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Source: South American Journal of Herpetology, 16(1) : 16-25

Published By: Brazilian Society of Herpetology

URL: <https://doi.org/10.2994/SAJH-D-18-00052.1>

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Home Range and Movement Pattern of the Broad-Snouted Caiman (*Caiman latirostris*) in a Silviculture Dominated Landscape

Thiago S. Marques^{1,*}, Luis A.B. Bassetti², Neliton R.F. Lara²,
Thiago C.G. Portelinha³, Carlos I. Piña⁴, Luciano M. Verdade²

¹ Laboratório de Ecologia Aplicada, Núcleo de Estudos Ambientais, Universidade de Sorocaba, Rodovia Raposo Tavares, Km 92 a 100, Vila Artura, 18023000, Sorocaba, SP, Brazil.

² Laboratório de Ecologia Isotópica, Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, Caixa Postal 96, 13416-000, Piracicaba, SP, Brazil.

³ Universidade Federal do Tocantins, ALCNO 14, Avenida NS 15, s/n, Bloco III, 77010-970, Palmas, TO, Brazil.

⁴ Proyecto Yacaré, CICYTTP-Consejo Nacional de Investigaciones Científicas y Técnicas, Dr. Matteri y España, Diamante, 3105, Entre Ríos, Argentina.

* Corresponding author. Email: thiago.marques@prof.uniso.br

Abstract. Information on the home range and movement patterns of Neotropical crocodylians is scarce for most species, despite being essential for developing management and conservation plans. The broad-snouted caiman (*Caiman latirostris*) is a Neotropical crocodylian with a wide geographical distribution in South America. This species inhabits artificial reservoirs (e.g., small weirs) in silvicultural areas. However, its use of space in such circumstances is still unknown. The present study aims to estimate home range and movement patterns of the broad-snouted caiman in a silviculture-dominated landscape in São Paulo state, southeastern Brazil. Eight adult caimans (four males and four females) were monitored by radiotelemetry (GPS-UHF system) from February 2010 to October 2011. The collected position points were used to estimate home range sizes and movement patterns. Mean home range size (\pm SD) of all individuals was 96.6 ± 183.9 ha and 43.2 ± 78.6 ha estimated by Minimum Convex Polygon (MPC) and 95% Kernel Density Estimate methods (KDE), respectively, without difference between the sexes. Individual mean daily movement was 37.6 ± 18.6 m/d, being greater during the reproductive period. The surrounding matrix formed by *Eucalyptus* plantations was relatively permeable to caiman movement. The present results suggest that the wide variation in the home range size of the broad-snouted caiman could be a result of the space-time distribution of resources and social interactions. Further, variations in environment temperature and reproductive activities can influence the movement pattern of the species. Future studies of crocodylians in agricultural landscapes should prioritize other dimensions possibly related to space use such as agricultural practices of the matrix, water contamination by agrochemicals, and hunting pressures.

Keywords. Anthropogenic environments; Crocodylians; Daily movement; Radiotelemetry.

INTRODUCTION

The broad-snouted caiman, *Caiman latirostris* (Daudin, 1802), is a Neotropical crocodylian with a wide geographical distribution in South America, including Brazil, Argentina, Paraguay, Bolivia, and Uruguay (Verdade and Piña, 2006; Verdade et al., 2010). This species inhabits a variety of habitat types, such as rivers, lakes, wetlands, and floodplains (Medem, 1983; Verdade and Piña, 2006), that have historically suffered anthropogenic pressure due to urbanization and agriculture. However, its ability to colonize man-made habitats (e.g., small weirs in forest plantations) has been reported in the last decades (Scott et al., 1990; Verdade and Lavorenti, 1990; Borteiro et al., 2008; Marques et al., 2013a,b).

The broad-snouted caiman presents a considerable degree of genetic isolation between subpopulations in the São Paulo state, Brazil, even on a microgeographic scale, with a relatively low number of individuals dispersing per

generation, possibly due to anthropogenic pressures (e.g., hunting; Verdade et al., 2002). The state of São Paulo is located in the central area of the geographical distribution of the broad-snouted caiman (Verdade and Piña, 2006), and the use of anthropogenic environments can hypothetically ensure gene flow between the southern and northern populations of the species (Villela et al., 2008).

Exotic timber plantations have great economic importance in Brazil, covering around 6.7 million ha (ABRAF, 2012). An increasing demand for *Eucalyptus* products (e.g., cellulose, paper, charcoal, and wood) has stimulated their expansion in Brazil in the last decades (SBS, 2013). The expansion of exotic timber areas provides new elements (e.g., *Eucalyptus* plantations) in landscape composition that directly influence the dynamics of animal populations by changing resource availability (Saunders et al., 1991; Threlfall et al., 2012).

Understanding how species use the resources available in their environments is essential for species man-

How to cite this article: Marques T.S., Bassetti L.A.B., Lara N.R.F., Portelinha T.C.G., Piña C.I., Verdade L.M. 2020. Home range and movement pattern of the broad-snouted caiman (*Caiman latirostris*) in a silviculture dominated landscape. *South American Journal of Herpetology* 16: 16–25. <http://doi.org/10.2994/SAJH-D-18-00052.1>

Submitted: 17 July 2018

Accepted: 10 April 2019

Available Online: 25 August 2020

Handling Editor: Taran Grant

<http://doi.org/10.2994/SAJH-D-18-00052.1>

agement and conservation plans because it provides data on their spatial requirements. One of the basic life history variables that must be understood is home range. Kenward (2001: 201) defined home range as “the area repeatedly visited by an animal.” Home range and movement patterns of wildlife animals can provide relevant information about social organization, mating system, foraging strategies, territoriality, and habitat use (Powell, 2000; Kernohan et al., 2001; Jacob and Rudran, 2003).

To date, only a few studies have been conducted to determine the home range and movement patterns of Neotropical crocodylians (e.g., Magnusson and Lima, 1991; Campos et al., 2003, 2006), likely due to the difficulty of applying conventional radiotelemetry to these often cryptic animals that inhabit in remote locations and frequently avoid humans (Read et al., 2007; Franklin et al., 2009). Magnusson and Lima (1991) showed that females of *Paleosuchus trigonatus* (Schneider, 1801) have small home ranges that are contained within the home range of at least one male, and Campos et al. (2003) reported coordinated terrestrial movement among *Caiman yacare* (Daudin, 1802) individuals. The present study aims to determine the home range and movement patterns of broad-snouted caimans in a modified silvicultural landscape of São Paulo state, southeastern Brazil, which is essential for understanding the strategies used by the species to survive in these anthropogenically modified environments.

MATERIALS AND METHODS

Study area

This study was carried out on the Arca (23°18'51"–23°20'0"S, 48°27'30"–48°28'20"W; 1,122 ha) and Três Lagoas farms (23°20'41"–23°22'0"S, 48°27'57"–48°28'0"W; 3,242 ha), located in the municipality of Angatuba, São Paulo state, Brazil. The climate in the area is sub-tropical (Cwa, Köppen system) with a mean monthly precipitation of 116 mm during the sample period. The local landscape is composed of a matrix of exotic timber plantations, native vegetation (fragments of semideciduous forest, cerrado, and riparian forests) and abandoned pastures. Caimans were captured in five water bodies: Lagoão, Lagoa Suja, Três Lagoas, Açude Vermelho, and Açude do Casemiro. More information about the study area can be found in Marques et al. (2016).

Sampling methodology

Caimans were captured with baited funnel traps (three iron hoops, 1 m diameter, 6 cm mesh; bait: bovine kidney) placed near the shores of the water bodies. In addition, caimans were captured using steel-cable snares

slipped around their necks after luminous spotting with sealed-beam headlights during nocturnal boat surveys (Hutton et al., 1987). The captured animals were manually immobilized without anesthetics and sexed by visual examination of the genitalia (Chabreck, 1963; Allsteadt and Lang, 1995). Snout–vent length (SVL) and body mass (BM) were recorded with a measuring tape and dynamometer, respectively.

Eight animals (four males and four females) were fitted with GPS-UHF (Global Positioning System, Ultra High Frequency) transmitters (Telemetry Solutions TM., model Q4000 Enhanced EXT memory_LS26500 SIRFIII, length: 85 mm, width: 50 mm, height: 54 mm, 257 g) attached subcutaneously to the tail base using flexible steel wire. These transmitters are equipped with a GPS pre-programmed to collect and store location records according to specified schedules. These data were downloaded weekly via a UHF base station without recapturing individuals. Transmitters were equipped with a VHF system that allowed researchers to locate the animals and reach the distance required for download via the UHF base station. The transmitters were equipped with a mortality sensor that doubled the pulse of the VHF signal if the transmitter was stationary for more than 24 h. Animals were released at the same place where they were captured immediately after attaching transmitters.

Crocodylians are ectothermic vertebrates that depend on external temperature for thermoregulation (Pough et al., 2003), and their thermoregulatory behavior involves different uses of the available environments to reach the body temperature for their metabolic activities (Fincatti and Verdade, 2002; Seebacher and Franklin, 2005). The thermoregulatory behavior of *Caiman latirostris* varies throughout the year in order to avoid extreme temperatures, which affects its use of space (Fincatti and Verdade, 2002; Bassetti et al., 2005; Verdade et al., 2006). Similarly, its activity pattern varies seasonally due to changes in climatic conditions; therefore, transmitters were programmed to record a greater number of locations during hot seasons. Two sampling periods were considered: spring/summer (September–April) and autumn/winter (May–August), with transmitters programmed to record locations three times per day in spring/summer (e.g., 1st day: 0:00, 8:00, 16:00; 2nd day: 1:00, 9:00, 17:00) and once per day in autumn/winter (e.g., 1st day: 12:00, 2nd day: 02:00; 3rd day: 04:00). Reproduction occurs in the spring/summer period. Caimans were monitored from February 2010 to October 2011, and transmitters were recovered at the end of the study.

Analytical methodology

Home range was estimated by two methods: Minimum Convex Polygon (MCP; convex polygon formed by

Table 1. Frequency VHF (Hz), sex (F: female, M: male), snout–vent length (SVL, cm), body mass (kg), number of position recorded, home range size estimated by Minimum Convex Polygon (MCP) and 95% fixed Kernel Density Estimate (KDE), number of activity centers (N° AC), area of activity centers (Area AC), and sampling period of each individual of *Caiman latirostris* monitored in silvicultural landscape, southeastern Brazil.

Freq. VHF (Hz)	Sex	SVL (cm)	Body Mass (kg)	N° points	MCP (ha)	KDE (ha)	N° AC	Area AC (ha)	Period
148.240	F	72	8.75	187	46.5	35.8	2	9.1	02/2010–08/2010; 01/2011–07/2011
148.200	F	76	14.75	79	7.2	2.8	1	0.4	03/2010–06/2010
148.320	F	74.5	11.00	195	41.9	14.0	2	2.8	03/2010–12/2010
148.300	F	84.5	15.50	214	34.2	18.9	1	2.8	04/2010–01/2011
148.280	M	98	27.00	134	11.8	6.2	2	0.5	03/2010–10/2010
148.260	M	80	15.00	124	72.2	21.4	1	4.0	11/2010–02/2011
148.220	M	80	14.00	148	10.8	10.2	2	0.8	12/2010–06/2011
148.180*	M	93	26.00	295	548.5	236.2	3	82.5	12/2010–09/2011

* outlier individual

the union of external recorded positions; Mohr, 1947; Fuller et al., 2006) and a 95% fixed Kernel Density Estimate (KDE; probability density contours based on kernels; Worton, 1987, 1989). MCP is unable to distinguish between areas of high and low use by the animal, so KDE has been considered more accurate than MCP. KDE uses nonparametric statistics to calculate the probability of finding an individual in a particular location. The number and size of activity centers (Hayne, 1949) were determined by 50% fixed KDE. Spatial analyses were performed in Animal Movement (Hooge and Eichenlaub, 2000) and Hawth's Analysis Tools extensions of the ArcView 3.2 and ArcGIS 9 (ESRI, 2011), respectively.

Normality and homoscedasticity of data (home range size and daily movements) were previously tested to guide the choice of parametric or nonparametric tests. Student's *t*-test (Zar, 1996) was used to examine possible differences in BM and SVL between sexes.

Home range analyses were carried out in two different ways: (a) including all individuals and (b) excluding the outlier individual (individual 148.180; see Table 1). The Whitney U Test and *t*-test (Zar, 1996) were used to examine possible sex differences in home range (MCP and KDE) considering all individuals and without the outlier, respectively. Linear regression (Zar, 1996) was applied to investigate the relationship between home range size and BM and between home range size and body condition (body mass/SVL). In addition, linear regression was used to evaluate the relationship between home range and number of recorded locations. Results are presented as mean \pm SD (min–max). Movement pattern was determined by the daily movement (m/day) of each individual during the sample period. The locations of each animal were transformed into a vector using ArcView 3.2 (ESRI, 2011) to construct a georeferenced image to estimate movement.

Daily movement was calculated by the linear distance (m) between subsequent locations. These daily movements were calculated on the basis of the probability of record one position per day independent of the period (spring/

summer and autumn/winter). Therefore, one position per day was selected at random for the movement estimates in spring/summer. The Whitney U Test was used to test for possible differences in mean daily movement between males and females. In addition, the Whitney U Test was used to detect possible differences in daily movement between the reproductive/hot period (October–February; Vac et al., 1992; Verdade, 1995) and the non-reproductive/cold period (March–September). All statistical tests were performed in Minitab 16 (Arend, 1993).

RESULTS

Caiman mean BM and SVL were 16.50 ± 6.58 kg (8.75–27.00 kg) and 82.25 ± 9.13 cm (72.00–98.00 cm), respectively. There was no difference in BM [$t = -2.00$, $df = 7$, $P = 0.105$; males: 20.50 ± 6.95 kg (14.00–27.00 kg); females: 12.50 ± 3.18 kg (8.75–15.50 kg)] and SVL [$t = -2.06$, $df = 7$, $P = 0.108$; males: 87.75 ± 9.18 cm (80.00–98.00 cm); females: 76.75 ± 5.42 cm (72.00–84.50 cm)] between sexes.

Mean home range size for all individuals was 96.6 ± 183.9 ha (7.2–548.5 ha) and 43.2 ± 78.6 ha (2.8–236.2 ha) estimated by MCP and KDE, respectively (Table 1). There was no difference in home range sizes of males and females neither for MCP (Whitney U Test, $P = 0.665$) nor for KDE estimates (Whitney U Test, $P = 0.885$; Table 2; Figs. 1 and 2).

Mean home range size without the outlier (see Table 1, Individual 148.180) was 32.0 ± 23.8 ha (7.2–72.2 ha) and 15.6 ± 11.0 ha (2.8–35.7 ha) estimated by MCP and KDE, respectively. There was no difference in home range sizes of males and females neither for MCP ($t = 0.04$, $df = 6$, $P = 0.973$) nor for KDE estimates ($t = 0.64$, $df = 6$, $P = 0.554$; Table 2). Caiman home ranges encompassed between 1 and 3 activity centers depending on the individual (Table 1). Considering all individuals, the mean activity-center area was 12.9 ± 28.2 ha (0.4–82.5 ha), being 22 ± 40.3 ha (0.5–82.5 ha) for males and 3.8 ± 3.7 ha

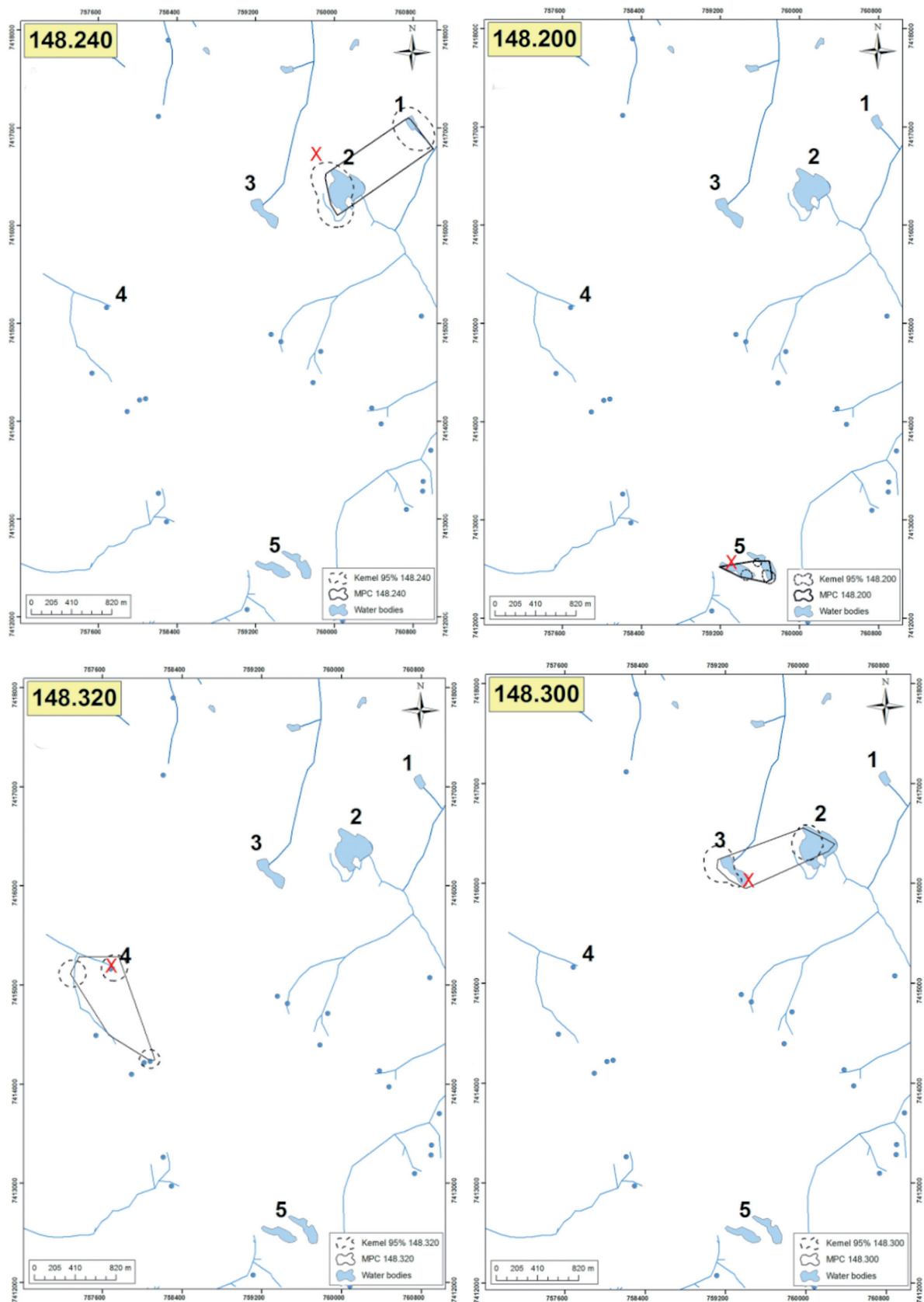


Figure 1. Home range estimated by Minimum Convex Polygon (MCP) and 95% fixed Kernel Density Estimate (KDE) for four female *Caiman latirostris* (each identified by a unique numerical code) in a silvicultural landscape, southeastern Brazil (Datum: SAD 69 - UTM). The numbers indicate the water bodies where the individuals were captured: 1, Açude Vermelho; 2, Lagoão; 3, Lagoa Suja; 4, Açude do Casemiro; and 5, Três Lagoas. X indicates capture location.

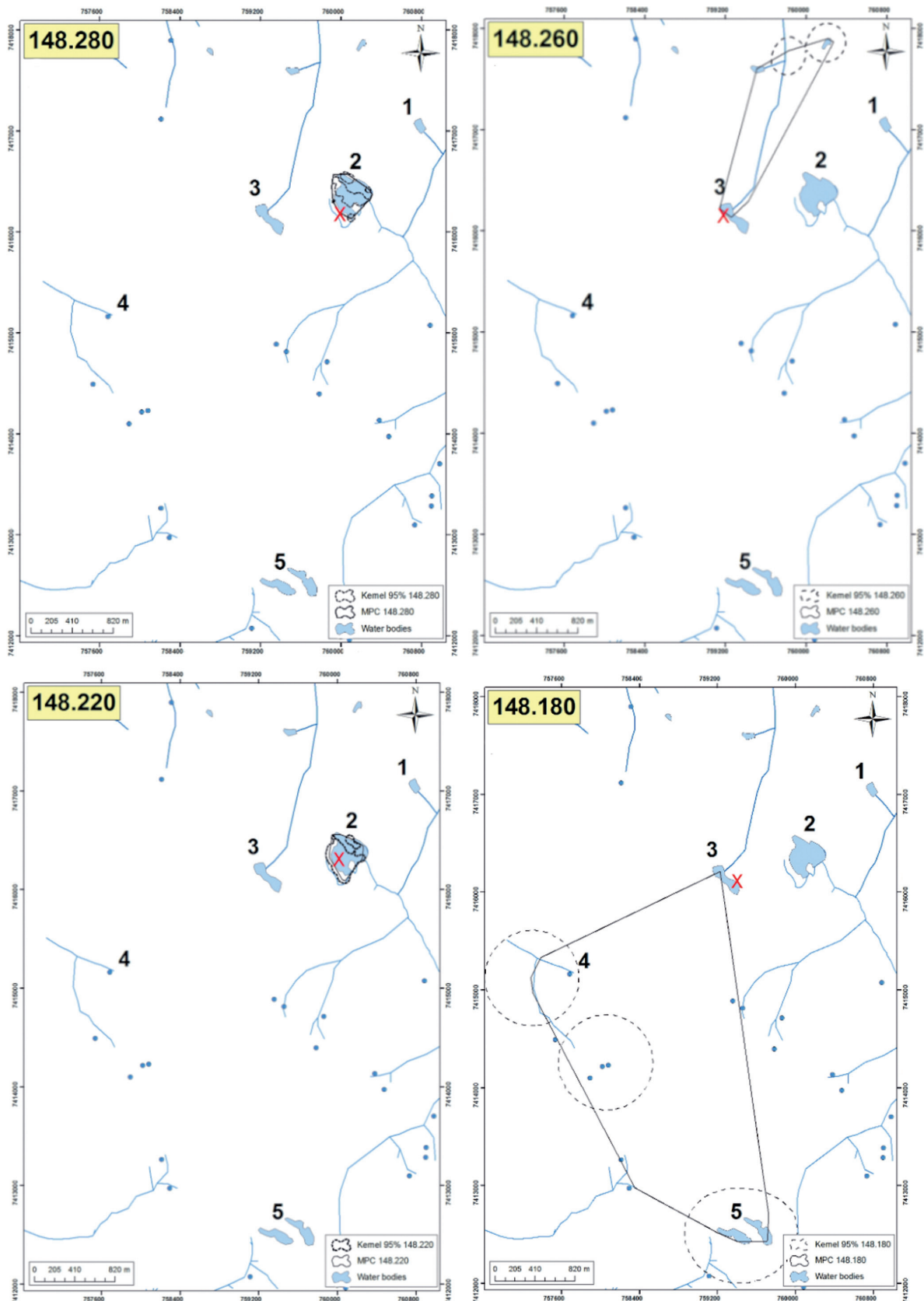


Figure 2. Home range estimated by Minimum Convex Polygon (MCP) and 95% fixed Kernel Density Estimate (KDE) for four male *Caiman latirostris* (each identified by unique numerical code) in a silvicultural landscape, southeastern Brazil (Datum: SAD 69 - UTM). The numbers indicate the water bodies where the individuals were captured: 1, Açude Vermelho; 2, Lagoão; 3, Lagoa Suja; 4, Açude do Casemiro; and 5, Três Lagoas. X indicates capture location.

Table 2. Mean home range size of males and females of *Caiman latirostris* estimated by Minimum Convex Polygon (MCP) and 95% fixed Kernel Density Estimate (KDE) in silvicultural landscape, southeastern Brazil. Home range analyses were carried out in two different ways: a) with home range sizes of all individuals and b) with home range sizes without the outlier (individual 148.180).

	All individuals		Without outlier	
	MPC (ha)	KDE (ha)	MPC (ha)	KDE (ha)
Males	160.8 ± 260.0 (10.8–548.5)	68.5 ± 112.0 (6.2–236.2)	31.6 ± 35.2 (10.8–72.2)	12.5 ± 7.8 (6.2–21.4)
Females	32.4 ± 17.5 (7.2–46.5)	17.8 ± 13.6 (2.8–35.8)	32.4 ± 17.5 (7.2–46.4)	17.8 ± 13.6 (2.8–35.8)

Table 3. Regression equations between home range size, body measurements (body mass and body condition), and number of position of *Caiman latirostris* in silvicultural landscape, southeastern Brazil.

#	Condition	Y	X	a	b	P	R ²	n
1	AI	MPC	BM	-151.5	0.01504	0.169	0.29	8
2	AI	MPC	BC	-264.3	1.846	0.148	0.31	8
3	AI	K95	BM	-58.72	0.0061	0.190	0.26	8
4	AI	K95	BC	-103.6	0.7508	0.173	0.28	8
5	WO	MPC	BM	58.15	-0.0017	0.351	0.17	7
6	WO	MPC	BC	72.5	-0.2203	0.319	0.19	7
7	WO	K95	BM	32.41	-0.0011	0.172	0.33	7
8	WO	K95	BC	43.87	-0.1540	0.101	0.44	7
9	AI	MPC	NP	-272.6	2.146	0.025	0.59	8
10	AI	K95	NP	-119.4	0.9449	0.018	0.63	8
11	WO	MPC	NP	6.55	0.1653	0.474	0.10	7
12	WO	K95	NP	-5.25	0.1350	0.176	0.33	7

Y = a + bX

Condition: AI, home range estimates of all individuals; WO, home range estimates without the outlier.

Y: MPC, Minimum Convex Polygon; K95, 95% fixed Kernel Density Estimate.

X: BM, body mass; BC, body condition (body mass/snout–vent length); NP, number of position.

(0.4–9.1 ha) for females. However, the mean activity-center area without the outlier was 2.9 ± 3.0 ha (0.4–9.1 ha), being 1.7 ± 1.9 ha (0.5–4.0 ha) for males and 3.8 ± 3.7 ha (0.4–9.1 ha) for females.

There was no relationship ($P > 0.05$) between home range size (MPC and K95) and BM nor body condition considering all individuals or excluding the outlier (Table 3). With the increase in the number of locations recorded, there was an increase in home range size when considering all individuals (MPC: $P = 0.025$; K95: $P = 0.018$); however, that relationship was not found when the outlier was excluded (Table 3).

Mean daily movement was 37.6 ± 18.6 m/day (1.2–238.0 m/day) for all individuals monitored during the study period. Males had higher mean daily movement than females (Whitney U Test, $P = 0.030$; females = 22.2 ± 4.8 m/day; males = 53.0 ± 12.7 m/day). Mean daily movement was higher during the reproductive/hot period than the non-reproductive/cold period (Whitney U Test, $P = 0.025$; reproductive/hot period: 61.8 ± 33.9 m/day, non-reproductive/cold period: 27.3 ± 17.3 m/day; Fig. 3). Movements of up to 850 m were recorded for some locations inside *Eucalyptus* plantations.

DISCUSSION

The wide variation in home range size among individuals found in this study was similar to that of other crocodylian species. *Crocodylus johnstoni* Krefft, 1873 had home ranges of 2–137 ha in Lynd River, Queensland (Tucker et al., 1997). *Alligator mississippiensis* (Daudin, 1802) had home ranges of 2.6–16.5 ha in Rockefeller Refuge (Joanen and McNease, 1970), 0.6–256 ha in northern Louisiana (Taylor, 1984), and 6.1–165 ha in southwestern Louisiana (Rootes and Chabreck, 1993). *Crocodylus porosus* Schneider, 1801 had home ranges of 110–7,250 ha in the Gulf of Cambridge in Australia (Campbell et al., 2013) and 127–6,427 ha in Wenlock river in Australia (Kay, 2004).

The home range size and movement pattern of wild animals can be influenced by several factors, such as availability of food resources, breeding period, social hierarchy, anthropogenic activities, predator presence, and population density (Kenward, 2001; Millspaugh and Marzluff, 2001). Therefore, animal movement in the landscape is usually related to spatial-temporal distribution of resources or interactions with other individuals (Pough et al., 2003). Large home ranges may be the result of long-distance movements to obtain the necessary resources for the survival of individuals (Milan and Melvin, 2001). This seems to be the pattern found for broad-snouted caimans in this study.

The home range size of the broad-snouted caiman varied greatly among the individuals monitored. The male 148.180 had a much larger home range size than other males (see Table 1). Campbell et al. (2013) reported two behavioral tactics adopted by males of *Crocodylus porosus* to increase their reproductive success: (1) site-fidelity: dominant males (larger body) patrol their territory, which includes the home ranges of several females; and (2) nomadic: subordinate males (smaller body) must travel long distances to find unprotected females. However, these dominance/subordination dynamics do not seem clear among males of the broad-snouted caiman in this study.

Subordinate males are smaller and have larger home ranges because they must travel long distances to find females. This was not observed in the study population, as the two males with the largest home ranges (individuals 148.180 and 148.260; Fig. 1) were not the smallest indi-

viduals (i.e., they were probably not subordinate males). Moreover, other factors probably influenced male home range size in the present study, such as anthropogenic disturbances occurring in the study area. *Caiman yacare* can move on land to avoid anthropogenic disturbances (e.g.,

hunting; Campos et al., 2006) or move to search and consume food resources (Campos, 2003). Furthermore, an individual pattern of space use may be occurring in the study area, as previously described in captivity (Verdade et al., 2006).

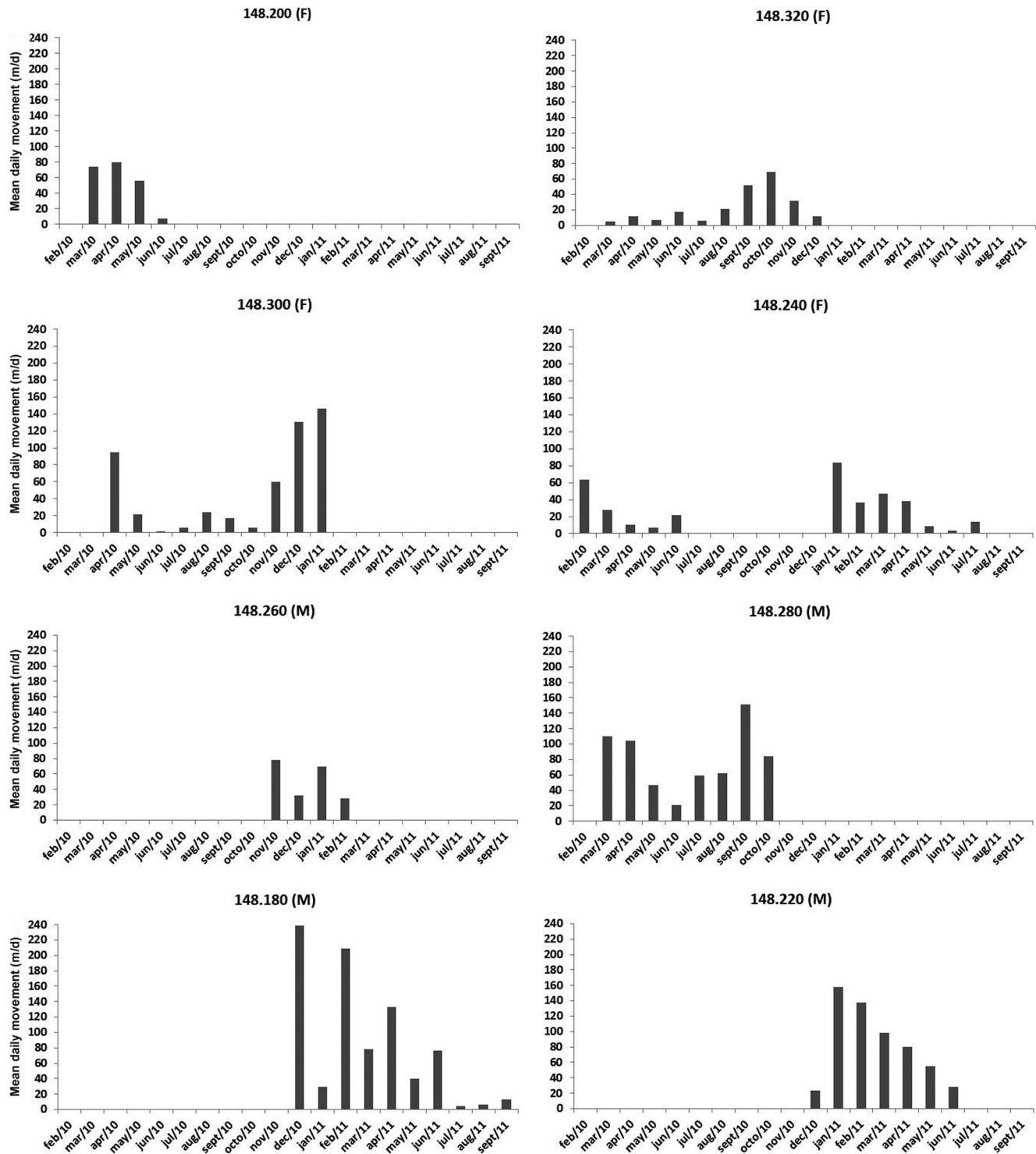


Figure 3. Mean daily movement (m/d) of individual *Caiman latirostris* (each identified by unique numerical code) in a silvicultural landscape, southeastern Brazil (M: male; F: female).

Broad-snouted caiman daily movement was higher during the reproductive period (October–February) than the non-reproductive period (March–September). Crocodylians are ectothermic animals that undergo considerable changes in their physiology and behavior in relation to environmental temperature (Lang, 1987b; Pough et al., 2003). Increased movement during the warm seasons is common in this taxon (Cott, 1961; Chabreck, 1965; Goodwin and Marion, 1979; Smith, 1979; Kay, 2004) and could be related to the search for food (Verdade et al., 2006) or females. Seasonal variation in temperature can affect metabolism and, hence, appetite and food consumption in crocodylians (Coulson and Hernandez, 1983; Larriera et al., 1990), and broad-snouted caimans increase food consumption, food conversion rate, and growth rates when exposed to higher temperatures (Larriera et al., 1990; Parachú et al., 2009).

During the reproductive season of the broad-snouted caiman, breeding occurs from October to December and nesting from January to February (Vac et al., 1992; Verdade, 1995; Portelinha et al., 2015). Males are hypothesized to increase their movement in order to find a higher number of females for reproduction, thus maximizing their fitness. On one hand, intra-sexual hierarchy can result in this process of partner search and promote agonistic interactions (Verdade, 1992). On the other hand, it can occasionally fail to prevent subordinate males to successfully breed, with consequent multiple paternity in some clutches (Amavet et al., 2008).

Females can also increase their movements in order to find nesting habitats (Zug, 1993; Campbell et al., 2013), which is possibly related to temperature-dependent sex determination (Campos, 1993; Piña et al., 2007) and fitness of the hatchlings (Verdade, 2001). According to Larriera (1995), female broad-snouted caimans can nest in savannah (sites with low slope that overflow in periods of heavy rain), floating vegetation (type of vegetation that floats when the water level increases), and forest. After nesting, females generally remain close to the nest area during the incubation period (Lang, 1987a). We did not find nests during this study period; however, the permanence of female 148.240 in vegetation during the reproductive period suggests that she was caring for her nest.

The use of different water bodies or wetlands by aquatic reptiles might be needed in areas where these environments are spatially dispersed (Joyal et al., 2001; Roe et al., 2003; Roe and Georges, 2007). As such, landscape characteristics (e.g., habitat area and connectivity) can directly influence movement (Roe and Georges, 2007), and the presence of activity centers in different water bodies within the home range of monitored individuals underscores the importance of matrix permeability to the movements of species. The present study suggests that *Eucalyptus* plantations can be considered permeable

to broad-snouted caiman movements. Permeability for specialist species as well as habitat quality for generalist species are crucial for biodiversity conservation in agricultural landscapes (Verdade et al., 2014).

The present results suggest that the wide variation in the home range sizes of the broad-snouted caiman might result from the combination of social behavior and seasonal variation in resource availability. Future studies on crocodylians in agricultural landscapes should prioritize other dimensions possibly related to space use, such as agricultural practices of the matrix, water contamination by agrochemicals, and hunting pressures.

ACKNOWLEDGMENTS

This study was funded by São Paulo Research Foundation (FAPESP grants 2006/60954-4, 2017/01304-4). The animals were captured under IBAMA license No 19221-6. TSM benefited from scholarships by grant 2008/07076, São Paulo Research Foundation (FAPESP), grant 142682/2011-0, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and the Student Research Assistance Scheme of the Crocodile Specialist Group SSC/IUCN. LMV had a Productivity Fellowship from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, grants 309468/2011-6 and 312049_2015-3).

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