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UNIVERSIDADE ESTADUAL PAULISTA
“JÚLIO DE MESQUITA FILHO”
INSTITUTO DE BIOCIÊNCIAS – RIO CLARO

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS (ZOOLOGIA)

MOVEMENT ECOLOGY AND SPATIAL DISTRIBUTION OF *TAYASSU PECARI* IN HETEROGENEOUS TROPICAL LANDSCAPES

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Tese apresentada ao Instituto de Biociências do Câmpus de Rio Claro, Universidade Estadual Paulista, como parte dos requisitos para obtenção do título de Doutora em Ciências Biológicas (Zoologia).

Setembro - 2019

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Movement ecology and spatial distribution of *Tayassu pecari* in heterogeneous tropical landscapes

Orientador: Prof. Dr. Milton Cezar Ribeiro
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Rio Claro
2019

O82m

Oshima, Júlia Emi de Faria
Movement ecology and spatial distribution of Tayassu pecari in heterogeneous tropical landscapes / Júlia Emi de Faria Oshima. -- Rio Claro, 2019
206 p. : il., tabs.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Instituto de Biociências, Rio Claro
Orientador: Milton Cezar Ribeiro
Coorientadora: Maria Luísa da Silva Pinto Jorge

1. Ecologia Espacial. 2. Conservação. 3. Ecologia do Movimento. 4. Mamíferos. 5. Ecologia de Paisagens. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca do Instituto de Biociências, Rio Claro. Dados fornecidos pelo autor(a).

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TÍTULO DA TESE: Movement ecology and spatial distribution of Tayassu pecari in heterogeneous tropical landscapes

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Rio Claro, 14 de junho de 2019

DEDICATÓRIA

Para os melhores companheiros: Fabiano e Pedro

Para meus pais Hissao e Wânia

Para meus irmãos Lígia e Victor

Para a melhor companheira canina Chicória

Obrigada pelo apoio desde a ideia inicial até o ponto final desta etapa, amo vocês.

AGRADECIMENTOS

Foram quase cinco anos esperando pra escrever estas linhas, cinco anos em que eu me senti muito privilegiada e grata por ter a oportunidade de crescer profissionalmente e aprender mais sobre assuntos de que gosto tanto. Agradeço aos meus mentores pela confiança pra desenvolver este trabalho e à UNESP de Rio Claro, universidade pública que foi minha casa desde 2002 na graduação e me deu todos os subsídios para desenvolver minhas pesquisas e para aprender a amar a ciência.

Agradeço ao Programa de Pós-graduação em Zoologia pelo apoio para o desenvolvimento deste trabalho, pelos prazos extras cedidos e pela bolsa inicial de doutorado do Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) 161089/2014-3. O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código de Financiamento 001 e da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) através da bolsa de doutorado concedida no âmbito do Convênio FAPESP/CAPES - processo 2014/23132-2, e também pela bolsa FAPESP - BEPE para estágio no exterior número 2016/09957-4 e processo 2013/50421-2. Agradeço a FAPESP pelo financiamento desta pesquisa, realizá-la foi certamente uma das melhores experiências da minha vida e me tornou uma pesquisadora melhor. Agradeço aos pesquisadores membros da banca: Cibele Biondo, Karl Mokross, Marcelo Magioli e Flávia Pinto pelas importantes contribuições e avaliações desta tese.

Ao Miltinho Ribeiro e sua família (Keila, Camilo e Nicolas) serei eternamente grata por terem aberto primeiramente as portas pra uma nova família no LEEC e depois para as oportunidades profissionais. Miltinho você me ensinou muito sobre outras maneiras de fazer pesquisa, sobre ciência colaborativa e compartilhada, sobre Ecologia de Paisagens, sobre como escrever grandes projetos e viver em grandes grupos de pesquisa, sobre SIG e programação, sobre dar oportunidade para as pessoas crescerem profissionalmente. Obrigada por tudo! Em meio à correria de inúmeros projetos eu fui ganhando conhecimento com as conversas, reuniões, cursos e discussões que tive com as pessoas maravilhosas que permeavam o meu dia-a-dia no Depto. de Ecologia, agradeço a todos meus colegas de profissão pela generosidade regada a inúmeros cafezinhos e *happy hours*.

À Malu Jorge agradeço pela co-orientação, confiança e por ter me conduzido ao mundo da pesquisa com queixadas desde as primeiras viagens para Mata Atlântica em 2012, aos ensinamentos sobre como usar as parafernálias dos colares GPS, às portas abertas pra trabalhar no MS, o financiamento de parte dos equipamentos pela Vanderbilt University e por ter me recebido em Nashville em 2015. Thank you also Jen and Trina for that great month in the USA.

À Alexine Keuroghlian agradeço também pela confiança e por ter ensinado o caminho das pedras pra fazer pesquisa no Pantanal e Cerrado do MS. Sua paixão pelas queixadas e dedicação para conservação é contagiante e muito inspiradora. Foi através do Projeto Pecarídeos, na época WCS Brasil e hoje IUCN, que aprendi a capturar queixadas e que tive apoio logístico e contato com os proprietários das fazendas que abriram as porteiras para desenvolvermos nossa pesquisa, além de termos utilizado grande parte dos equipamentos de captura e carros do projeto.

E agradeço também o melhor mateiro do MS, meu também mentor, naturalista, excelente observador de aves e também especialista em queixadas, Paulino Ângelo. Obrigada por todo apoio nas capturas, na montagem de armadilhas, e pela companhia pelos longos quilômetros percorridos nas estradas do MS, nas andanças pra achar queixadas com a antena VHF, pelas conversas e ensinamentos, pela tranquilidade e parceria em campo.

Aos amigos do LEEC e do Movement Ecology Group, muito obrigada por todo apoio, troca de conhecimentos, risadas, pela organização do I MEB, que deu trabalho mas que foi demais e pelas ajudas no dia-a-dia. Em especial, agradeço a Claudinha, Laurinha, Fábio, Thadeu, Natália, Bernardo, Renata, Julia Assis, Milene, Vanesa, Pati Rogeri, Camilinha, Fernando Lima, Dani Ramos, Urucum, Paula, Maurício, Vini, Mineiro, Ursinho, Paola Biz, Danilo Iha, Victor, Ju Silveira, Ju Coelho, Flávia, Felipe Martello, John, Gió e Kauã. Devo estar esquecendo muitos, mas adoro todos vocês. Também agradeço a Laurinha (e família de gente e de bichos) por me dar um segundo lar em Rio Claro, seu apoio foi essencial, obrigada! E às minhas alunas de iniciação científica: Pati Kalaf, Dani e Tainara, obrigada pela troca de experiências e pela confiança, orientar é tão difícil e no fim eu que aprendi muito com vocês.

Aos amigos e professores do Depto. de Ecologia agradeço demais pela convivência tão inspiradora e momentos de diversão pra descontrair, em especial Rafa, Helena, Barbarete, Cleber, Larissa Sayuri, Erison, Fernandinha, Raul, Xuleta, Karl (meu primeiro professor de Ecologia do Movimento!), Mauro, Zezé, Thiago, Antônio, Maria Inês e Marina. Também agradeço à super secretária do Depto. de Ecologia, Cris Antunes, e à Ivana do PPG por toda ajuda com as dúvidas do dia-a-dia.

À todas as queixadas que cederam um pouquinho do seu tempo e paciência pra este estudo, essa espécie tão incrível com suas *big happy families*. Espero que este trabalho traga contribuições efetivas pra conservação das queixadas. E às fazendas que apoiaram nosso projeto, agradeço pelas porteiras abertas e aos amigos que nos receberam por lá: Duca

Andrade e Lídia na RPPN Quinta do Sol. Às Fazendas Safira, Santa Tereza, Jacobina, Colorado e Cláudia na região do Taboco-MS. A Lilian Rampin, Leo, Mario Haberfeld e toda equipe do Projeto Onçafari e do Refúgio Ecológico Caiman, obrigada por permitirem e apoiarem nossa pesquisa, também agradeço ao Ronaldo Morato e o Rogério Cunha de Paula pela ponte pra podermos trabalhar lá. Sou grata também a Lucas, Marina, Corine, Fernando e Claudia da Fazenda Barranco Alto por todo apoio. E ao Cláudio Nascimento, Aparecido, Norma, Rosana e a maravilhosa Chiquinha (o cateto que me ensinou muito sobre pecarídeos) da Fazenda 23 de março, obrigada pela ajuda e momentos de risadas. Também agradeço ao nosso veterinário Marcello Nardi por todo companheirismo em campo, além de todos que ajudaram nas capturas: Claudinha, Sean, Trina, Jen, Nacho, Nômade, Leanes, Nathan, Melissa e Renata.

I am very grateful to Ben Collen and Luca Börger for accepting me as a visiting student in Centre for Biodiversity and Environment Research (CBER-UCL) and in the Swansea University. Thank you for the trust in this amazing opportunity to study abroad, it was great to learn more about different cultures, to do the courses in Frankfurt and Faido, and to learn with such great science that is done in the UK. It was a pleasure to meet you Ben, I am so grateful that I got this chance. For the CBER and Swansea friends, thank you for all the lunch time, cultural exchange and fun specially: Gui Ferreira, Sergio Milheiras, Alison, Holly, Hannah, Roi, Henry, Fiona, Talassa, Jess, Lydia, Benjamin, Adam, Dan, and Judith. Thank you Chris Langridge for all the help in CBER.

Agradeço o apoio e carinho da minha família, meus pais Hissao e Wânia, meus irmãos Lígia e Victor e à tia Vera e Deo sempre presentes. Ao Fabiano agradeço por viver toda essa jornada comigo, obrigada pelas conversas no café da manhã, almoço e antes de dormir e pelo apoio quando eu decidi seguir neste caminho. Esta tese é nossa, te amo. E por fim agradeço aos meus filhotes Pedro e Chicória, que acompanharam a fase final de escrita deste documento juntinhos de mim, um dentro da barriga e a outra ao meu lado no escritório.

SUMÁRIO

RESUMO

Modificações da cobertura do solo, perturbações antropogênicas e mudanças climáticas na região Neotropical têm sido associadas à crise da biodiversidade. Nesta tese, o objetivo principal foi investigar os efeitos que a estrutura da paisagem (incluindo a perturbação antropogênica) e a qualidade do habitat têm na distribuição espacial, nos padrões de movimento e na seleção de habitat da queixada - *Tayassu pecari*. Esta espécie é o único ungulado florestal Neotropical que forma grandes bandos e é uma espécie-chave nos ecossistemas florestais, pois sua extinção local pode causar perdas adicionais de biodiversidade por meio de efeitos em cascata. Ainda assim, pouco se sabe sobre uso do espaço e movimentos de queixadas em escala fina. Para tanto, estudamos a distribuição e movimentação da espécie em diferentes escalas e biomas do Brasil, investigando quais variáveis de paisagem influenciaram a mesma em diferentes escalas e ordens de seleção. Nossos resultados mostram fortes efeitos negativos da modificação da paisagem e fragmentação do habitat na distribuição de queixadas, restando apenas 47% do território brasileiro com áreas adequadas para a espécie. Verificamos que menos da metade de todas as áreas protegidas nos biomas Cerrado e Mata Atlântica têm um habitat adequado para a queixada. Para a análise do movimento, rastreamos 30 indivíduos com colares de GPS de julho de 2013 a outubro de 2016 no Pantanal e no Cerrado do estado do Mato Grosso do Sul. Nossos principais resultados mostraram uma seleção positiva de queixadas para áreas florestais quando comparada com a matriz composta principalmente por pastagens. Uma porcentagem maior de cobertura de árvores, maiores áreas de floresta, proximidade de fontes de água e proximidade com o centro de fragmentos tiveram um efeito positivo na seleção de habitat. A queixada evitou áreas de declividade mais íngremes, estradas pavimentadas e áreas de maior densidade populacional humana. A distância máxima que as queixadas cruzaram na matriz da paisagem não excedeu 700m. Nossos resultados mostraram que a conectividade funcional para a queixada pode ser limitada pelo tipo de cobertura da terra, por estradas pavimentadas e por regiões altamente povoadas, e essa informação pode ser aplicada para determinar novas ações de manejo de conservação em nossa região de estudo. Além disso, a distância média diária percorrida para os indivíduos monitorados foi de 3501m. O tamanho total da área de vida teve valores médios que variaram dependendo do estimador utilizado: 28 km^2 (MCP), 33 km^2 (minHREFK) e 52 km^2 (AKDE). Com este estudo, pudemos identificar que mudanças sazonais nos recursos e no contexto da paisagem podem desencadear mudanças nos padrões de movimento e na área de vida durante a vida dos animais. Analisar o comportamento de movimento e área de vida de indivíduos em diferentes biomas e escalas de

tempo e espaço pode levar a diferentes conclusões sobre os requisitos de habitat para a persistência da espécie, e essa informação é essencial para a conservação da mesma em paisagens heterogêneas produtivas.

Palavras-chave: Ecologia espacial, Conservação, Ecologia de paisagens, Perda de habitat, Mamíferos, Área de vida.

ABSTRACT

Land cover modifications, anthropogenic disturbances and climate change in the Neotropical region have been linked to the biodiversity crisis. This thesis proposal was to investigate the effects that landscape structure (including anthropogenic disturbance) and habitat quality have in the spatial distribution, in the movement patterns and in the habitat selection of the white-lipped peccary - *Tayassu pecari* (WLP). This species is the only Neotropical forest ungulate that forms large herds, and it is a keystone species in forest ecosystems because its local extinction may cause additional biodiversity losses through cascading effects. Still, little is known about WLPs space use and fine-scale movement. For that aim we studied the species distribution and movements in different scales and biomes of Brazil, investigating which landscape variables would influence the species in different scales and orders of selection. Our findings show strong negative effects of landscape modification and habitat fragmentation on white-lipped peccary distribution, with only 47% of the Brazilian territory with suitable areas for the species. We also found that less than half of all protected areas in the Cerrado and the Atlantic Forest biomes have suitable habitat for WLP. For the movement analysis we tracked 30 individuals with GPS collars from July 2013 to October of 2016 in the Pantanal and in the Cerrado of Mato Grosso do Sul state. Our main results showed a positive selection of WLP for forest areas when compared with the matrix composed mainly by pasture. A higher percent of tree cover, larger forest patches, proximity to water sources and proximity with fragment center had a positive effect on habitat selection. WLP avoided steep slope areas, paved roads, and areas of higher human population density. The maximum matrix crossing distance for pasture cover did not exceed 700m. Our results showed that functional connectivity for WLP can be limited by land cover, roads and highly populated regions and this information can be applied to determine new conservation management actions in our study region. Also, the mean daily distance traveled for the monitored individuals was 3501m. The total home range size had mean values varying depending on the estimator used: 28 km^2 (MCP), 33 km^2 (minHREFK) and 52 km^2 (AKDE). With this study, we could identify that seasonal changes in resources and the landscape context can trigger changes in the movement

patterns and in the home range during the animals' lifetime. Analyzing movement and home range behavior of individuals in different biomes and scales of time and space can drive different conclusions about the habitat requirements for the species persistence, and that information is essential for its conservation in heterogeneous productive landscapes.
Keywords: Spatial Ecology, Conservation, Landscape Ecology, Habitat loss, Mammals, Home range.

I INTRODUCTION

Land-use changes have been causing reduction of terrestrial biodiversity globally (Newbold et al., 2015). Anthropogenic impacts associated with landscape alterations can direct or indirectly affect biodiversity, and one of the main current impacts is habitat loss and fragmentation. These land-use m theodifications can affect the range (Yackulic et al., 2011), movement (Tucker et al., 2018), and activity patterns (Gaynor et al., 2018) of mammal population. Therefore, currently a central challenge for the conservation biology of mammals is to monitor the influences and predict the future consequences that environmental changes have on animal populations' distribution and persistence.

In heterogeneous environments, investigating how the landscape structure (composition and configuration) affects range distribution, home range and movements of animals allow us to understand what the habitat requirements for species persistence are. We can also gain insights on how individuals are currently adapting their movements (inside and among habitat patches), space use and activity patterns to survive in altered landscapes (Fahrig, 2007; Gaynor et al., 2018; Shepard et al., 2008). Understanding and simulating how landscape changes will affect natural populations and communities in the long-term are important steps for determining more effective conservation actions' planning (e.g. Crouzeilles et al., 2015; Hanski and Gilpin, 1991; Jeltsch et al., 2013; Morales et al., 2005).

Exploring the effects of habitat loss and fragmentation in habitat selection may also require multi-scale approaches (Benhamou, 2014; Mayor et al., 2009; McGarigal et al., 2016) to explore how the impacts of landscape alterations can change if we focus in a different scale of analysis. Habitat selection assumes a disproportional use of space when comparing used versus available habitat categories (Beyer et al., 2010; Johnson, 1980; Lele et al., 2013). Multi-scale approaches explore how different spatial scales can affect the ratios of use and availability in habitat selection (Mayor et al., 2009). In addition, habitat selection may not be scaled up or down because different habitat variables can be selected in different scales and consequently the tradeoff between fitness costs and benefits can also be affected differently depending on the scale of analysis (Mayor et al., 2009; McGarigal et al., 2016). Thus, using a multi-scale approach allows to evaluate and to quantify those differences.

Another challenge to integrate landscape elements in habitat selection studies is evaluating the hierarchical nature within different orders of selection (Johnson, 1980; McGarigal et al., 2016). This evaluation comprise exploring the selection in the range distribution of a species (first order), the home range of individuals (second order), the habitat components within the home range (third order), and finally, the specific habitat components in focal sites for feeding or specific resources in preferred core areas of use (fourth order) (Johnson, 1980). More than a multi-scale approach, knowing the different impacts that landscape structure can have for species persistence in those different orders of selection, require thinking also about which biological responses and ecological processes are affected in each scale. Information provided for those different orders of selection can help to develop conservation strategies in different economic and political levels (i.e., local, regional and global).

Using multi-scale approaches to define what are the main scales in which different species respond (and how that response happens) to land-cover change, fragmentation, agriculture expansion, and creation of barriers such as roads is of extreme importance to determine how the anthropogenic matrix affects the permeability for different species, and how functional connectivity can be re-created in a dynamic changing world (Fahrig, 2017; Vasudev and Fletcher, 2015). However, it is also necessary to avoid confounding effects that fragmentation per se can have on different biological groups to determine the positive and the negative effects of landscape modifications on biodiversity (Ewers and Didham, 2006; Fahrig, 2017, 2003).

Spatial data collected using GPS technology can provide new information about behavior and decisions made by animals while moving through the landscape (Fortin et al., 2005; Gurarie et al., 2016). This information combined with new statistical approaches create new possibilities to explore species spatial distribution, movement behavior and habitat selection changes with much more detail and in shorter periods of time (Bracis et al., 2018; Gurarie et al., 2009; Morales et al., 2004; Ovaskainen et al., 2014). It also makes the identification of ecological corridors and key habitats a more dynamic and reasonable task (Chetkiewicz et al., 2006; Thurfjell et al., 2014; Vasudev and Fletcher, 2015). This is especially interesting for forest mammals that are sensible to habitat loss and fragmentation (Magioli et al., 2015; Pardini et al., 2017) since habitat alteration and anthropogenic impacts also affect mammal occurrence, movements and space use patterns (e.g. Beca et al., 2017; Betts et al., 2017; Davies et al., 2017; Ferreira et al., 2017; Morato et al., 2016; Tucker et al., 2018). Therefore, the use of environmental thresholds to predict effects of habitat loss on biodiversity occurrence and movement, may produce valuable information for species conservation, especially for forest dependent mammals.

Usually, monitoring the movement of several species in a given area is difficult and expensive. Surrogate species may be used to understand the effects of landscape composition on biodiversity by monitoring a few key species, due to the high costs to study and to create strategies to protect all threatened species (Sanderson et al., 2002). Because of their biological requirements and ecological role in forest ecosystems, the white-lipped peccary (WLP) (*Tayassu pecari*) is a good example of a surrogate species to identify the effects of habitat loss and modification on forest dependent mammals (Altrichter et al., 2012; Jorge et al., 2013; Keuroghlian et al., 2015; Reyna-Hurtado et al., 2016). They are frugivorous-omnivorous ungulates living in large herds and composing the largest biomass of mammals in the Neotropical forests (Beck, 2006; Eisenberg, 1980; Peres, 1996). WLP depend on forests to survive, and the forests are also affected by their absence because the extirpation of WLP may cause habitat alterations and additional biodiversity losses (Altrichter et al., 2012; Beck, 2006; Galetti et al., 2017; Keuroghlian et al., 2015; Keuroghlian and Eaton, 2009, 2008a). For all those reasons, WLP is excellent candidate to be used as surrogate "*landscape species*" (Sanderson et al., 2002) allowing deeper understanding of how landscape structure and anthropogenic impacts can affect the distribution and movements of other medium and large sized forest mammals.

Finally, despite the progress on the habitat selection and movement ecology research, much work is needed to account for the types of movement behavior often observed in long-lived species with spatial memory, learned behavior and social structure (Fryxell et al., 2008; Morales et al., 2004; Mueller and Fagan, 2008). Therefore, the study of the WLP habitat selection and movement addresses new information for movement ecology itself and may provide answers about what are the habitat-specific parameters and traits of large social mammals that influence their population persistence in altered landscapes.

1.1. General objectives

Our main objective in this research was to understand the effects that landscape structure (including anthropogenic disturbance and habitat quality) have in the habitat suitability and in the fine-scale movement patterns of WLP. Thus, we studied the species distribution and movements in different scales and biomes of Brazil, investigating which landscape variables would influence the species in different scales and orders of selection. More specifically, in this research we ask:

In Chapter 1 - *Bioclimatic and landscape suitability models as planning tools for the conservation of a Neotropical forest ecosystem engineer*

1. What is the amount of remaining suitable habitat areas for WLPs in Brazil?
2. Is habitat suitability in different regions of Brazil predicted by the same landscape and bioclimatic variables?
3. How are the remaining suitable areas distributed across different Brazilian biomes?
4. How forest loss in recent years affected the amount of suitable habitat available for the WLPs in Brazil?

In Chapter 2 - *Planning my next step: how landscape variables influence movement decisions of a forest ungulate within tropical landscapes?*

1. What are the main landscape variables that influence movement decisions and habitat selection for WLPs in the Pantanal and Cerrado of Mato Grosso do Sul state?
2. What is the gap crossing capacity for the species in the studied region?

In Chapter 3 - *Can movement patterns, home range and displacement rates be used as indicators of habitat quality for the last large-herd-living ungulate of neotropical forests?*

1. Do WLP herds in the Pantanal and Cerrado display similar patterns of movement, home range and displacement?
2. Is there a difference in the movement patterns of male and female WLPs?
3. Can we detect different movement modes and average daily distance traveled per day in the different seasons and regions of study?
4. How landscape structure is influencing the herds' space use patterns and can we detect non-optimal movements of WLP in response to landscape modification and habitat disturbance?

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CONCLUSION

In this study, we brought new information about white-lipped peccary (*Tayassu pecari*) distribution and movements explored in different scales and biomes of Brazil. We investigated which landscape variables would influence the species space use in different scales and orders of selection. Our results represent an important step to evaluate where are the remaining suitable areas for WLPs in Brazil, providing spatial information about how landscape modifications and anthropogenic pressure is affecting the species persistence. This is essential to determine the species current conservation status and to define more efficient conservation actions, such as defining new areas for population surveys and monitoring, placement of ecological corridors and target regions for educational programs that seek to reduce habitat loss and illegal hunting. Finally, our models showed that *T. pecari* responds to landscape changes and have been losing habitat in recent years with only 47% of Brazil remaining with suitable areas for the species. Forest loss in Brazil impacted 337,318 km^2 that were suitable for the species in the last decade and only half of all protected areas in the Cerrado and the Atlantic Forest biomes have suitable habitat for the species. With the movement analysis, we showed that higher percent of tree cover, larger forest patches, proximity to water sources and proximity with fragment center had a positive effect on habitat selection by white-lipped peccaries. But the species avoided steep slope areas, paved roads, and areas of higher population density. We showed that riparian areas are essential to improve functional connectivity for the species and that the matrix crossing distance for pasture cover did not exceed 700m, which means that connectivity for *T. pecari* can be limited by land cover, paved roads, and highly populated regions. This information can be applied to determine new conservation management actions in our study region. As previous studies have also shown, white-lipped peccaries are highly mobile moving on average 3501m per day in our study region. The total home range size can be affected by the estimator used and in our study, it was 52 km^2 (AKDE) on average. Considering autocorrelation in the home range estimates was important to verify that the species can require even larger areas than previously expected. With this study, we could identify that seasonal changes in resources and in the landscape structure can trigger changes in the movement patterns and in the home range during the animals' lifetime. Analyzing movement and home range behavior of individuals in different biomes and scales of time and space can drive different conclusions about the habitat requirements for the species persistence, and that information is essential for its conservation in heterogeneous productive landscapes. Monitoring movements of *T. pecari* can be challenging and safety procedures aiming animal welfare during capture and tracking of white-lipped peccaries should be considered for future studies. Our research also provided data to fill in some gaps about wildlife GPS tracking information that was incorporated in a collaborative manuscript recently published about the performance of satellite telemetry in terrestrial wildlife research by Hofman et al. 2019 in Plos One. In that document there are recommendations for both researchears and manufactures working with wildlife telemetry. Finally, despite the progress on the habitat selection and movement ecology research that have been developed for WLP, much work is still needed so we can better understand how spatial memory, learned behavior and social organization is influencing the species spatial use. Therefore the study of the WLP habitat selection and movement addresses new information for movement ecology itself and may provide answers about what are the habitat-specific parameters and the traits of large social mammals that influence their population persistence in altered landscapes.