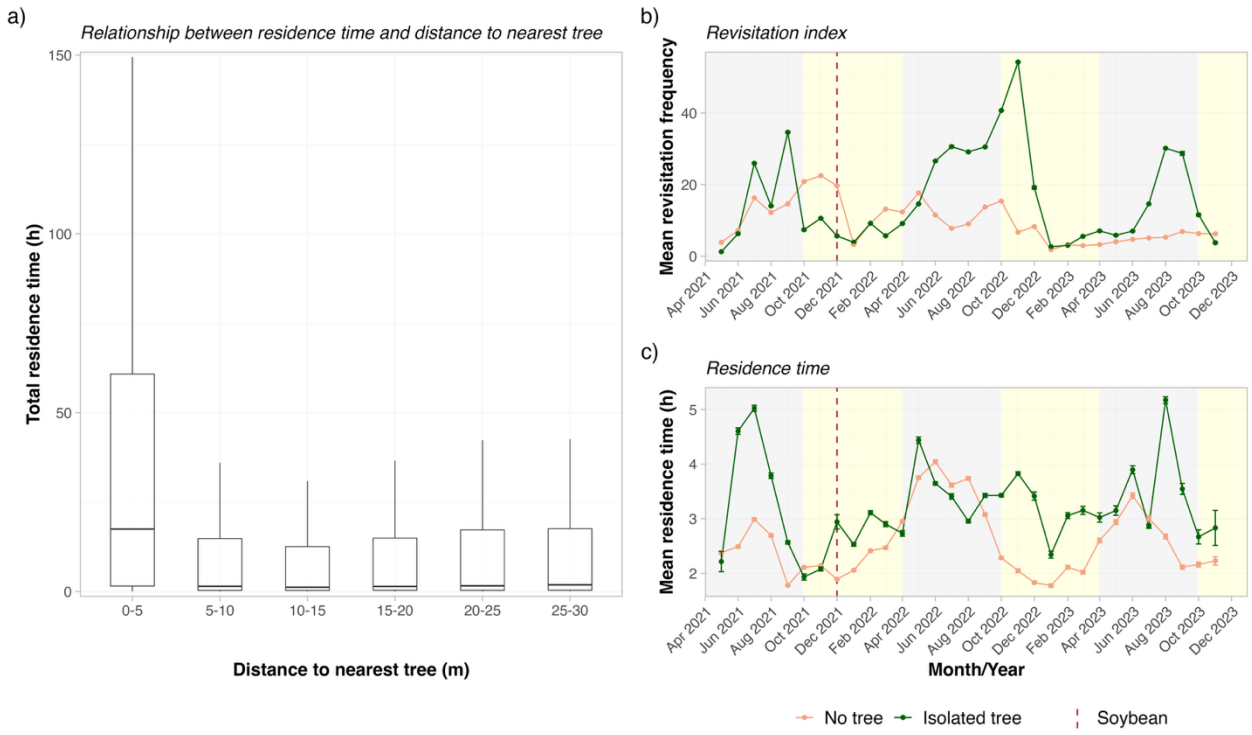

Figure 5. Giant anteater residence time and revisitation index for isolated trees within pastures, adjacent to areas impacted by soybean plantation: (a) Total residence time in a specific location based on the distance to the nearest tree; (b) Mean revisitation frequency by month and year; (c) Average residence time per month and year. Gray shading indicates dry winter, and lighter shading represents wet summer in the Brazilian Savanna. Vertical red dashed line marks the soybean establishment. Note that we only used animals in the impact area that were impacted by soy plantation established in December 2021 (i.e., polygon C, Fig. 1)

The habitat selection submodel within TEHS reveals that giant anteaters in the impact area consistently showed a stronger selection for isolated trees and avoided soybean plantations compared to pasture (Figure 6a). Additionally, the time submodel indicates that giant anteaters moved more slowly (positive values) in areas with isolated trees, whereas they moved faster (negative values) in soybean plantations compared to pasture (Figure 6b).

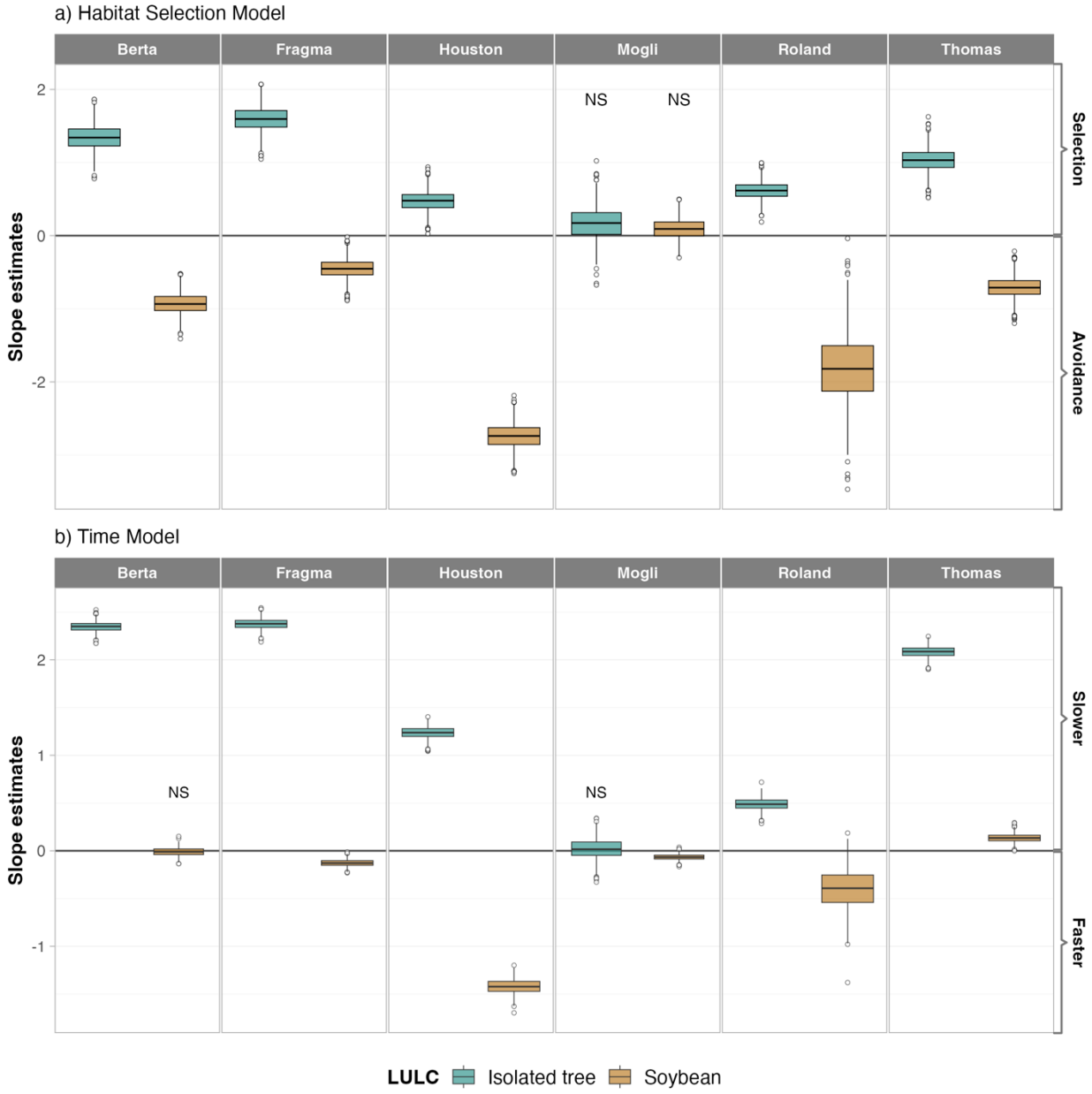

Figure 6. Results from the TEHS model indicate that giant anteaters select and spend more time in areas with isolated trees while avoiding and spending less time in areas with soybean plantations. (a) Habitat selection model indicating greater selection for isolated trees and avoidance of soybean plantation relative to the baseline LULC (i.e., pasture); (b) Time model reveals that giant anteaters move more slowly (positive values) close to isolated trees but faster (negative values) in soybean fields when compared to pasture. Each boxplot represents the results for a specific individual within the impact area after the establishment of soybean plantation. “NS” indicates non-significant results (i.e., the 95% credible interval encompasses zero) in relation to pasture.

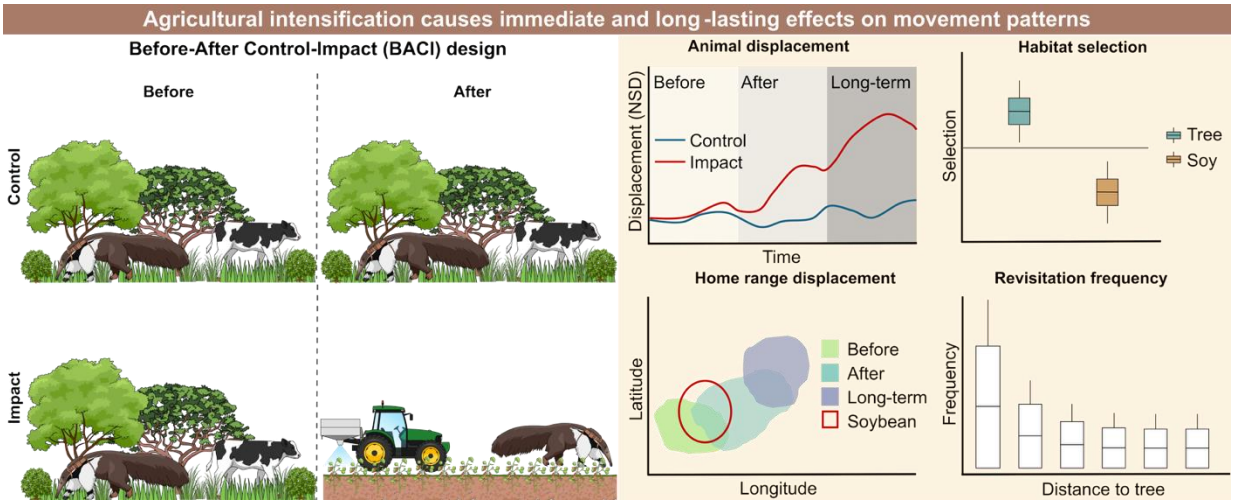

Figure 7. Take home illustration showing that transitioning from low- to high-intensity agriculture led animals to shift home ranges and increase displacement. Additionally, animals often return and select for isolated trees in pastures.

4 Discussion

We investigated how agricultural intensification impacts the movement of a flagship mammal, particularly focusing on the removal of isolated trees that may provide thermal shelters for wildlife. While previous studies offer insights into how animals respond to agricultural landscapes, none have employed a before-after control-impact (BACI) approach to investigate the effects of agricultural intensification using detailed long-term GPS telemetry. Using a BACI design in which animals were monitored before and after the soybean plantation in the control and impact areas, we found that agricultural intensification not only causes immediate disturbances but also long-lasting effects on giant anteaters' movement patterns, and that isolated trees remaining in pastures play a key role as shelters for these imperfect homeotherms (McNab, 1984). Crucially, changes in movement patterns and restricted shelter are likely to drive significant shifts in population dynamics and long-term viability (Arnold et al., 2025). Therefore, our findings emphasize the importance of raising awareness of the effects of agricultural intensification on wildlife.

As expected, giant anteaters avoided soybean plantations by shifting their home ranges after the crops' establishment. One of the reasons for this home range displacement is likely that soybean plantations provide fewer shelter options than pastures, as the removal of isolated trees reduces protection from extreme temperatures. Furthermore, our results also suggest that giant anteaters perceive soybean plantations as high-risk environments, evidenced by their avoidance behavior and faster movement patterns when traversing these areas. This response is particularly notable as it differs from typical responses to physical barriers, where animals exhibit avoidance and slower movements (Valle et al., 2024a). Another

252 possible reason animals shift their home ranges is a decrease in food resources in crop fields. Our results
253 support previous research indicating that landscape simplification often reduces food resources and shelter
254 (Donald et al., 2001; Heldbjerg et al., 2018). Evidence shows that smaller mammals tend to avoid agricultural
255 fields due to limited resources and higher predation risk, whereas some large-sized mammals can feed on
256 cash crop plantations throughout the cultivation cycle (Lima et al., 2019). A recent review found that animal
257 avoidance of crop fields is influenced by field size, management practices, and species traits; sensitive
258 species are more likely to avoid agriculture, whereas generalists may use them occasionally. A related study
259 on habitat suitability for giant anteaters in sugarcane plantations found that sugarcane expansion reduced
260 habitat suitability due to environmental simplification (Bertassoni et al., 2019). Similarly, in a protected area
261 surrounded by human-modified landscape, giant anteaters tended to avoid timber plantations (Bertassoni et
262 al., 2020), and their abundance declined in intensively farmed landscapes (dos Reis et al., 2025). Finally,
263 increased noise, vehicle traffic, and human activity during the soy-harvesting period may also drive shifting
264 home ranges, as there is evidence that concurrent human activities impact wildlife (Rutz, 2022).

265 We believe that the before-after-control-impact paired series (BACIPS) is a robust tool that
266 effectively quantifies the impacts of specific environmental interventions, distinguishing these effects from
267 other spatiotemporal variations (Thiault et al., 2017). More specifically, we observed a slow initial change in
268 animal net squared displacement, which intensified over time until it eventually stabilized. This pattern of
269 giant anteaters' displacement, along with the home range analysis, shows that individuals in the impact area
270 moved away from soybean plantations and were forced to establish their home ranges in different locations.
271 There is an inherent trade-off between energy costs and the fitness implications of resource acquisition and
272 threat avoidance when animals must decide whether to move away in response to human disturbance
273 (Cosgrove et al., 2018; Doherty et al., 2021). For instance, dispersal behavior often results in higher energy
274 expenditure and increased risks of exploring unknown areas, often compromising individual survival and
275 reproductive success (Arnold et al., 2025; Perona et al., 2019).

276 A key finding of our study was that giant anteaters exhibit site fidelity to isolated trees in pastures,
277 consistently revisiting these areas and spending longer periods near trees, indicating that these trees are
278 valuable resources (Barraquand & Benhamou, 2008; Bracis et al., 2018). This revisitation behavior could
279 also be linked to tree-marking for communication, particularly during mating or in response to stress (Braga
280 et al., 2010). However, we investigated whether males visited trees more than females for mating-related

281 marking, but found no differences in revisitation patterns between the sexes (Appendix 3). Strong revisitation
282 patterns are typically associated with habitat characteristics and, more recently, with the memory of
283 previously used locations (Verzuh et al., 2025). Interestingly, our TEHS results confirm that giant anteaters
284 select isolated trees and spend more time close to these trees compared to soybean plantation. Surprisingly,
285 giant anteaters also revisited isolated trees during winter, suggesting that trees provide shelter from heat and
286 cold. Similarly, isolated trees regulate microclimates in rural and urban areas (Van den Bossche et al., 2025),
287 offering cooler summers and warmer winters (Su et al., 2020). This microclimate regulation is crucial for
288 giant anteaters, as they have a low physiological capacity for body heat production (McNab, 1984) and
289 exhibit strong selection for forested habitats during colder periods in preserved wetlands (Giroux et al.,
290 2023). Additionally, other mammals have been observed using forests as thermal shelters (Attias et al.,
291 2018; Melin et al., 2014), indicating that isolated trees may also provide shelter for several mammals.
292 Moreover, isolated trees are important stepping-stone structures for birds and help maintain frog diversity in
293 deforested areas (Almeida-Gomes et al., 2025), enhancing connectivity and resources for certain wildlife
294 species (Silva et al., 2020). Therefore, we support the suggestion of maintaining and planting isolated trees
295 across pastures and deforested areas to benefit wildlife (Almeida-Gomes et al., 2025). Finally, management
296 plans that identify and protect frequently visited sites are essential, especially in rapidly changing landscapes
297 (Merkle et al., 2022).

298 When considering the conservation implications of our study, it is important to highlight that the
299 Brazilian savanna has primarily been used for cattle ranching since the 1960s, with significant soybean
300 cultivation expanding on pasturelands in recent years (Song et al., 2021). Brazil is now a leading global
301 soybean producer, with projections indicating a 318% production increase by 2050 (Song et al., 2021;
302 Soterroni et al., 2019). Most conservation efforts focus on raising awareness and implementing certification
303 programs to reduce deforestation of native savanna habitat (Aragão et al., 2022; Flach et al., 2021).
304 However, less attention is given to how soybean expansion on cleared pastureland contributes to landscape
305 simplification and biodiversity loss, with only a few studies addressing this (Bolfe et al., 2024; Yoshikawa,
306 2023). Notably, our findings highlight the need to go beyond addressing deforestation and raise awareness
307 of the impacts of agricultural intensification on wildlife. For example, in the case of giant anteaters, this
308 species appears to have the flexibility to persist in pasture areas as long as these areas maintain isolated
309 trees and nearby forest patches (Giroux et al., 2023).

It is important to emphasize that our findings should not be misinterpreted as validating pastures as suitable habitats for giant anteaters, since even in degraded landscapes, these animals select native habitats over human-modified areas (Meiga et al., 2026). Instead, our study reveals that converting pastures to soybean plantations – often promoted as an environmentally responsible alternative to deforestation – entails unrecognized ecological impacts. This insight is relevant to Brazil's "Programa Nacional de Conversão de Pastagens Degradadas", which aims to transform degraded pastures into sustainable agricultural and forestry systems (Brasil, 2023). Additionally, our results are particularly relevant to the "zero deforestation" policies (e.g., soy moratorium), which encourage the use of previously cleared areas to prevent further Amazon deforestation (Gibbs et al., 2015). While these initiatives have reduced Amazon deforestation, they have inadvertently led to increased agricultural intensification in the less protected Brazilian savanna (Cerrado), where only 20% of land must remain as legal reserves compared to 80% in the Amazon (Klink & Machado, 2005; Soterroni et al., 2019). Furthermore, it has been suggested the implementation of a similar policy to protect natural areas in the Cerrado while expanding agriculture by replacing pastures with crops (Strassburg et al., 2017). While preventing Amazon deforestation is essential, managing deforested land is equally important (Maeda et al., 2023). For instance, sustainable practices, such as agroforestry, can enhance agricultural production (Dobhal et al., 2024), and integrated landscape management can improve agricultural yields and ecosystem conservation (Estrada-Carmona et al., 2014). Finally, implementing multiple sustainable practices helps maintain ecosystem services, mitigate climate change, improve environmental health, and enhance food security (Medrano et al., 2025).

5 Conclusion

Our study indicates that transitions from low to high-intensity agriculture, such as converting pasture to soybean plantation, can significantly impact wildlife. Understanding these impacts on animal behavior is crucial for developing effective conservation and management strategies. By employing a before-after control-impact approach, we gained valuable insights into the impact of soybean plantation on the movement and behavior of a vulnerable species. More specifically, giant anteaters avoided soybean plantations, increasing dispersal movements, and shifting their home ranges farther away from the crops. Additionally, we were able to infer one of the mechanisms driving the change in the movement patterns by investigating the role of isolated trees within pastures. Indeed, our study reveals the ecological importance of isolated trees remaining in pastures for giant anteaters, as these trees provide shelter during both warm and cold

periods. This finding likely extends to other species as well. Therefore, we stress the need to look beyond deforestation and emphasize that conservation policies should consider the impact of agricultural intensification on biodiversity. This is particularly relevant in regions like the Brazilian Savanna (Cerrado), which is a biodiversity hotspot and a non-forest biome that currently receives significantly less legal protection when compared to the Amazon biome.

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7 CRediT authorship contribution statement

AYYM: Writing – original draft, Writing – review and editing, Conceptualization, Data curation, Methodology, Formal analysis. ALJD: Writing – review and editing, Conceptualization, Data curation, Data collection, Methodology. RAPD: Writing – review and editing, Data curation, Formal analysis. AG: Writing – review and editing. EM: Writing – review and editing. AB: Writing – review and editing. NA: Writing – review and editing. VH: Writing – review and editing. GS: Writing – review and editing, Data collection. MHA: Writing – review and editing, Data collection. DV: Writing – review and editing, Conceptualization, Formal analysis, Methodology, Funding acquisition, Supervision. All authors reviewed and edited the manuscript, substantially improving it. All authors have read and approved the final version of the manuscript.

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9 Supplementary Material

Appendix 1: Summary table with monitoring period of each individual giant anteater (*Myrmecophaga tridactyla*) in relation to soybean plantation establishment (before, immediate after, or long-term after).

Table A1. Monitoring periods before and after soybean plantation

Dates indicate the start and end of monitoring for each analysis period.

				Monitoring periods: start, end and duration (months)		
ID	Sex	Area	Soy Establishment	Before Soy	Immediate After	Long-term After
Fernanda	Female	Control	Dec 2021	Jan 2021 - Dec 2021 (11 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Hannah	Female	Control	Dec 2021	Jan 2021 - Dec 2021 (11 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Maria	Female	Control	Dec 2021	Jan 2021 - Dec 2021 (11 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Nobilis	Female	Control	Dec 2021	Jun 2021 - Dec 2021 (5 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Poly	Female	Control	Dec 2021	Jun 2021 - Dec 2021 (6 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Sheron	Female	Control	Dec 2021	Jan 2021 - Dec 2021 (11 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Spatzle	Female	Control	Dec 2021	Jun 2021 - Dec 2021 (5 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Annie	Female	Impact	Apr 2021	May 2018 - Mar 2021 (34 mo)	May 2021 - Oct 2021 (6 mo)	Nov 2021 - Apr 2022 (6 mo)
Berta	Female	Impact	Dec 2021	Sep 2021 - Dec 2021 (2 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Fragma	Female	Impact	Dec 2021	May 2021 - Dec 2021 (7 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Houston	Female	Impact	Apr 2021	May 2018 - Sep 2019 (15 mo)	Sep 2021 - Oct 2021 (2 mo)	Nov 2021 - Apr 2022 (6 mo)
Mogli	Male	Impact	Dec 2021	May 2021 - Dec 2021 (7 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Roland	Male	Impact	Dec 2021	May 2021 - Dec 2021 (7 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)
Thomas	Male	Impact	Dec 2021	May 2021 - Dec 2021 (7 mo)	Jan 2022 - Jun 2022 (6 mo)	Jul 2022 - Dec 2022 (6 mo)

Appendix 2: Summary table with individual information on sex, treatment area (control or impact), total number of GPS locations, date of start and end of monitoring, time interval between GPS location fixes, and total monitoring period (days).

Table A2. Giant anteater tracking data summary

ID	Sex	Area	Total locations	Start monitoring	End monitoring	Tracking period (days)	Time interval (mins)
Fernanda	Female	Control	31322	Apr 20, 2019	Aug 21, 2023	1584	73
Hannah	Female	Control	52947	May 16, 2018	Jul 05, 2023	1876	51
Maria	Female	Control	59206	May 20, 2018	Aug 22, 2023	1920	47
Nobilis	Female	Control	12914	Jun 20, 2021	Jul 05, 2023	746	83
Poly	Female	Control	13666	Jun 15, 2021	Aug 21, 2023	797	84
Sheron	Female	Control	44728	Jul 30, 2018	Jun 23, 2023	1789	58
Spatzle	Female	Control	14165	Jun 18, 2021	Aug 22, 2023	795	81
Annie	Female	Impact	39890	May 24, 2018	Sep 26, 2022	1586	57
Berta	Female	Impact	13191	Sep 29, 2021	Nov 15, 2023	777	85
Fragma	Female	Impact	14875	May 14, 2021	Sep 12, 2023	851	82
Houston	Female	Impact	35805	May 27, 2018	Jun 19, 2023	1849	74
Mogli	Male	Impact	11518	May 11, 2021	Apr 19, 2023	708	89
Roland	Male	Impact	14311	May 13, 2021	Sep 12, 2023	852	86
Thomas	Male	Impact	27237	Jul 27, 2018	Oct 23, 2023	1914	101

Appendix 3: Giant anteater's revisitation events in areas with isolated trees compared to areas without trees, categorized by sex.

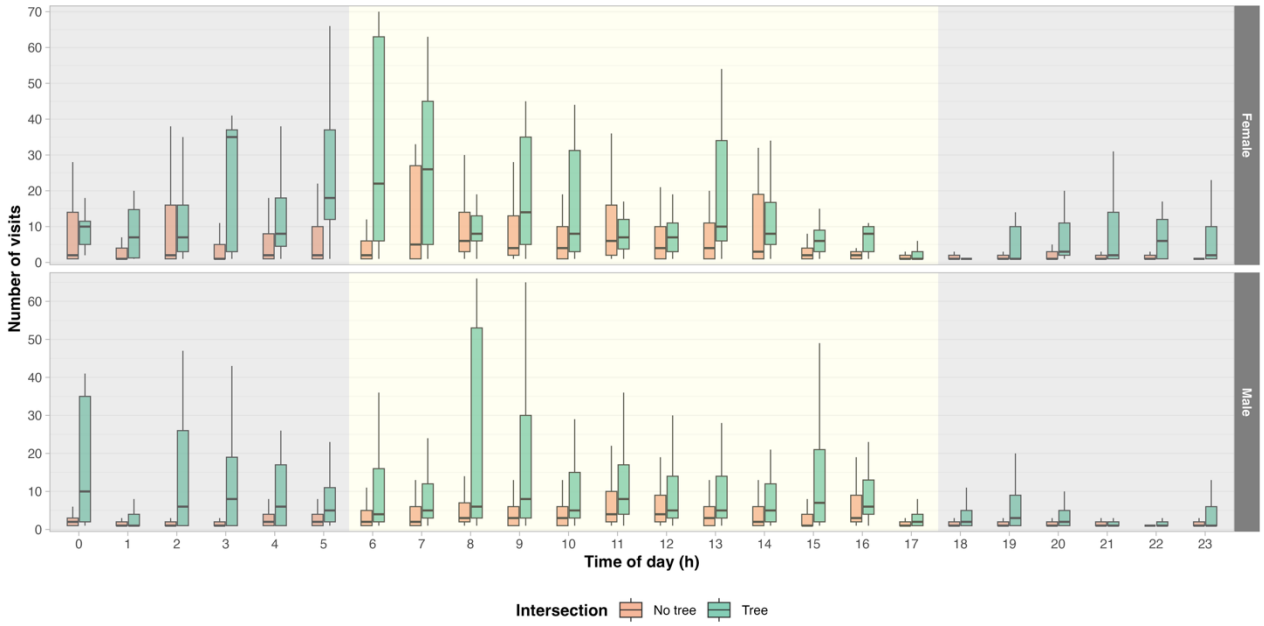

Figure A1: Giant anteater revisitation index: Boxplot of hourly revisitation events in areas with isolated trees compared to areas without trees by sex.