

Short Note

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The effects of deforestation on white-lipped peccary (*Tayassu pecari*) home range in the southern Pantanal

Abstract: In the neotropics, white-lipped peccaries (*Tayassu pecari*) are important indicators of intact natural landscapes and the status of medium- to large-sized mammals dependent on forest habitats. Recognizing the species' value as an environmental indicator of landscape and forest conditions in the southern Pantanal, we evaluated the impacts of deforestation and fragmentation on forest mammals by analyzing *T. pecari* home ranges in a pristine area with intact natural vegetation cover, and a relatively disturbed area where deforestation and conversion to exotic grass pasture is becoming prevalent. In the relatively disturbed region, the home range area was 51% larger than it was in the pristine area, and there were two centers of activity separated by a large unused deforested patch. In the pristine region, there was only one activity center without large unused patches. We relate the differences in the disturbed area to fragmentation of the original *T. pecari* home range and loss of forest fruit sources. We discuss the implications of ongoing forest fragmentation and predicted climate change for *T. pecari* and other forest frugivores in the naturally patchy and highly seasonal environment of the Pantanal.

Keywords: deforestation; fruit scarcity; home range; Pantanal; white-lipped peccary.

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Despite increased human interference during the past 50 years, the Pantanal ecosystem is considered to be one of the most well-preserved biomes in Brazil (Mittermeier et al. 2002, Embrapa Pantanal et al. 2014). From a conservation perspective, its preservation has resulted from a favorable combination of environmental and socio-economic factors (Santos et al. 2002, Junk et al. 2006, Eaton 2013). While extensive flooding produces highly productive seasonally available pastures for native grazers and cattle, it also, until recently, has limited large-scale development of the floodplain. However, the region is threatened by a variety of environmentally unsound human activities that have intensified during the last 50 years, e.g., deforestation and expansion of large-scale cattle ranching and agriculture on the plateaus encircling the Pantanal, hydroelectric projects in headwater basins, gold and iron mining, and environmentally disastrous development schemes for increasing barge traffic on the Rio Paraguay (J. S. V. Silva et al. 1998, M. P. Silva et al. 1999, Gottgens et al. 2001, Padovani et al. 2004, Tomas et al. 2009, Eaton et al. 2011).

Owing to a variety of economic factors, many large fazendas (i.e., ranches) in the Pantanal have been sold and divided into smaller, less viable properties. As a result, traditional grazing practices, which included the seasonal movement of herds among large patches of native savanna, have been abandoned by some ranchers (Silva et al. 1999, Santos et al. 2008, Padovani et al. 2004, Eaton 2013). In an attempt to improve the economic viability of their properties, some ranchers have clear-cut native forests and planted exotic grasses to increase the grazing area and short-term productivity (Silva et al. 1999, Eaton et al. 2011). On these intensively used ranches, vegetation clearing and conversion have exacerbated environmental problems and impacts such as soil erosion, degradation of water quality, uncontrolled burning, carbon dioxide emissions, and fragmentation of natural habitats. For wide-ranging mammals, like the subject of this study, white-lipped peccaries (*Tayassu pecari*, Link, 1795), deforestation and fragmentation of natural habitats

have been shown to alter movements and area requirements (Saunders et al. 1991, Keuroghlian et al. 2004). For example, mammalian frugivores may respond to deforestation and fragmentation by emigrating from forest fragments, especially during periods of fruit scarcity (Lovejoy et al. 1986, Terborgh 1986, Rylands and Keuroghlian 1988).

In the Pantanal and other neotropical biomes, *Tayassu pecari* are wide-ranging frugivores and important indicators of forest and landscape conditions because the species has a large home range, travels in herds of 30 to >100 individuals, uses a wide range of forest and other habitat types, is vulnerable to human alterations of habitat cover, and plays important ecological roles in the ecosystem, e.g., as a seed predator and disperser, an ecosystem engineer that strongly affects forest soils and plant communities, and as an important prey of puma (*Puma concolor*, Linnaeus, 1771) and jaguar (*Panthera onca*, Linnaeus, 1758) (Keuroghlian and Eaton 2009, Reyna-Hurtado et al. 2009, Beck et al. 2010, Cavalcanti and Gese 2010, Altrichter et al. 2012, Keuroghlian et al. 2012). Therefore, investigations of *T. pecari* can provide important information on the general status of medium- to large-sized mammals dependent on forest habitats. For the International Union for Conservation of Nature and Natural Resources Red List, the conservation status of *T. pecari* was recently revised from “near threatened” to “vulnerable,” due mainly to habitat loss, hunting, and sudden population declines and extinctions in large protected areas (Altrichter et al. 2012, Keuroghlian et al. 2012, 2013). These threats and population declines vary in intensity throughout the species’ range, which extends from southern Mexico to northern Argentina.

The Pantanal landscape is naturally heterogeneous in terms of flooding regime, edaphic characteristics, and vegetation cover (Nunes da Cunha et al. 2009, Padovani 2010). Consequently, fruit availability as determined by fruiting patterns and fruit species distributions varies according to ecoregion and habitat characteristics, e.g., whether vegetation tracts are relatively continuous, like gallery forests, or naturally patchy, such as drier non-riparian forests like regionally named “cordilheiras” and “capões.” The latter two forest types, rather than being closely associated with river channels, are interspersed among low-lying seasonally flooded plains and wetlands. Despite this regional variability, the overall dominance of fruits in peccary diets and the existence of dramatic fruit-scarcity periods during the dry season are factors that are common throughout most of the Pantanal (Desbiez et al. 2009, Keuroghlian et al. 2009a, Eaton 2013). In this environment, where fruit resources are naturally patchy and seasonally scarce, we expected that deforestation and

fragmentation would have strong impacts on the movements of *Tayassu pecari* and other forest frugivores.

For the current study, we evaluated the impacts of deforestation and fragmentation on forest mammals by analyzing the home ranges of *Tayassu pecari* herds in the southern Pantanal. Specifically, we compared herd home range size and areas of concentrated activity from a relatively undisturbed region to those from a region where deforestation and conversion of native habitat to exotic grass pasture has been more prevalent. The sites were located 80 km apart within the alluvial plain of the Rio Negro. The relatively undisturbed site spanned the lower Rio Negro and lower Nhecolândia ecoregions, LRN (S19°34', W56°14'; elevation 95–115 m), while the site with a higher level of deforestation-related disturbance was located in the upper Rio Negro ecoregion, URN (S19°32', W55°37'; elevation 110–125 m; Figure 1; ecoregions of Padovani 2010). Within the URN site, 1500 ha of native forest and savanna was converted to exotic grass pasture approximately 1 year before we began monitoring *T. pecari* movements (see dates below, Figure 2A).

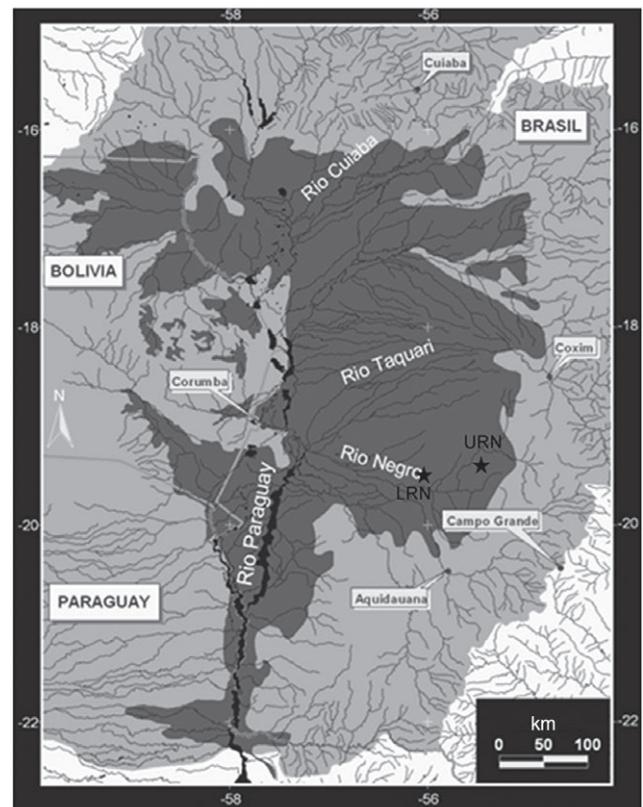


Figure 1 Locations of the study sites (LRN and URN) within the Pantanal (dark gray region) and upper Rio Paraguay basin (light gray region).

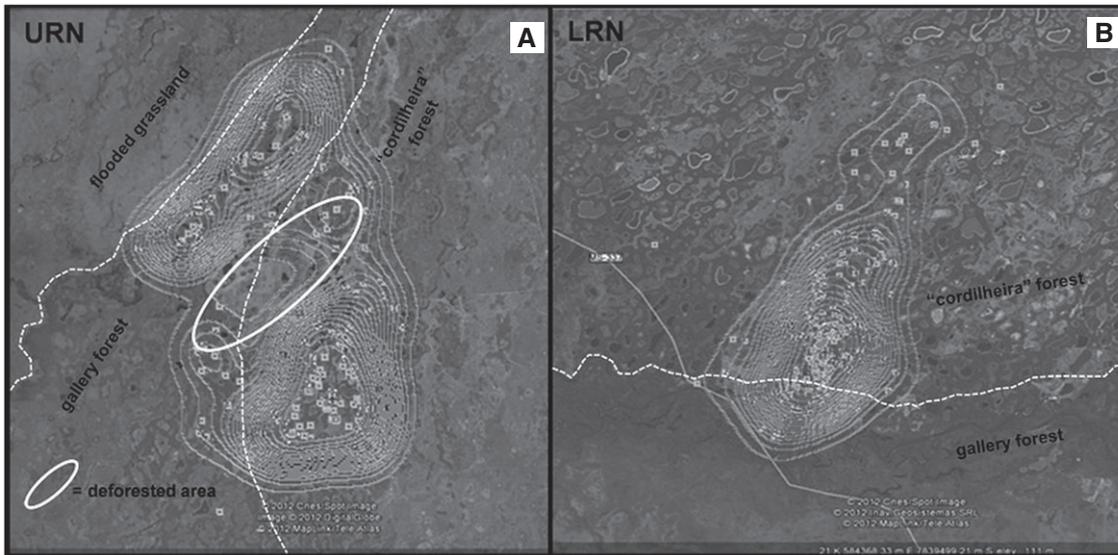


Figure 2 Home range areas based on the kernel method (95% to 15% isolines) for *Tayassu pecari* herds from two different locations in the southern Pantanal, Mato Grosso do Sul, Brazil.

(A) A relatively disturbed area in the upper Rio Negro ecoregion (URN), where deforestation and conversion to exotic pasture are more prevalent, and (B) a relatively pristine area spanning the lower Rio Negro and lower Nhecolândia ecoregions (LRN). White squares show *T. pecari* radio-telemetry fixes and direct observations from 10 individuals tracked during 4–5 years in each study area. In (A), an ellipse highlights a deforested exotic pasture region, and in both (A) and (B), dashed lines show the approximate boundaries between gallery and “cordilheira” forests. (Google Earth imagery, 2012.)

Other human impacts and environmental/ecological characteristics known to have a strong influence on *Tayassu pecari* movements, namely hunting pressure, types of natural habitat cover, fruit availability, and predator occurrence (Cullen et al. 2000, Beck 2005, Keuroghlian et al. 2004, 2012, Keuroghlian and Eaton 2008, 2009, Altrichter et al. 2012), were similar between the two sites. Hunting pressure was very low at both sites and largely restricted to exotic feral pigs (Desbiez et al. 2011). In both locations, the main natural habitat gradients, which extended from the river toward the floodplain, consisted of gallery forest transitioning to a mosaic of cordilheira forest, savanna, and wetland formations (Figure 2A and B; Keuroghlian et al. 2009a, Eaton 2013). On the basis of monthly fruit censuses and camera-trap surveys conducted during the periods that we monitored *T. pecari* herds, principal fruit resources and the occurrence of predators (i.e., *Puma concolor* and *Panthera onca*) were also very similar between the locations (Keuroghlian et al. 2009a, Eaton 2013). *Tayassu pecari* herd dynamics and abundance, which are described in results and highly relevant to our analyses of herd home ranges, were also similar between the two study sites.

Our capture methods for *Tayassu pecari* were as described by Keuroghlian and Desbiez (2010). Once captured, selected adult animals were fitted with a MOD 500

model radio collar (Telonics Inc., Mesa, AZ, USA; total weight of battery and collar=570 g). Radio-collar signals were monitored with a Wildlife Materials TRX 1000S receiver and a handheld directional antenna. Animal positions or fixes were determined by triangulating compass bearings taken from receiver locations (obtained with a handheld GPS unit) to the radio collars. For each fix, we took two to three bearings during a 3–5 min time span, with receiver locations at least 100 m apart. The time interval used to ensure independence between fixes was a minimum of 120 min (Keuroghlian et al. 2004).

In each study region, we monitored 10 adult radio-collared animals (five males and five females). In the LRN region, we radio tracked animals between 2001 and 2005, and in the URN region, between 2005 and 2008. During bimonthly (every 2 months) tracking periods of 7–14 days, we attempted to locate all animals with radio collars (two to five during any one tracking period), monitoring them throughout the battery lifespan of individual radio collars (between 2 and 3 years). In addition to monitoring radio-collared animals, all captured individuals (newborn to adult) were implanted subcutaneously with tiny passive identification tags or microchips. Each microchip had an identification number that could be read with a scanner and used to identify recaptured individuals throughout their lifetimes.

For each study site, we combined radio-telemetry fixes obtained from the 10 adult individuals to estimate herd home ranges and identify herd activity centers (justified in results). To analyze the home ranges, we used the Ranges 8, version 2.9, software (Kenward et al. 2008). As a preliminary step, we used incremental area analysis plots to determine whether the number of fixes were sufficient to describe stable home range area estimates. To determine the areas of herd home ranges, we used three estimation methods: (i) the minimum-convex polygon (MCP) (Mohr 1947), (ii) harmonic mean (HM) (Dixon and Chapman 1980), and (iii) kernel method (KM) (Worton 1989). We used the 95% isolines for the HM and KM estimates of home range area because this and previous studies have shown that the 95% estimates were realistic representations of *Tayassu pecari* home range area; that is, they encompassed most fixes while including a minimum of outliers and unused range area (Keuroghlian et al. 2004, Jacamo et al. 2013). We also reported the 95% MCP estimate, which potentially overestimates the area of complex home ranges, like those of *T. pecari* herds, because it is widely used and facilitates comparisons with studies from other regions and species (Keuroghlian et al. 2004, Jacamo et al. 2013). For activity centers, we used the KM range analysis because, in addition to estimating the range area, it demonstrated the number and spatial arrangement of activity centers within the home ranges (Keuroghlian et al. 2004).

To fully explain the home range results, it is necessary to briefly describe *Tayassu pecari* herd dynamics, which were similar between the two study sites. As described by Keuroghlian et al. (2004) for an Atlantic Forest herd and as observed during the current study at both Pantanal sites, dynamics were characterized by the presence of a single large herd divided into spatially overlapping but temporally separated subherds that periodically fused and exchanged individuals. This view of herd dynamics based on radio telemetry and recapture of microchip-tagged individuals was strongly supported by recent genetic studies showing high levels of relatedness, and therefore genetic exchange, between individuals in different subherds within both study areas (Biondo et al. 2011, Rufo 2012, Rufo et al., unpublished data). On the basis of this high level of relatedness and the dynamic nature of subherd membership, we concluded that each of the study sites was occupied by interacting subgroups comprising a much larger group of closely related individuals, which we define here as a *T. pecari* herd.

On the basis of direct counts during opportunistic sightings of animals when they crossed roads or open

areas, the number of animals in subherds ranged from 20 to 80, and a t-test showed that the number of animals per subherd was not significantly different between the study sites (URN mean=55.6 animals, LRN mean=55.2 animals, $t=-0.046$, $df=13$, $p=0.964$). Using the radio-telemetry data and recapture records of microchip-tagged individuals to determine subherd membership and exchanges, we estimated that each study site contained six subherds and a total of approximately 330 individuals (i.e., 6 subherds \times 55 individuals/subherd=330 total individuals).

Because *Tayassu pecari* home range areas were very large and contained sections that were challenging to reach (especially during flood periods), and the movements of the subherds were frequent and difficult to predict, we obtained an average total of only eight fixes during each bimonthly monitoring period at a study site. With a mean of 22 fixes per animal obtained during the study, stable home range area estimates were not obtained for individual animals as shown by incremental area analysis plots (Kenward et al. 2008); that is, the number of fixes were inadequate to analyze individual animal home ranges (Kenward et al. 2008). However, because *T. pecari* individuals were socially cohesive and members of one large herd (as discussed above), it was possible to combine fixes from individual animals to determine herd home range sizes and activity centers from each study site. For the herd home range estimates from both sites, incremental area analysis plots combining fixes from the 10 radio-collared animals within each study site showed that stable home range area estimates were reached after obtaining approximately 140 fixes.

Herd home range areas in the LRN study area ($n=246$ locations), as estimated by 95% KM, 95% HM, and 95% MCP, were 4637, 5477, and 7585 ha, respectively (95% KM shown in Figure 2B). In the URN study area ($n=204$ locations), herd home range areas were 7013, 7778, and 8037 ha as estimated by 95% KM, 95% HM, and 95% MCP, respectively (95% KM shown in Figure 2A). Thus, in the URN area, where the level of disturbance from deforestation was higher, the 95% KM and 95% HM home range estimates were 2376 ha (51%) and 2301 ha (42%) larger, respectively, compared with those of the more pristine LRN area (Figure 2A and B).

Also, in the disturbed URN area, there were two centers of herd activity (defined approximately by the 70% isolines) that were clearly separated by a largely unused deforested patch (Figure 2A). In contrast, there was only one main center of activity (also defined approximately by the 70% isoline) in the LRN area (Figure 2B). In the LRN area, activity was most concentrated in gallery forest and decreased gradually perpendicular to the river toward the

drier naturally occurring forest patches, the “cordilheiras,” in the Nhecolândia lakes ecoregion (Figure 2B). In the southern activity center of the URN area, herd activity was also divided between gallery and cordilheira forest patches, while in the upper activity center, most activity was concentrated in gallery forest (Figure 2A). Routes between the activity centers in the URN area as defined by >75% isolines extended along the edges of the deforested patch through both gallery and cordilheira forests (Figure 2A).

Three lines of evidence strongly suggested that *Tayassu pecari* ranges were altered by deforestation and fragmentation at the URN site. The near absence of fixes within the deforested patch, the existence of two well-separated centers of activity, and the larger home range size in comparison with the LRN site were all consistent with the presence of an inhospitable area avoided by the herd, i.e., the deforested patch. By contrast, other key human, environmental, and autoecological factors known to affect *T. pecari* ranges were similar between the two study sites, namely, hunting pressure, types of natural habitat cover, fruit availability, number of animals per subherd (and per herd), and herd dynamics. The deforested patch in the URN area presumably fragmented the original home range of the herd, forcing the animals to alter routes and use a larger area to obtain sufficient resources, e.g., forest fruits. In the Pantanal, fruits comprised >60% of *T. pecari* diets (Desbiez et al. 2009), and habitat use trends indicated that there was a strong positive association between *T. pecari* occurrence and forested areas (Desbiez et al. 2009, Keuroghlian et al. 2009b). Extrapolating from these trends and this study’s results, we expect current rates (as well as recently proposed accelerated rates) of deforestation (Embrapa Pantanal et al. 2014) and consequent losses of forest fruit resources to significantly alter the natural ranging patterns of *T. pecari* and other forest-dependent frugivores in the Pantanal.

As in other biomes, the impacts of climate change in the Pantanal are expected to exacerbate the consequences of ongoing deforestation and fragmentation of natural habitats (Mantyka-Pringle et al. 2012, Watson et al. 2013). Models and assessments indicate a relatively large shift in the Pantanal’s climatic conditions by 2050 (Watson et al. 2013). Specifically, they predict overall drier conditions with a 35–45% decrease in rainfall by the end of the century (Araujo et al. 2012). Because fruit production in the Pantanal is positively related to rainfall, and the dry season is characteristically a period of fruit scarcity in terms of both diversity and quantity (Keuroghlian et al. 2009a), we expect that future drier climate conditions will reduce overall fruit availability.

The areal extent of gallery and drier forest formations, such as cordilheiras and capões, may also decline as drier climatic conditions predominate. Although the diet of *Tayassu pecari* in the Pantanal also includes non-fruit resources, especially during fruit-scarcity periods, e.g., aquatic plants and, more rarely, trapped fish in drying wetlands (Desbiez et al. 2009, Keuroghlian et al. 2009a, Fernandes et al. 2013), the availability of these alternative resources is linked to water sources, like lakes and floodplains, which may also be threatened by predicted drier climatic conditions.

Compared with the highly threatened Cerrado and Atlantic Forest biomes of Brazil, the natural vegetation cover in the Pantanal is relatively well preserved (Embrapa Pantanal et al. 2014). As a strong indication of vegetation intactness in the region spanning the 80-km distance between the URN and LRN study sites, genetic surveys of 72 *Tayassu pecari* individuals captured during the current study showed that a high level of gene flow existed between the two *T. pecari* herds; that is, >30% of males and females were dispersers (Biondo et al. 2011). However, the range alterations documented at the URN site showed that ongoing deforestation and fragmentation of the naturally patchy and seasonally resource-limited Pantanal may have serious future consequences for *T. pecari* and other forest frugivore populations. These potentially include increased energetic costs in an environment with fewer and more widely spaced fruit resources, increased isolation of previously cohesive populations, forced emigrations across inhospitable matrix habitats, and local extinctions as the populations respond to changes in both vegetation cover and climate. Conservation efforts preserving remaining natural habitat cover and optimizing connectivity between habitat patches will be essential for maintaining current *T. pecari* populations and increasing the capacity of future populations to adapt to climate change (Watson et al. 2013).

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