**Research Article**

# Distribution and abundance of water buffalo populations in eastern Amazonian floodplains

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## Abstract

The Asian water buffalo was introduced in Brazil in in the late nineteenth century. Today the country harbours one of the largest populations in the world, most of it in the Amazon basin. The majority of populations are domesticated, but feral populations have established in several protected areas. One of the largest, comprising both feral and free-living domestic individuals, is in Lago Piratuba Biological Reserve (LPBR) and Maracá-Jipioca Ecological Station (MJES) in Amapá state. Water buffalo cause serious damage to floodplains in both areas and their population control has been recommended. In 2017, we conducted aerial surveys using the double-count technique to estimate the size and distribution of the water buffalo population at LPBR and MJES. To assess population trends, we compared our results with two previous population estimates (2007 and 2013) for the same areas as well as with data from the Brazilian agricultural census (2007 to 2017) for the region. We estimated a population of 17,782 and 686 buffalo at LPBR and MJES, respectively. Compared to previous surveys, the population at MJES has remained stable, but the LPBR population declined by more than 40% compared to the last survey. The decline was virtually limited to one survey sector at LPBR. The decline is mirrored by the agricultural census data, but its reasons are unclear. We recommend continued monitoring, as the population can quickly rebound to previous numbers if left unchecked.

**Key words:** Amazon, *Bubalus bubalis*, invasive alien species, introduced mammals, protected area, wetland

## Introduction

The water buffalo *Bubalus bubalis* (Linnaeus, 1758) is a large-bodied (> 200 kg) domesticated bovid originating from South Asia currently distributed on every continent except Antarctica due to human intervention (Werner 2014; Zhang et al. 2020). Over the last two centuries, domestic and feral populations of water buffalo have become established in several countries, notably in Australia and Brazil (Werner 2014). In Brazil, the species was introduced in the late nineteenth century, first on Marajó island at the mouth of the Amazon river, and then to other regions throughout the twentieth century (Smith 1999; Bernardes 2007; da Rosa et al. 2017). Today, the country has the largest population in extensive farming in the world, with approximately 3.5 million – more than half of these in the Amazon basin (Camarao et al. 2004; Sheikh et al. 2006; da Silva et al. 2015). Feral populations are now established in several Brazilian states and at least 20 Brazilian protected areas currently harbour feral water buffalo (Moraes et al. 2016). The largest feral populations are currently found in Amapá and Rondônia states (Bisaggio et al. 2013; da Rosa et al. 2017).

Water buffalo are highly susceptible to heat stress (da Silva et al. 2015) and depend on water for cooling (Werner 2014). For this reason, the species is frequently associated with floodplains (Tomas et al. 2008; Werner 2014), where it outperforms cattle in productivity, weight gain, fecundity, longevity, disease resistance and dairy production (Camarao et al. 2004; Sheikh et al. 2006). In addition, water buffalo are resistant to flooding due to their ability to swim, dive and even feed underwater (Werner 2014). The species has therefore become an important economic resource on floodplains, where populations are steadily increasing (Smith 1999; Sheikh et at. 2006; Bernardes 2007; Pires 2015).

However, water buffalo can cause serious environmental damage to floodplains. For example, they may damage native vegetation, cause soil erosion or compaction, trample breeding sites and contaminate water sources through urine and faeces (Skeat et al. 1996; Petty et al. 2007; Tomas et al. 2008; Monteiro 2009; Werner 2014). Buffalo ranching is also a source of social conflict between ranchers and fishermen (Sheikh et al. 2006; Monteiro 2009), and the species is a reservoir of bovine tuberculosis (Ridpath and Waithman 1988).

The Lakes region of Amapá state in Brazilian Amazonia harbours almost 90,000 buffalo in the Araguari river basin alone (Funi et al. 2014). The highest buffalo densities are observed in the eastern part of the basin, near the Atlantic Ocean and the mouth of the Araguari river. This includes two protected areas, Lago Piratuba Biological Reserve (LPBR) and Maracá-Jipioca Ecological Station (MJES). Aerial surveys conducted in 2007 and 2013 revealed large, but stable, water buffalo populations in both areas, with about 32,000 individuals at LPBR and about 600 individuals at MJES (Tomas et al. 2008, 2014). Water buffalo populations were causing significant damage to wetlands in both areas, and a reduction of the feral portion of the population was recommended (Tomas et al. 2008, 2014; ICMBio 2017; Monteiro 2009). Continued monitoring is important to understand trends and track the state of buffalo population over time. This study presents updated information on the population size and distribution of water buffalo at LPBR and MJES, based on aerial surveys performed in 2017.

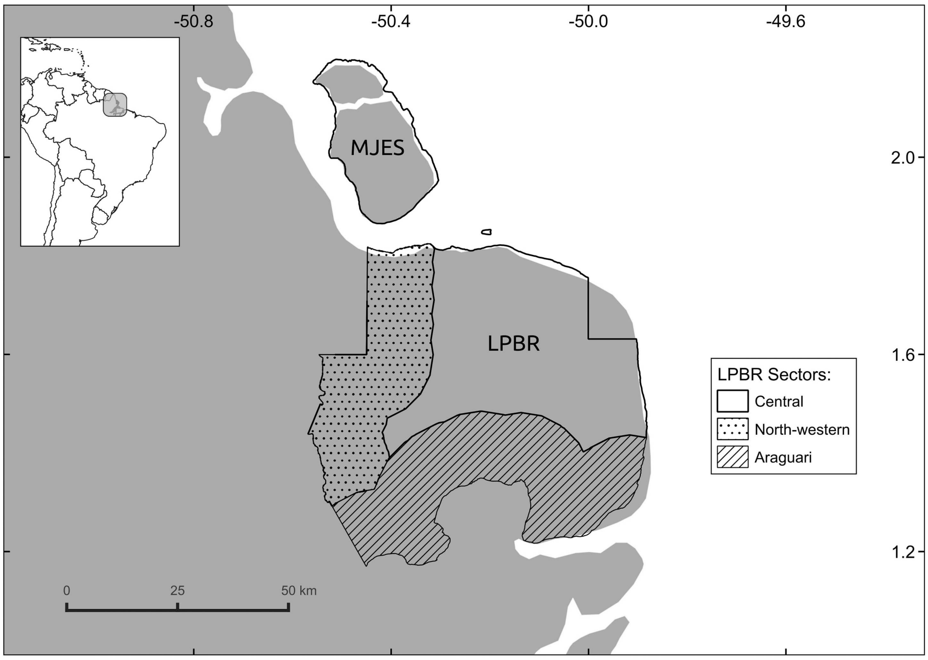


**Figure 1.** Map of the study area, showing Maracá-Jipioca Ecological Station (MJES), Lago Piratuba Biological Reserve (LPBR) and the limits of the three survey sectors at LPBR.

## Materials and methods

### *Study area*

Lago Piratuba Biological Reserve (1°29′50″N; 50°13′29″W) and Maracá-Jipioca Ecological Station (1°59′50″N; 50°25′34″W) are two protected areas located on the eastern coast of the Brazilian state of Amapá (Figure 1). LPBR covers 392,475 ha and is delimited by the Atlantic Ocean to the east and the Araguari River to the South. MJES is 58,757 ha and comprises two offshore islands, six km from LPBR on the mainland.

Climate is tropical monsoonal with mean annual temperatures > 26 °C and annual precipitation above 3000 mm (Alvares et al. 2013). The reserves are covered by a mosaic of mangroves, grasslands and patches of tropical forest (Padua and Quintao 1982; Pathek et al. 2014). In addition, they harbour a number of large lakes, which are important fishing grounds for local livelihoods, and serve as breeding and feeding areas for caiman and waterfowl, including several migrant bird species (Campos et al. 2008; Aguiar et al. 2010; Pinha et al. 2015). Water buffalo were already present in the area before the two reserves were decreed (Pinha et al. 2015; ICMBio 2017), but come from different sources and belong to different breeds. At LPBR, buffalo are mostly Jafarabadi and Murrah cross-breeds, herded in extensive ranches. Before the reserve was decreed, ranches were largely unfenced. As a result, escaping individuals moved to the interior of LPBR, establishing a feral population (ICMBio 2017). According to the last survey at LPBR, around two thirds of the 32,000 buffalo at LPBR were in managed free-living populations, and the remaining were feral (Tomas et al. 2014). However, this figure has been contested by local ranchers, who claim that most buffalo tallied as feral were free-living domestic individuals (I. Coutinho *pers. obs.*). At MJES, buffalo belong to the Carabao breed. The population of approximately 600 individuals is entirely feral, tracing back to a single cattle ranch that was abandoned in 1987, after the reserve was created (Tomas et al. 2014; ICMBio 2017).

*Aerial surveys*

The distribution and abundance of water buffalo in the study area were assessed using the double-count technique (Magnusson et al. 1978), a widely used method in aerial wildlife surveys (Bayliss and Yeomans 1989; Graham and Bell 1989; Mourão et al. 2000; Tiepolo et al. 2010). The double-count is a variation of the mark-recapture technique. In brief, two observers, positioned on the same side of an aircraft, count animal groups independently. Groups sighted by the first observer are equivalent to captures and groups sighted by the second observer are equivalent to recaptures. Detection rates and correction factors can be obtained by comparing the independent counts, and population size can be estimated using the Petersen index (Magnusson et al. 1978; Caughley and Sinclair 1994).

Aerial surveys were conducted in December 2017. Counts were made from a helicopter flying at 100 meters altitude at 180 km/h. Two observers independently counted the number and size of all water buffalo groups spotted along a series of 300 metre wide transects. To increase count accuracy, large groups (> 15 individuals) were photographed by one of the observers and group size was estimated from the photographs (Lubow and Ransom 2016). To facilitate pairing of observations, counts were recorded for every 30 seconds of flight time, equivalent to 1.5 km transect length (Bayliss 1986; Graham and Bell 1989). Independent counts from each observer for each 30-second flight sub-unit were paired, and all sighted groups were matched by flight sub-unit and group size. Whenever group sizes diverged between observers, the largest group size or the count derived from the photographs was used.

According to previous surveys (Tomas et al. 2008, 2014), water buffalo populations are not evenly distributed at LPBR. Most individuals were concentrated in ranches near the southern limit of the reserve, along a strip bounded by the Araguari River to the south and extending approximately 10 km to the north, with most of the remaining populations scattered along the north-west of the reserve. For the present survey, LPBR was divided into three sectors (Araguari, north-west and centre) and the water buffalo population was estimated separately for each of them (Figure 1, Table 1). Transects were regularly spaced at two-kilometre intervals, except in the north-west sector, where spacing was one kilometre. Total distance travelled at LPBR was 1,685 km, translating into 1,133 units of 30 seconds of flight time. Some transects traversed more than one sector. In these cases, the sub-units were allocated to their respective sectors.

**Table 1.** Area of the survey sectors and corresponding sampling intensity at Lago Piratuba Biological Reserve (LPBR) and Maracá-Jipioca Ecological Station (MJES).

| Protected area | Area ($km^2$) | Sampling intensity ($km^2$) (%) |
|---|---|---|
| LPBR | | |
| Araguari | 1,389 | 191.7 (13.8%) |
| north-west | 932 | 199.7 (21.4%) |
| centre | 1,601 | 73.1 (4.5%) |
| MJES | 461 | 64.7 (14.0 %) |

According to previous surveys (Monteiro 2009; Tomas et al. 2008, 2014), the water buffalo population of MJES is restricted to the southern Maracá island. This was confirmed by a reconnaissance flight over the northern island in December 2017. Therefore, only the southern Maracá island was systematically surveyed. A total of 14 east-west transects, spaced at two-kilometre intervals, were flown over MJES. Total distance travelled at MJES was 197 km, amounting to 128 sub-units of 30 seconds of flight.

*Data analysis*

The number of buffalo groups in the sampled areas was estimated by the formula:

$$Y = [(B + S1 + 1)(B + S2 + 1)/(B + 1)] - 1$$

where Y is the estimated number of groups, B is the number of groups spotted by both observers, S1 is the number of groups spotted by the first observer but not by the second, and S2 is the number of groups spotted by the second observer but not by the first (Caughley and Sinclair 1994). Population density D was calculated by multiplying Y by the average group size and dividing the result by the sampled area. The total population size in each sector was calculated by multiplying density D by area A of the sector. Confidence intervals were estimated by bootstrap (n = 10,000) in the R software (Manly 1997; R Development Core Team 2019). Population trends were described by combining estimates from this study with estimates from two previous surveys in the same area, also conducted using the double-count technique (Tomas et al. 2008, 2014). Additionally, population trends at LPBR were compared with the population time series for the three municipalities that partially overlap the reserve (Amapá, Pracuúba and Tartarugalzinho) provided by the Census of Agriculture of Instituto Brasileiro de Geografia e Estatística (IBGE 2017). The data and R codes used in the analyses are available at https://github.com/ICMBio-CENAP/buffalo.

## Results

A total of 162 buffalo groups, comprising 2336 individual buffalo were sighted during the surveys. Mean detection rate was 0.7 in LPBR (0.78 and 0.63 for the first and second observer, respectively) and 0.9 in MJES (1 and 0.8 for the first and second observer, respectively).

**Table 2.** Buffalo population estimates for Lago Piratuba Biological Reserve (LPBR) and Maracá-Jipioca Ecological Station (MJES), December 2017.

| Protected area/sector | Population estimate (SD) | 95% CI | Density (ind/km$^2$) |
|---|---|---|---|
| LPBR (total) | 17,782 (2,260) | 13,232–22,012 | – |
| Araguari | 15,537 (2,040) | 11,443–19,306 | 11,18 |
| north-west | 856 (491) | 159–1,510 | 0,9 |
| centre | 319 (20) | 0–543 | – |
| MJES | 692 (330) | 48–1,136 | 1,5 |

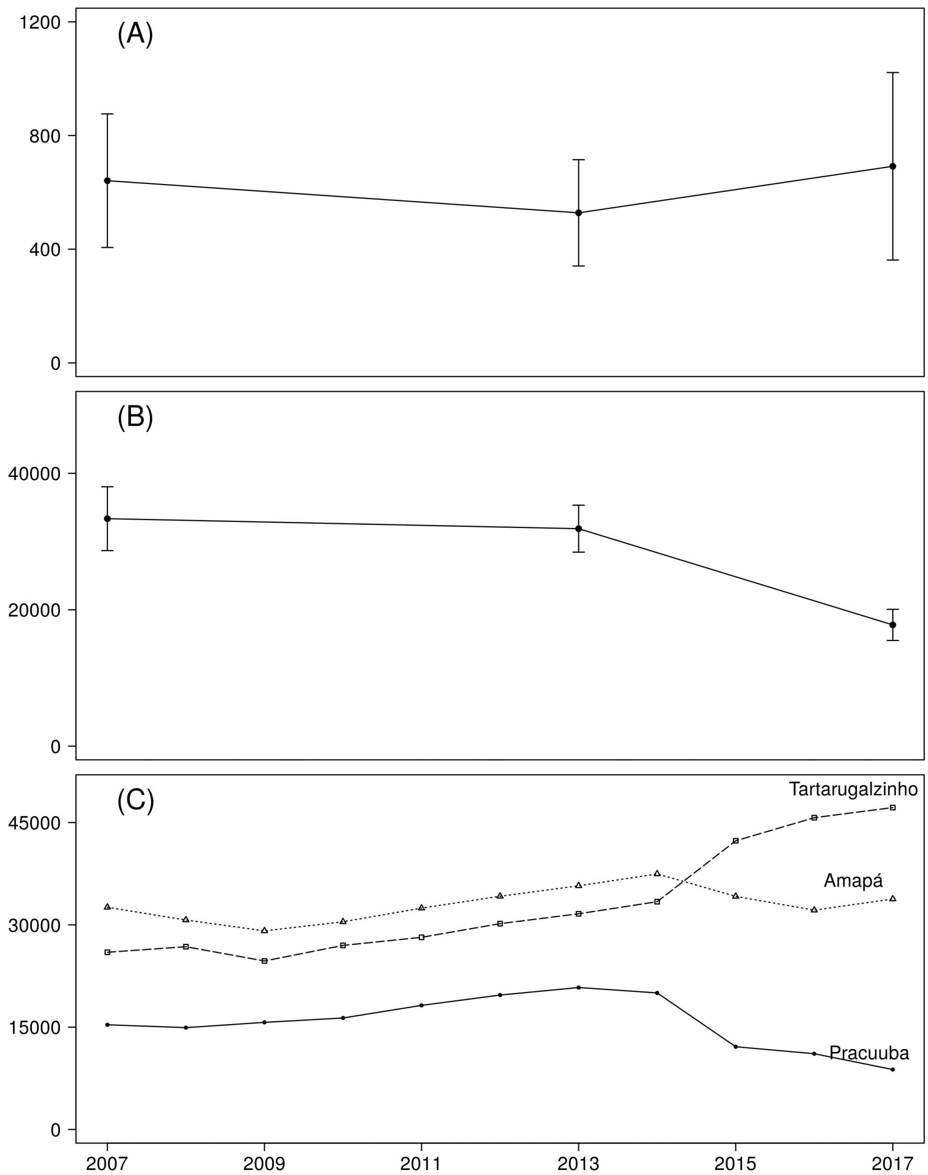


**Figure 2.** Water buffalo population estimates at (A) Maracá-Jipioca Ecological Station and (B) Lago Piratuba Biological Reserve in 2007, 2013 and 2017. Vertical bars correspond to standard deviations. Estimates from 2007 and 2013 are from Tomas et al. (2008, 2014). (C) Buffalo population sizes at the municipalities of Amapá, Pracuúba and Tartarugalzinho, 2013–2017 (source: IBGE 2017).

The water buffalo population at MJES was estimated to be 692 (95% CI: 48–1136) individuals (Table 2). This is similar to the two previous estimates (Figure 2A). All sighted groups were on the western side of the southern Maracá island (Figure 3) – most of them near temporary lagoons.

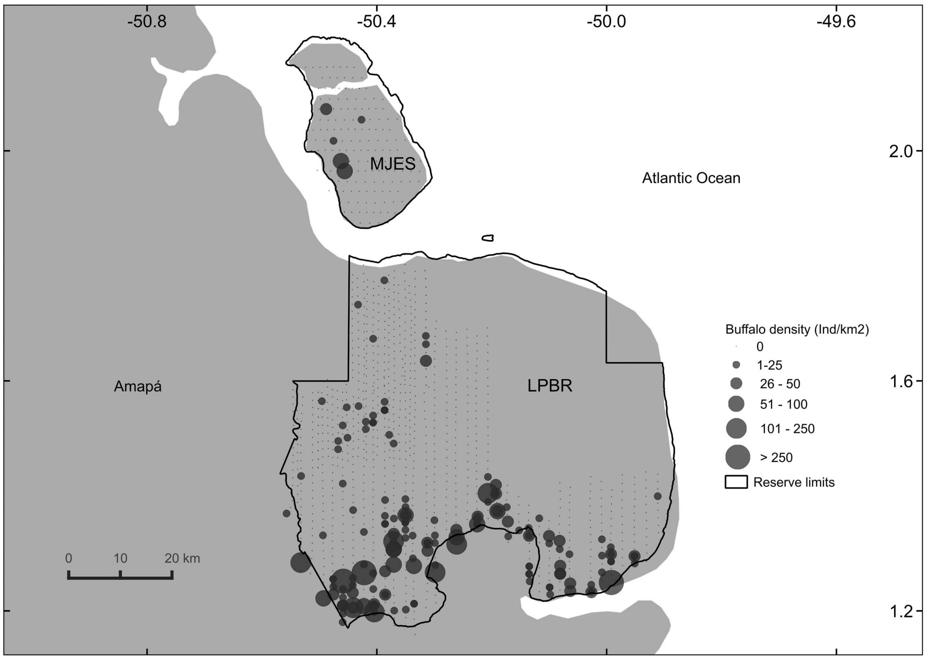


**Figure 3.** Spatial distribution and observed densities of water buffalo at Lago Piratuba Biological Reserve (LPBR) and Maracá-Jipioca Ecological Station (MJES), December 2017. Each circle corresponds to a flight sub-unit of 30-seconds.

Average group size at MJES was 17.6 individuals, and average density was 1.5 individuals per $km^2$ (Table 2).

The total water buffalo population in LPBR was estimated to be 17,782 (95% CI: 13,232–22,012) individuals (Table 2). This figure is considerably lower than the previous estimates (Figure 2B). Most of the population was concentrated in the Araguari sector, on ranches located near the Araguari river (Table 2, Figure 3). The few remaining groups were scattered throughout the north-western sector (Table 2, Figure 3) and only a single group was spotted in the centre sector. Average group size was 16.3 individuals (range: 1–181) in the Araguari sector and 5.5 individuals (range: 1–116) in the north-western sector. Densities ranged from 0.9 individuals per $km^2$ in the north-western sector to 11 individuals per $km^2$ in the Araguari sector (Table 2).

The IBGE Census of Agriculture data shows a slow but consistent increase in buffalo population sizes at the three municipalities covered by the reserve from 2007 to 2014. From 2014 onwards, trajectories of each municipality began to diverge (Figure 2C). After 2014, the Tartarugalzinho population began to increase at faster rates than previously, while the Amapá and Pracuúba populations began to decline. In Amapá, the trend reversed after 2016, but in Pracuúba the decline persisted, with the population losing more than 12,000 individuals between 2014 and 2017 (Figure 2C).

## Discussion

We found that the water buffalo population for LPBR was much lower than previous estimates (Tomas et al. 2008, 2014), corresponding to a 44%

decline compared to the most recent estimate. However, this decline was not evenly distributed in space. In the Araguari sector, where buffalo occur in large, managed free-living populations, the population declined only slightly – from approximately 18,500 individuals in 2008 (Tomas et al. 2008) to around 15,500 individuals in 2017. In contrast, in the north-western sector, where buffalo were assumed to be predominantly feral (Tomas et al. 2008), the population declined dramatically from approximately 12,000 individuals in 2013 (Tomas et al. 2014) to < 1,000 individuals in 2017. This massive and uneven difference is unlikely a result of methodological differences, either in crew experience, statistical methods, or criteria used to define the boundaries of each sector.

The most likely explanation for this population decline is a massive removal of individuals from the north-western sector after the last population survey was conducted. The removal of approximately 10,000 individuals in a 4-year period may seem unlikely, but previous experiences suggest that it is feasible. Harvest models show that a 30% annual offtake would be sufficient to eliminate a 10,000 water buffalo population in five years, while a 60% annual offtake would do the same within two years (Boulton and Freeland 1991). Accordingly, management experiments in northern Australia succeeded in reducing large buffalo populations to minimum levels over relatively short periods, by intensive captures complemented by culling. For example, a management operation in Kakadu National Park removed more than 100,000 water buffalo from the park over a five-year period (Skeat et al. 1996). Similarly, a systematic removal operation in the Kapalga region, Australia, took only 3.5 months to reduce a population of 6,500 water buffalo by 97% (Ridpath and Waithman 1988). However, complete eradication is virtually impossible, because as population density decrease, removal becomes increasingly expensive, or less profitable (Boulton and Freeland 1991).

Yet, there is one major caveat – there are no official records of buffalo removals from LPBR. However, there is evidence, albeit limited, for two non-mutually exclusive explanations for the putative buffalo removal. First, most of the population within the north-western sector of LPBR may have been moved to ranches outside the reserve after the last survey was conducted in 2013. Data from the IBGE Agricultural Census is consistent with this explanation, as it reveals a large population decrease in the municipalities of Amapá and Pracuúba in the same period that the population declined at LPBR. During this period there was an increase in the Tartarugalzinho population. This municipality straddles the border of the reserve and it is possible that part of the population was moved from sites within LPBR in Amapá and Pracuúba to sites outside LPBR in Tartarugalzinho. Unfortunately, the spatial resolution of the IBGE data is too coarse to warrant a definite conclusion. Furthermore, for this scenario most of the north-western buffalo population must have been domestic free-living animals, not feral as previously inferred. Additional *in situ* investigations, such as interviewing local ranchers and agricultural unions, are needed to clarify the greater regional trends.

Alternatively, most buffalo in the north-western sector were indeed feral and may have been removed clandestinely after data from the previous population surveys were disclosed to the public. There is anecdotal evidence for clandestine removals, particularly after maps showing the distribution of feral buffalo were made public. For example, local people reported to LPBR managers that ranch owners were offering a prize for each feral buffalo caught in the reserve (PRS Pinha *pers. obs.*). Furthermore, from 2012 onwards managers noted an increase in the number of illegal temporary camps in the reserve, as well as in the incidence of fires, which are used to round-up buffalo. However, although clandestine removals certainly occurred, there is no quantitative information on the scale of the activity.

A third, less likely explanation is that the population declined due to natural causes. Water buffalo populations may suffer catastrophic mortality rates after prolonged periods of food scarcity, such as severe droughts, or when the population exceeds carrying capacity (Petty et al. 2007; Werner 2014). However, this is unlikely to have occurred at LPBR. There are no reports of large-scale mortality in the region, and there is little reason to suppose that such an event would be confined to the north-west sector. Whatever the reasons for the decline, the reduced number of feral buffalo are likely beneficial for conservation of LPBR ecosystems, as it would decrease buffalo damage to native fauna and flora.

In contrast to LPBR, the water buffalo population at MJES has remained stable since the previous surveys. This is surprising since water buffalo populations generally grow exponentially until reaching environmental carrying capacity (da Rosa et al. 2017). As the buffalo population in MJES is restricted to a limited area on the west of the island (Figure 3; Tomas et al. 2008), there seems to be plenty of room for the population to expand and increase. Perhaps the population already reached carrying capacity on the island, with unoccupied areas representing sub-optimal habitats. Ideal conditions for buffalo include high precipitation, wide availability of fodder and surface water deep enough for animals to wallow, in addition to elevated areas for rest and for calving (Werner 2014). During the rainy season, water is no limiting factor, but with advancing droughts animals concentrate around available water sources leading to overgrazing (Werner 2014). Thus, the restricted distribution of water buffalo on the southern Maracá island may be related to seasonal water shortages. This is consistent with (i) the absence of freshwater sources on the island, with all freshwater coming from rains and becoming seasonally restricted to temporary ponds in the dry season (Vergara 2011); (ii) the fact that most buffalo groups were spotted near temporary ponds; (iii) the evidence of seasonal movements of water buffalo populations on the island (Tomas et al. 2008), suggesting that areas unoccupied during the dry season may be used at other times of the year. Alternatively, the population may be controlled by hunting by local people or predation of calves by jaguars *Panthera onca* (Linnaeus, 1758; Hoogesteijn and Hoogesteijn 2008; Azevedo et al. 2010), which occur in high densities on the island (Vergara 2011). As with LPBR, more data is needed to elucidate the mechanisms behind the water buffalo population dynamics on this island.

In short, we found that the water buffalo population remained stable at MJES, but declined considerably at LPBR. From the point of view of protected area management, the decline at LPBR is good news, as it demonstrates the feasibility of removing large buffalo populations in a remote protected area. Furthermore, the reduction of the buffalo population will certainly decrease damage to native fauna and flora. The downside is that this was done without the awareness and consent of the reserve managers and the removal itself may have had an impact on the reserve ecosystems (e.g., the use of fire as a tool to round up buffalo populations is highly detrimental to the local environment). In any case, the buffalo population must continue to be monitored, since it can quickly rebound to former numbers if left unchecked. This will largely depend on regulating the domestic free-living population within the reserve, which can cause as much environmental damage as the feral population, and limiting its potential to source new individuals to the feral population that ideally should be eradicated.

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