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Artículo

ACTIVITY PATTERN AND HABITAT SELECTION BY INVASIVE WILD BOARS (*Sus scrofa*) IN BRAZILIAN AGROECOSYSTEMS.

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ABSTRACT. Wild boar populations are rapidly spreading through midwest Brazil, causing crop damage, impacting biodiversity and, possibly, spreading diseases to livestock. Despite their threat, little is known about introduced populations in Brazilian agricultural landscapes. The critical lack of knowledge about basic aspects of wild boar spatial ecology led us to evaluate home range sizes, activity pattern and habitat selection in interface regions of agricultural crops and natural riparian forests. We captured and monitored seven individuals using global position system collars throughout 19 to 77 days. The home range sizes calculated by Minimum Convex Polygon and Biased Random Bridge Kernel ranged from 273 to 1253 ha (median = 497 ha) and from 129 to 779 ha (median = 235 ha), respectively. Animals were more active at night, with an activity peak during the first half of the night (between 19:00-03:00 h) and less activity during the hottest hours of day (12:00 h). Wild boars positively selected riverine forests both during the day and night. They also avoided open areas (like crops and pastures), mainly during daylight. Our study provides information to improve control plans, directing capture efforts towards periods of high activity in the preferred habitats used by wild boars in the studied region.

RESUMO. **Padrão de atividade e seleção de habitat por javalis invasivos (*Sus scrofa*) em agroecossistemas brasileiros.** As populações de javali estão se espalhando rapidamente pelo centro-oeste do Brasil, causando dano às lavouras, impactando a biodiversidade e, possivelmente, carreando doenças para os animais de criação. Apesar do seu perigo, pouco se conhece sobre as populações introduzidas em áreas agrícolas do país. A crítica falta de conhecimentos sobre aspectos básicos da ecologia espacial dos javalis na região nos levou a capturar e monitorar sete javalis com colares equipados com sistema de posicionamento global de modo a avaliar seus padrões de atividade, características das áreas de vida e padrões de seleção de habitat em áreas de interface entre zonas agrícolas e matas ciliares. Capturamos e rastreamos os animais usando coleiras GPS entre 19 e 77 dias. As áreas de vida estimadas através dos métodos Mínimo Polígono Convexo e Kernel de Pontes Aleatórias Tendenciosas variaram de 273-1253 ha (mediana = 497 ha) e 129-779 ha (mediana = 235 ha) respectivamente. Os animais monitorados foram mais ativos no período noturno, com pico de atividade durante a primeira metade da noite (entre 19:00-03:00 h) e menor atividade nas horas mais quente do dia (12:00 h). Os javalis tiveram clara preferência por áreas de mata ciliar tanto em períodos diurnos quanto noturnos. Eles também evitaram áreas abertas (como lavouras e pastagens), principalmente no período diurno. Nosso estudo fornece informações importantes para aumentar a eficiência dos planos de controle, direcionando esforços de captura para os períodos de maior atividade e para os habitats preferidos pelos javalis na região estudada.

Key words: agricultural landscape, GPS collar, habitat preference, home range.

Palavras chave: área de vida, coleira GPS, paisagem agrícola, preferência de habitat.

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INTRODUCTION

Sus scrofa is one of the most prolific mammals of the world (Heise-Pavlov et al. 2009; West et al. 2009). Their free-ranging populations can increase fast when the conditions are suitable (Heise-Pavlov et al. 2009). Wild boars and their hybrids with domestic pigs cause negative effects in almost every region where feral populations are known to occur (Hegel & Marini 2013). Their negative effects are extensive and range from environmental damages to agricultural losses, and because of that, it is considered a problematic species in many countries (Hegel & Marini 2013; Cuevas et al. 2016). For the International Union for Conservation of Nature (IUCN) and the Invasive Species Specialist Group (ISSG), *S. scrofa* is one of the 100 species world's worst invasive alien species. Besides, there is no sufficient number of natural predators of free-ranging wild boars in most regions outside their native range (Lowe et al. 2000).

Favorable environmental conditions, such as large food supply, may lead wild boar populations to increase uninterruptedly (Bieber & Ruf 2005). Since its diet is dominated by plant material (Schley & Roper 2003), the agroecosystems from the Brazilian midwest provide large amount of food for wild boars, including monocultures of corn (*Zea mays*), soybean (*Glycine max*) and sugarcane (*Saccharum* sp.). These systems also provide sheltering areas in the remnant riverine forests and its adjacent wetlands. Wild boars are expanding rapidly their distribution in the midwest Brazil. For example, in 2007 wild boars were found in rural areas of seven municipalities of the state of Mato Grosso do Sul - MS (Deberdt & Scherer 2007). However, by 2015 they already occurred in rural areas of at least 46 municipalities in MS (Pedrosa et al. 2015), a fast and unforeseen invasion in the state.

According to the local farmers, the invasion in agricultural areas of south MS occurred in the 90's, when the first individuals escaped from a wild boar farm located at Dourados River's margins, where pure lineages were raised for commercial purposes and started to breed with pigs that have fled the sty. The invasion in south MS clearly differs from that observed in the Pantanal, a large and pristine floodplain in the center of South America. In the Pantanal, pigs became feral about 300 years ago (Oliveira-Santos et al. 2016) and are locally known as "porco-monteiro". To date, the Brazilian regulation makes no distinction between "pure" wild boars and hybrid lineages of feral pigs, which are subject to management for population control in Brazil (IBAMA 2013), but protect the "porco-monteiro". Because of this, hereafter we will use "wild boars" to refer to pure wild boars and to their hybrid lineages from most of Brazil, and "porco-monteiro" to refer to feral-pigs from the Pantanal.

The space use of free ranging pigs was seldom studied in Brazil (Oliveira 2012). Recently, Oliveira-Santos et al. (2016) supplied data for spatial ecology of "porco-monteiro", describing the influence of spatial memory on space use for animals inhabiting the Pantanal of Brazil. However, to date there is a lack of information about the space use of wild boars occurring in agricultural areas of Brazil. Information on habitat use and selection of invasive species may have direct application in management and population control (Saunders & Kay 1991).

Our main goals were to evaluate the activity patterns, home range characteristics, time budget and habitat selection by invasive wild boars living in agricultural regions of MS, midwest Brazil.

MATERIALS AND METHODS

We conducted this study in two sites (farms) in the Rio Ivinhema catchment in midwest Brazil (**Fig. 1**). The sites are about 23 km distant to each other: Site 1 (21° 54′ 32″ S, 54° 13′ 14″ W) is close to the Brilhante River, a tributary of the Ivinhema River and Site 2 (21° 41′ 48″ S, 54° 14′ 12″ W) is close to the Vacaria River, another Ivinhema's tributary. The soil is rich and the topography favors the use of agricultural machinery. Therefore, this region is an important producer of agricultural commodities, such as soybean, corn, and recently, sugarcane (Oliveira et al. 2000).

In the studied area there is an intersection of tropical and subtropical humid climates, according to Köppen classification. The average monthly temperature ranges from 18 to 27 °C and the monthly mean

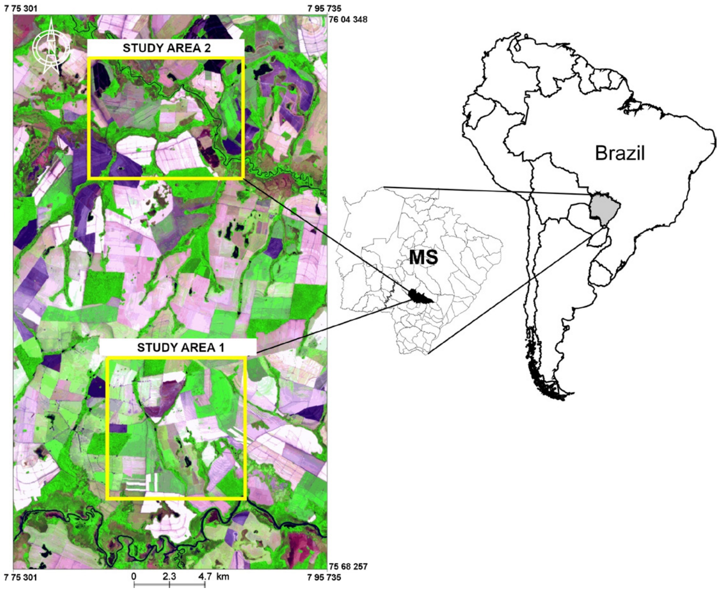

Fig. 1. Location and land use of the study sites. Upper right: South America indicating the position of the Mato Grosso do Sul state (MS) (light grey) in midwestern Brazil. Center: Rio Brilhante city in MS. Left: Satellite image of the two study sites (Universal Transverse Mercator system (UTM), zone 21k).

rainfall ranges from 56 to 175 mm while the annual rainfall is about 1500 mm (Embrapa 2018). The original vegetation included a mosaic of savannas, semi-decidual forests, marshes and riverine forests. Nowadays, grain crops and sugarcane plantations dominate the landscape but strips of riverine forests and some marshes are still present, as they are protected under Brazilian Law as "Permanent Preservation Areas."

To capture the wild boars, we used two corral traps and one box trap in each study site from October 2014 to December 2015. The traps were baited with fermented corn and inspected daily (in the morning) during 36 trapping campaigns of about 7 days each, totaling 1584 trap nights. Captured boars were chemically immobilized with an intra-muscle injection of 5.0 mg/kg of a combination of tiletamine hydrochloride and zolazepan hydrochloride (Zoletil, Virbac, Carros-Cedex, France). After immobilization the animals were sexed and classified as adults, subadults or juveniles according to teeth eruption and body weight (Matschke 1967; Anezaki 2009). Boars were weighted with 200 kg spring scale (precision 5 kg) and only animals above 20 kg were fitted with GPS collars. Handling time was less than 40 minutes and we waited for animals recovery in the proximities of the release site. This study and the handling procedures were authorized under licenses SISBIO Nº: 36636-4; 36636/5; 51134/3 of Brazilian Institute of Environment and Renewable Natural Resources and sanctioned by the Committee of Ethical Considerations and Animals Use from the Universidade Federal de Mato Grosso do Sul (CEUA-UFMS 01/2012).

We trapped wild boars for 264 days, totaling 1584 trap-nights and 56 captured individuals. Most of the captured individuals (n = 40) were piglets < 10 kg. Only 16 wild boars were large enough (25-92 kg) to fit the GPS-collars without suffocation risk. We used two types of GPS-collars: ATS collars (G2110B, Advanced Telemetry Systems, Isanti, Minnesota) and EP collars (adapted collars following Oliveira-Santos et al. 2016), using a modified commercial GPS unit used by runners attached to a VHF transmitter). Of the 16 boars fitted with GPS-collars (eight with ATS collars and eight with EP collars), only seven (four ATS collars and three EP collars) were successfully recovered in the field and provided sufficient data for spatial analysis (**Table 1**). The nine remaining collars were damaged by the wild boars or destroyed by hunters that are very active in this area. The main hunting method in the study area is ground shooting (with or without dogs), in some occasions hunters use cars or trucks to cover large areas.

We programmed the ATS collars to attempt fixes every 5 hours, with fixes attempts lasting 10 minutes, while the EP collars were programmed to acquire fixes every 5 minutes. The expected lifespan was 200 days for the ATS collars and about 100 days for the EP collars under the programmed schedules. We programmed ATS and EP collars differently because we intended to compare tracks from large and short periods. However, since the wild boars destroyed the collars in periods shorter than 100 days, this comparison was not feasible. We radiotracked the animals within the study area by car or walking with a Yagi antenna connected to a digital receiver (RS4500S, Advanced Telemetry Systems, Isanti,

Table 1

Summary information of the seven wild boars monitored in agroecosystems of midwest Brazil, from October 2014 to December 2015. ID = identification number of the animal; Site = Study site (see **Fig. 1**); Sex: M = male, F = female; W = body mass in kg; Collar = collar type: EP = assembled in Embrapa Pantanal, ATS= Advanced Telemetry Systems; Start= monitoring start date; days = number of monitoring days; fixes = number of relocations obtained from the GPS; dt = programmed time interval between relocations; CV= coefficient of variation, defined as the standard deviation of measured time interval between locations divided by the programmed dt; MCP = range (ha) estimated by the Minimum Convex Polygon; BRB-K= range (ha) estimated by the Biased Random Bridge Kernel.

ID	Site	Sex	W	Collar	Start	days	fixes	dt	CV	MCP	BRBK
J 2	1	M[1]	25	EP	10/08/14	36	7270	5	4.73	550	129
J 4	1	F	76	ATS	12/15/14	19	51	300	5.45	286	219
J 5	1	F	40	EP	12/16/14	39	381	5	140.16	273	180
J 8	2	M	86	EP	02/27/15	30	1904	5	46.59	759	235
J 10	1	M	56	ATS	06/03/15	54	72	300	1.97	497	404
J 12	2	M	42	ATS	10/22/15	77	45	300	5.15	290	341
J 13	2	F	82	ATS	11/23/15	36	158	300	0.53	1253	779

[1] Sub adult individual, all others were adults.

Minnesota). Boars' signals were monitored once a day, in the morning, during the trapping period.

We used two different methods to estimate wild boars' home range: the Minimum Convex Polygon with 100% of the locations (MCP 100%) (Mohr 1947), and the Biased Random Bridge Kernel with 95% of the locations (BRB 95%) (Benhamou & Cornelis 2010; Benhamou 2011). The MCP 100% is estimated by the smallest possible convex polygon encompassing all locations of an individual (Mohr 1947). This method is frequently used as home range estimator (Row & Blouin-Demers 2006; Nielsen et al. 2008; Boyle et al. 2009) and allowed comparisons of our results with previous studies. The BRB method considers the paths between locations and the locations distributions, providing a more accurate home range estimate.

We used the package adehabitatHR (Calenge 2006) of the R software (R Core Team 2017) to estimate the MCP100% and BRB 95% for the seven monitored wild boars. For the BRB estimates we defined T_{max} (maximum time threshold to consider connected two successive locations) = 10 hours, D_{min} (minimum distance threshold) = 50 meters and E_{min} (minimum GPS error) = 20 meters. We evaluated the asymptotic sizes of home ranges, considering the MCP method, using a bootstrap estimation (Kranstauber et al. 2017). The analyses of asymptotic sizes are showed in **Fig. S1 (Supplementary Material 1)**.

To describe the hourly activity pattern of wild boars, we used the information obtained from the three boars monitored by EP collars. We could not use the information provided by ATS-collars since they were programmed to acquire fixes every five hours. Therefore, two males (individuals J 2 and J 8) and one female (individual J 5) were tracked during spring 2014 (J 2) and summer 2014-2015 (J 5 and J 8). We used the square root of the distance between locations as an index of the animal's activity. This transformation allows to detect the slow movement usually associated with foraging animals (Attias et al. 2018) and it also resulted in residuals that conformed better to the assumption of normality. Since the time of day (TOD) has a cyclic nature, we represent the values of this variable as points on a unit circle, given by four harmonics of this value, calculated as: $s1$ = sine (2π*TOD/24); $c1$ = cosine (2π*TOD/24); $s2$ = sine (4π*TOD/24); $c2$ = cosine (4π*TOD/24) (Forester et al. 2009). Then, we used a linear mixed effects model (nlme) in the package nlme (Pinheiro et al. 2017) to adjust the activity index as a function of the harmonics (fixed variables), including the animals as a random variable. Finally, we plot the predicted output of the resulting model against TOD.

We used LANDSAT TM satellite images (30 m resolution) recorded in 2013, Google earth images, and field observations to categorize the study sites in four habitat types that we consider relevant to wild boar biology: Permanent Preservation Areas (PPA) - riverine forests, riparian zones and adjacent wetlands; Grain Crops (GC) - corn and soybean crops; Sugarcane Crops (SCC), and Pasture (P). Although GC and SCC are both crops, they were classified in distinct categories due to strong difference in dynamics and physical characteristics between them. Furthermore, soybean and corn crops occupy the same space but they are cultivated in different periods (soybean is cultivated from September to February while corn is cultivated from February to September). We classified the habitat types using Spring v.5.5.1 software (Câmara et al. 1996).

To show the time budget of wild boars, we plotted the average hourly proportion of habitat use (proportion of locations in each habitat category throughout the day) of the three wild boars monitored by the EP collars (two individuals from site 1and one from site 2, **Table 1**).

We understood habitat as a "category of physical environment that occurs in a determined area and that is available to an organism or its group" (Leuchtenberger et al. 2013). Studies on habitat selection commonly evaluated the habitat use and availability for some organisms (Calenge & Dufour 2006). In this study, we evaluated resource selection using design II analyses (Manly et al. 2002; Thomas & Taylor 2006). Habitat use was measured individually but habitat availability was measured at population level. We used the approach proposed by Manly et al. (2002) which use Chi-square analysis to test the hypothesis that animals are using resources in proportion to their availability and to test the hypothesis of identical use of habitat by all monitored individuals. We defined use as the location of an animal within a specific habitat category and availability as the proportion of each habitat type within each study site. Study sites were defined as rectangles that encompassed all locations of tracked animals (Thomas & Taylor 2006).

We determined whether selection was positive, negative or neutral for habitat categories using the package adehabitatHS (Calenge 2006) in the R 2.12 program (R Development Core Team 2012). Selection ratios were calculated as the ratio use/availability, and the selection at the population level was calculated by averaging individual selection ratios (Manly et al. 2002). According to Manly et al. (2002), habitat selection was evaluated based on the selection ratio ($\hat{w}$) and whether it differed significantly from 1 calculating its confidence interval (CI) and interpreting positive selection for a habitat category if the lower limit of the CI was >1, negative selection if the upper limit was <1, or neutral selection if the confidence interval contained the value 1. We used Eigen analysis of selection ratios and the graphical approach to analyze the variation in habitat selection among wild boars (Calenge & Dufour 2006). To explore differential habitat selection between day and night periods we separated the locations acquired during day (06:00-18:00 h) and night (18:01-05:59 h). We defined day and night periods according to the sunrise and sunset times recorded in the study area during the study period. For this analysis, we considered as daytime the period in which the sun was visible above the horizon, therefore, twilight periods were considered as night time.

RESULTS

Seven radio-collars were successfully recovered in the field and allowed to download series of relocations that varied from 19 to 77 days (**Table 1**). In total, we obtained 9881 fixes from four wild boars tracked in site 1 and three in site 2.

As expected, the home ranges estimated by the MCP 100% (median = 558 ha) were larger in average than those estimated by the BRB 95% method (median = 326 ha) (Wilcoxon signed ranks test $Z = 2.19$, $p = 0.03$) (**Table 1**). When we plotted the number of fixes versus cumulative home range sizes, the home range of only one wild boar (J 2) reached the asymptotic size (400 ha with 2000 fixes) (**Fig. S1, SM 1**). All home ranges were associated to PPA and agricultural areas (**Figs. 2** and **3**).

All four harmonics that represented time of the day affected the activity index ($t_{(s1)} = -3.89$, $t_{(c1)} = 18.81$, $t_{(s2)} = -4.04$, $t_{(c2)} = -6.93$, df = 9545 and $p < 0.001$ for every harmonics). When considering all the three individuals, boars were more active at night, especially during the first half of the night, and less active during the daytime, especially at the warm hours around noon (**Fig. 4**).

Wild boars monitored with EP collars used PPA habitats (riverine forests and their adjacent wetlands) all day long, however, the use of this habitat decreased in the first half of the

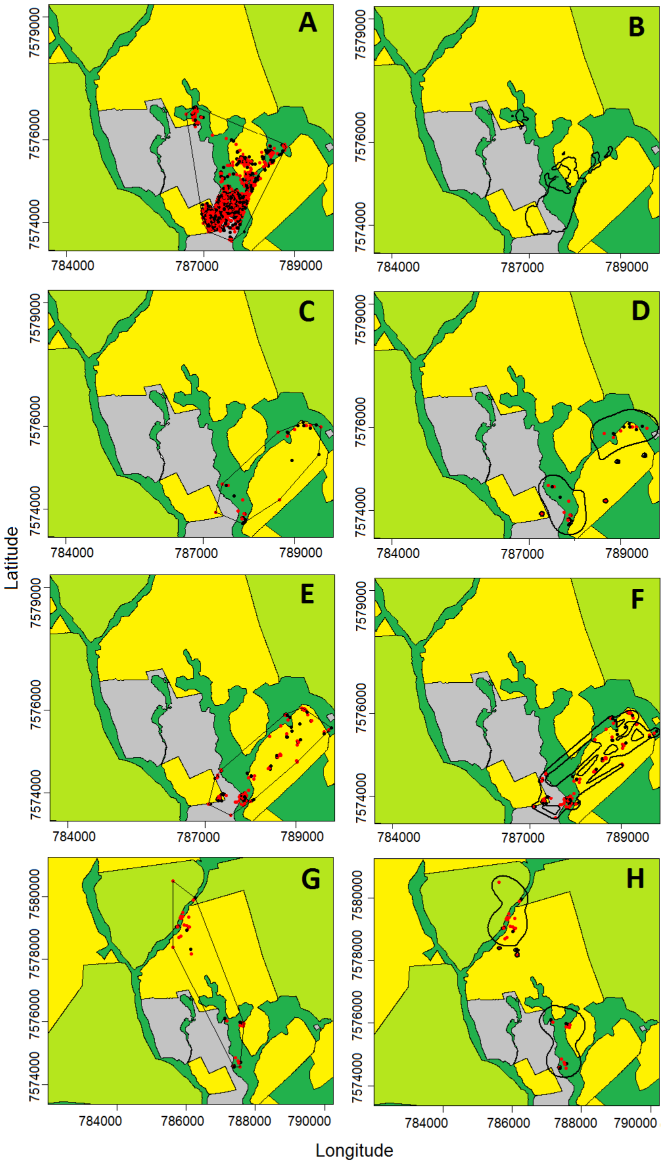

Fig. 2. Estimated ranges and relocations of four wild boars in study area 1, in midwest Brazil, from October 2014 to August 2015. Left column: ranges estimated using the Minimun Convex Polygon method. Right column: ranges estimated using the Biased Random Bridge Kernel method. Black dots represent locations taken during daylight period while red dots represent night locations. We omitted the dots in panel B to facilitate the visualization. Panels A and B refer to the subadult male J 2, panels C and D to the female J 4, panels E and F to the female J 5, and panels G and H to the male J 10 (see **Table 1**). Dark green represents riverine forests and their adjacent wetlands, light green represents sugarcane plantations, yellow represents grain crops, and grey represents pastures. Grids are presented in Universal Transverse Mercator system (UTM), zone 21k.

night, when animals used more grain crops and pasture habitats (**Fig. 5**). In lower proportion than PPA, sugarcane plantations were regularly used all day long.

The monitored wild boars did not randomly select the habitat in proportion to their availability at both sites, both at night (study area 1: $\chi^2 = 6956$, df = 3, $p < 0.001$; study area 2: $\chi^2 = 360.7$, df = 3, $p < 0.001$) and day time (study area 1: $\chi^2 = 9785.4$, df = 3, $p < 0.001$; study area 2: $\chi^2 = 344.3$, df = 3, $p < 0.001$). The habitat selection was not identical for all animals at night (study area 1: $\chi^2 = 123.6$, df = 9, $p < 0.001$; study area 2: $\chi^2 = 287.7$, df = 6, $p < 0.001$) and day (study area 1: $\chi^2 = 123.3$, df = 9, $p < 0.001$; study area 2: $\chi^2 = 89.2$, df = 6, $p < 0.001$). The habitat availability was clearly distinct between the two study sites; the site 1 had lower availability of PPA than site 2 (**Tables 2** and **3**). The tracked boars showed distinct selection patterns between the sites. In the site 1, during the night time (high activity period) they positively selected PPA habitats and negatively selected SCC habitats, meanwhile, at daytime they positively selected PPA habitats and negatively selected all other habitat categories. In the site 2, during the night time, boars positively selected SCC habitats and negatively selected P and PPA habitats, meanwhile, at daytime they positively selected SCC habitats and negatively selected P and GC habitats (**Tables 2** and **3**).

In site 1, all boars preferred PPA habitats and the selection of this habitat category was stronger during daytime (**Fig. 6**). In site 2,

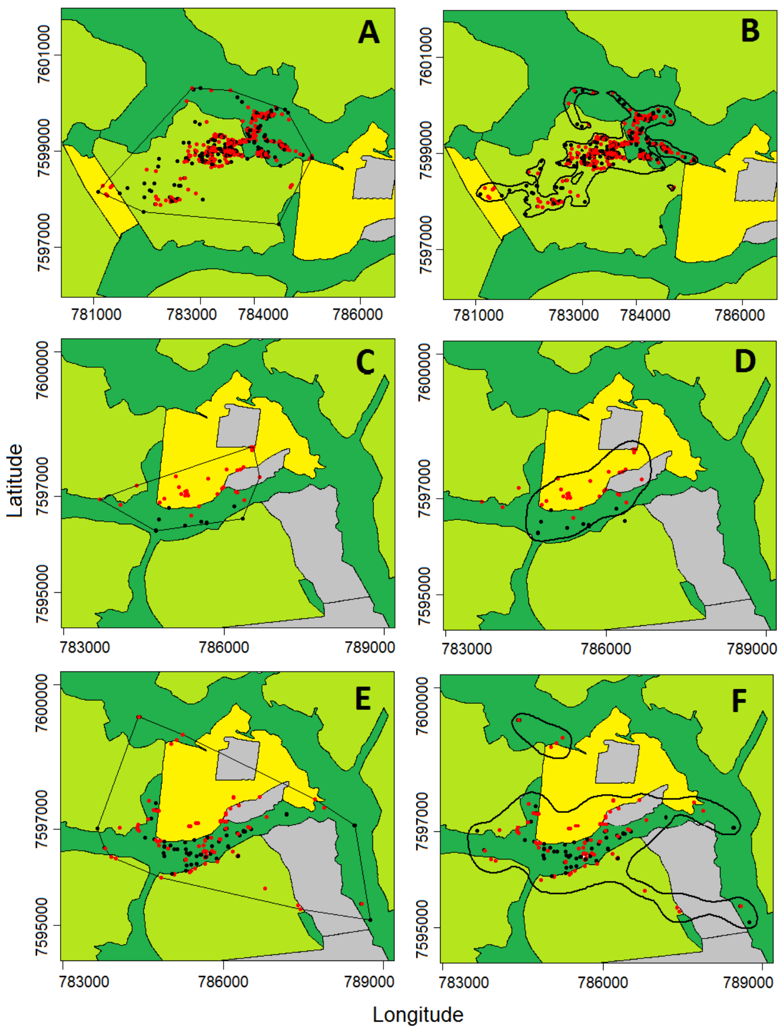

Fig. 3. Estimated ranges and relocations of three wild boars in study area 2, in midwest Brazil, from February to December 2015. Left column: ranges estimated using the Minimun Convex Polygon method. Right column: ranges estimated using the Biased Random Bridge Kernel method. Black dots represent locations taken during daylight period while red dots represent night locations. Panels A and B refer to the male J 8, panels C and D to the male J 12, panels E and F to the female J 13 (see Table 1). Dark green represents riverine forests and their adjacent wetlands, light green represents sugarcane plantations, yellow represents grain crops, and grey represents pastures. Grids are presented in Universal Transverse Mercator system (UTM), zone 21k.

boars selected habitat categories in different ways (Fig. 7). Two individuals (12 and 13) preferred agricultural habitats during the night and PPA habitats during daytime; meanwhile, one individual strongly selected SCC habitats both during night and daytime.

DISCUSSION

Monitoring wild boars in the agroecosystems of midwest Brazil proved to be a challenging task. As in other studies (e.g., Singer et al. 1981; Baber & Coblentz 1986; Saunders & Kay 1991, 1996) we had to deal with the rusticity of the wild boars that often damaged the collars and with the rapid turnover of the population likely caused by a high hunting pressure, leading to short monitoring periods of the marked individuals. The short term data could have underestimated the real home ranges of wild boars in our study area. However, our estimates of home ranges, which varied from 273 to 1253 ha (MCP 100%) and 129 to 779 ha (BRB 95%), were within the range observed in previous studies. For example, a study in a tropical area developed by Oliveira-Santos et al. (2016) tracked feral pigs in the Pantanal of Brazil over 45 to 233 days and found MCP 100% home ranges ranging from 24.4 to 2388.5 ha ($\bar{x} = 822.8$ ha), and BRB home

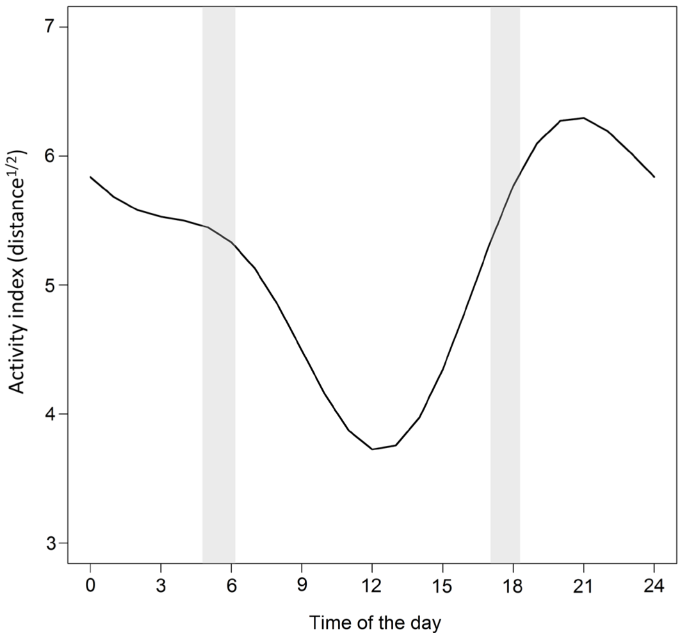

Fig. 4. Estimated activity of three wild boars, indexed by the square root of the distance moved between consecutive locations, as a function of the time of the day. These wild boars were GPS-monitored for 19-39 days from October 2014 to January 2016 in agroecosystems of Midwest Brazil. Grey bands represent the range of sunset and sunrise hours throughout the study period (see text).

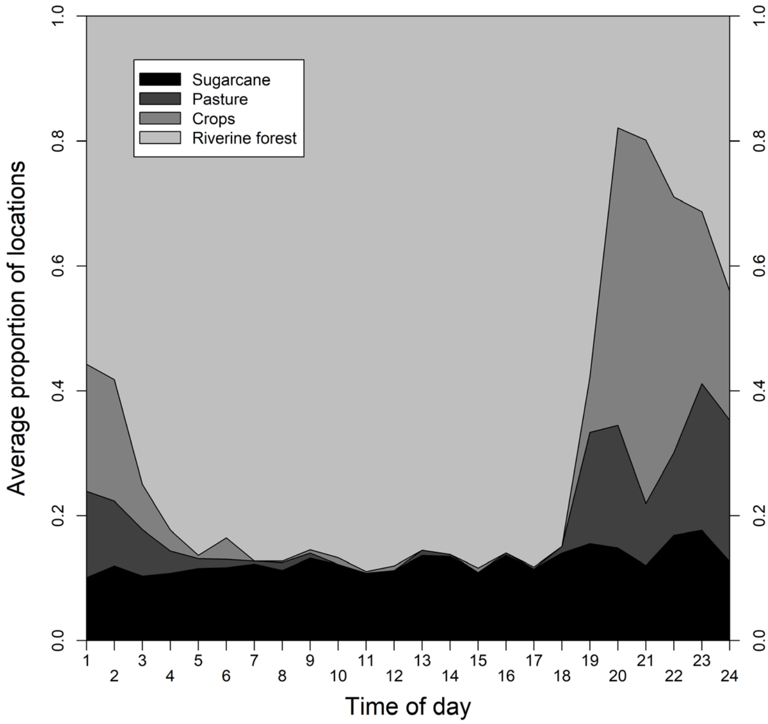

Fig. 5. Time budget displaying the proportion of locations among four habitat categories throughout the hours of day for the three wild boars monitored with GPS collars for 19-39 days from October 2014 to January 2015 in agroecosystems of Midwest Brazil.

Table 2

Estimated selection ratios ($\hat{w}$), standard errors (SE), lower and upper confidence intervals (CI) of habitat selection for wild boars in study area 1 during day and night periods. Bolded values refer to significant selection, values marked with $^+$ refer to positive selection (> 1) and values marked with $^-$ refer to negative selection (< 1), non bolded values of $\hat{w}$ refer to neutral selection. Animals were monitored from October 2014 to August 2015 in agroecosystems of Midwest Brazil (Rio Brilhante city, Mato Grosso do Sul state).

		Night						Day				
Habitat	Available	Used	$\hat{w}$	SE	Lower CI	Uper CI	Used	$\hat{w}$	SE	Lower CI	Uper CI
Sugarcane	0.435	0.0002	**0.0005$^-$**	0.0008	-0.002	0.003	0.000	**0.000$^-$**	0.000	0.000	0.000
Pasture	0.110	0.138	1.258	0.103	1.000	1.516	0.004	**0.034$^-$**	0.020	-0.017	0.084
Grain crop	0.304	0.277	0.910	0.096	0.671	1.150	0.007	**0.023$^-$**	0.027	-0.044	0.090
PPA	0.150	0.584	**3.884$^+$**	0.121	3.582	4.187	0.989	**6.574$^+$**	0.066	6.409	6.739

Table 3

Estimated selection ratios ($\hat{w}$), standard errors (SE), lower and upper confidence intervals (CI) of habitat selection for wild boars in study area 2 during day and night periods. Bolded values of $\hat{w}$ refer to significant selection, values marked with $^+$ refer to positive selection (> 1) and values marked with $^-$ refer to negative selection (< 1), non bolded values refer to neutral selection. Animals were monitored from February to December 2015 in agroecosystems of Midwest Brazil (Rio Brilhante city, Mato Grosso do Sul state).

		Night					Day				
Habitat	Available	Used	$\hat{w}$	SE	Lower CI	Uper CI	Used	$\hat{w}$	SE	Lower CI	Uper CI
Sugarcane	0.417	0.658	**1578$^+$**	0.197	1.086	2.070	0.485	**1.164$^+$**	0.149	0.792	1.537
Pasture	0.075	0.004	**0.059$^-$**	0.083	-0.150	0.267	0.000	**0.000$^-$**	0.000	0.000	0.000
Grain crop	0.107	0.042	0.394	0.451	-0.732	1.520	0.002	**0.020$^-$**	0.028	-0.050	0.000
PPA	0.402	0.296	**0.736$^-$**	0.090	0.512	0.960	0.512	1.274	0.148	0.904	1.643

ranges from 50.2 to 908.7 ha ($\bar{x} = 266$ ha). Our home range estimations are also within values obtained for wild boars in temperate regions. In Italian Mediterranean coast, Massei et al. (1997) estimated wild boar's MCP 100% home ranges ranging from 118 to 284 ha. Keuling et al. (2008) in a revision about females' wild boar home ranges, pointed out that seasonal (two-three months) MCP 100% varied from 190 to 5140 ha. However, since the home range of only one of the boars we tracked reached the asymptotic size, more data are needed to accurately estimate wild boar home ranges in our study area. Furthermore, the absence of sex-related differences in boars' home range areas in our study sites needs further investigation.

Although the activity pattern of free ranging wild boars varies within and among populations (e.g. Singer et al. 1981; Russo et al. 1997; Keuling et al. 2008; Oliveira-Santos et al. 2013; Morelle et al. 2015) and between sexes (Boitani et al. 1994), many authors have observed more nocturnal than diurnal movements. Usually the movements start to increase around sunset (Lemel et al. 2003; Keuling 2008; Oliveira-Santos et al. 2013) in association to foraging behavior (Boitani et al. 1994; Cahill et al. 2003). Our results also indicated an activity increase at night. According to Keuling et al. (2008), exceptionally when hunting pressure is low, diurnal activity should increase. This is not the case in our study area, where local farmers

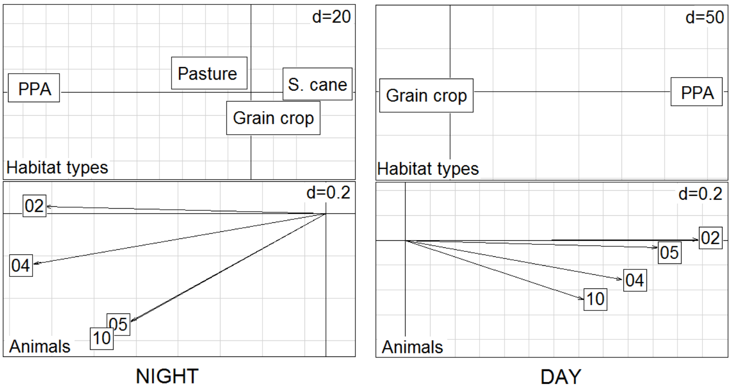

Fig. 6. Eigenanalysis of selection ratios conducted to determine day and night habitat selection by four wild boars from study area 1 considering four habitat categories in agroecosystems of Midwest Brazil (Rio Brilhante city, Mato Grosso do Sul state). Above: habitat types loadings on the first two factorial axes, which combined explain 97% of data variability for night period and 99% for day. Below: animal scores (represented as vectors) in the first factorial plane. PPA = riverine forests assigned in Brazilan law as Permanent Protected Areas; grain crop = soybean and corn crops; s.cane = sugarcane plantation. The "*d*" value is a parameter related to grid size inside the panels.

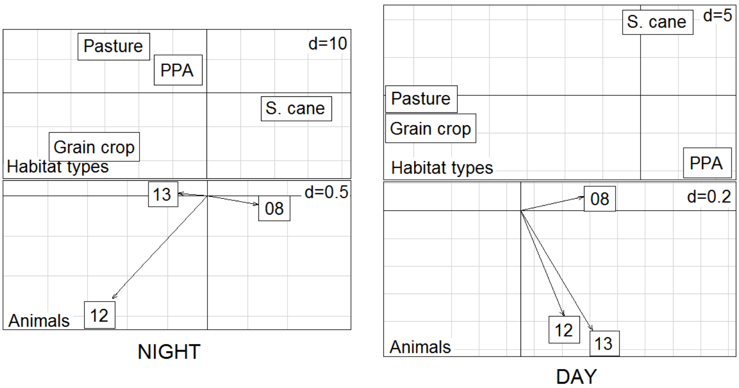

Fig. 7. Eigenanalysis of selection ratios conducted to determine day and night habitat selection by three wild boars from study area 2 on four habitat variables in agroecosystems from Midwest Brazil (Rio Brilhante city, Mato Grosso do Sul state). Above: habitat types loadings on the first two factorial axes, which together explain 98% of data variability for night and 99% for day. Below: animal scores (represented as vectors) in the first factorial plane. PPA = riverine forests assigned in Brazilan law as Permanent Protected Areas; grain crop = soybean and corn crops; s.cane = sugarcane plantation. The "*d*" value is a parameter related to grid size inside the panels.

actively hunt the boars throughout the year in an attempt to protect their crops.

As in other studies, the wild boars used and positively selected the forested areas associated with riverine forests, which are close to water or food sources, and avoided open areas (Gerard et al. 1991; Dexter 1998; Thurfjell et al. 2009; Schiafini & Villa 2012; Oliveira-Santos et al. 2016). The wild boar preference for PPA habitats likely reflects the trade-offs among thermal regulation, predation risk and forage quality. Wild boars lack sweat glands so they must rely on behavioral thermoregulation (e.g. staying in shadow areas or wallowing in mud or water) to avoid overheating (Baber & Coblentz 1986). As hunting pressure exists in our study area, boars may choose to stay in forested areas that provide shelter and reduce the chances of being shot by hunters. Finally, in our study areas PPA habitats are completely surrounded by agricultural fields where animals could easily find large amounts of food throughout the year. In fact, studies indicate that wild boar diet frequently include agricultural crops (Herrero et al. 2006; Ballari & Barrios-García 2013; Ballari et al. 2014) and we personally have observed the animals feeding on sugarcane, corn and soybean crops throughout the study period.

Wild boars used grain crops during night periods, however, no more than expected according to their availability. Conversely, they avoided the crops during day light. This is an expected pattern since wild boars tend to prevent the exposition to sun and hunters in agricultural fields (Hayes et al. 2009; Thurfjell et al. 2009). The sugarcane crop was negatively selected in site 1, regardless the period of the day. However, it was positively selected in site 2, where one individual stayed in the sugarcane plantation virtually 24 hours per day. Sugarcane was already described in wild boar diet (Ballari & Barrios-García 2013), and the physical structure of this crop provides a shelter environment, commonly used by medium size mammals in Brazil (Beca et al. 2017).

Herrero et al. (2006) suggested that the riparian zones of agroecosystems in Spain were not important foraging habitats for wild boars, but provided refuge sites adjacent to the crops, where food was abundant. Although food availability is known to limit most of wild boar populations (Matschke 1964; Baber & Coblentz 1986), the lack of shelters may retain the population growth, especially where the food is abundant.

Our study presents new information on space use and habitat selection by wild boars in agroecosystems from midwest Brazil, in a landscape dominated by monocultures of corn, soybean and sugarcane. Despite the relatively recent invasion, wild boars are spreading fast throughout Brazilian forests and agricultural zones. The efficacy of control actions in the studied region could be improved if hunters use our information to concentrate capture effort on habitats and time of the day when the animals are more vulnerable.

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SUPPLEMENTARY ONLINE MATERIAL

Supplement 1

https://www.sarem.org.ar/wp-content/uploads/2019/07/SAREM_MastNeotrop_26-1_Martins-sup1.doc

Fig. S1. Boostrap estimation of the 25%, 50%, and 75% percentile of the 100% Minimum Convex Polygon (MPC) area with increasing number of locations per calculation.