Effectiveness of protected areas for jaguars: the case of the Taiamã Ecological Station in Brazil

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Abstract. The largest feline in the Americas and the third largest in the world, the jaguar is an apex predator in the food chain and a key species in the ecosystems where it occurs, developing important ecological functions in maintaining ecosystem balance. In Brazil, the Pantanal is considered an important refuge for the species, and protected areas such as the Taiamã Ecological Station (TES) are relevant for conservation of pristine ecosystem where the species persist. Thus, considering that this area is located in one of the regions with the highest concentration of this large cat in the Pantanal, the objective of this study was to evaluate the effectiveness of the protection given by the TES for the jaguar population. The station is a flooded island in the middle of the Paraguay river and surrounded by extensive wetlands. We monitored ten jaguars using GPS collar at the TES and its surroundings. The samples were separated into high-water season (January to June) and low-water season (July to December), and the estimated home ranges were grouped as: 1) residents only and 2) all monitored individuals. The stabilization of the home ranges of eight jaguars, considered residents, was determined through variograms. When all jaguars were analysed together there was 55% overlap between the clustered areas of the two analysed seasons. In the analysis excluding non-resident individuals there was 72% overlap between the clustered areas. The type of land cover inside these areas was very similar between these periods. The range of this protected area is not sufficient to effectively protect these jaguar populations, since the grouped home ranges of the resident animals studied are 3.5(wet)/2.5(dry) times larger than the area of the TES. However, the surroundings of the TES have low human impact and no deforestation and, in this way, the landscape context of the station may have a significant effect on the persistence of a large carnivore like the jaguar. However, it is necessary to create more protected areas in order to prevent possible future environmental changes in the areas surrounding TES.

Key-Words. Pantanal wetland; *Panthera onca;* Protected area; GPS-collar; Home range size.

INTRODUCTION

Jaguars (*Panthera onca,* Linnaeus 1785), the only neotropical representative of the subfamily Pantheridae, is the largest wild cat in the Americas and the third largest in the world (Seymour, 1989; Silver *et al.,* 2004). As the apex predator of the food chain and key species in the ecosystems where it occurs, the species has important ecological functions in the maintenance of the ecosystem balance (Terborgh, 1990). In Brazil, the Amazon and the Pantanal are considered im-portant jaguar refuges (Sanderson *et al.,* 2002). The Pantanal wetlands (150,355 km²) is located in the Upper Paraguay River Basin, in the centre of South America, covering neighbouring areas in Brazil, Bolivia and Paraguay, with roughly 80% of this area in the Brazilian side. This ecosystem has a high concentration and abundance of wildlife, and the annual flood pulse is the main determinant of ecological processes and patterns in the Pantanal (Harris *et al.,* 2005; Alho, 2008; Tomas *et al.,* 2019). In this biome, the jaguar occupies about 47% of the territory, with an effective pop-

ulation size smaller than 1,000 individuals (Morato *et al.,* 2013). Hunting for retaliation, prevention and sport, as well as the loss of habitat associated with agricultural expansion, are the main threats to the population in this region (Morato *et al.,* 2013). The species is categorized as vulnerable (VU) in Brazil (ICMBio, 2018) and near threatened (NT) by the IUCN (Quigley *et al.,* 2017).

There is wide variation in home range used by jaguars, which varies according to the type of environment, the availability of prey, seasonality, the rainfall regime and differences associated with sex (Schaller & Crawshaw-Jr., 1980; Crawshaw-Jr. & Quigley, 1991; Cavalcanti & Gese, 2009; Cullen-Jr. *et al.,* 2013; Morato *et al.,* 2018a).

In the Pantanal, the largest populations of *P. onca* are found in the central-northern region, where the Taiamã Ecological Station (TES) is located, as well as in the southern portion of the floodplain (Quigley & Crawshaw-Jr., 1992). These regions are considered extremely important for the long-term conservation of this large feline (Quigley & Crawshaw, 1992). Besides being relevant for jaguar conservation, TES has been also considered as important for the maintenance of local fish stocks (Muniz *et al.,* 2016; ICMBio, 2017) and bird diversity (Frota *et al.,* 2020).

Protected areas (PAs) that have small populations of large carnivores are vulnerable to extinction through stochastic processes because of their naturally large home range and low densities (Nowell & Jackson, 1996; Woodroffe & Ginsberg, 1998). Additionally, in small to medium-sized PAs an important part of the large carnivores' range is at the periphery or outside these areas, and thus, the mortality outside negatively affects the population dynamics inside PAs (Inskip & Zimmerman, 2009). In this context, it is known that the success of conservation measures of many species and communities that inhabit protected areas but constantly cross the administrative limits is highly influenced by the areas outside these protected spaces (Woodroffe & Ginsberg, 1998; Ogada *et al.,* 2003; Baskett *et al.,* 2007). In this way the main objective of our study is an evaluation of the TES effectiveness in protecting jaguar inside and around its limits.

MATERIAL AND METHODS

The TES is a federal protected area (16°48'S-16°58'S, 57°24'W-57°40'W) between the Paraguay and Bracinho rivers and is located in the northern Pantanal, Cáceres municipality, Mato Grosso state of Brazil, and comprehends 115.55 km². The Pantanal is one of the largest freshwater wetlands in the world (Harris *et al.,* 2005; Junk & Cunha, 2005; Tomas *et al.,* 2019), harbouring a great diversity of aquatic environments influenced by the the flooding pulse (Junk & Silva, 1999; Oliveira & Calheiros, 2000). This protected area is mainly composed of floodplains, and its interior contains a great variety of aquatic environments, such as permanent, temporary lagoons, meander lagoons and 'corixos' (natural connections between rivers and lagoons that have great importance to water bodies in the Pantanal). The TES has high levels of

biodiversity, high rates of fishing productivity and the occurrence of populations of vulnerable or endangered species (ICMBio, 2017).

The Station is characterized by different functional units. These are Aquatic-Terrestrial Transition Zones, swamps, and permanently aquatic areas. Among the main macrohabitats are the Purple Coraltree Monospecific Forest (forest dominated by *Erythrina fusca* Lour., which is locally known as "abobral"), Shrubland, Pioneer Polyspecific Forest which is present of the river margins, Flooded Grasslands composed of herbaceous plants, aquatic macrophytes, and floating islands and meadows (locally known as "campos de batumes", composed of plants and layers of organic matter accumulated by hydrological changes), lakes, and river channels (Frota *et al.,* 2017). The buffer zone is characterized by irregular depression lakes, some of which are interconnected by floodplain channels (Wantzen *et al.,* 2005), flooded grasslands, aquatic macrophytes, "abobral", and "campos de batumes". The Station was declared a Ramsar site in 2018.

The TES is inserted in a region that plays important roles in flood control and sediment depositional processes of the north Pantanal. This region is characterized by the overflow of waters in the Paraguay River and it is flooded during most of the year (Assine & Silva, 2009).

In the vicinity of the TES, an environmental regulation (Resolution 02/2018 of the State Fisheries Council of the State of Mato Grosso, Brazil) delimits an area where fishing is prohibited (Fig. 1) to protect the fish fauna present in this region. Around the Station there is a private reserve, RPPN Jubran, with an area of 355,31 km².

The period between January and June are the 6 months with the highest water level in the TES region, and at this time the plain beside a river channel is inundated. The other months (between July and December) are characterized by lower water levels (Santana *et al.,* 2013).

Ten jaguars (six males and four females) were monitored using GPS collars in the TES between October 2013 and April 2016 under license from the Instituto Chico Mendes de Conservação da Biodiversidade (SISBIO number 30896-3). All data used to develop this study are available to the scientific community (Morato *et al.,* 2018b).

The animals were captured according to the foot snare method (Balme *et al.,* 2009), immobilized with a combination of tiletamine and zolazepam (Zoletil 100®, Virbac SA, Carros-Cedex, France) and fitted with GPS-satellite collars (Lotek-Iridium).

These collars were programmed to obtain locations every hour. The drop-off system was programmed for 400 days, and when triggered, the transmitter collar automatically loosened from the animal. The collars were programmed to send data to the Iridium satellite system every 24 hours.

The location coordinates were separated into a 6-month wet period and a 6-month dry period. This separation into only two seasons occurred because the animal data did not show location points in all months of
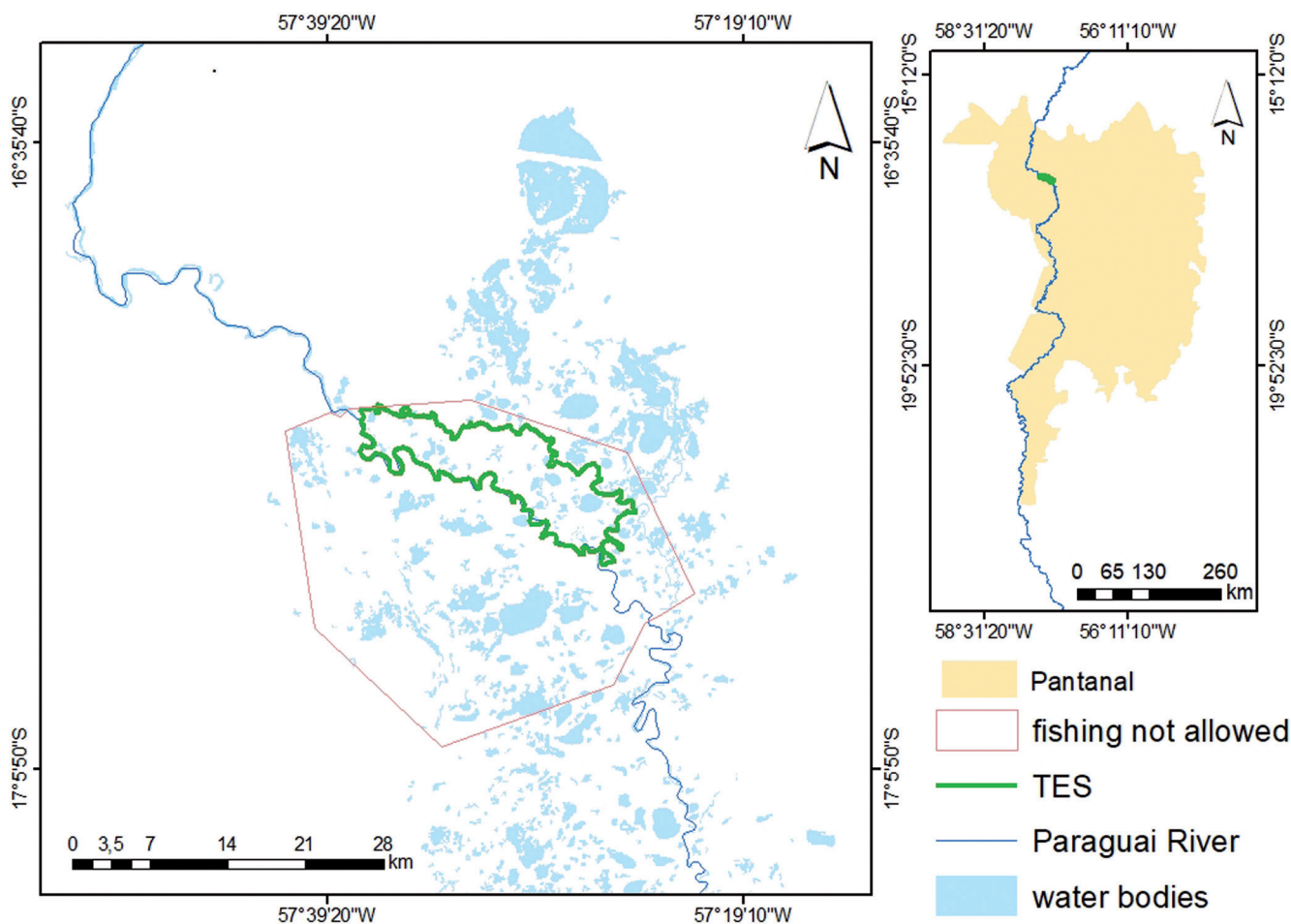
Figure 1. Pantanal Biome and the location in the flooded region of the Taiamã Ecological Station, Cáceres, Mato Grosso, Brazil.

the year. We gathered 42,126 individual locations from our sample of 10 jaguars.

In order to estimate the home range of the monitored animals, the Autocorrelational Kernel Density Estimation (AKDE) methodology was used through the software RStudio v1.0.143 with the Continuous-Time Movement Modeling (CTMM) package (Calabrese *et al.,* 2016), which generates the probability of occurrence density based on parameters of the individual's own movement (for example, the time spent to reach the most extreme areas of their distribution), in addition to the basic parameters of Kernel Density Estimation. To generate home ranges in different seasonal periods, the location data for each animal were analysed separately in Rstudio to obtain shapefiles with information on occupation of the area during the wet and dry periods. Each shapefile resulted in home ranges with three confidence intervals, but only the mean maximum contour range/interval where the animal spent 95% of its time was considered for analysis.

One of the functions of the CTMM package (variogram) allowed us to verify the stabilization of the home ranges through variograms, and the stabilization of animal movement is represented by an asymptote, which is used to classify the animal as a resident. The variograms of non-resident animals, which do not yet have a fixed living area, do not reach the asymptote. These analyses were performed to correct possible distortions observed during the process of constructing comparative maps

between the different periods, since the data on animals that do not yet have defined home ranges can generate different results from the observed patterns for resident individuals.

To verify if it would be possible to compare home ranges between dry and wet periods, the number of points in each period were obtained as a proportion of the total points for each individual. This analysis was performed for all individuals. The Kolmogorov-Smirnov test was performed to verify the normality of the data distribution in both periods. The *t*-test of one sample for the wet and dry periods was carried out separately using GraphPad Instat software version 3.0 to verify if the mean of the proportion of points per period (dry and wet) differed from 50%.

In order to compare the different seasonal periods (low-water season and high water-season), the areas of use of all animals were grouped using the union tool in the Quantum Gis 3.0 program.

The *t*-test to compare difference between means (individual home ranges in km² – without non-residents and M4) for the wet and dry periods was carried out separately using GraphPad Instat software version 3.0. The individual M4 was not included in this analysis because it was monitored only in the wet period.

The land cover classes were obtained through the MapBiomas Project (Brazilian Annual Land Use and Land Cover Mapping Project) (Projeto MapBiomas, 2020).

RESULTS

The animals that provided the greatest amount of data were individual M1, monitored for 20 months and individual F2, monitored for 14 months.

The distribution of coordinate ratios between dry and wet periods was considered normal for the dry ($p = 0.15$) and wet ($p = 0.18$) periods. The means of the proportion of sampling points for each animal in each period were not significantly different from 50% (dry: $p = 0.1599$ and wet: $p = 0.1435$).

The stabilization of the home ranges of eight jaguars, considered residents, was determined through variograms. In two animals (M1 and F3), the asymptote was not observed, and these two individuals were considered non-resident (Fig. 2). The latter were the individuals with the highest estimated areas of use, 514.33 km² and 483.90 km², respectively (Table 1).

The averages of the individual home ranges in the two periods did not differ statistically ($p = 0.1825$).

When grouping the home ranges of all jaguars observed in the high-water season and low-water season, 868.35 km² and 393.54 km² were obtained, respectively. When the non-resident individuals were removed from the grouping, the area in the wet was 375.97 km² and that in the dry was 278.79 km² (Figs. 3, 4).

When all jaguars were analysed together, there was overlap between the clustered areas of the two analysed seasons, with 55% of the area occupied during the wet season being used in the dry season and the other 45% not being used in the dry season. There was no change in the type of land cover inside clustered areas between seasons (Pearson's coefficient = 0.9984), and the classes with the highest proportions observed were Natural Non-Forest Wet Area (57.20% for dry and 58.13% for wet), formation forest (33.86% for dry and 31.26% for wet) and water bodies (7.15% and 7.26%, respectively). The other types of soil cover present in the clustered areas were savanna formation, countryside formation and pasture, all with very low proportions (< 1.3%).

Table 1. Home ranges of 10 monitored jaguars *(Panthera onca)* at the Taiamã Ecological Station, Mato Grosso, Brazil, from October 2013 to April 2016.

| ID	Home Range size (km²)			Sampling period (months)
	Whole period	Dry	Wet	
M1	514.327	336.527	582.499	10/2013 to 05/2015 (20)
M2	106.773	106.560	78.406	09/2014 to 05/2015 (09)
M3	119.661	83.344	122.117	11/2014 to 04/2015 (06)
M4	34.063	34.063		09/2014 (01)
M5	51.594	100.634	32.898	12/2014 to 08/2015 (09)
M6	206.900	117.774	308.779	10/2015 to 04/2016 (07)
F1	74.112	89.488	32.723	10/2013 to 04/2014 (07)
F2	43.507	61.624	19.756	10/2014 to 12/2015 (15)
F3	483.896	38.368	501.27	12/2014 to 04/2015 (05)
F4	44.764	48.006	36.555	10/2015 to 02/2016 (04)
average (± SE)	167.960 ± 57.573	89.873 ± 29.373	190.556 ± 73.035	
average whitout non-residents (± SE)	85.172 ± 20.574	65.480 ± 12.955	90.176 ± 34.083	
average without non-residents and M4 (± SE)	97.473 ± 22.211	69.968 ± 14.033	91.561 ± 38.841	
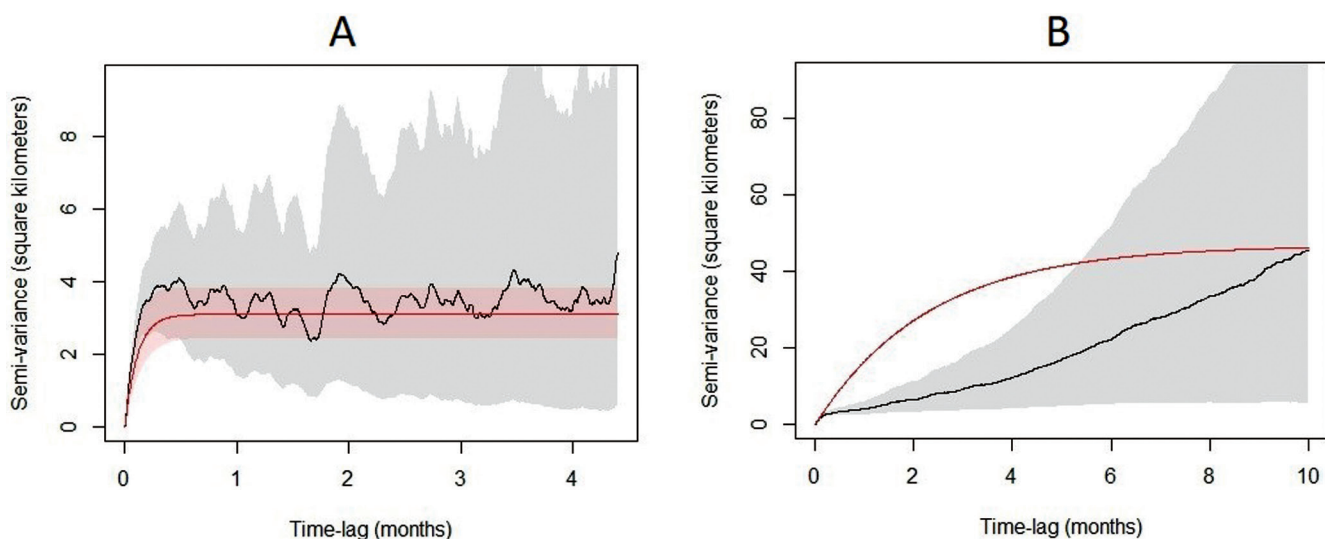
Figure 2. Variogram of the resident (A) and non-residents jaguars (B) at the Taiamã Ecological Station, Cáceres, Mato Grosso, Brazil, monitored by GPS collar from October 2013 to April 2016. The red line represents the fitted model, and the red shading represents the 95% CI. (B) The non-resident jaguar M1. Note the lack of a clear asymptote despite the fact that the animal was monitored for a long period (591 days). This lack of asymptote indicates that this animal is not a range resident. For both A and B, the fraction of the variogram displayed is 65% of the duration of each dataset.
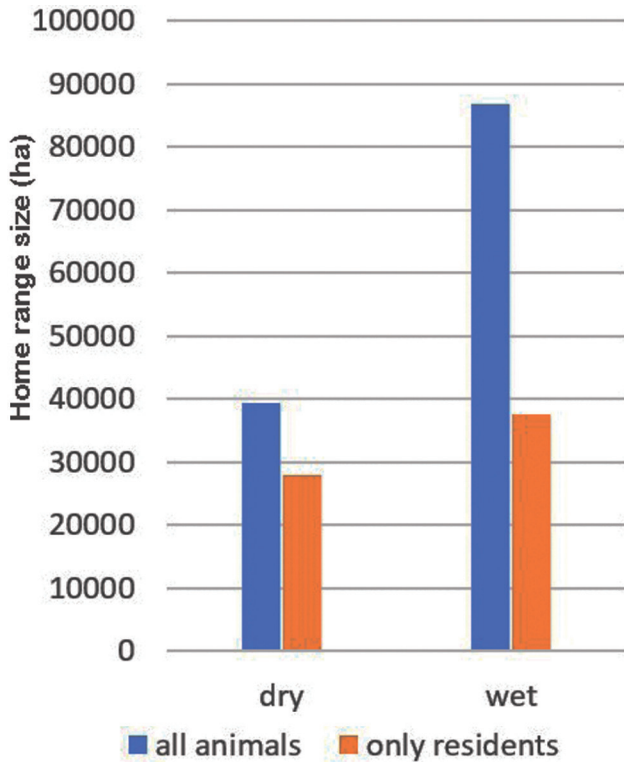
Figure 3. Grouped home ranges of the jaguars at the Taiamã Ecological Station, Cáceres, Mato Grosso, Brazil, monitored by GPS collar from October 2013 to April 2016.

In the analysis excluding non-resident individuals (M1 and F3), 72% of the area occupied during the wet period was used by the jaguars during the dry season. There was no change in the type of ground cover inside clustered areas between seasons (Pearson's coefficient = 0.9937), and the classes with the highest proportions observed were Natural Non-Forest Wet Area (60.45% for dry and 60.05% for wet), formation forest (33.85% for dry and 28.67% for wet) and water bodies (3.94% and 5.25%, respectively). The other types of soil cover present in the clustered areas were savanna formation, countryside formation and pasture, all with very low proportions (< 1.5%).

Moreover, when all jaguars were considered, only 0.45% of the dry season area did not overlap with the wet season, and when non-resident animals were removed, this value was 1.73%.

The clustered areas used by jaguars, at any time, with all animals or without non-resident animals, is directly related to the Paraguay River, since the polygons follows the course of the river (Fig. 4).

DISCUSSION

The proportion of coordinates per individual in each season was not significantly different from 50%, indi-
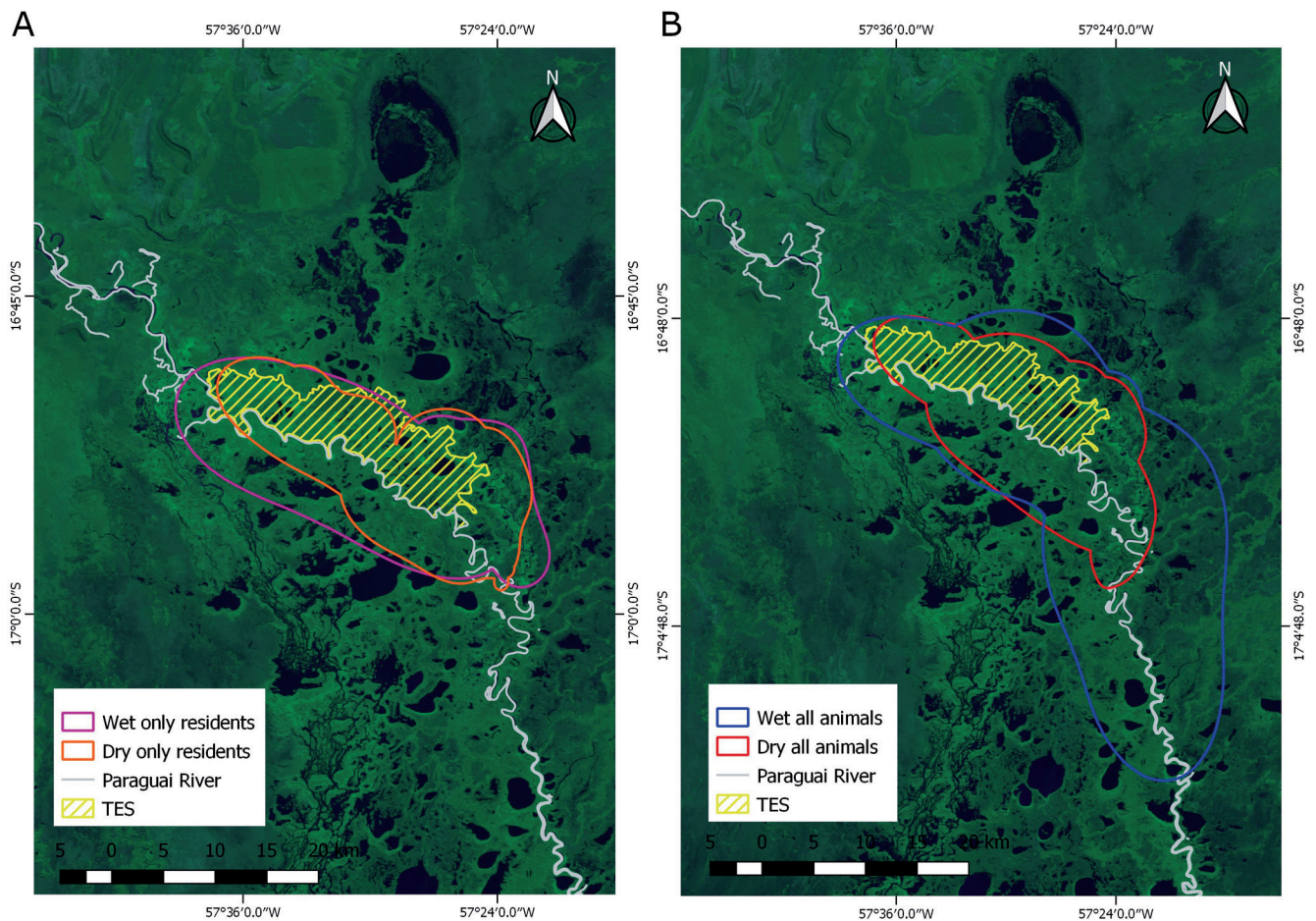

Figure 4. Grouped home ranges of resident jaguars (A) and all animals (B) during the high water-season (July to December – wet) and low-water season (January to June – dry) at the Taiamã Ecological Station and surroundings, Cáceres, Mato Grosso, Brazil, monitored by GPS collar from October 2013 to April 2016.

cating the suitability of the data for comparison of the two seasons. Jaguars are solitary animals and are considered residents when they define their home range and non-residents when they do not define a home range (Schaller & Crawshaw-Jr., 1980). We chose to analyse the overlap of clustered home ranges with and without the non-resident animals, since migrant individuals tend to increase their areas of use significantly, which would alter the results making comparisons difficult. Thus, in the analysis without the non-resident animals, individuals M1 and F3 were not used because they were considered non-resident animals during the sampling period. The jaguars considered resident in this study are mostly adult animals and have concentrated their home ranges in the TES and adjacent areas. The non-resident individuals were also identified at the time of capture as adults (4 years of age) (Morato *et al.,* 2016) but with little life experience, as jaguars up to 13 years of age have been observed in the wild (Brown & Lopez-Gonzales, 2001). The dispersal of M1 and F3 was possibly related to the age of these jaguars. Environmental dispersal of animals is defined as migration from their place of birth in response to conditions of overcrowding, selection of partners, territoriality, lack of adequate homes or parental expulsion (Howard, 1960). In addition, migration of young mammals avoids inbreeding (Dingle & Drake, 2007). Dispersion of other felines such as *Puma concolor* (Morrison *et al.,* 2015) and *Panthera tigris* (Gour *et al.,* 2013) were also reported in the literature. Unlike M3, which did not migrate in a specific direction, the F3 female migrated to the TSE southward along the Paraguay River, using a region of the Pantanal that is still very conserved and considered an ecological corridor (Silveira *et al.,* 2014).

Jaguars' home range data from wet and dry seasons in the southern Pantanal revealed that the largest areas were occupied during the dry season, with a reduction in the area occupied in the wet period. This is due, according to the authors, to the isolation and concentration of prey on dry islands, resulting in a smaller displacement to capture animals with terrestrial habits, such as cattle, which correspond to 31.7% of the jaguar diet and are the main food item for this population. The increase in the home range of jaguars in the dry period is related to the dispersal of prey (Cavalcanti *et al.,* 2012). The jaguars from the TES behave differently, in the grouped analysis they used a small estimated area in the dry period and increased the area used in the wet period (Fig. 4). However, when individual home ranges were compared, no statistical difference was observed. The different results observed between the two studies were possibly due to differences in the diet of these two populations and the type of environment they use. The area studied in the Southern Pantanal is less flooded than the TES region, and the jaguars analysed in our study feed mainly on aquatic prey (C. Eriksson, *pers. comm.,* September 2018). In addition, there are no livestock in our study area. These differences in the behaviour of jaguars, both between environments and between time of the year, reflect the opportunistic nature of the species, which seems to take advantage of constantly changing environments and the variation of food resources in time and space (Emmons, 1987; Cavalcanti & Gese, 2009; Morato *et al.,* 2018a). More than 85 species of prey (wild and livestock/domestic), including mammals, reptiles and birds, were recorded in their diet throughout their geographical distribution (Seymour, 1989).

A study carried out about macrohabitats at the TES stipulated that during the period when the level of the Paraguay river is low, 48% of the area is composed of marshland (batume), 47% is transitional aquatic and terrestrial areas with a predominance of terrestrial areas (flooded fields) and 5% is permanent aquatic areas, indicating that in the flood season almost the entire station and its surroundings are flooded (Frota *et al.,* 2017). In addition, the annual variation of the water level of the Paraguay River in the study region is approximately 1.50 m, which is the smallest amplitude recorded for the entire Paraguay river (Oliveira *et al.,* 2013). This indicates that the region is very flat and that water from the river channel overflows, laterally flooding large plains (Silva *et al.,* 2007). Due to the small amplitude and flat feature of the region (ICMBio, 2017), the water level above most of the station's soil is approximately 1 m during the peak of the annual flood, a fact that makes it possible for jaguars to move within the flooded area, without the need to constantly swim in their ranges. These movements within the water also suggest a facility for catching aquatic prey. Jaguars moving during the flooding period in flooded areas of the TES and surroundings have already been observed by managers and researchers, as well as through photographic trap images installed in the TES area (D.L.Z., Kantek, *pers. comm.,* September 2018).

It is concluded that the jaguars continued to use the flooded areas of the TES during the flooding period of the Paraguay River. In addition, individuals F3 and M1, although not resident, remained in flooded areas, evidencing the suitability of this population for this type of environment. The data obtained in this study are complementary to the positive association between jaguars and water bodies detected by several researchers (Crawshaw-Jr. & Quigley, 1991; Cullen-Jr. *et al.,* 2013; De Angelo *et al.,* 2011; Morato *et al.,* 2018a). In addition, the animals in these localities are installed in one of the wettest regions of the Pantanal (Padovani, 2010) and apparently are already habituated to this situation, which makes these populations differentiated in relation to the other populations of jaguars already registered in the scientific literature.

Finally, from an environmental conservation standpoint, the range of this protected area is not sufficient to effectively protect these jaguar populations, since the grouped home ranges of the resident animals studied are 3.5(wet)/2.5(dry) times larger than the area of the TES (Fig. 2). In another study conducted at the TES, Kantek & Onuma (2013) also identified the need of increasing the size of the station. The fact that PAs often fail to provide adequate area to support viable populations of wide-ranging species, such as large carnivores, is not

a new finding and has been documented extensively in the scientific literature (Baeza & Estades, 2010; Johnson *et al.,* 2006; Mulongoy & Chape, 2004; Simonetti & Mella, 1997; Newmark, 1985). In addition, PA size and extinction risk in carnivores is highly correlated (Woodroffe & Ginsberg, 1998). However, small PAs for large carnivore conservation can be enhanced by improving the quality of the surrounding landscape (Baeza & Estades, 2010). The surroundings of the TES have low human impact, since there is a private reserve contiguous in the northeast and a flooded region in the southwest where there is no productive human activity, such as crop cultivation, livestock production and aquaculture (ICMBio, 2017). In addition, fishing in the southwest is not allowed, making difficult the access to this area. Furthermore, there is no deforestation between 1990 and 2017 in the region (Projeto MapBiomas, 2020). In this way, our study showed that the landscape context of a protected area may have a significant effect on the persistence of a large carnivore like a jaguar. Even though this population of jaguars is apparently in good conservation status, the expansion or creation of new protected areas is necessary to ensure more efficiency in protecting this jaguar population because environmental changes may occur as a result of future human actions in the private areas surrounding TES. Future efforts to create new areas for conservation should focus mainly on the regions of occurrence of jaguars detected in this study that are not yet legally protected. In addition, the region between the TES and the Pantanal Matogrossense National Park is still very well conserved (Silveira *et al.,* 2014), is connected by the Paraguay River and the land cover is similar to the coverage obtained for the jaguars from TES (Projeto MapBiomas, 2020). So that the region between these two PAs must also be considered to become protected in the future.

AUTHORS' CONTRIBUTIONS

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