*The influence of population-control methods and seasonality on the activity pattern of wild boars (*Sus scrofa*) in high-altitude forests*

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SHORT COMMUNICATION

The influence of population-control methods and seasonality on the activity pattern of wild boars (*Sus scrofa*) in high-altitude forests

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Abstract

The wild boar (*Sus scrofa*) is a problematic invasive species which has colonized the threatened Brazilian Atlantic Forest. Our objective was to evaluate if population control and seasonality affect the circadian rhythm of wild boar activity. Wild boar activity was monitored by camera-traps for 1 year without population-control methods and 1 year with population-control methods implemented in the area. Before population control was implemented, wild boar activity was uniform across 24 h, with animals being active at any given time (cathemeral). After the population control, wild boars concentrated their activities on the daylight period. Also, wild boars were more active during the wet season, possibly influenced by the presence of seeds of *Araucaria angustifolia* trees. Based on these results, control measures should be conducted during the wet season and different management strategies, such as the use of rifles with telescopic sights and silencers, should be tested.

Keywords Brazilian Atlantic Forest · Invasive alien species · Introduced mammals · Protected areas · *Sus scrofa*

Biological invasions are considered one of the main causes of biodiversity loss worldwide, affecting areas under intensive human usage as well as protected areas (Spear et al. 2013). The wild boar (*Sus scrofa* Linnaeus 1758) is listed as one of the 100 worst invasive alien species in the world (Lowe et al. 2000) due to high dispersal and reproduction rates, low predation rates and high competitiveness (Mapston 2007). Wild boars root the soil and pluck out plant roots, altering soil and vegetation structure and processes

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(Barrios-Garcia and Ballari 2012; Boughton and Boughton 2014). They also transmit several diseases, such as foot and mouth disease, leptospirosis and swine fever to humans and wild and domestic animals, causing environmental and economic damage (Mapston 2007).

Wild boars can be active at any time of day or night depending on environmental conditions, such as temperature and humidity (Barrios-Garcia and Ballari 2012; Brivio et al. 2017). During the hottest part of the day, wild boars tend to be inactive (Russo et al. 1997), but Lemel et al. (2003) showed that wild boars in Sweden were more active when air humidity was high. Boars can also modify their activity pattern depending on seasonality, being more active during the dry season, since they need to search for food and water resources more intensively (Lemel et al. 2003; Podgórski et al. 2013).

Wild boars may change their behavior when exposed to certain threats and human activities, especially hunting and other population-control activities. In Argentina, wild boars were predominantly nocturnal, with minimum activity overlap with their main predator, the cougar (*Puma concolor*) (Caruso et al. 2018). Wild boars also became more nocturnal because of human hunting in Japan (Ohashi et al. 2013) and avoided rice crops that were near high human densities, because these areas pose more risk to the animals (Saito et al. 2011). The same pattern of human avoidance was observed in wild boars living in urban areas of Poland (Podgórski et al. 2013).

Hunting may affect wild boar movement and use of space, as the animals tend to hide, moving around less, staying inside forests instead of using open areas and becoming more active during the night to reduce the chances of been detected and hunted (Brown et al 1999; Rosell et al. 2004; Scillitani et al. 2010; Barrios-Garcia and Ballari 2012; Podgórski et al. 2013; Thurfjell et al. 2013).

The invasion of tropical environments by wild boars is recent (Rosa et al. 2017), so there is no knowledge of wild boar behavior under population-control pressure in those environments. In Brazil, the main wild boar control technique used is hunting (Rosa et al. 2018). The objective of our work was, therefore, to understand if population-control using trapping and stand hunting affect the daily and seasonal activity patterns of wild boars in a tropical forest of Brazil. Based on available knowledge, we hypothesized that after control pressure, wild boars would modify their activity patterns to hours where no control is undertaken. We also analyzed whether wild boars are more active during the dry season when food is scarcer.

Our study was undertaken in the Alto-Montana Natural Heritage Private Reserve (NHPR; 22° 21′ 08″ N/-44° 48′ 04″ W), which covers 672 hectares and is one of the protected areas in the Mantiqueira Mountain Range, southeastern Brazil. The area is controlled and no record of poaching exists for the area in more than 10 years of fauna monitoring. Wild boar population density for NHPR was estimated to be 15.8 ind./km^2 (Gonçalves 2015). In the study area, the cougar is potentially the main predator of wild boars, especially piglets (Hegel and Marini 2018), but data on predation are not available for the NHPR. The climate is classified as high-elevation tropical (CWB) (Köppen 1936), with two distinct seasons: a dry season between April and September and a wet season between October and March.

We installed eight motion-activated camera traps in the area (Bushnell HD, © Bushnell Outdoor Products, California, USA) in the places most visited by wild boars, as evidenced by signs (footprints, hair, feces, fresh diggings, wallowing, etc.) and by previous studies (near water, on trails used by animals and people) (Srbek-Araujo and Chiarello 2007, 2013; Gonçalves 2015). The distance between the cameras was 1 km, to increase the independence of each sampling station (Goulart et al. 2009; Harmsen et al. 2010; Gonçalves 2015). This distance is recommended and is commonly used for the study of medium and large mammals (body mass of adults greater than 1 kg) (Emmons 1987). Cameras were distributed within an area of 3.5 km^2 because the other areas of the NHPR are covered by open rock-fields and cliffs in which wild boars have not been recorded.

The camera traps were active between October 2013 and November 2015. We checked the cameras every 1 or 2 months for cleaning, changing batteries and downloading data. We programmed camera traps to take three consecutive photographs with 30-s intervals. We did not use bait to avoid attracting other animals and to increase the chance of equal capture (Karanth and Nichols 2002).

We assessed wild boar activity patterns between October 2013 and October 2014, when no population control of wild boars was carried out (no animals were culled, because poaching did not occur in the study area) and between November 2014 and November 2015, when active control of wild boars (hereafter "population control") was carried out by corral trapping and stand hunting in accordance with Brazilian legislation [IBAMA Normative Instruction 03/2013]. Ten animals were culled per year by 4 hunters in 152 person-nights and 28 trap-nights; animals were culled after successful trapping (71.43%) and from the hunting stands, using the silent weapons (crossbow; 28.57%). Hunting occurred between November 2014 and November 2015. Both control methods were applied to the whole study area at the same time. Hunters did not actively search for the wild boars; they used bait to attract them to the shooting range.

The timestamp of the photographs taken by the camera traps was used to define wild boar activity patterns. We conducted a Rayleigh uniformity test using the Oriana® 4.0 statistical software (Oriana 2012), adopting, for each management type, the p value < 0.05 significance in all cases. We also conducted a Watson's test for homogeneity

on two samples for circular data to detect different patterns of activity time depending on the type of management. Wild boars were then classified according to the times of day: (a) diurnal: when more than 90% of the records were made in daylight (time between 06h00min and 16h59min); (b) predominantly diurnal: between 90 and 70% of records taken in daylight (time between 06h00min and 16h59min); (c) cathemeral: animals active during the day and night (between 30 and 70% of records in the dark—time between 18h00min and 03h59min); (d) nocturnal: between 70 and 90% of records taken in the dark (time between 18h00min and 03h59min); (e) crepuscular: more than 50% of records at dawn or twilight—time between 04h00min and 05h59min and between 17h00min and 17h59min (Gómez et al. 2005). We built generalized linear models (GLMs) with a binomial distribution to evaluate the effects of the seasonality and population control on the activity period of wild boars. We used the occurrence of wild boars per hour (0 = not registered; 1 = registered) as a response variable, and the existence or not of the population control in the region and seasonality as predictive variables. Finally, we fitted segmented linear regression models with month as a predictor variable for each year and the number of wild boar records as the response variable using the package 'segmented' of the software R (Muggeo 2008; R Core Team 2019).

In 791 sampling days (395 days without population control and 396 days with population control), with an effort of 5659 traps*nights (3130 traps*nights without population control and 2529 traps*nights with population control), we obtained a total of 428 independent records of wild boars (one photograph per hour; 234 records without control methods and 194 records with control methods), with an average of 2.65 wild boars per independent record (658 wild boars recorded without control methods: average of 2.81; 480 wild boars recorded with control methods: average of 2.47). The sampling effort was obtained considering only the days in which the camera functioned properly the entire time.

Before the population control was implemented, wild boar activity was uniform throughout 24 h (Rayleigh test $Z = 1.919$; $P > 0.05$), with animals being active at any given time (cathemeral). After the implementation of the population control, wild boars changed their behavior and their activity pattern was no longer uniform (Rayleigh test $Z = 16.482$; $P < 0.01$). A striking difference between pre- and post-population control was detected in the wild boar's pattern of activity (Watson's U^2 test = 0.472; $P < 0.001$), with the boars concentrating their activities during the day after the implementation of active control management. Wild boars became predominantly diurnal (06h00min to 16h59min) according to the classification of times of day (26% of records in the dark). Activity dropped drastically at twilight (around 19h00min) and the animals became active again at dawn, with an activity peak at 07h00min.

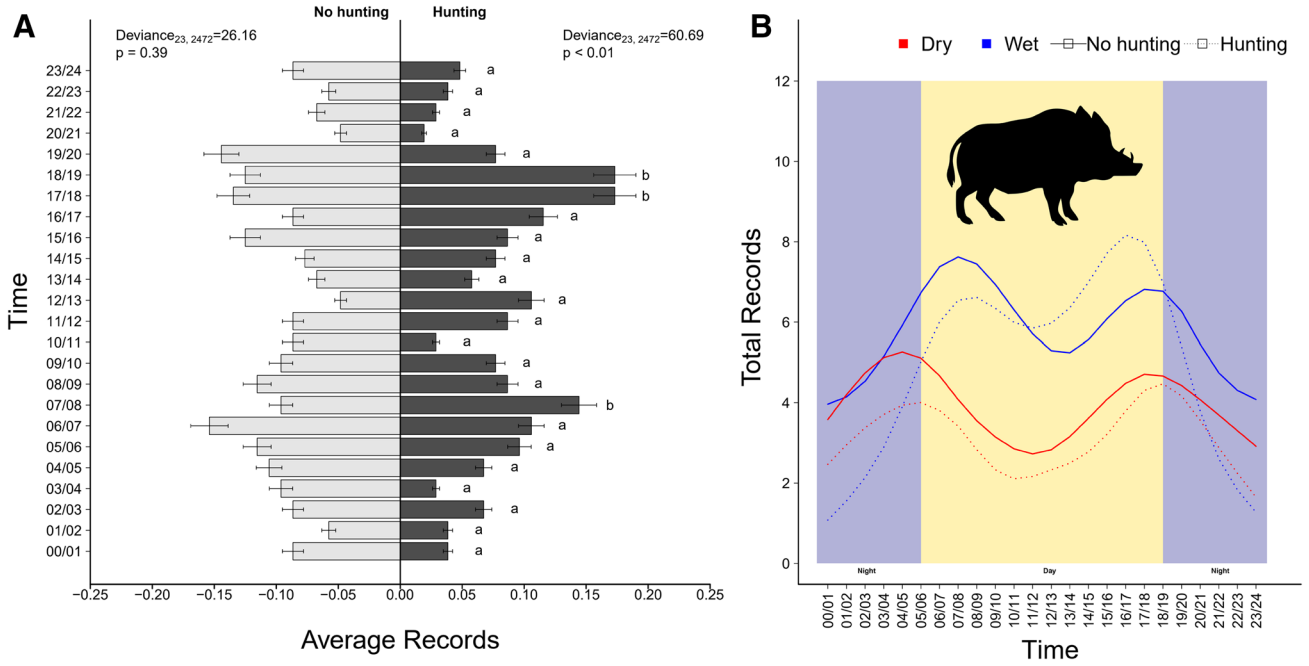

Fig. 1 Results of the GLMs for the activity pattern of *Sus scrofa* in the Alto-Montana Natural Heritage Private Reserve (NHPR) in Brazil. **a** Activity budget with no population control (light gray bars: mean and standard error) and with population control (dark gray bars: mean and standard error) of wild boars. **b** Activity budget variation depending on seasonality and the presence of population control methods

Wild boars were active during the entire day when no population control was implemented (GLM: deviance = 24.16, $P = 0.39$); however, when the population control was implemented, wild boars became more active around 14h00min, 16h00min and at 07h00min (GLM: deviance = 60.69, $P < 0.001$) (Fig. 1). Seasonality showed to be important in regulating the activity of wild boars, with the animals being more active during the wet season and less active during the dry season (deviance = 7.87, $P = 0.005$) (Fig. 1). The same pattern was shown by the segmented linear regression, with pigs diminishing their activity in the dry season, increasing again in the wet season, especially in the year without control methods. In the year with control methods, wild boars became more inactive earlier in the year (June–July; November–December without control methods) and remained less active even at the beginning of the wet season (Fig. 2).

As expected, wild–boar activity was not concentrated at a specific time of day in the absence of management efforts. However, once the population control became common, wild boars changed to a diurnal activity pattern, which differed from the nocturnal pattern expected as a reaction to management (Gómez et al. 2005), with peaks of activity around dawn and dusk. The predominantly diurnal activity pattern or the lack of a pattern is common in areas where no hunting or control is carried out (Keuling et al. 2008; Barrios-Garcia and Ballari 2012; Podgórski et al. 2013). This indicates that hunting pressure is more disturbing for wild boars than the predation risk of being active during daylight. The lack of a defined pattern in the absence of management in the study area stands out due to low human presence in general, leaving the animals predisposed to being active throughout the 24 h of a day (wild boars avoid areas with high human presence; Barrios-Garcia and Ballari 2012; Podgórski et al. 2013; Ikeda et al. 2019).

Wild boars and many other species tend to become nocturnal in places under hunting pressure as well as hunting techniques that use large groups of people (> 20), firearms and trained dogs (eight or more) (Scillitani et al. 2010; Thurfjell et al. 2013; Gaynor et al. 2018). Also, during periods of hunting, wild boars also change the use of space, being more active closer to forested and protected areas (Tolon et al. 2009). In contrast, after control efforts were initiated in the NHPR, wild boar activity became predominantly diurnal. Control techniques used in the NHPR were restricted to trapping and stand hunting, and carried out mainly between 5 and 9 p.m. using baiting and bows and arrows, and crossbows. Techniques less stressful than hunting dogs (Massei et al. 2011) and the absence of poaching or firearms in the area may have generated less pressure upon wild boars to the point that they did not feel threatened in the NHPR, adopting a diurnal activity pattern (Keuling et al. 2008; Thurfjell et al. 2013). The use of silent weapons is suggested because their effects on animal behavior are minimal, which could

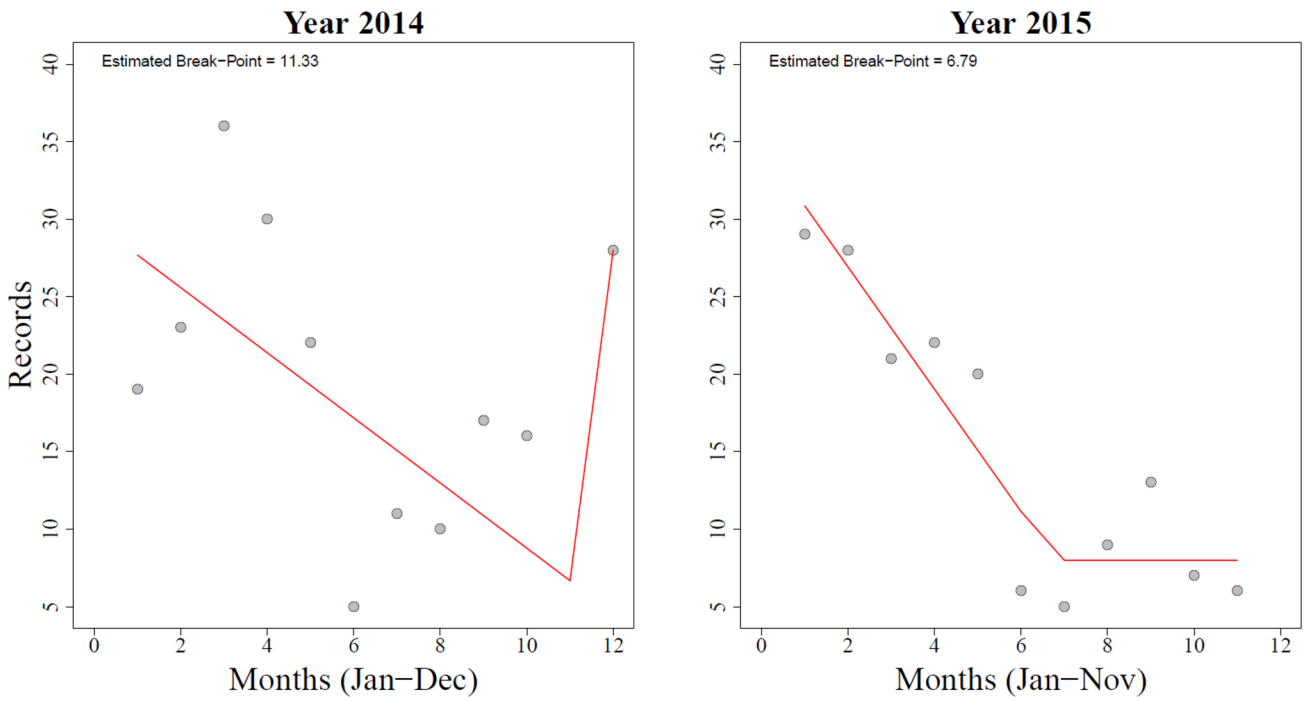

Fig. 2 Segmented linear regressions showing the activity pattern of wild boars in the Alto-Montana Natural Heritage Private Reserve (NHPR, Brazil) with no population control methods (year 2014) and with population control methods (year 2015)

increase the rate of hunting success (Thurfjell et al. 2017; European Bowhunting Federation 2019). In the present study, all animals were culled using this type of weapon.

Although providing a low rate of culled wild boar, the pressure exerted by the presence of hunters in the study area may be sufficient to modify the wild boar activities. Braga et al. (2010) also found low rates of wild boar extraction in Portugal. In their study, stand hunting by 6 hunters in 30 nights resulted in an extraction rate varying between 2.8 and 7.6 boars per 100 hectares. In the Alto-Montana Natural Heritage Private Reserve, there was 15.8 wild boars/km^2. If we consider a number of 16 boars/100 hectares (Gonçalves 2015), we would have around 107 boars in 672 hectares. Thus, the extraction of 10 individuals per year represents near 10% of the population. It is important to state that wild boars were considered a stealthy prey by the Brazilian hunters, making their shooting difficult. This could contribute to the low numbers of wild boars killed annually. With time, hunters' skills would increase and the culling efficiency would be higher than the current numbers. This is corroborated by the fact that with control methods, wild boars become less active earlier in the year, moving less even during the wet season.

Changes in the activity pattern of wild boars have been related to seasonality (Lemel et al. 2003; Podgórski et al. 2013). It was expected wild boars to be more active during the dry season when they need to search for food and water farther. However, we found the opposite result. This may be due to the fructification of the *Araucaria angustifolia* trees, which occur at the end of the wet season and the beginning of the dry season (from March to May in the studied area), providing food resources for the wild boars. In the wet season, wild boars expand their home range to explore abundant food items distributed in their areas. Besides, in the study area, wild boars adjusted their reproduction to the availability of the *Araucaria* fruits, and male and females become more active at that time, searching for mates (Gonçalves 2015).

Our study area is highly relevant to the conservation of global tropical forests and biodiversity, including one of the most important high-altitude forest remnants in the Atlantic domain. In our study, we observed that wild boars change their circadian rhythm of activity between years, possibly, but improbably, to avoid hunting pressure and in response to seasonal changes in the environment. Thus, it is necessary to schedule varied management strategies, such as increasing in the trapping effort, the use of rifles with telescopic sights (if needed with night vision) and silencers, and the use of professional hunters to properly control this invasive species. The implementation of control methods during the wet season could also increase the efficiency of the control methods because wild boars are more active and easier to be found.

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Compliance with ethical standards

Conflict of interest The authors declare that they do not have any conflict of interest.

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