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Cover: Ryan *et al.* (in this issue) studied colour ringed Tristan Thrushes (*Turdus eremita*) to determine population size, movements and breeding biology, while Biagolini-Jr. & Macedo (also in this issue), described GenTag, a package to improve color tagging studies. Photo author: Peter G. Ryan.

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ARTICLE

Nesting biology of the Aplomado Falcon (*Falco femoralis*) at Parque Nacional das Emas, central Brazil

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ABSTRACT: The objective of this study was to investigate aspects of the nesting biology of the Aplomado Falcon, *Falco femoralis* (Temminck, 1822), at Parque Nacional das Emas, Brazil. Woodland (Campo Cerrado) firebreaks were searched for nests in October 2006 and October 2009 by driving a vehicle along a road adjacent to these fire managed vegetation strips. Most (62%) of the eight nests found were in canopies of fruiting *Pouteria torta* trees. Nests were at 2.2–3.8 m above ground. Invariably, clutch size was of three cream eggs and nestlings had a white plumage in the first days of life. For two active nests, adults also defended an additional empty nest located in the surroundings. No evidences of nest destruction or predation were detected. *Falco femoralis* successfully uses firebreaks for breeding at Parque Nacional das Emas.

KEY-WORDS: bird, breeding season, egg, Falconidae, fire, nest, reproduction, savanna.

INTRODUCTION

The Aplomado Falcon, *Falco femoralis* Temminck, 1822, is widely distributed through the American continents, where it inhabits numerous habitats, except dense forest and mountain tops (del Hoyo *et al.* 1994, Stotz *et al.* 1996, Mata *et al.* 2006). They are often found in grasslands, savannas and open areas, including landscapes dominated by agriculture (Stotz *et al.* 1996, Sick 1997, Ferguson-Lees & Christie 2001). This mid-sized falcon feeds mainly on insects and small vertebrates such as birds, lizards, bats and rodents (del Hoyo *et al.* 1994, Ferguson-Lees & Christie 2001, Macías-Duarte *et al.* 2004). Generally, they are resident but some groups can be migratory, such as those that migrate between the high Andes and coastal Peru and Chile; in regions such as the Cerrado, they are resident (Sick 1997, Ferguson-Lees & Christie 2001).

Despite its wide distribution and commonness, information on its breeding is scarce for numerous regions. Its reproduction has been studied extensively only in North America, where investigations are concentrated in the Chihuahua region, northern Mexico (*e.g.*, Montoya *et al.* 1997, Macías-Duarte *et al.* 2004, Meyer & Williams 2005, Brown & Collopy 2008). On the other hand, studies in the Neotropical region are lacking. Timing of breeding varies enormously through its extensive geographic distribution and clutches have between 2 and 4 eggs (del Hoyo *et al.* 1994, Ferguson-Lees & Christie 2001).

In Brazil, its nesting has been studied in detail in the Atlantic Forest by Granzinolli *et al.* (2002) but not in other regions. For example, no study examined its breeding in the Cerrado, where only their feeding ecology (Silveira *et al.* 1997) and habitat use (*e.g.*, Antas & Cavalcanti 1988, Tubelis & Cavalcanti 2001, Pacheco & Olmos 2010) have been studied. This study aimed to investigate aspects of the nesting biology of *F. femoralis* at Parque Nacional das Emas, central Brazil. Characteristics of their nests, eggs and nestlings, and trees used for nesting were described. Results were discussed in terms of its nesting biology in the Cerrado and other regions.

METHODS

Observations were made at Parque Nacional das Emas, Goiás state, Brazil. This 132,000 ha conservation unit harbors several vegetation physiognomies typical of the Cerrado ecoregion. Grasslands and savanna woodlands are the major matrix types and usually cover uplands (França *et al.* 2007). Savanna woodlands (Campo Cerrado and Cerrado *sensu stricto*) have a dense herbaceous stratum, and numerous shrubs and trees (Eiten 1972 & 1993). Climate in this region is marked by two well-defined periods: the rainy season occurs between October and April, while the dry season occurs between May and September. Annual precipitation ranges between 1200 and 2000 mm (Assad 1994) and elevation ranges between 720 and 900 m a.s.l. (França *et al.* 2007).

At Parque Nacional das Emas, park managers usually burn strips of grasslands and savanna woodlands in the dry season almost annually to stop the spreading of fire originated on adjacent farmland. These firebreaks called *aceiros* by managers and scientists lie between two unsealed roads and are usually 25–100 m wide (Ramos-Neto & Pivello 2000, França *et al.* 2007). Woodland firebreaks have a grassy stratum dominated by Capim Flecha grass (*Tristachya leiostachya* Ness), that can be near 200 cm high when fully developed with reproductive parts. If controlled burnings occur every 1–2 years, Capim Flecha grass keeps 10–30 cm high at firebreaks (França *et al.* 2007). Campo Cerrado patches, managed or not by fire, are a major habitat for *F. femoralis* at this park and in central Cerrado (Silveira *et al.* 1997, Antas & Cavalcanti 1988, Tubelis & Cavalcanti 2001, Pacheco & Olmos 2010).

Campo Cerrado woodland firebreaks were searched daily for nests in mornings (08:30 to 11:00 h) and afternoons (14:30 to 18:30 h) between 01 and 11 October 2006 and between 05 and 08 October 2009 by driving a vehicle slowly along a road adjacent to them. This search was initiated in early October because active large nests built in trees of firebreaks were found in September 2006, when the park was visited by the author to carry out other ornithological studies. Only firebreaks were sampled due to the facility of their access from adjacent roads. The search covered a total of 32 km of firebreaks crossing six extensive patches of Campo Cerrado vegetation located in the interior (n = 2; 12 km) and at the edge of the park (n = 4; 20 km). Campo Cerrado patches not managed by fire were not sampled due to time unavailability, and because firebreaks provide a better visibility than unmanaged patches due to short Capim Flecha grasses.

When a large nest was detected, the observer approached it on foot to identify the bird associated to it. This because the Red-legged Seriema *Cariama cristata* (Linnaeus, 1766), the Buff-necked Ibis *Theristicus caudatus* (Boddaert, 1783), the Curl-crested Jay *Cyanocorax cristatellus* (Temminck, 1823) and raptors also build large nests in tree canopies in Campo Cerrado patches at this park (pers. obs.).

After being examined on the occasion of their findings, nests were visited 2–3 times until 11 October and once between 11 and 14 November 2006. Nests found in 2009 were not re-visited. Nests were visited whenever possible (logistic), thus, visits varied between 1 and 3 (Table 1). During each visit to a nest, eggs and nestlings were counted, but not handled. Nest contents were examined by using a mirror attached to a telescopic pole. The inferior portion of the nests had their height from the ground measured with a Bosch laser tape. A branch of the tree used for nesting was collected to help identification of the plant species. Four tall trees were climbed once to photograph eggs and nestlings.

RESULTS AND DISCUSSION

Eight nests of *F. femoralis* were found in Campo Cerrado firebreaks at Parque Nacional das Emas in October 2006 and October 2009 (Table 1). As the observer did not record the precise location of the nests found in 2006, it was not possible to know if falcons used the same trees for nesting in 2009. Further, considering only nests found within a given Campo Cerrado patch, two nests were

Table 1. Content and height of nests of the Aplomado Falcon (*Falco femoralis*) found in Campo Cerrado firebreaks (strips of savanna woodlands managed by fire) at Parque Nacional das Emas, central Brazilian Cerrado, in 2006 and 2009, with the number of visits to each nest. The sequence of nests follows the first day of inspection.

Nest	Nest content	Height (m)	Number of visits
2006			
1	Three eggs (02 and 03 Oct); three nestlings (08 Oct); empty nest (13 Nov).	3.6	4
2	Three eggs (03 and 07 Oct); Two eggs and one nestling (08 Oct); Three nestlings (09 Oct); Two young flying with difficulties with adults (12 Nov).	3.4	5
3	Three eggs (03 Oct); Two nestlings and one egg (07 Oct); Three nestlings (08 Oct); One young flying with difficulties with adults (13 Nov).	3.8	4
4	Three eggs (04, 05 and 06 Oct); three nestlings (11 Oct). empty (12 Nov).	2.2	5
5	Three eggs (07, 08 and 10 Oct); Two young flying with difficulties with adults (12 Nov).	2.4	4
2009			
6	Three eggs (06 Oct).	3.6	1
7	Three nestlings (07 Oct).	4.2	1
8	Three eggs (08 Oct).	3.1	1

distant only 800 m from each other in 2006. The other patches had only one nest, in both years. Calculating an overall mean distance for the eight nests would not be adequate, as it would strongly reflect the distribution of the surveyed areas, and not real distances between existing nests. This is because other nests could be located in areas of savanna located between the sampled patches. Six of the eight nests were at less than 70 m from the park's frontier, while other two were in more interior portions of the park (firebreaks located at 2–8 km from its frontier). As longer distances were driven at the park's edge than in its interior, these numbers might reflect the sampling effort, and not nest-site selection.

Nests were rough and nearly round structures built with numerous sticks and twigs, a few leaves and clay; contrary to that described by Ferguson-Lees & Christie (2001), grasses were absent (Fig. 1). They were built in tree canopies, and five (62.5%) of them were in fruiting *Pouteria torta* (Mart.) (Sapotaceae). Trees that supported the other three nests could not be identified due to the loss of branches and photographs, but certainly were not *P. torta*. The height of nests ranged between 2.2 m and 3.8 m above the ground (Table 1), with a mean of 3.29 m (SD = 0.35).

Eggs and nestlings of *F. femoralis* were found in both years (Table 1). Eggs were of cream color and had some darker patches originated from dust (Fig. 1C). Clutches were always of three eggs. Observations permitted to examine hatching only for nests 1, 2, 3 and 4 (Table 1). Based on them, it was known that the 12 eggs originated 12 nestlings. Nestlings were born between 03 and 11 October in 2006 and before 07 October in 2009. Nestlings had a white plumage when aging 1–2 days (Fig. 1D). For two nests, no adults or young were found in the nest or in their surroundings in November 2006. Due to the long interval between visits, it was not possible to know if young had success or not, as predation, infanticide and fledging can be involved in nest success (Ferguson-Lees & Christie 2001, Brown & Collopy 2008). On the other hand, reproduction was successful (*sensu* Brown & Collopy 2008) for nests 2, 3 and 5, as adults were detected when flying with one or two young in the surroundings of their nests (Table 1).

As incubation by *F. femoralis* lasts for about 30–32 days (del Hoyo *et al.* 1994, Ferguson-Lees & Christie 2001) and young were born in early October, egg laying might have occurred in early September or late August. Thus, breeding activities such as pairing, the search for nesting sites and its nest building might start in August, coinciding with the end of the dry season in central Cerrado. October appears to be the main month involving young-care; this activity also reaches the next month, as adults still fly with their young around the nest until at least mid-November. The conduction of

Figure 1. Aspects of the nesting biology of the Aplomado Falcon (*Falco femoralis*) in Campo Cerrado woodland firebreaks at Parque Nacional das Emas, central Brazilian Cerrado, in October 2006: (**A**) a nest in a short *Pouteria torta* tree; (**B**) detail of a nest built in a fruiting *P. torta* tree; (**C**) a nest with three eggs; (**D**) two days old nestlings in a nest.

observations year-round in future studies will bring more detailed information on the length of different activities of their breeding in central Cerrado.

Generally, when the observer approached the nests in October, the adults left it; then, the pair kept flying around the tree and, alternately, performed a few flights towards the observer, with no physical contact, as often reported for falcons (*e.g.*, del Hoyo *et al.* 1994, Sick 1997, Ferguson-Lees & Christie 2001). On the other hand, the adults associated with two nests with eggs or nestlings also performed these defensive flights when the observer approached other nest distant about 15 m and 20 m from their nests. These nearby nests were very similar in structure to the active nests, but were empty (had no eggs or nestlings in October 2006). This behavior appears to be an attempt of distraction to make the observers (or potential predators) not find the real active nest.

No evidences of nest destruction or predation were detected in nests during this study. As observations made in October and November 2006 were separated by about 30 days, the absence of a nestling or young in the nests might represent predation, infanticide or a successful fledging prior to the latest inspection. The hatching rate of 100% (*n* = 4) observed in this study is higher than that recorded in other regions (*e.g.*, Montoya *et al.* 1997, Macías-Duarte *et al.* 2004, Meyer & Williams 2005, Brown & Collopy 2008). It was not possible to know what happened with eggs or young in the other four nests.

This is the second study to reveal a high percentage of occurrence of nests of Aplomado Falcons in a particular tree species. This is because Montoya *et al.* (1997) reported a preference for *Yucca elata* trees in Mexican desert grasslands, considering a sample of seven nests. Other studies have not identified the plant species used for nesting or involved a few nests, not being able to identify a choice (*e.g.*, de Lucca & Saggese 1996, Granzinolli *et al.* 2002, Macías-Duarte *et al.* 2004, Meyer & Williams 2005). Also, studies that investigated nest-site selection by these falcons examined physical nest-site characteristics, but not the plant species used for nesting (*e.g.*, Brown & Collopy 2008).

The preference for *P. torta* trees observed at Parque Nacional das Emas is weaker than that (86%) reported for Yuccas in Mexican grasslands by Montoya *et al.* (1997). It was not possible to know the reasons of this differential use of *P. torta* trees, especially because there is a high species richness of trees in Campo Cerrado firebreaks. Differently from that occurred with Yucca trees in Mexican grasslands (Montoya *et al.* 1997), where they were the only woody plants taller than 2 m, numerous plants were taller than *P. torta* at firebreaks. However, a similarity between them occurs - *Y. elata* is the second most abundant plant species in the desert grasslands (Montoya *et al.* 1997), while *P. torta* is abundant in the studied firebreaks (pers. obs.). In both regions, nest height was higher than 2 m. However, the mean height of nests found at firebreaks is lower than that reported for other regions, such as Argentina (de Lucca & Saggese 1996) and the Brazilian Atlantic Forest (Granzinolli *et al.* 2002).

Factors related to the access of adults to the nest, their departure from it, vigilance and avoidance of predators might be involved in the choice of trees for nesting. Interestingly, *T. caudatus* (pers. obs.) and *C. cristata* (Tubelis 2019) also use *P. torta* trees for nesting at firebreaks in October–November at Parque Nacional das Emas. This later study showed that *C. cristata* also built most (69%) of their nests in *P. torta* trees. As Aplomado Falcons sometimes use abandoned nests of other birds (del Hoyo *et al.* 1994, Ferguson-Lees & Christie 2001), further observations are necessary to know if these falcons use abandoned nests of seriemas, ibises and other bird species in the Cerrado.

The finding of clutches of 3 eggs in woodland firebreaks agrees with results of major compilations of information on the breeding biology of *F. femoralis,* that reported nests with 2–4 eggs (del Hoyo *et al.* 1994, de Lucca & Saggese 1996, Ferguson-Lees & Christie 2001). Similar to this study, several studies had reported as frequent clutches of 3 eggs in a diverse range of regions (*e.g.*, Newton 1977, del Hoyo *et al.* 1994, Montoya *et al.* 1997, Granzinolli *et al.* 2002).

This is the third study to examine the use of firebreaks as nesting sites by birds at Parque Nacional das Emas, as it has been shown that Burrowing Owls [*Athene cunicularia* (Molina, 1782)] and Red-legged Seriemas build their nests in fire managed grasslands and savanna woodlands, respectively (Tubelis & Delitti 2010; Tubelis 2019). In both cases, nests were more abundant at firebreaks than in unmanaged vegetation, and it was argued that a major reason leading to this nest choice was the shortening of tall Capim Flecha grasses by frequent burning. Apparently, the burning of firebreaks in June–July (França *et al.* 2002) is also leading to suitable conditions for the breeding of *F. femoralis*. Likely, a short grassy stratum favors vigilance and prey capture by falcons at firebreaks. As unmanaged woodlands were not investigated in this study, further research is necessary to understand the influence of fire management on the breeding biology of this species in the Cerrado. This study has shown that Aplomado Falcons can successfully reproduce in Campo Cerrado firebreaks at Parque Nacional das Emas.

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ARTICLE

Fire management and aspects of the nesting biology of the Red-legged Seriema (*Cariama cristata*) in woodlands at Parque Nacional das Emas, central Cerrado

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ABSTRACT: In the Brazilian Cerrado Biome, fire management within conservation units is usually restricted to burning grassland and woodland strips during the dry season to stop fires from spreading. Although it is a common practice, the impact of fire management on birds remains poorly investigated. This study aimed to examine the effects of fire management on nest-site selection by the Red-legged Seriema, *Cariama cristata*, and to describe nest-building characteristics at Parque Nacional das Emas (PNE). Nests were searched and monitored throughout 34 study sites between October and November 2006. These sites were 2.5-km strips of Campo Cerrado woodlands with (firebreaks) and without fire management, located at the interior and boundaries of the park. A total of 13 nests were found, all within firebreaks at the edge of the park. Nine (69%) of them were in fruiting *Pouteria torta* (Mart.) (Sapotaceae). Two or three white eggs were found in the nests. Nests had eggs and nestlings in October and no nestlings were found in November. Nests were usually in tree canopies and some of them were built nearly over the park's fence. At PNE, breeding pairs of *C. cristata* are attracted to firebreaks located at the park's boundaries. This is probably due to mobility through often burnt vegetation and ease in obtaining food from adjacent unsealed roads, exotic plantations and cleared areas. This study suggests that fire managers should: 1) avoid extinguishing natural fires initiated during the rainy season and 2) rotate controlled burning of patchy areas of Campo Cerrado woodlands. These two procedures should ensure the presence of suitable woodlands with short grasses in interior portions of PNE.

KEY-WORDS: bird, breeding season, Cariamidae, egg, nest, reproduction, Savanna.

INTRODUCTION

Fire management for biodiversity conservation is a common practice in several temperate and tropical regions (*e.g.*, Miranda *et al.* 2009, Bardsley *et al.* 2019, Phalan *et al.* 2019). Birds' responses can vary with characteristics of prescribed fires, such as severity, frequency, heterogeneity and season (Greenberg *et al.* 2019, Zlonis *et al.* 2019). Fire management may affect birds' abundance and breeding due to changes in the vegetation and associated resources (*e.g.*, O'Loughlin *et al.* 2019, Ragheb *et al.* 2019). Studies on avian response to different types of fires have predicted future fire scenarios, thus promoting the conservation of target species (*e.g.*, Connell *et al.* 2019).

In the Cerrado, a Savanna eco-region in central Brazil, fire management in conservation units usually involves burning woodland and grassland strips almost every year (Miranda *et al.* 2002, 2004, França *et al.* 2007). These strips of managed vegetation are firebreaks that lie between two unsealed roads and are settled along borders and in the interior of conservation units (Ramos-Neto & Pivello 2000, França *et al.* 2007). Firebreaks usually occur in the dry season to create areas of vegetation with reduced biomass that stop fires from adjacent farmlands (Pivello 2006, França *et al.* 2007).

Although the impact of fires on the Cerrado flora is well known, information about its influence on many groups of native fauna is lacking (Mistry 1998, Miranda *et al.* 2004, 2009). Few studies have examined the impacts of natural or accidental fires on bird communities (*e.g.*, Fry 1970, Cavalcanti & Alves 1997, Cintra & Sanaiotti 2005), and research on the impact of fire management on particular species is scarce. For example, at Parque Nacional das Emas (PNE), in central Brazil, two investigations showed that Blue-and-yellow Macaws, *Ara ararauna*, are attracted to grassland and woodland firebreaks. They seek the firebreaks to eat fruits of Cashew-apples *Anacardium humile*, a species benefited by fire (Tubelis 2009a, b). Further, the only study investigating the influence of fire management on bird reproduction in the Cerrado, also at PNE, has shown that active nests of Burrowing Owls, *Athene cunicularia*, are more numerous in managed grasslands than in unmanaged patches (Tubelis & Delitti 2010). However, the influence of fire management within

Cerrado conservation units is still unknown for most bird species.

This lack of information includes the Red-legged Seriema, *Cariama cristata* Linnaeus, 1766, a large terrestrial bird species typical of Cerrado landscapes (Antas & Cavalcanti 1988, Sick 1997). Adults of this species are about 90 cm high and body mass around 1.5 kg (Gonzaga 1996, Sick 1997). Their long legs allow them to walk and run on unsealed roads and through non-forest vegetation in landscapes covered by native matrix types, exotic plantations and cleared areas (Miranda-Ribeiro 1937, Redford & Peters 1986, Brooks 2014). They are territorial animals (Souza *et al.* 2018) that feed on arthropods, small rodents, lizards and snakes (Gonzaga 1996).

Red-legged Seriemas breed between September and January in Brazil. Nests are round, rough structures composed of sticks and twigs lined with leaves, grasses and clay (Miranda-Ribeiro 1937, Almeida 1994, Silva *et al.* 2016). Birds usually build nests in trees, 1–5 m above ground, and lay up to four eggs that are incubated for one month (Redford & Peters 1986, Almeida 1994, Gonzaga 1996). Red-legged Seriemas inhabit burned and unburned savanna vegetation at PNE (Redford & Peters 1986), and their responses to fire management remain unstudied. The objective of this study was to investigate the effects of fire management on nest-site selection by *C. cristata* at PNE. I compared the number of nests in areas of Campo Cerrado woodlands with (firebreaks) and without fire management. I also described characteristics of their nests, eggs, nestlings, plant support for nest building, and nest position in the woodlands. Results are discussed in terms of the influence of fire management on birds in Cerrado conservation units.

METHODS

Study area

This study took place at Parque Nacional das Emas (PNE), a 132,000 ha conservation unit in the state of Goiás, central Brazil (Fig. 1). This reserve harbors several vegetation physiognomies commonly found in the Cerrado. Grasslands are the main matrix type, covering mostly flat uplands (França *et al.* 2007). Another matrix type occurring in uplands is the Campo Cerrado woodland (Eiten 1993). Its herbaceous stratum is also developed but shrubs and trees are more numerous than in grasslands (Eiten 1972, Oliveira-Filho & Ratter 2002). However, the woody strata are open enough to allow large terrestrial vertebrates to pass through (Antas & Cavalcanti 1988, Marinho-Filho *et al.* 2002). Less dominant physiognomies in this park are gallery forests and *veredas* – wet grasslands with scattered palm trees (França *et al.* 2007). Further information on Cerrado landscapes can be found in general references about this eco-region (*e.g.*, Eiten 1972, Oliveira & Marquis 2002, Scariot *et al.* 2005).

Elevation at PNE ranges between 720 and 900 m a.s.l. (França *et al.* 2007). The regional climate is marked by two well-defined periods: the dry season, between May and September; and the rainy season, between October and April. Annual rainfall ranges between 1200 and 2000 mm and temperatures usually range between 10°C in the winter (July) and 40°C in the summer (January) (Assad 1994).

At PNE, fires can be natural or human-induced (Redford 1985, França *et al.* 2007). During the rainy period, natural fires from lightning tend to burn small areas, which are stopped by the rain (Ramos-Neto & Pivello 2000). Illegal human-induced fires originate on adjacent farms and are used to renew the grassy vegetation for cattle. These fires start during the dry period and can reach the park, where they can spread through extensive portions of the landscape (Ramos-Neto & Pivello 2000, França *et al.* 2007). Fire management by park managers is restricted to maintaining the firebreaks, *i.e.*, grassland or woodland strips that usually burn in the dry season (June, July). These procedures avoid fire from spreading to the inner area of the park during the dry season. Firebreaks are located between two unsealed roads and are usually 25–100 m wide (Ramos-Neto & Pivello 2000, França *et al.* 2007).

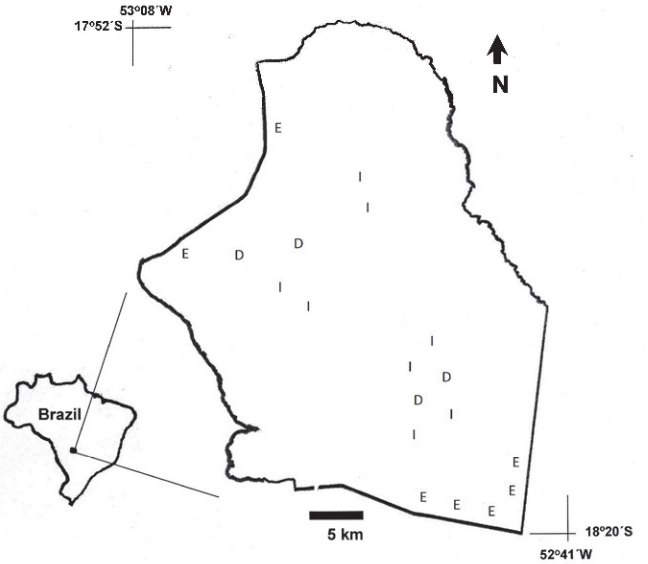

Figure 1. Location of the 34 study sites searched for *Cariama cristata* nests at Parque Nacional das Emas, in Goiás state, central Brazil, in October and November 2006: (**E**) pairs of study sites formed by a firebreak and an adjacent unmanaged woodland located at the edge of the park; (**I**) pairs of study sites formed by a firebreak and an adjacent unmanaged woodland located in the interior of the park; (**D**) unmanaged woodlands distant from roads and located in the park's interior.

Study sites

I selected a total of 34 study sites (2.5-km long and 30 to 80-m wide transects) at PNE (Fig. 1). These were portions of Campo Cerrado woodlands grouped into five treatments, with a variable number of replicates: 1) "edge firebreaks", *i.e.*, fire-managed Campo Cerrado woodland strips adjacent to the park frontier (seven replicates), 2) "adjacent to edge woodlands", *i.e.*, unmanaged Campo Cerrado woodland strips adjacent to the edge firebreaks (seven replicates), 3) "interior firebreaks", *i.e.*, fire-managed Campo Cerrado woodland strips located more than 3 km away from the park frontiers (eight replicates), 4) "woodlands adjacent to interior firebreaks", *i.e.*, unmanaged Campo Cerrado woodland strips adjacent to interior firebreaks (eight replicates), 5) "distant woodlands", *i.e.*, Campo Cerrado woodland strips more than 3 km away from the park frontiers and more than 400 m away from roads (four replicates). Sampled firebreaks and adjacent woodlands were separated by an unsealed road about 7 m wide. These study sites were spread at least 700 m apart throughout the park (Fig. 1).

The vegetation of the sampled firebreaks and unmanaged woodlands differed mainly in relation to the height of the grassy stratum. All study sites were dominated by Capim Flexa grass (*Tristachya leiostachya* Ness.), usually 80–150 cm high in unmanaged woodlands and 20–30 cm high in firebreaks (pers. comm.). These differences in vegetation occur because unmanaged woodlands are usually burned every 6–10 years by natural or accidental fire, while park managers usually burn firebreaks every 1–2 years at PNE (França *et al.* 2007). Some firebreaks had sparse fully developed Capim Flexa grass, since there was lack of funding for burning.

To ensure the sampling for comparable areas with different treatments, I selected uniform firebreak sections and sampled the same width in adjacent woodlands. The width of firebreaks and adjacent woodland sites ranged between 30 and 70 m. Distant woodland sites were 100 m wide due to a lower number of replicates, thus, the observer had about 50 m of woodlands on each side. The length of study sites was determined using a Garmin GPS with an error of 8 m.

Search for nests

I searched for *C. cristata* nests in the study sites every morning (09:30 h to 11:00 h) and afternoon (15:00 h to 17:00 h) between 01 and 12 October 2006. Four to eight study sites were searched in a given day. I slowly drove a vehicle along the road between firebreaks and adjacent woodlands. When a high density of fully developed Capim Flexa grass hindered visibility, I would leave the vehicle and enter the woodland to continue the search on foot. After sampling a firebreak, the adjacent woodland was surveyed in the opposite direction. Distant woodlands were always searched on foot, since there were no roads.

Sightings favored large size nests in tree canopies. Every large nest detected was approached on foot to verify whether it was a Seriema nest. Species such as the Aplomado Falcon, *Falco femoralis* (Temminck, 1822), and the Buff-necked Ibis, *Theristicus caudatus* (Boddaert, 1783), also build large arboreal nests at firebreaks during this period (Tubelis 2019b). When I approached, adult birds were identified when they flew (falcons and ibises) or ran away (Seriemas) from the nests.

Observations and measurements

After been found, nests were visited 2–3 times during the search period and once in a second period (between 11 and 14 November 2006) to verify the presence and conditions of eggs and nestlings. This interval of about 30 days between the two periods occurred due to time availability. During each visit to a nest, I used a mirror fixed to a pole to count nestlings and eggs. The distance between the bottom of the nests and the ground was measured with a Bosch laser tape. Additionally, small branches from where nests were built were collected and photographed to identify the plant. I did not measure nests and did not handle nestlings or eggs. On a few occasions, eggs and nestlings were counted and photographed by climbing the tree.

RESULTS

Thirteen *C. cristata* nests were found in the 34 study sites located at PNE. All of them were at edge firebreaks, and one (*n* = 1) or two (*n* = 6) nests were found at each of the seven study sites. Thus, no nests were found in interior firebreaks, nor in sites of the three treatments regarding unmanaged woodlands.

Nests were rough and nearly round structures built with diverse materials, such as sticks, twigs and clay (Fig. 2A, B). Eight (61%) nests contained white eggs with some brownish dust patches (Fig. 2B). Only one nest had three eggs, while seven had two eggs. Another five (39%) nests had no eggs, but did have two nestlings, when examined for the first time (Table 1). Nestlings were mostly gray, with thin white feathers mainly on the head and belly (Fig. 2C).

On three occasions, adult birds showed aggressive behavior in response to the observer's approach (Fig. 2D), thus nests were not examined. This behavior occurred during the late incubation period, as revealed by examination of the nests a few days later (Table 1). Eggs were found in nests from the second to the last day of the

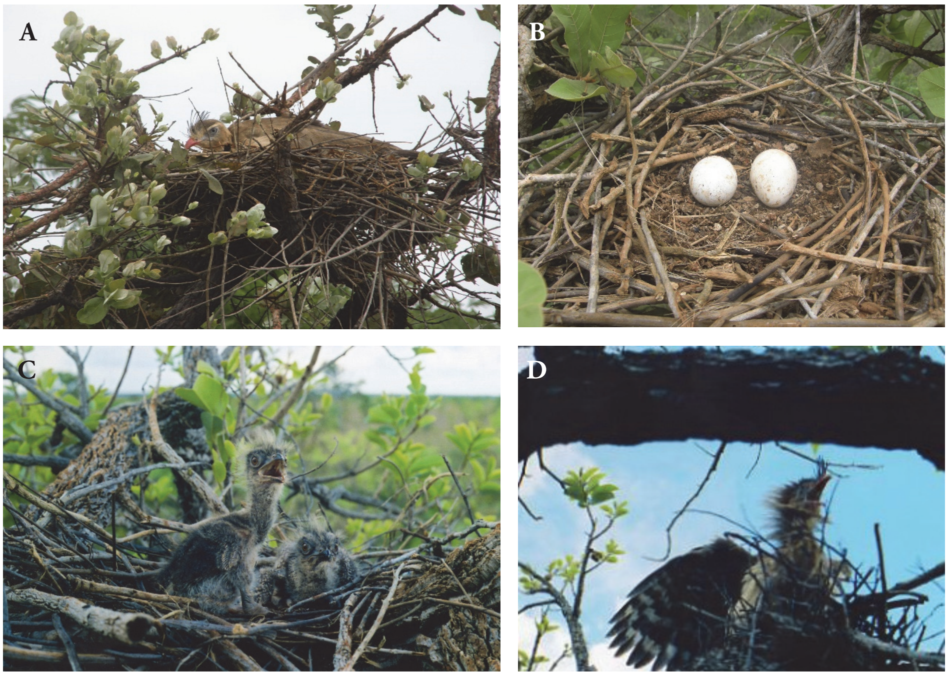

Figure 2. Aspects of the nests, eggs, nestlings and adults of *Cariama cristata* in woodland firebreaks at Parque Nacional das Emas, central Brazilian Cerrado, during the 2006 breeding season: (**A**) an adult incubating eggs; (**B**) two eggs in a nest; (**C**) two nestlings in a nest; (**D**) an adult with aggressive behavior in response to the observer's approach.

Table 1. Nest contents, height and distance to park's fence of Reg-legged Seriemas, *Cariama cristata*, in woodland firebreaks (Campo Cerrado strips managed by fire) at the edge of Parque Nacional das Emas, central Brazil, in October and November 2006.

Distance (m)	Height (m)	Nest content
01	2.8	Two eggs (02 and 10 Oct); two nestlings (12 Oct); empty (14 Nov).
25	2.2	Three eggs (03, 05 and 07 Oct); empty (14 Nov).
12	2.3	Two eggs (04, 08 and 12 Oct); empty (13 Nov).
74	3.8	Two nestlings (04, 10 and 12 Oct); empty (12 Nov).
20	2.4	Two nestlings (01, 02 and 11 Oct); empty (14 Nov).
38	2.6	Two nestlings (05, 06 and 09 Oct); empty (12 Nov).
08	2.9	Two eggs (02, 04 and 09 Oct); empty (14 Nov).
01	2.7	Two eggs (04, 06 and 08 Oct); two nestlings (11 Oct); empty (13 Nov).
10	3.2	Two eggs (04, 07 and 09 Oct); empty (12 Nov).
18	2.2	Two eggs (03 and 07 Oct); two nestlings (08 Oct); empty (14 Nov).
32	1.8	Adult did not leave the nest (05 Oct); two nestlings (07 and 10 Oct); empty (12 Nov).
22	4.3	Two eggs (03 Oct); adult did not leave the nest (08 Oct); two nestlings (11 Oct); empty (11 Nov).
54	2.7	Adult did not leave the nest (02 and 09 Oct); two nestlings (10 Oct); empty (11 Nov).

search period (02–12 October). Similarly, nestlings were found in nests between 01 and 12 October. For four nests, I recorded two nestlings a few days after finding two eggs, indicating egg hatching between 07 and 12 October. The number of eggs and nestlings found per nest was always the same for the consecutive inspections in October. All nests had no eggs or nestlings in mid-November (Table 1). There was no evidence of nest predation or destruction.

All nests were built on trees. They were up to 74 m away from the park boundaries, and two nests were nearly on top of the fence (Table 1, Fig. 3B). The mean distance of the nests to the fence was 24.2 m (SD = 21.1). Nest

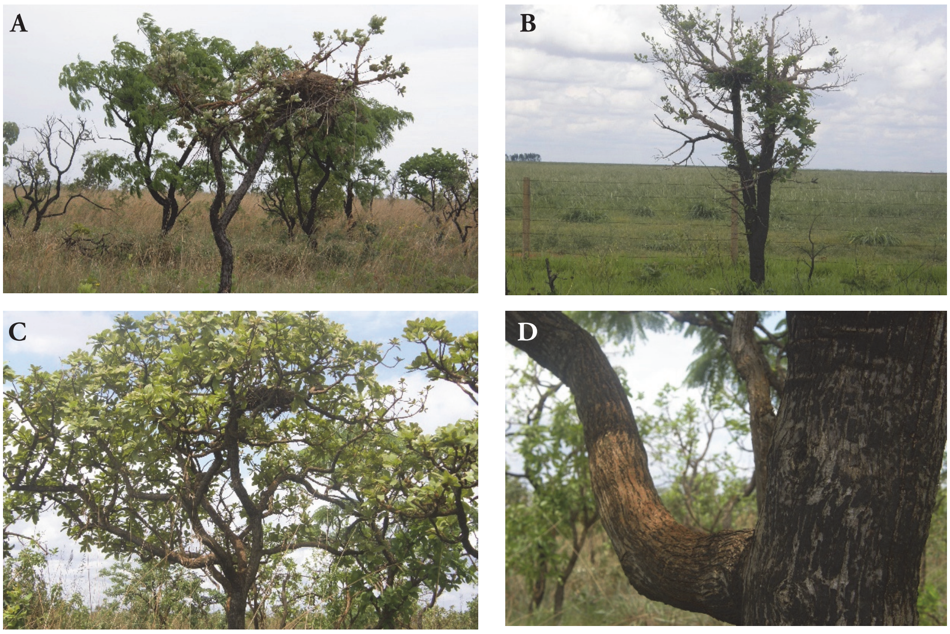

Figure 3. Aspects of the vegetation and nests of *Cariama cristata* at firebreaks located along the edge of Parque Nacional das Emas, central Brazil, in October 2006: (**A**) a nest built in the canopy of a small tree located in an area with sparse trees; (**B**) a nest built nearly over the park's fence adjacent to a pasture; (**C**) a nest built in a tree canopy in an area with denser woody vegetation; (**D**) a branch often used by adults to jump to the nest.

height ranged between 1.8 and 4.3 m, with a mean of 2.8 m (SD = 0.9). Trees that supported the nests could be short with a few branches or tall, highly ramified and with numerous leaves (Fig. 3A, B, C). As nests were built on canopies, adults usually perched on branches and leaves. Some trees had lower branches adults used to jump up to the nest (Fig. 3D). Nine (69%) nests were in fruiting *Pouteria torta* (Mart.) (Sapotaceae), one in *Piptocarpha rotundifolia* (Less.) Baker (Vernonieae) and the others in *Annona crassiflora* Mart. (Annonaceae). Other plants could not be identified due to missing photographs and branches.

DISCUSSION

Nest distribution in the study sites

Nests were found exclusively at edge firebreaks, not been recorded in sites of the other treatments. Their absence in unmanaged Campo Cerrado might be mainly due to factors related to vegetation. Probably, young and adult Seriemas have trouble walking through the dense and tall grassy stratum dominated by fully developed Capim Flexa in unmanaged woodlands. On other hand, frequent controlled fires mean shorter grass, probably favoring mobility and vigilance at the firebreaks.

Further, the two unsealed roads adjacent to managed woodlands could favor nesting on edge firebreaks. *Cariama cristata* often use the roads in this park (Redford & Peters 1986), which are important for mobility, especially for the younger birds. Another factor that contributes to choosing boundary firebreaks for nesting is the presence of exotic plantations and cleared areas adjacent to the park, where Seriemas often forage. From November to February, pairs and families expand their home range up to 400–500 m into soybean plantations and harvested areas adjacent to PNE to search for food resources such as grasshoppers, beetles, rodents, lizards and birds (pers. com.), similarly to that observed for Southern Caracaras, *Caracara plancus* Miller, 1777 (Tubelis 2019a).

On the other hand, obstacles to establish territories and home ranges, which usually encompass about 20 ha in the Cerrado (Souza *et al.* 2018), meant there were no nests in the interior firebreaks. Breeding pairs would need to increase their home range to nest in interior firebreaks, as these managed strips were surrounded by an unsuitable matrix marked by high densities of tall Capim Flexa grass. In interior portions of the park, these managed woodlands and adjacent roads usually measure 30 m and 7 m in width, respectively. Thus, home ranges would measure about 44 m in width and 4.5 km in length to reach 20 ha. Such extremely long home ranges would bring negative consequences for nestling care and foraging efficiency (see Pyke *et al.* 1977, Tubelis *et al.* 2004).

The absence of *C. cristata* nests in four treatments most likely did not result from low detectability in tall grasses, since nests are easily seen as large and dark structures in trees. Moreover, in cases of low visibility due to tall grass, the observer occasionally left the vehicle and walked for hundreds of meters on adjacent woodlands. The sampling in this study was enough to discover nests in a selection of edge firebreaks. This pattern should not be interpreted as a total dependence on edge firebreaks, but as a general tendency to use managed woodlands that are adjacent to the frontiers of PNE.

Eggs, nestlings, nests and trees

Clutches with two and three eggs recorded at firebreaks agrees with findings from previous studies (*e.g.*, Redford & Peters 1986, Almeida 1994), and clutches with one to four eggs were also reported in major reviews regarding the reproduction of Seriemas (*e.g.*, Miranda-Ribeiro 1937, Gonzaga 1996). Redford & Peters (1986) reported nests found in September and October at PNE. Although in the present study I did not search in September, all nests found at firebreaks had eggs or nestlings in the first half of October. Considering that incubation period lasts a month (Gonzaga 1996), eggs were laid in early September or late August at firebreaks. Thus, breeding activities of the studied Seriemas began during the dry season at PNE. Also in agreement with Redford & Peters (1986), I found no eggs or nestlings during the second period of inspections (mid-November). As the two periods of observations of this study were separated by nearly 30 days, I cannot be sure whether the absence of nestlings in November represents predation or successful fledging. However, there is no evidence of nest destruction by storms, humans or animals, since as all nests were still in the trees and had no signs of damage in the last period of field activities.

The nest heights at firebreaks are within the range reported in the most recent review on the biology of Seriemas (Gonzaga 1996), which reported nests at heights of 1–5 m. Additionally, the general aspect of the nests, their size and materials were similar to those reported in previous studies (*e.g.*, Miranda-Ribeiro 1937, Redford & Peters 1986, Almeida 1994).

Seriemas probably consider accessibility as a factor when selecting trees for nesting. Since adults bring vegetal material to the nest on short flights (Almeida 1994, Silva *et al.* 2016), they may choose tree canopies with a certain branch architecture and amount of leaves to perch, move in the nests during incubation, care for nestlings, and detect potential predators. Moreover, they may prefer trees with one or a few nearly horizontal branches at lower heights for their frequent jumps towards the nest. *Pouteria torta*, the plant species most frequently used for nesting, appears to provide these advantages for Seriemas. It is abundant in Campo Cerrado firebreaks and its height is like most trees (pers. obs.). This tree was fruiting in October and November, but the fruit was not ripe, so it was probably not attractive for potential omnivorous predators during the Seriemas' nesting period. Previous studies on Seriema breeding have not reported nests in *P. torta* trees (*e.g.*, Redford & Peters 1986, Almeida 1994, Marini *et al.* 2012). The literature has not identified a preference for any given species, since few nests were found.

Fire management and conservation issues

For large mammals conservation, Silveira *et al.* (1999) recommended a fire management program including rotating controlled fires in different sections of PNE. Additionally, Ramos-Neto & Pivello (2000) stressed the need for reevaluating policies and management procedures concerning fire in this park. They argued that the natural fire regime benefits biodiversity, since fires started by lightning create mosaics of grassland and woodland patches with different amounts of biomass throughout the park (Ramos-Neto & Pivello 2000).

My study of *C. cristata* agrees with these two investigations. Natural fires in the rainy season shortened grasses, creating suitable patches of Campo Cerrado woodlands for Seriemas. Similarly, fire management programs can generate such patches (woodlands surrounded by firebreaks) by rotating human-induced fires on several sections of the park. These patches of Campo Cerrado woodland without fully developed Capim Flexa grass would be essential to nest a desirable number of Seriemas inside the park. Although firebreaks mitigate the negative effects of dominant tall Capim Flexa grass, this could lead to negative consequences for Seriemas if this is the sole fire management practice at PNE. Without enough suitable habitat throughout the park, the population of Seriemas will remain concentrated near its boundaries.

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ARTICLE

Nest, eggs and nestling description of the Silvery-flanked Antwren *Myrmotherula luctuosa* (Pelzeln, 1868) in the Atlantic Forest of northeast Brazil

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ABSTRACT: In the present study, we describe the nest, eggs, and nestlings of the Silvery-flanked Antwren, *Myrmotherula luctuosa*. One nest was found on 08 May 2017 on the edge of one of the forest fragments of the Serra de Itabaiana National Park, in the state of Sergipe, northeast Brazil, and was monitored until 21 May 2017. The nest, presented the following dimensions: external height: 7.6 cm; outside diameter: 21 × 19 cm; internal diameter: 13.3 × 11 cm; depth of the oologic chamber: 4.7 cm; and height in relation to the ground: 84 cm. The two eggs found in the nest were white with reddish-brown dots, patches and stripes and weighed 1.7 and 1.5 g. Incubation was performed by both the male and female, as well as feeding of the nestlings. A single egg hatched, giving rise to a 3.9 cm, 3.7 g nestling. According to our estimates, the young fledged with about 11 days. This is the first study to present information about the reproductive biology of the Silvery-flanked Antwren.

KEY-WORDS: Itabaiana National Park, parental care, reproduction, Thamnophilidae.

INTRODUCTION

Most species of the Thamnophilidae family are considered socially monogamous and form permanent breeding pairs who defend their territories with considerable vigor throughout the year (Zimmer & Isler 2003). Within this family, the genus *Myrmotherula* is the most numerous. Chaparro-Herrero & Ruiz-Ovalle (2014) pointed out that information on the reproductive biology of this genus is limited to nest descriptions and parental care in a few species. Of the 20 species within this genus in Brazil, there is enough information about reproduction only for seven species (*M. surinamensis*, *M. pacifica*, *M. multostriata*, *M. axillaris*, *M. longipennis*, *M. unicolor* and *M. menetriesii*); for other six species there is no information about reproduction or, only anecdotal information is available (Zimmer *et al.* 2019).

Nests are described as a ball of dead leaves with a mean diameter of 8 cm, suspended in forks varying from 2 to 10 m above the ground; normal clutch size of 2 white eggs with reddish spots; incubation varying from 16 to 19 days and parental care provided by both parents (Zimmer *et al.* 2019).

The Silvery-flanked Antwren (*Myrmotherula lucutosa*) inhabits the understory of primary and secondary Atlantic Forest areas from Brazil (Sick 1997, del Hoyo *et al.* 2019). It presents a marked sexual dimorphism, with males paler than females, presenting a blackish belly and a pale grey flank; females are more olive-tinged grey with an ochraceous belly (Grantsau 2010). It is insectivorous and little is known about its reproduction, only mentioned that its nest is similar in shape, size and materials to that of the White-flanked Antwren *M. axillaris* (Zimmer & Isler 2003, del Hoyo *et al.* 2019). In this way, this study aimed to provide information on the reproductive biology of the Silvery-flanked Antwren, presenting for the first time information about nest, eggs, and parental care.

METHODS

The study was carried out in May 2017 in the Serra de Itabaiana National Park (PARNASI), Sergipe state, northeastern Brazil (10°40'S; 37°25'W). PARNASI is formed by a complex of three mountain ranges: Cajueiro, Comprida and Itabaiana. The three mountain ranges together comprise an area of 7966 ha, and the highest point is in the Itabaiana mountain range, 660 m a.s.l. (Carvalho & Vilar 2005). The park area is in a transition between the Atlantic Forest and Caatinga Biomes. The climate of the region is tropical with dry summer and moderate wet winter, with temperatures varying between 17 and 23°C (Vicente 1999).

Nest monitoring started at the time of its discovery; it was visited at intervals of 3 to 4 days. The nest, eggs and the nestling were described, weighed and measured using a caliper, accurate to 0.01 mm, and a spring scale, accurate to 0.1 g. During critical phases, such as hatching and fledging, the nest was monitored at shorter intervals of 1 to 2 days, always trying to minimize the impacts caused by human presence. The measurements of the nest were obtained on the day of its discovery, to avoid natural deformations due to its use. Nest characteristics measured were: height of the external part of the nest, external and internal diameter, depth of the oological chamber (edge of the nest until the deepest area of its center) and height of the nest in relation to the ground (the latter with the aid of a measuring tape). In the case of the nestling, its developmental stage was described based on its mass (g), size (cm), shape and color of feathers, beak and tarsi, and on the presence of closed or open eyes.

RESULTS

On 08 May 2017, a nest of *M. luctuosa* was found on the edge of one of the fragments of Atlantic Forest located in the PARNASI. The nest was found hidden beneath a leaf of *Heliconia* sp. (Heliconiaceae) and was strongly attached to a horizontal fork of a sapling, 84 cm above the ground. At that time, the female was incubating two eggs. The nest was a deep cup made up mainly of fragments of dry leaves of different plant species, and the incubatory chamber was lined with a large amount of light brown flexible rootlets. The whole structure was contained within a flimsy basket of black rootlets filaments that also provided attachment to the horizontal fork (Fig. 1). Nest measurements were: height of the external part of the nest (7.6 cm), external diameter (21 × 19 cm), internal diameter (13.3 × 11 cm), depth of the oological chamber (4.7 cm), and height of the nest in relation to the ground (84 cm).

Eggs were white with reddish-brown dots and stripes on the terminal portion of the rhombus pole (Fig. 1A). On 12 May 2017, it was observed that only one chick had hatched. The mass, diameter and length of the eggs are presented in Table 1.

The nestling registered on 12 May 2017 measured 3.9 cm and weighed 3.7 g. It had no feathers, had closed eyes, pale skin and tarsi, and yellow-orange beak, labial commissure, tongue and mouth lining (Fig. 1B). On 14 May 2017, there were already open eyes and clear

Figure 1. Nest (**A**), eggs (**A**, **B**) and nestling (**B**, **C**, **D**) of *Myrmotherula luctuosa*. Photo author: Cleverton da Silva.

presence of black feather cannons, mainly on the wings, back and head (Fig. 1C). The presence of the first feathers was recorded on 18 May 2017. On that day, the nestling measured 7.2 cm, weighed 7.2 g, had greyish feet and tarsi and black beak, contrasting with the yellow labial commissure and mouth lining (Fig. 1D).

On 21 May 2017, the nestling was seen outside the nest with very short wings and tail, moving between the medium forest extract through short and weak flights. A plumage of color similar to that of the adult female was already observed.

DISCUSSION

The nest form, position and materials of the *Myrmotherula* species are diverse (Chaparro-Herrera & Ruiz-Ovalle 2014), which makes comparison difficult if there are no clear descriptions (see Simon & Pacheco 2005). The nest of *M. luctuosa* in this study is similar to that of *M. axillaris*, which is described as a deep bowl made of dried leaves and rhizomorphic black filaments on the outside and light filaments on the inside (Zimmer & Isler 2003). Other *Myrmotherula* species, such as *M. multostriata*, *M. pacifica*, *M. cherriei*, *M. longipennsis* and *M. unicolor*, also use plant fibers, roots and dry leaves to build their nests (Zimmer & Isler 2003, Chaparro-Herrera & Ruiz-Ovalle 2014), being similar in shape but not in type or color of materials used if compared to the nest of *M. luctuosa*.

Table 1. Morphometry of the *Myrmotherula luctuosa* eggs found in the Serra de Itabaiana National Park, Sergipe, Brazil, on 08 May 2017.

Characteristics	Egg 1	Egg 2
Mass (g)	1.7	1.5
Diameter (mm)	12.55	12.53
Length (mm)	17.15	17.16

The height at which the nest of *M. luctuosa* was built (84 cm) is similar to that found in nests of other species of the Thamnophilidae family, such as *Cercomacra melanaria* (98 cm; Pinho *et al.* 2006), *Hypocnemoides maculicauda* (113 cm; Evangelista 2008), *Taraba major* (128 cm; Lara *et al.* 2012) and *Thamnophilus pelzelni* (102 cm; Silva & Carmo 2015). In addition, it was similar to the nest height of other *Myrmotherula* species: *M. assimilis* (380 cm; Leite *et al.* 2016), *M. surinamensis* (50–100 cm; Chaparro-Herrera & Ruiz-Ovalle 2014), *M. multostriata* (300–400 cm; Chaparro-Herrera & Ruiz-Ovalle 2014), *M. axillaris* (20–400 m; Chaparro-Herrera & Ruiz-Ovalle 2014) and *M. unicolor* (80–200 cm; Zimmer *et al.* 2019). *M. brachyura*, *M. ignota*, *M. cherriei*, *M. minor*, *M. longipennis* and *M. menestrierii* build nests high above the ground (more than 300 cm high) (Zimmer *et al.* 2019).

In general, the species of the Thamnophilidae present a clutch of two eggs, with rare cases of three eggs (Skutch 1996, Sick 1997, Robinson *et al.* 2000, Zimmer & Isler 2003, Pinho *et al.* 2006, Perrella *et al.* 2015). Thamnophilidae species present eggs different in colors, and in the genus *Myrmotherula* important differences can be observed in the color patterns of their eggs (Zimmer & Isler 2003, Chaparro-Herrera & Ruiz-Ovalle 2014). The *M. luctuosa* eggs observed in this study are similar to the color pattern found in *M. axillaris* eggs (Zimmer & Isler 2003, Chaparro-Herrera & Ruiz-Ovalle 2014).

The young fledged with 11 days, but it could have occurred early due to the manipulation to obtain its measurements. Other species of Thamnophilidae showed similar nestling periods, such as *C. melanaria* (10 days; Pinho *et al.* 2006), *H. maculicauda* (11 days; Evangelista 2008), *Rhopias gularis* (11 days; Perrella *et al.* 2017) and *Taraba major* (13 days; Lara *et al.* 2012).

During the reproductive activity, it was observed that both the female and the male participated in the incubation of the eggs (Fig. 2), and fed the nestling, like observed in other Thamnophilidae, such as *C. melanaria*

Figure 2. Female (**A**) and male (**B**) of *Myrmotherula luctuosa* inside the nest during the incubation and parental care periods. Photo author: Cleverton da Silva.

(Pinho *et al.* 2006), *H. maculicauda* (Pinho *et al.* 2006), *T. pelzelni* (Silva & Carmo 2015) and *R. gularis* (Perrella *et al.* 2017).

This is the first study to present information about the reproductive biology of the Silvery-flank Antwren *M. luctuosa*. The description of its nest, eggs and parental care add valuable information about the reproductive biology of the genus *Myrmotherula*, thus contributing to the understanding of the life history pattern of this group of Neotropical passerines.

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First record of death-feigning in Black Vultures (*Coragyps atratus*) (Cathartidae)

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ABSTRACT: Death-feigning is a behavior ability with the purpose of allowing prey to evade from predators. Despite death-feigning is recorded on a wide variety of bird species, it has been recorded only once in vultures, more specifically on a Turkey Vulture (*Cathartes aura*) nest. In addition to this record, we report this behavior while manipulating an individual of Black Vulture (*Coragyps atratus*) in Brazil. This behavior is not usual in Cathartidae since adult vultures do not have a known natural predator.

KEY-WORDS: anti-predator behavior, Brazil, physical contact, thanatosis.

Although Black Vultures (*Coragyps atratus*) are considered gregarious and group-forming species that can reach hundreds of individuals that feed, soar and roost together, they do not breed in colonies. They are not territorialists and fly large areas in search of food and shelter, considered rapid colonists, mainly in newly-opened anthropic-formed areas. Since individuals fly widely, they are considered as partially migratory birds, keeping longer periods of time in areas where a higher amount of resources is available (Mundy 1985, Souto 2008, Ribeiro *et al.* 2010). On the other hand, they have a strong agonistic behavior when it comes to a resource dispute, due to food competition. Among age-groups there are different behavioral features, such as juveniles being more submissive to the elders, as reported by Kruuk (1967), Houston (1975) and Ribeiro *et al.* (2010).

Aggregation in American Black Vultures brings about advantages, such as increased social interactions. Individuals may also benefit by being close to one another, mainly through thermoregulation mechanisms by using communal perches in trees, rocks or urban infrastructure (Campbell 2015, Ballejo 2016).

Thanatosis (or death-feigning) frequently occurs in response to the presence of predators, generating a state of immobility by the prey (Miyatake *et al.* 2004, Humphreys & Ruxton 2018). Although thanatosis has been described in many groups, such as mammals, birds, fish, reptiles, amphibians, arachnids and insects (Miyatake *et al.* 2004, Humphreys & Ruxton 2018), it is more frequently found in prey than predators, like vultures. Few studies have reported thanatosis in predators, for example, Vogel-Jr. (1950) recorded thanatosis in a wild adult Turkey Vulture (*Cathartes aura*) in Indiana, USA, when the vulture was nesting in a Sycamore Tree, with two white downy chicks. Due to the human presence looking at the nest, the adult remained completely motionless, remaining in a prone position with its wings opened and its head down. Although it had been prodded with a stick and lifted off the ground, one could only notice eye movements (Vogel-Jr. 1950). On another occasion, Martin-Jurado *et al.* (2011) reported thanatosis in an adult individual of Red Kite (*Milvus milvus*) after anesthesia for a surgical procedure aiming for sex determination. This behavior was confirmed through the bispectral index, which evaluates the electrical activity of the brain of the bird. After finishing the surgery, followed by extubation, the Red Kite remained immobile and unresponsive, despite the bispectral index corresponded to a full awake bird.

In this report, we characterized thanatosis in one Black Vulture individual, recorded in 2018 during the removal from a handling-net (Fig. 1).

The individual was captured at the *Fundação Parque Zoológico de São Paulo*. The survey comprised biological sample collections such as feces, regurgitates as well as any ectoparasite encountered during the procedure. This individual was captured, quickly pulled out of the trap with a handling net and immediately released afterward. However, when released, the Black Vulture remained lying in the dorsal position. We could even lift the individual off the ground by holding it only by its legs.

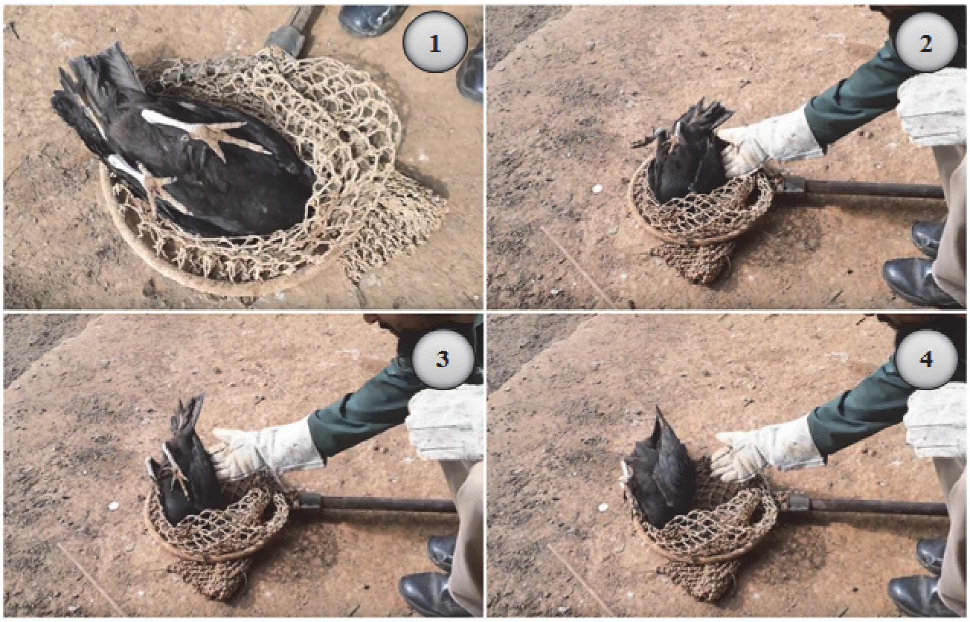

Figure 1. Picture description showing thanatosis in a Black Vulture captured at the *Fundação Parque Zoológico de São Paulo*. (**1**) Individual lying down in dorsal decubitus; (**2**) touched without showing any response; (**3**) pushed out of the handling net without showing any response; (**4**) sideway-fallen Black Vulture seconds before rising.

After realizing that either it was expressing thanatosis or having a health issue, we placed the individual back on the handling net, in which it remained for a few seconds and it stood and flew away.

Thanatosis is an anti-predatory strategy frequently adopted by prey after physical contact by predator (Humphreys & Ruxton 2018). However, such behavior is uncertain in this particular situation described here. Even though vultures are vulnerable to predation by terrestrial carnivores when they are fledglings and juveniles, few reports of adults being predated are known (Houston 1994, Teixeira *et al*. 2019). In spite of being quite common in several taxa, the adaptive significance of thanatosis is still uncertain. Lack of studies may be attributed to the fact that the usual consequence of thanatosis may be predation, being less likely to be seen or tested in the field and laboratory due to ethical reasons. Besides that, the success or failure of death feigning depends largely on the foraging techniques adopted by the predator. More studies are needed with regards to the predator-prey dynamics of vultures, in order to fully understand the predator-avoidance tactics involved within this species (Honma *et al*. 2006, Humphreys & Ruxton 2018).

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ARTICLE

Short-term movement patterns, population estimates and breeding biology of an island endemic bird, the Tristan Thrush

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ABSTRACT: The Tristan Thrush *Turdus eremita* is the only land bird that survived human colonisation of the main island of Tristan da Cunha and is listed as "Near Threatened". Population estimates are confounded by the thrushes' inquisitive and gregarious nature as well as limited information on their movements. We report the first measures of nest densities on Nightingale Island: 6 nests·ha^{-1} in *Phylica arborea* woodland and 4–5 nests·ha^{-1} in tussock habitat, which suggests that the population is approximately double the previous estimate. At Inaccessible Island, we individually color ringed 110 thrushes over two months to track their short-term movements and estimate the local population size. Individuals moved up to 950 m along the coast, but 96% of resightings were < 100 m. A Bayesian data augmentation approach estimated that some 260 thrushes visited the core study area, a 200-m stretch of cobble and boulder beach where birds come to drink, bathe and forage. This result suggests that the population on Inaccessible Island also is substantially larger than reported previously. We estimate the total population to be 8000–15,000 Tristan Thrushes. The main need is a population estimate for the nominate subspecies on the main island of Tristan.

KEY-WORDS: *Turdus eremita*, Inaccessible Island, Nightingale Island, Bayesian population estimate.

INTRODUCTION

The Tristan Thrush or Starchy *Turdus eremita* is endemic to the Tristan da Cunha Archipelago in the central South Atlantic Ocean (37°S; 12°W). Until recently it was placed in its own genus, *Nesocichla*, reflecting its morphological adaptations to life on oceanic islands: reduced wings, robust legs and a brush-tipped tongue adapted for lapping up egg contents (Lowe 1923, Rand 1955, Fraser *et al.* 1994). However, genetic sequence data suggest that it is nested within the South American radiation of *Turdus* thrushes (Klicka *et al.* 2005, Voelker *et al.* 2007), and like the other land birds found at Tristan (Ryan *et al.* 2013, Stervander *et al.* 2018), it probably reached the islands in the last few million years.

The thrush is the only land bird that survived human colonisation of the main island of Tristan, where a small population of the nominate subspecies persists mainly above 300 m elevation on the steep coastal scarps and upper plateau or "base" (Ryan 2007, BirdLife International 2017). Thrushes are common at the two uninhabited islands in the archipelago: *T. e. gordoni* on Inaccessible Island and *T. e. procax* on Nightingale Island and its offshore islets, Middle and Stoltenhoff (Elliott 1957, Richardson 1984, Ryan *et al.* 2011). The species is listed as "Near Threatened" globally, and although the population is thought to be stable, there is a need for up-to-date population estimates (BirdLife International 2017). Current estimates are extrapolated from crude density estimates made by field workers. In the early 1970s, Richardson (1984) suggested that there were 40–60 pairs at Tristan, 300–500 pairs at Nightingale Island, 20–40 pairs at Middle, 10–20 pairs at Stoltenhoff and 100–500 pairs at Inaccessible Island. His estimate for Inaccessible Island was particularly crude because he was unable to spend much time on that island. Subsequent field work on Inaccessible Island in the 1980s improved the estimate there to 850 pairs (Fraser *et al.* 1994), giving the current total population estimate of around 6000 birds (BirdLife International 2017). Estimates to date have focused on breeding pairs because the thrushes' inquisitive and gregarious nature (*e.g.*, Hagen 1952, Fraser *et al.* 1994) confounds estimates of the density of non-breeding individuals using transect or point counts.

We studied thrushes at two of the three islands in the Tristan Archipelago: on Inaccessible Island, we aimed to individually mark a sample of thrushes to better understand their movements and estimate their population size; and on Nightingale Island we aimed to accurately estimate nest densities and gather data on breeding phenology over three seasons of fieldwork. Lastly, we aimed to use these data to refine the population estimate of Tristan Thrushes in the archipelago.

METHODS

Breeding biology and nest densities

We recorded the contents of all nests found. Tristan Thrush nests are hard to locate during incubation and early chick stage (Fraser *et al.* 1994), but are conspicuous once the chicks start to beg noisily when being fed. We estimated the approximate age of chicks in nests from the nestling descriptions in Fraser *et al.* (1994). Authors B.J.D. and D.D. systematically recorded nests while conducting research on Nightingale Island in 2015 and 2017. Additional *ad hoc* observations were made by P.G.R. on Nightingale Island in October–November 2007 and Inaccessible Island in November 1999–February 2000, September–December 2004 and October–December 2009.

In 2015 and 2017, thrush nests were recorded systematically on Nightingale Island along the path from the huts to the Ponds (1.1 km) and in First Wood, a 4.3 ha patch of *Phylica arborea* woodland, which was searched intensively for nests. The pathway, which runs through tall *Spartina arundinacea* Tussock grassland, was used daily to reach First Wood, so most nests were found that reached the large chick stage. To estimate nest densities in Tussock grassland, we assumed the path represented a strip transect between 20–40 m wide (10–20 m either side of the path, 2.2–4.4 ha). All nests were within 10 m of the path, but the path created a favourable foraging area and might have biased the distribution of thrush nests (*e.g.*, several pairs of Brown Skua *Catharacta antarctica* breed along the path, and thrushes often scavenge from carcasses of petrels killed by the skuas). We divided the path into three sections: the lower 300 m runs through mostly level ground close to Northern Rockhopper Penguin *Eudyptes moseleyi* colonies; the next 330 m is also mostly level ground but lacks penguin colonies, and the final 470 m is on sloping terrain.

Resighting data at Inaccessible Island

We ringed Tristan Thrushes on Inaccessible Island (37°18'S; 12°41'W) from 22 September to 23 November 2018, which coincides with the species' breeding season. Only females develop well-defined brood patches, and thus the sex of at least some birds could be inferred. Fledged chicks were observed from early November, but no juveniles were ringed, and thus all data refer to birds at least 1 year old. Thrushes were mainly caught with hand nets, but a few birds were caught in mist nets set for finches. Thrushes initially received two color-rings as well as a metal ring, allowing them to be identified individually without recapture. However, we ran out of distinct color combinations after ringing 110 birds, and from 09 November, birds in the study area received a metal ring only (no further thrushes were ringed outside the study area). Ringing ceased on 23 November when we ran out of metal rings, but resighting observations continued until 25 November, the day before we left the island.

Ringing and resighting effort was concentrated along a 200-m long stretch of cobble and boulder beach backed by low tussock-covered cliffs centered on Runaround Beach (Fig. 1). Several fresh-water springs and seeps emerge along the base of the cliffs in this area, attracting thrushes to drink and bathe. Thrushes also forage along the shoreline (Fraser *et al.* 1994, Ryan & Dilley 2019), and are much easier to resight in this habitat than in the dense vegetation that covers most of the island. We attempted to resight color-ringed Thrushes and catch unringed individuals at Runaround Beach on 20 days from 29 September to 25 November. Most visits involved two observers, and lasted at least 2 h. On 19 and 25 November, visits lasted 4 h, and were divided into two sessions, recording individuals present in each 2-h period to give a total sample of 22 observation events. We calculated individual detection probabilities as the proportion of observation periods when color-ringed birds were resighted after initial ringing (n = 12–21 observation periods).

Most sighting effort occurred along the coast. In addition to the main study area, the shoreline between Runaround Beach and Blenden Hall Bay, where there is a small research hut (Fig. 1), was checked for ringed thrushes on each visit to the study area. The coast between Tern Rock and West Point (Fig. 1) also was searched on 55 days from 22 September to 26 November, and any ringed thrushes noted. Occasional visits also were made to the accessible section of coast to Warren's Cliff, east of Runaround Beach, and between West Point and Dirleton Point (Fig. 1). On 01 December we also checked 1.7 km of the northeast coast between the Waterfall and north of Salt Beach.

Systematic searches for ringed thrushes away from the coast were complicated by the dense vegetation, especially on the coastal slopes. The main paths followed on the western side of the island, although the East Road was used much less than the West Road to access the plateau (Fig. 1). In addition, a few thrushes were ringed

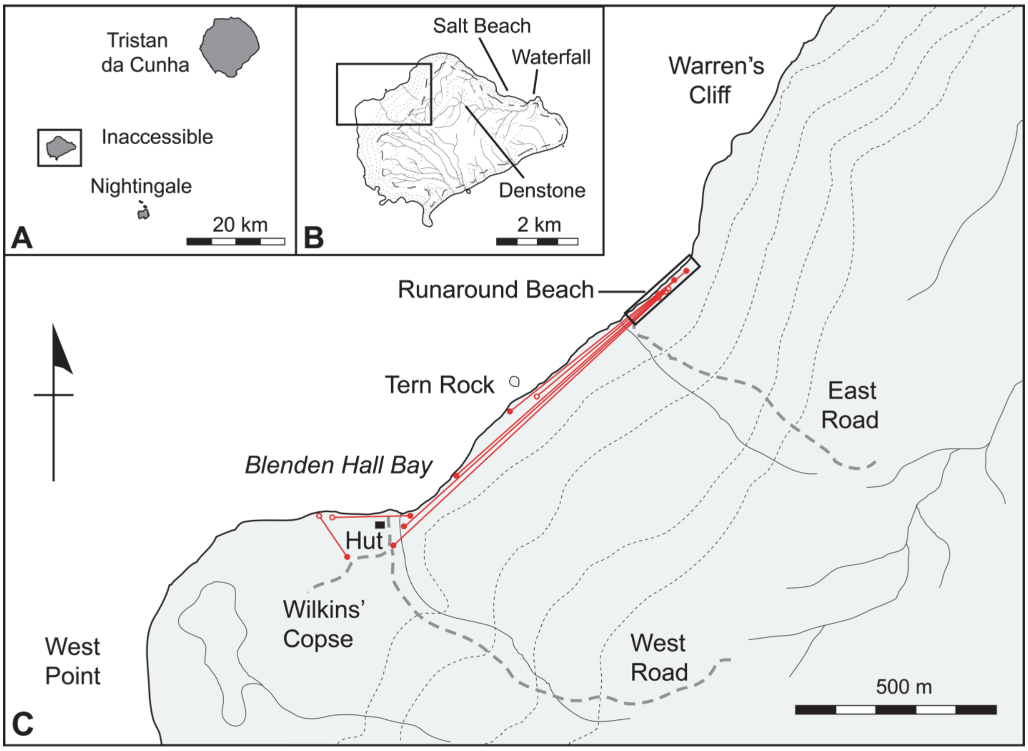

Figure 1. The Tristan Archipelago (**A**), Inaccessible Island (**B**), and main study area at Runaround Beach (black rectangle). Red lines show Tristan Thrush movements > 100 m (closed circle = ringing location; open circle = resighting location).

around our campsite on the eastern plateau at Denstone Junction (37°17.61'S; 12°40.43'W). All distances moved and habitat areas were estimated from Google Earth.

Estimating thrush abundance

Our initial plan was to mark 50 birds on the coast and 50 on the plateau in areas that would be visited frequently over the two months we were on the island, but it soon became apparent that the number of birds was greater than anticipated, and we focused most attention on a single coastal site where we attempted to ring as many thrushes as possible. Repeated visits to this site, coupled with regular checks along the adjacent coastline, allowed us to gauge movement distances and use a Bayesian approach to estimate the numbers of thrushes visiting the main study site. We used closed population models (Otis *et al.* 1978) to estimate abundance of the Tristan Thrush population at the core study area at Runaround Beach. All models were implemented using a Bayesian data augmentation approach (Royle & Dorazio 2012), boosting the observed 147 encounter histories with a large number of individuals (M) that had all-zero encounter histories. We used a hierarchical approach to describe the models. First, we used a Bernoulli distribution to determine whether an individual was a member of the true population exposed to sampling. That is,

$$Z_i \sim Bernoulli(\psi)$$

where $Z_1 = 1$, if the i^{th} individual was a member of the population and 0 otherwise, and ψ is the inclusion probability. The closed population (N) was then estimated as the sum of Z_i (*i.e.*, $N = \Sigma Z_i$). Second, we modeled the encounter histories of each individual conditional on the latent variables (Z_i) as

$$Y_{it} \sim Bernoulli(Z_i p_{it})$$

where Y_{it} if the i^{th} individual was alive and detected at occasion t and 0 otherwise. p_{it} is the detection probability of the i^{th} individual at occasion t. We imposed two possible constraints on detection probability: time and individual heterogeneity (*i.e.*, individual variation in detection probability) (Table 1). Under M_t, M_h and M_{ht} models, we used a random-effect approach to model the time effect and individual heterogeneity. Hence, ε_t and γ_i are time and individual random effects, respectively. Birds marked with metal-rings only were given a detection probability of zero after first capture, because there were no resighting data for these individuals.

To implement the models in a Bayesian framework, we specified vague prior distributions for all model parameters: U (0,1) for ψ, N(0, 0.01) for β_0, and U(0, 10) for σ_ε and σ_γ. For each model, we ran three independent Markov Chain Monte Carlo (MCMC) iterations of length 100,000 with a burn-in of 50,000, and a thinning rate of 50. We used the Brooks-Gelman-Rubin $\hat{R}$ statistic (Brooks & Gelman 1998) to assess the convergence of the

Table 1. Models fitted to the Tristan Thrush resighting data in the core study area at Inaccessible Island, and associated DIC and ΔDIC scores.

Model	Variation in detection probability (*p*)	logit model for *p*	DIC score	ΔDIC
M_{ht}	Individual + time	$logit(p_{it}) = \beta_0 + \varepsilon_t + \gamma_i$ $\varepsilon_t \sim N(0, \sigma^2_{\varepsilon}); \gamma_i \sim N(0, \sigma^2_{\gamma})$	2475.6	0.0
M_t	Time	$logit(p_{it}) = \beta_0 + \varepsilon_t$ $\varepsilon_t \sim N(0, \sigma^2_{\varepsilon})$	2584.0	108.4
M_h	Individual heterogeneity	$logit(p_{it}) = \beta_0 + \gamma_i$ $\gamma_i \sim N(0, \sigma^2_{\gamma})$	2674.2	198.6
M_0	Null	$logit(p_{it}) = \beta_0$	2789.2	313.6

MCMC chains to the targeted posterior distributions. Both the $\hat{R}$ statistic and visual inspections of the MCMC plots indicated model convergence. The model with the smallest Deviance Information Criterion (DIC; Spiegelhalter *et al.* 2002) was considered the best model. All analyses were performed using the JAGS software (Plummer 2003), called from R (R Core Team 2018) using the package jagsUI (Kellner 2018).

RESULTS

Nest densities at Nightingale Island

We found 60 nests over the study period. All thrush nests along the path were in Tussock stands (*n* = 32). Nests in First Wood (*n* = 28) were found in Tussock stands (9), *Asplenium* ferns (11), *Carex* sedge (5), in small rock crevices sheltered by hanging *Scirpus* grass (2), and in New Zealand Flax *Phormium tenax* (1). Flax is an invasive species at Tristan, so this nest was moved ~ 1 m to an adjacent *Carex* stand to allow the flax plant to be removed; the female continued to incubate, and all three eggs hatched. Tussock nests were 0.2–1.4 m off the ground, but other nests were within 5–10 cm of the ground. Eight eggs at 4 nests measured 30.7 ± 0.8 mm (29.3–31.6 mm) in length and 21.7 ± 0.6 mm (20.9–22.4 mm) in width. Clutch size at 9 nests with eggs averaged 2.1 ± 0.6 (1–3 eggs), but some clutches may have been incomplete. Average brood size at 55 nests was 2.4 ± 0.6 chicks, with 51% of nests containing three chicks. The number of thrush nests found along the main path to the Ponds was 18 in 2015 and 14 in 2017, with densities tending to decrease with distance from the coast and elevation (Table 2). A total of 28 nests were found in *Phylica* woodland at First Wood in 2017. We were unable to tell whether any nests were repeat lays after breeding failure, but this is unlikely to greatly influence the estimate of the number of breeding pairs because few nests were found during incubation or the small chick stage, when most failures likely occur. Based on the inferred ages of chicks when nests were found, most eggs hatched from early October to late November. Our results suggest a crude density of 3–10 nests·ha^{-1} in tussock habitat and ~6 nests·ha^{-1} in *Phylica* woodland.

Movements at Inaccessible Island

Of the color-ringed thrushes, 71 were caught at the core study site, 30 were caught farther west along the coast between Runaround Beach and Blenden Hall Bay or immediately inland around the hut (Fig. 1), and 9 were caught on the plateau (seven at Denstone Junction) or high on the West Road (two). The resighting probability of color-ringed thrushes in the core study area ranged from 0–0.83, with 32% of birds observed on less than 10% of visits, and 85% seen on less than 50% of visits (Fig. 2). Overall, the most common number of resightings was 0 (Fig. 1 in Appendix I), even though most color ringing away from the study area ceased in mid-October, allowing more than a month for ringed birds to be resighted. A few birds were seen regularly in the same area. Some of these birds held breeding territories and subsequently were seen with fledglings, whereas others seemingly were non-breeders that foraged along the shoreline (see Ryan & Dilley 2019). Most non-breeders remained on more or less the same stretch of coast throughout, but one bird moved ~120 m west midway through the study period, remaining in this new site until we left the island.

The pattern of a few resident individuals and larger numbers of transient birds was obvious at the hut, where catching and resighting effort was arguably greatest. Fourteen thrushes were caught at the hut. Of these, one pair of birds was resident, being seen virtually every day ranging 50 m between the hut and the adjacent coast; this pair nested in dense tussock next to the beach in front of the hut. Of the remaining 12 thrushes, one was seen regularly in Blenden Hall Bay, 90 m from the hut, two were resighted once in the core study area (~950 m from the hut; resighted 28 and 32 days after ringing), one

Table 2. Numbers of Tristan Thrush nests in Tussock grassland along the path from the huts to First Wood on Nightingale Island in 2015 and 2017.

Habitat	Distance	Number of nests		Density* (nests·ha^{-1})
		2015	2017	
Level ground with penguins	300 m	8	5	5.4–10.8
Level ground, no penguins	330 m	4	6	3.8–7.6
Sloping ground	470 m	6	3	2.4–4.8

*assumes average number of nests and strip transect 20–40 m wide; see methods for further details.

was seen once in *Phylica* trees 20 m behind the hut (44 days after ringing), and the other 8 were not seen again. A similar pattern also occurred at the plateau camp, although only 7 thrushes were ringed here: 2 were seen on most visits to the camp, 1 was seen once (recaptured in a mist net the day after initial capture), and 4 were not seen again.

Most resightings were within 100 m of the original ringing site (96%, $n = 427$ of 446). However, we frequently observed thrushes making flights > 100 m, mainly along the shore. One male that defended a territory at the western edge of the study area frequently chased birds out of sight along the coast to the west (at least 200 m), but was not observed outside the study area. The maximum movement distance recorded was 950 m, from the hut to the core study area ($n = 2$). Two other birds ringed in Blenden Hall Bay moved as far as the study area (700–900 m), and 1 ringed near Tern Rock also was seen in the core study area (500 m). The farthest movement of birds ringed in the study area was to the Tern Rock area (400–500 m, $n = 4$ of 71 birds). No ringed birds were seen inland from the study area, but access to the dense *Spartina* tussock in this area was restricted to the East Road, which was only visited a few times. In the more accessible Blenden Hall area, one thrush caught in a mist net midway between the hut and Wilkins' Copse, 130 m inland (Fig. 1), was subsequently seen regularly on the adjacent coast.

Thrush numbers in the study area at Inaccessible Island

The population estimate for the core study area was based on encounter histories for 76 color-marked thrushes (71 ringed at the site and 5 birds ringed along the adjacent coast as far west as the hut) and 71 metal-only ringed birds caught at the study sight after we ran out of color combinations. Average resighting rate of the 76 ringed thrushes in the 12 2-h observation periods in the core study area after color-ringing ceased was 29 ± 6% (21–38%). The model including individual heterogeneity and a time effect (M_{ht}) provided the best fit to the resighting data (Table 1). The posterior mean thrush population visiting Runaround Beach under this model was ~258 birds (95% credible interval, CRI: 212–314), and this estimate was largely independent of M, providing M ≥ 200 (Table 1 in Appendix I, Fig. 2 in Appendix I). The rate at which thrushes were ringed at the study site showed no evidence of decreasing over time (Fig. 3), supporting the large population estimate for the site. The posterior mean detection probability was 0.031 (95% CRI: 0.016–0.053), and posterior estimates for σ_ε and σ_γ were 0.91 (0.63–1.29) and 1.92 (1.57–2.39), respectively, confirming the considerable temporal and individual variation in detection probability.

DISCUSSION

The main challenge to estimating the population size of Tristan Thrushes is their inquisitive nature. As Hagen (1952) noted "they immediately fly to meet every new thing", including people. As a result, any attempt to estimate the population density by random transects or point counts is confounded by the unknown radius over which thrushes are attracted. Individually marking thrushes does not directly solve this problem, because the act of catching and ringing the birds makes them more cautious around people (Fraser *et al.* 1994, pers. obs.). Current population estimates are crudely estimated from the approximate density of breeding pairs (Richardson 1984, Fraser *et al.* 1994). Richardson (1984) estimated 300–500 pairs on Nightingale Island, but our observations show that this is conservative.

We present the first estimates of nest densities for Tristan Thrushes. On Nightingale Island, the estimate for *Phylica* woodland at First Wood (6 nests·ha^{-1}) is likely to be fairly accurate, as the entire area was searched intensively. It is likely that some thrushes re-lay if their initial breeding attempt fails but this is unlikely to have inflated the nest count because most nests were only recorded at the chick stage and there is no indication of double brooding (the breeding season is short, with adults starting to moult from late November while still feeding fledged chicks; Fraser *et al.* 1994). Estimating nest density for tussock habitat is complicated by the fact that the path is not a random transect through this habitat. However, incidental observations made while walking through tussock away from the path suggest that the density of thrush nests along the path is not atypical, and a density of 4–5 nests·ha^{-1} is thought to be a reasonable average across the island. Extrapolating these densities based on the total area of each habitat at Nightingale Island (160 ha tussock and 11 ha woodland) suggests a population of some 700–850 breeding pairs, roughly double that estimated by Richardson (1984). This number of breeding pairs suggests a total population of 2000–3500 thrushes on Nightingale Island, including pre-breeders (few if any thrushes breed until they are at least two years old, Hagen 1952).

Our breeding observations confirm that clutch sizes on Nightingale Island are consistently larger than those on Inaccessible Island. Roughly half of all broods on Nightingale were of three chicks, whereas three-egg clutches have not been recorded on Tristan or Inaccessible Island (Elliott 1957, Richardson 1984, Fraser *et al.* 1994, P.G.R. unpub. data). Quite what causes this difference is not known. Elliott (1957) reported that eggs of *T. e. procax* on Nightingale Island were larger than those of *T. e. gordoni* on Inaccessible Island, but our egg measurements at Nightingale averaged smaller (30.7 × 21.7 mm) than those reported by Elliott (1957) of 33.5 × 22.7 mm.

Thrush densities are thought to be lower at Inaccessible than at Nightingale Island. Fraser *et al.* (1994) estimated thrushes occurred at 1.0 pair·ha^{-1} in tussock grassland, and 0.2–0.8 pairs·ha^{-1} in three habitats on the island plateau. However, densities are hard to assess, particularly along the coastal cliffs where nests are concealed in the densest, most inaccessible Tussock grass (Fraser *et al.* 1994), and as on Nightingale Island, probably are conservative estimates. We attempted to gain an independent estimate of thrush density by color-ringing a large sample of birds at Inaccessible Island. Our results support previous records on the movement of ringed Tristan Thrushes. The 36 thrushes color-ringed at Inaccessible Island in 1982/83 were largely sedentary, with regular movements of around 250 m between the hut and Wilkins' Copse, and a maximum movement of 800 m (Fraser *et al.* 1994). Similarly, of the "nearly 100" thrushes Elliott (1957) ringed at the landing area on Nightingale Island, none was resighted more than 300 m away, suggesting they seldom undertake large movements. However, 2 of the 5 color-ringed birds resighted at Inaccessible Island from 1987–1989/90 were observed only once over the three seasons (Fraser *et al.* 1994), suggesting that they are not regular visitors to areas accessible to observers. Our results confirm that individual variation in resighting rates is characteristic of this species. Despite ample opportunities for birds to be resighted, and high resighting rates for some individuals, the most common result was for color-ringed birds to be not seen again (Fig. 2 & Fig. 1 in Appendix I). More observations are needed to assess whether such birds remain in areas of dense tussock, not readily accessible to observers, or are more vagile. Until this conundrum is resolved, we will struggle to derive accurate population estimates.

Despite the issue of possible transient birds, the number of thrushes caught at the core study site at Inaccessible Island was impressive, with no decrease in the rate at which unringed birds were caught over 2 months (Fig. 3). In fact, the proportion of unringed birds caught

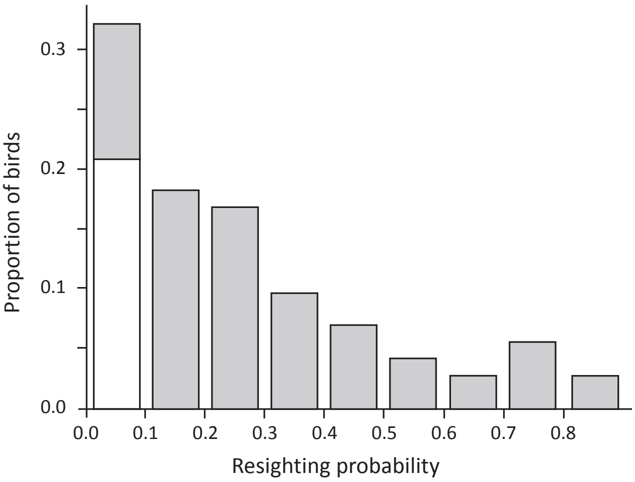

Figure 2. The probability that a Tristan Thrush color-ringed in the core study area was resighted in subsequent visits (white = 0 probability; *n* = 71).

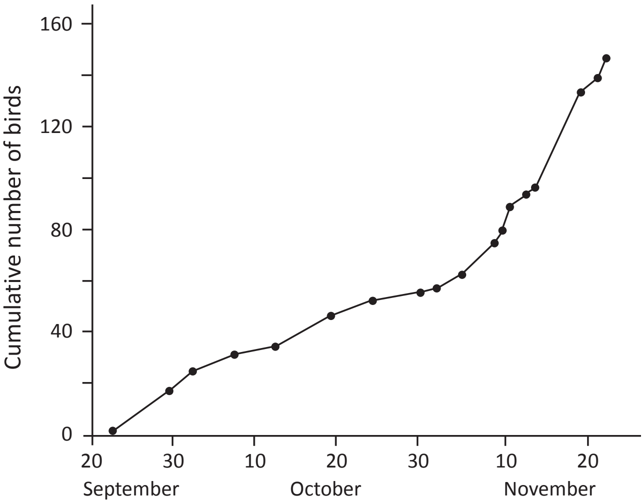

Figure 3. The cumulative number of Tristan Thrushes ringed at the core study area from 22 September to 23 November 2018. Color-ringing ceased from 09 November, making it faster to process birds and thus increasing the catch rate.

decreased over the course of the study, as individuals became more wary of being approached with a hand net – had this not been the case, even more birds would have been caught later in the study. On the final day of observations (25 November) we estimated that there were almost as many unringed birds as there were color-ringed and metal-only birds, which lends credence to the Bayesian estimate of around 260 birds visiting the study site. If we assume that thrushes from the lower half of the coastal cliffs (*i.e.*, up to *c.* 200 m elevation) visit the core study site, and travel up to 500 m along the coast (likely a minimum estimate, given the limited movement of most birds), then the population at the site represents birds from a catchment area of around 20 ha. Increasing the radius along shore to the maximum movement recorded would increase this to around 40 ha. These catchment areas give a density of 6.5–13 thrushes·ha^{-1}, which if extrapolated across the coastal scarp (500 ha), suggests a population of roughly 3250–6500 fully grown thrushes. The density on the plateau (1000 ha) is perhaps 1/3 to 1/2 that along the coast (Fraser *et al.* 1994), giving a crude population of 5500–11,000 thrushes on Inaccessible Island.

Elliott (1957) does not specify the period over which he ringed "nearly 100" thrushes in the immediate vicinity of the landing-place on Nightingale Island, but his experience mirrors ours on Inaccessible Island, and supports our inference of a large thrush population from nest densities on Nightingale Island. Combined with recent estimates of thrush populations on Middle (5–10 pairs) and Stoltenhoff Islands (10–20 pairs; Ryan *et al.* 2011) and "hundreds" on Tristan da Cunha Island (BirdLife International 2017), we estimate the total population to be 8000–15,000 Tristan Thrushes. Although this increases the global population, we recommend the species status should remain as "Near Threatened" globally. A more accurate estimate of the tiny population on Tristan is a conservation priority.

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APPENDIX I

Table 1. The estimated population size (*n*) of Tristan Thrushes in the core study area as a function of M, the number of augmented individuals that had all-zero encounter histories.

M	*n* (95% credible interval)
50	193 (183–197)
100	233 (206–247)
150	256 (212–293)
200	258 (212–309)
300	258 (212–314)
500	259 (212–312)
1000	259 (214–313)

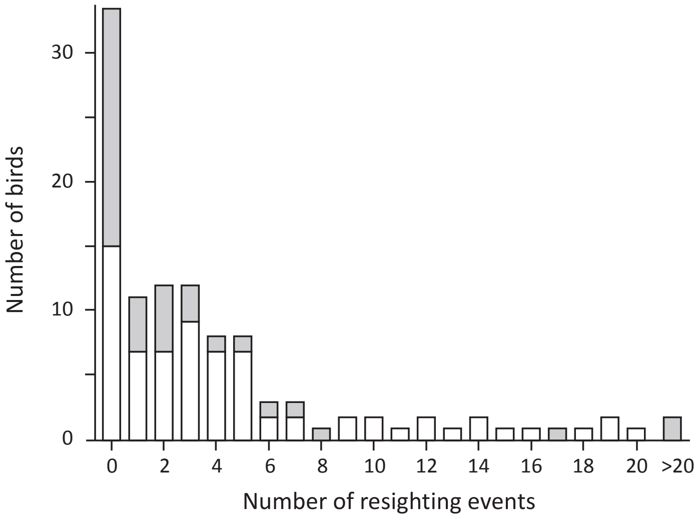

Figure 1. The frequency distribution of the number of times color-ringed Tristan Thrushes were resighted at Inaccessible Island in 2018 (white = birds ringed in the core study area; grey = other areas).

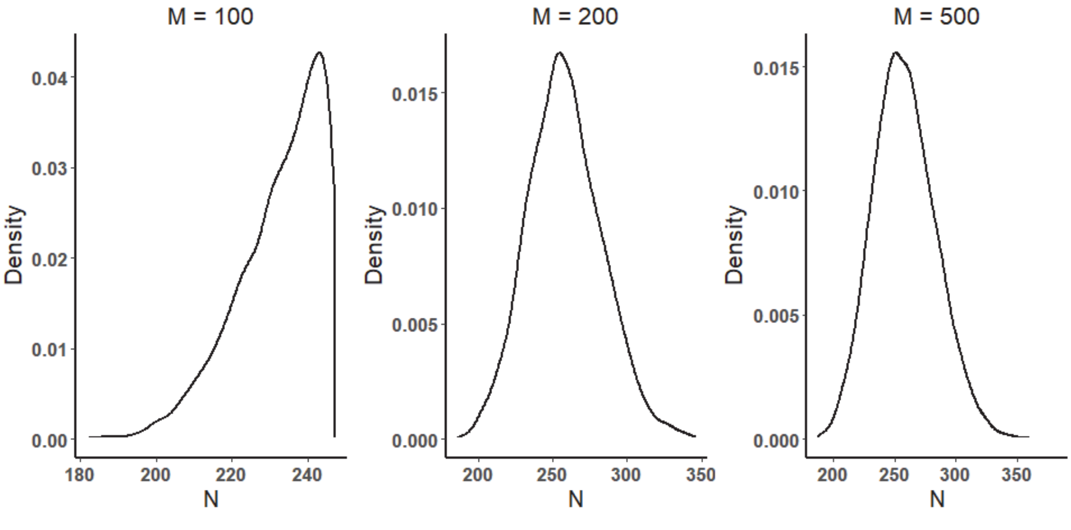

Figure 2. Posterior distributions of Tristan thrush abundance (N) from the best model (M_{ht}), under different values of M. The posterior distribution of N was not right truncated for M ≥ 200.

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ARTICLE

GenTag: a package to improve animal color tagging protocol

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ABSTRACT: The individual identification of animals by means of tagging is a common methodological approach in ornithology. However, several studies suggest that specific colors may affect animal behavior and disrupt sexual selection processes. Thus, methods to choose color tagging combinations should be carefully evaluated. However, reporting of this information is usually neglected. Here, we introduce the GenTag, an R package developed to support biologists in creating color tag sequence combinations using a random process. First, a single-color tag sequence is created from an algorithm selected by the user, followed by verification of the combination. We provide three methods to produce color tag sequences. GenTag provides accessible and simple methods to generate color tag sequences. The use of a random process to define the color tags to be applied to each animal is the best way to deal with the influence of tag color upon behavior and life history parameters.

KEY-WORDS: animal behavior, ecology methods, field ecology, leg bands, marks, ringing.

INTRODUCTION

The individual marking of animals in natural populations is a widespread methodological approach for field ecologists and provides the foundation for several methods to determine population size, lifespan, animal movements in the landscape, and migration patterns, among other possibilities (Sutherland 2006, McCrea & Morgan 2014). For birds, the most popular marking method is the application of color rings (Calvo & Furness 1992), where individuals receive unique combinations of color bands that allow the researcher to individually identify animals by recapture or observation at a distance.

Since the early 1980's, several studies have reported the influence of color tags on bird social behavior (Burley *et al.* 1982, Burley 1986). Because of methodological limitations, most of these studies were carried out with captive populations (*e.g.*, Burley 1986, Jennions 1998, Song *et al.* 2017). Few studies took place in the field, and these suggest that some patterns of color tagging have an influence on social behavior (*e.g.*, Zann 1994, Johnsen *et al.* 1997 & 2000). It appears that tag colors between 600–700 nm, in the warm range of the spectrum (*e.g.*, yellow, orange and red), influence behavioral contexts associated with conspecific preferences (Burley *et al.* 1982, Johnson *et al.* 1993, Fiske & Amundsen 1997, Song *et al.* 2017), reproductive investment (Zann 1994, Gil *et al.* 1999), offspring sex ratio (Burley 1986), dominance behavior (Cuthill *et al.* 1997), mate-guarding (Johnsen *et al.* 1997), and levels of cuckoldry (Johnsen *et al.* 2000).

Despite the negative effects of tags on animal behavior and survival (Calvo & Furness 1992), and the fact that 40% of research projects use color rings to identify birds, 98% of publications do not mention the possibility of potential injury and reduced survival due to tags (Alisauskas & Lindberg 2002). The potential for injury differs between taxonomic groups (Sedgwick & Klus 1997, Pierce *et al.* 2007, Broughton 2015, Nietmann & Ha 2018) and animal body sizes (Griesser *et al.* 2012). Notwithstanding these issues, colored tags are still very popular, mainly due to their lower cost when compared with other identification methodologies such as radio trackers or PIT-tags (Schlicht & Kempenaers 2018). On the other hand, there is no evidence of changes in predation rate due to tags (Cresswell *et al.* 2007), and even leg flags do not substantially increase predation (Weiser *et al.* 2018).

Given the above overview, we emphasize that the methodology used to choose color tagging combinations should be carefully evaluated during project development and subsequently reported in the methods section of publications. However, this information is rarely reported. When developing their tagging methodology, investigators may unconsciously select more conspicuous colors to tag animals as these are more likely to result in fast identification. To avoid biases in their choices, field ecologists should necessarily adopt a randomized strategy to determine tag colors and their combinations. We suggest that the best way to deal with the possibility of tag color influence is to generate a list of color tag combinations before tag application, and to follow the list regardless of individual characteristics of the animal (*e.g.*, body size, percentage of feather coverage, color, etc.).

PACKAGE DESCRIPTION

The genseq function in the GenTag package is the main function to create a list of color tag sequences (functions are summarized in Table 1). First, a single sequence is generated by an algorithm, followed by confirmation of its uniqueness. Previously used sequences can also be used for the uniqueness test. Users can request sequences with specific tags, such as metal or flag bands for numbered tagging. This function was designed to sort out sequences using equal numbers of tags. If the user wants to create sequences with different numbers of tags, it is necessary to use "EMPTY" as a proxy for a special color for the non-tag, and then change the parameter emptyused to TRUE (see genseq help for more information of application). In this scenario, genseq will take into account synonyms of combinations with the "EMPTY" code, for example: "EMPTY"-"Red"-"Blue" is synonymous for: "Red"-"EMPTY"-"Blue" and "Red"-"Blue"-"EMPTY".

Although there is no evidence of conspecific preferences based on number of tags (Jennions 1998), we recommend avoiding applying different numbers of tags to individuals in the same population, as this may generate confusion in identification. Some animals may actively remove tags, and some colors appear to have a higher rejection rate than others (Kosinski 2004), leading researchers to misidentify individuals in the field.

Sequences are created by a replaceable algorithm that selects among tag colors. Here we provide three algorithms: "*All equal*", creates combinations of tags in which all colors have the same probability of being sampled; "*Variable frequency*", creates combinations of tags using different probabilities for each color, where the probabilities are defined by the user; and the "*Life expectancy*" algorithm creates a restriction based upon color combinations, so that all colors will be represented in similar frequencies in the natural population under study. The latter algorithm requires information of all previously used combinations and dates of applied tags. Additionally, this algorithm can be improved by providing an estimation of survival probability and lifespan. The routine first estimates the quantity of remaining color tags in the natural population. The estimates of survival probability and lifespan provided to the algorithm removes the number of tags that are lost through individual mortality. The sample ratio for each color is then determined by Equation 1. The *speed* parameter can range from 0 to 1, and can be used to relax the restriction in the sampling procedure. When speed is set at 1 (default) the color that was previously used most extensively will not be sampled in any combination, and other colors occurring in a large number of combinations will only rarely be sampled. Intermediate values allow the occurrence of combinations with commonly used colors, but with a degree of restriction. Alternatively, when speed is set at 0, no adjustments will be made. The user can also select colors that will be ignored in sample adjustment (see lifexp help for more details).

$$r = 1 - ((c/m) \times s) \qquad \text{Equation 1}$$

r = ratio for sampling a given color.
c = estimated number of remaining tags of the given color.
m = estimated number of remaining tags of the most used color.
s = speed.

Our algorithms were developed for three different situations, where researchers: *i*) require a non-biased color tag generator, where all colors will be equally represented in the produced combinations; *ii*) have a restriction in the proportion of each color availability, a common occurrence, for example, when researchers receive donations of color tags; and *iii*) have ongoing

Table 1. Summary of the main functions of the GenTag package.

Functions	Description
genseq	Creates sequences of colors for animal tags.
allequal	Creates a sequence of colors with the same frequency for all colors.
vfrequency	Creates a sequence of colors with different probabilities for each color.
lifexp	Creates a sequence of colors based on survival, lifespan and date of previously used tags.
scy	Summarizes number of colors used per year.
erc	Estimates number of remaining color tags in the field.

studies and realize a possible bias in color tag effect, and need to implement a quick adjustment so all colors are equally represented in the natural study population.

RECOMMENDATIONS

For new studies we recommend using the "*All equal*" algorithm, because it will ensure that all colors are equally represented in the study population. For ongoing studies, we recommend both "*All equal"* and *"Life expectancy*" methods. Across a long time period, "*All equal"* will adjust tag color representation as animals die. For a fast adjustment, *"Life expectancy"* is more appropriate since it changes the sample probabilities based upon differences in previously used color frequencies. Both methods do not assume limitation in color tag availability. For any situation with limitations of color tag availability, we recommend the use of *"Variable frequency"* algorithms, to take advantage of the maximum number of combinations using current tag availability. The use of different numbers of tags is an option to save tags, since it increases the number of possible combinations while using fewer tags. We recommend avoiding this procedure, because it may result in misidentifications if an individual loses or removes a tag (Kosinski 2004). Furthermore, by using the same number of tags for all individuals, tag weight will be equivalent for all animals, despite a possible effect of color.

In Appendix I we provide a tutorial of how to generate the list of color tag combinations for both new and ongoing studies. We exemplify how to apply the three methods to generate color tag sequences.

The GenTag package provides accessible and simple methods for ecologists and field researchers to generate color tag sequences. The use of a random process to define the color tags to be applied to each animal is the best way to deal with the influence of tag color upon behavior and life history parameters in general. We highlight that the method used to choose color tagging combinations should be carefully evaluated and reported in the methodology section of publications. The GenTag package provides a straightforward and flexible way to deal with tagging effects on natural populations under study.

GenTag is written in the R programming language (version 3.5.0) and can be run on Windows, Mac OS X, and Linux systems. There are no package dependencies in the current stable version (version 1.0). It can be installed from CRAN (https://cran.r-project.org/web/packages/GenTag/), and a development version can be found on GitHub (https://github.com/biagolini/GenTag).

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APPENDIX I

Tutorial for GenTag package.

INTRODUCTION

This tutorial illustrates how to use the GenTag package to improve bird color tagging protocols. We provide examples and advice based on our experience with bird field surveys. The theoretical background of the available methods presented in the main paper must be consulted before following this tutorial. This tutorial was written for R beginners; however, it demands a minimum knowledge of how R works (user must know what is an object, working directory, and how to apply functions).

Choose parameters to generate sequences

The first step is to determine three fundamental parameters: *i*) number of tags that each bird will receive; *ii*) colors to be used; *iii*) which algorithm will be used. The first two parameters are fundamental to determine the number of possible combinations that can be created for color tagging. The maximum number of color tag combinations is given by the formula:

$$Mcomb = Ncolors^{Tags}$$

$Mcomb$ = *Maximum number of unique color tags combinations*
$Ncolors$ = *Number of available colors*
Tag = *Number of tags used for each animal*

Thus, it is clear that each new possible color tag has a significant impact on the number of possible combinations. Therefore, to achieve a large number of possible combinations, the researcher should use as many colors as possible. The definition of which color will be used, depends on some factors. First, similar colors, such as white and light blue, should be avoided because natural conditions (*i.e.* sunlight, dust) can result in tags with similar colors becoming impossible to tell apart during focal observations, even with binoculars. Conspicuous bands make visual identification easy, however they can impact social behavior and the probability of the bird being detected by a predator. The use of band colors similar to bird plumage or leg tissue, reduces this impact.

The number of tags used on each animal also has a large impact on the number of possible combinations. However, it should be kept to a minimum, because color tags generally have a negative effect on birds. There is no rule of thumb concerning the number of tags to be used on each animal. Decisions are based upon the number of tags needed to cover the expected sample size, but take into account effects on bird behavior and survival. For instance, too many tags can be detrimental for flight, color rings can catch on vegetation leading to the bird's death (see Broughton 2015), and colors of tags may disrupt social behavior (*e.g.* Burley *et al.* 1982, Johnson *et al.* 1993, Fiske & Amundsen 1997, Song *et al.* 2017).

We suggest that a good starting point is to use four tags per animal, two on each leg. For instance, using four tags with seven *available* colors to produce different combinations will yield over 16,000 unique combinations.

In terms of the best algorithm for color sampling, we recommend use of the "*All equal*" method. This is a method designed to produce non-biased color sequences, where all colors will be equally represented in the combinations generated. It is recommended for both new and ongoing studies, because over the long term, the method ensures that all colors are equally represented in the study population. However, if new color tags are introduced in the system, researchers must consider the use of the "*Life expectancy*" method. Finally, to take advantage of the maximum number of combinations with a restricted number of available tags we recommend the use of the "*Variable frequency*" method. This latter method is useful in situations where color tags were donated, a common occurrence in laboratories with several ongoing field surveys. We describe each sample routine method in the main paper.

Generate color tag sequences

In this section, we show how to apply the main functions of and provide all sequences of codes necessary to use GenTag. For a minimum and necessary acquaintance with R, we recommend Crawley (2012). Make sure commands are typed exactly as illustrated, as they are case sensitive. The first step is to install and load GenTag. You can follow this tutorial by typing the following commands at the R prompt.

```
install.packages(“GenTag”)
```

```
library(“GenTag”)
```

You must create an object to hold the name/code of available colors. Make sure that all color names are types exactly the same in your database. For instance, if you typed "Green", "green", and "GREEN", R will recognize these as different colors/codes.

```
tcol<-c(“Black”,”Blue”,”Brown”,”Gray”,”Green”,”Pink”,”Purple”,”Red”,”White”,”Yellow”)
```

At this point you can create your first color tag sequences list. For this first example, we will use the "*All equal*" algorithm. Use the function `genseq` to create combinations, the argument `ncombinations` will determine the number of combinations to be produced, `ntag` is the argument for the number of tags used in each animal, and the `colorsname` argument is to determine the available colors to be sampled (*i.e.*, the object created in the last step).

```
genseq(ncombinations=30, ntag=4,colorsname=tcol)
```

If you have any difficulties in applying a function, access the help documentation by using the help command.

```
help(genseq)

# or just type

?genseq
```

Note that in our example, we do not inform the algorithm used to generate color sequences. In this situation, `Genseq` will automatically use the default "*All equal*" algorithm. If a different algorithm is desired, it must be informed in the argument `gen_method`, as will be shown below. Another important point is to notice that in this example, previous used combinations were not taken into account in the uniqueness test. Thus, using the above example, previously used combinations can be generated again, leading to duplicates in your database.

There are several ways to import data into R, as shown in Fig. 1. In this tutorial we use simulated data of previously used combinations provided within the GenTag package.

```
data(pre_used) # Load data example
```

In the example, data are stored in an object named `pre_used`, a type of data frame. Information in a data frame can be accessed in various ways. To see what is contained in the pre_used object, type the following code to check the first elements of your data frame:

```
head(pre_used)
```

You can see that this data frame contains 5 columns, the first 4 are colors used in sequence (the order is: upper left, bottom left, upper right, bottom right), the last column is the year when each combination was used. You can use this to assess previously used sequences. Set the argument usedcombinations to the object (data frame or matrix) that contains color tag records (columns 1 through 4 in the example).

```
genseq(ncombinations=30, ntag=4, colorsname= tcol, usedcombinations=pre_used[,1:4])
```

To create sequences that contain special codes, such as metal for numbered tagging: set the argument nspecial to the number of special codes, and the argument name1 and location1 to inform the tag codes and where each special tag can be placed. In the following example, one metal tag will be used for all birds, in positions 2 or 4 (left or right bottom).

```
genseq(ncombinations=30, ntag=4, colorsname= tcol, nspecial=1, name1="Metal", location1=c(2,4))
```

Special codes can also be used to create combinations with different numbers of tags. In this situation, a special "color" named as "EMPTY" can be a proxy for non-tags. Two problems arise with using different numbers of tags: *i*) misidentification of individuals in the field, since some animals can actively remove tags; *ii*) several synonyms of combinations, for example, by using 2 tags in each leg "EMPTY"-"Green"-"Red"-"Blue" is synonymous with: "Green"-"EMPTY"-"Red"-"Blue". To adjust the test of uniqueness for codes with "EMPTY" data, set the argument emptyused to TRUE, inform which code is the proxy of non-tag at argument emptyname, and define which tags are in the same group (*e.g.*, applied on the same leg) by arguments g1,g2,…g6 (in the example g1 represents left leg and g2 represents right leg).

```
genseq(ncombinations=30, ntag=4, colorsname= tcol, usedcombinations=pre_used[,1:4], emptyused = TRUE,
emptyname = "EMPTY", g1 = c(1,2), g2 = c(3,4))
```

Until now, the combinations were just displayed on R console. To export combinations, you can address combinations to an object, and then export this object as a .txt or .csv file.

```
setwd(choose.dir())# Choose a working directory to save your data

combinations <-genseq(100, 4, tcol) # Save a set of sequences in an object

# Export the object to csv file
write.csv(combinations, file="Color_sequences.csv", row.names=F)

# Export the object to txt file
write.table(combinations, file = "Color_sequences.txt", sep = "\t", row.names = F)
```

The tools presented above provide the versatility to adjust combinations to fit any particular study. All specifications are equally used for all sample algorithms. As mentioned before, to change the sample method you must use the argument gen_method. The "*Variable frequency*" creates combinations of tags using different probabilities to sample each color. Thus, to apply this method it is also necessary to inform a proportion of each available color. You can set the sample ratio by an object with ratios present in the same sequence as the color name, tcol object in our example.

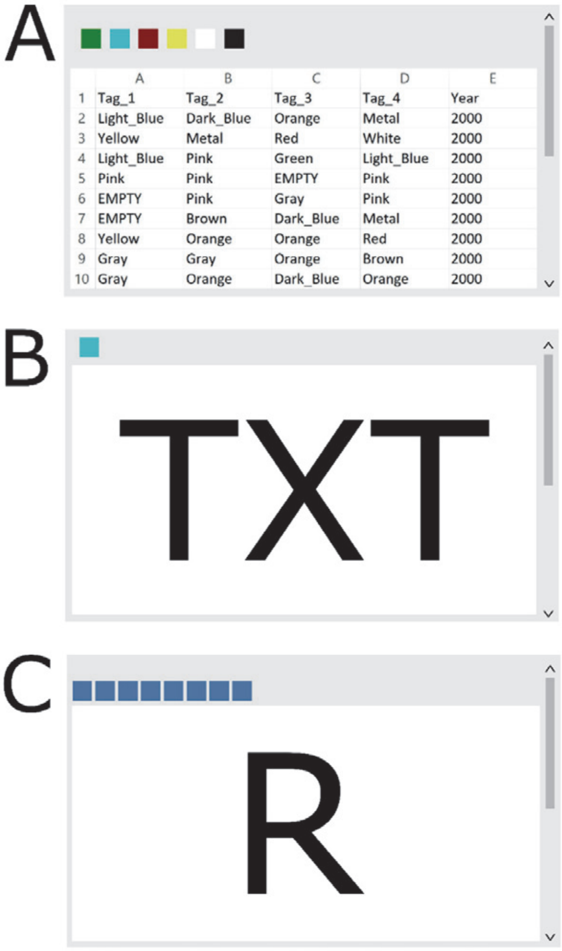
```
# Create an object to hold the ratio for sampling
p<-c(1,2,5,1,2,2,4,5,8,5)

# Generate sequences by Variable frequency algorithm
genseq(ncombinations=30, ntag=4, colorsname=tcol, gen_method="vfrequency", colorsf=p)
```

A good practice for those that decide to use this method is to create a spreadsheet with two columns, where the first column contains the name of the colors and the second contains the number of available tags. Next, import the table (as shown in Fig. 1), and use the first column to address color name (in colorsname argument), and the second column as a reference for the sampling ratio (in usedcombinations argument).

For a quick adjustment in color representation, we recommend the use of the "*Life expectancy*" method. This algorithm creates a restriction based upon color combinations. The sample ratio for each color is adjusted based upon an estimate of how many color tags still exist in nature. This method allows a proportional adjustment of colors in the population faster than the "*All equal*" method. To apply this method it is necessary to inform when each combination was used (yearusedcombinations argument). To improve accuracy, you can provide an estimation of yearly survival rate (yearsurvival argument), and lifespan (lifespan argument), which will provide an estimate on the remaining color tags present in nature based on ringing date. If yearsurvival and lifespan are undefined, it will be assumed that animals never die, and that the proportion that occurs in the natural population equals the total number of tags used. In a long-term survey, it is reasonable to not take into account old tag records.

```
# Generate sequences by Life expectancy algorithm
genseq(ncombinations=30, ntag=4, gen_method="lifexp", colorsname= tcol, usedcombinations=pre_used[,1:4],
yearusedcombinations=pre_used[,5], yearsurvival= 0.8, lifespan=5, currentyear=2019)
```



	A	B	C	D	E
1	Tag_1	Tag_2	Tag_3	Tag_4	Year
2	Light_Blue	Dark_Blue	Orange	Metal	2000
3	Yellow	Metal	Red	White	2000
4	Light_Blue	Pink	Green	Light_Blue	2000
5	Pink	Pink	EMPTY	Pink	2000
6	EMPTY	Pink	Gray	Pink	2000
7	EMPTY	Brown	Dark_Blue	Metal	2000
8	Yellow	Orange	Orange	Red	2000
9	Gray	Gray	Orange	Brown	2000
10	Gray	Orange	Dark_Blue	Orange	2000

Figure 1. General overview of how to import pre-used sequences into R. There are several ways to import data into R, this is just one approach. **A**) Use a spreadsheet software (*e.g.* Microsoft Excel, LibreOffice Calc, Apple Numbers) to type your pre-used combinations. In the example, the first row is the header, and five columns are used to present information of color tags. Columns 1, 2, 3 and 4 denotes positions upper left, bottom left, upper right, and bottom right, respectively; the last column denotes the year/breeding season when the bird was color tagged. **B**) Export your spreadsheet as a ".txt" file. **C**) Import your pre-used records and store in an object, by typing the following command at the R prompt: `pre_used<-read.table(choose.files(), header = TRUE)`

Two additional functions facilitate awareness of previously-used color patterns. First, `scy` provides a historical log of used tag colors. To estimate remaining colors in the natural study population, the `erc` function can be used. The arguments `yearsurvival` and `lifespan` can also be used to improve estimate accuracy `erc`. If you used the “EMPTY” code, you can hide this information on reports using the argument `hide_color`.

```
# Summary the number of color tags used by year
scy(usedcombinations=pre_used[,1:4],yearusedcombinations=pre_used[,5], hide_color=“EMPTY”)

# Estimates remaining color tags in the field
erc(usedcombinations=pre_used[,1:4],yearusedcombinations=pre_used[,5],yearsurvival=0.8, hide_color=“EMPTY”, currentyear=2019)
```

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ARTICLE

Ground nesting birds in roadside borders of the Argentine Pampas: habitat use and predation risk of artificial nests

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ABSTRACT: Habitat loss and fragmentation have led to grassland bird declines, with ground nesters particularly vulnerable. Roadsides could provide habitat, although their suitability depends on several roadside and field characteristics. Vegetation structure determines foraging and nesting site availability. In addition, road delimits sharp edges where the activity of nest predators is usually higher, whereas herbaceous vegetation determines ground nest concealment. Trees could provide lookouts to predators, and modified habitat and woodlands in surrounding fields could offer additional resources to predators. Our objective was to assess habitat suitability for ground nester birds in roadsides belonging to one modified grassland of the Argentine Pampas. We surveyed birds (90 plots) and monitored artificial nests (60 plots) in different road types: unpaved, paved of one-lane per side, and paved of two-lanes per side. Within each road type, we evaluated the relationship that ground nesters abundance had with vegetation structure of roadsides and surrounding fields. In addition, we related predation of artificial nests with the proximity to the road, roadside vegetation, and modified land and woodlands of surrounding fields. We made 2832 records of 84 species using roadsides, including 1083 records of 13 ground nesting species. Abundance of ground nesters increased with tall grass cover of roadsides and decreased with the number of native trees within roadsides. Roughly half (31/60) of the artificial nests were predated and 82.6% of the identified egg-marks were of mammal teeth. Nest predation decreased with nest proximity to the road. Our results emphasize the importance of tall grass cover of roadsides for the conservation of ground nesting species, and the necessity of monitoring natural nests in order to clarify the effect of trees, proximity to the road, and other environmental variables on nest success.

KEY-WORDS: corridors, field margins, grassland birds, habitat remnants, survival analysis.

INTRODUCTION

Habitat loss and fragmentation have led to the decline of grassland bird populations worldwide (Askins *et al.* 2007, Zuckerberg *et al.* 2009, Azpiroz *et al.* 2012, Reif 2013). Amongst them, ground nesting birds are particularly vulnerable due to the greater exposure of eggs, chicks and incubating adults to mammalian and bird predators (Pietz *et al.* 2009, Fletcher *et al.* 2010), which increases with habitat fragmentation due to higher amounts of habitat edges with which predators are associated (Evans 2004, Huijser & Clevenger 2006). Thus, conservation researchers have become interested in habitat remnants that could benefit the conservation of these species (Weidman & Litvaitis 2011, Duchardt *et al.* 2016, Port & Schottler 2017). In this context, it has been proposed that roadside networks can provide habitat (Meunier *et al.* 1999, Bergin *et al.* 2000), although their suitability for grassland birds depends on several factors affecting bird abundance and nest predation.

One key factor influencing the abundance of grassland birds in roadsides is vegetation structure, which determines the availability of shelter, foraging sites and nesting sites (Meunier *et al.* 1999, Kociolek *et al.* 2011). Moreover, habitat availability in the surrounding fields may also promote bird abundance in roadsides (Huijser & Clevenger 2006), while woodlands and modified land (*i.e.*, crops or human settlements) have exhibited a negative association with the abundance of birds inhabiting grassland remnants (Leston 2013, Dotta *et al.* 2016, Pretelli *et al.* 2018). Some grassland birds might avoid these areas since woodlands can increase the abundance of specialist predators (Vickery *et al.* 2009, Ellison *et al.* 2013) and brood parasites (Patten *et al.* 2006, Pietz *et al.* 2009), and modified land may offer resources to generalist predators (Evans 2004, Benítez-López *et al.* 2010).

In addition, roadside characteristics can affect ground nesting bird populations due to their influence on nest predation risk. Nest detectability by predators decreases with greater structural complexity of the vegetation, which contributes to nest concealment (Weidinger 2002, Conover *et al.* 2011). In contrast, detectability may be increased by the proximity to trees, which offer lookouts to avian predators that use visual cues (Söderström *et al.* 1998, Bergin *et al.* 2000, Flaspohler *et al.* 2001) as well as to brood parasites (Patten *et al.* 2006). Moreover, roads lack structural complexity, and nest proximity to the road could imply the proximity to hard habitat edges where predator activity is higher (Fletcher & Koford 2003, Weldon & Haddad 2005, King *et al.* 2009). Likewise, predation can depend on wider scale factors such as the prevalence of woodlands and modified lands, which offer resources to generalist predators and may enhance their abundance in the landscape (Hogrefe *et al.* 1998, Vickery *et al.* 2009, Ellison *et al.* 2013).

Analyzing factors that affect both abundance and predation risk, therefore, constitutes an appropriate method to assess roadsides' suitability for birds in threatened grasslands. In particular, some of the most important Neotropical grasslands are those of southeastern South America, constituted by a part of Uruguay, southern Brazil and mainly by the Pampas in Argentina (Soriano *et al.* 2001). The conservation status of the Pampas is critical since currently more than 75% of their extent has been converted into croplands (Viglizzo *et al.* 2011). Such habitat loss has caused a decrease in the abundance and distribution of many grassland bird species, including a high proportion of ground nesting birds (Fraga 2003, Di Giacomo & Di Giacomo 2004, Filloy & Bellocq 2007, Azpiroz *et al.* 2012). Roadside conservation and management practices are still uncommon in the region, although it has been reported that ground nesting birds and many other bird species use roadsides more frequently than adjacent pastures and crops (*i.e.*, soy and maize, Leveau & Leveau 2011), and that grassland nesting bird richness increase with the amount of roadside borders in rural areas (Codesido & Bilenca 2011).

Our objective here was to assess breeding habitat suitability for ground nesting birds in roadsides belonging to one modified grassland of the Argentine Pampas. In particular, we analyzed the effects that roadside and surrounding field characteristics have on bird abundance and nest predation. To achieve that aim, in different road types, we performed bird surveys and evaluated the relationship of bird abundance with vegetation structure of roadsides and surrounding fields. Additionally, we conducted an experiment with artificial nests to identify nest predators, and to evaluate the effects that proximity to the road and vegetation structure of roadsides and surrounding fields have on ground nest predation.

METHODS

Study area and sampling sites

Field work was carried out near General Madariaga city (37°0'7''S; 57°8'10''W), Buenos Aires province, Argentina, within the flooding Pampa. In the flooding Pampa, mean temperature varies from 23°C in January to 13°C in July with mean annual precipitation of 1000 mm (Soriano *et al.* 2001). The area exhibits subtle topographic variations (most lands are less than 4 m above sea level), with lowlands remaining flooded for long periods. For this reason, the flooding Pampa is the least cropped portion of the Pampas and the distribution of many native bird species is restricted to this area, giving it a high conservation value (Codesido *et al.* 2011). However, since 1990's increasing crop lands and cattle production pose conservation implications (Agra *et al.* 2015). Vegetation in this area is a mosaic of extensive grasslands disrupted by wetlands with a high presence of *Schoenoplectus californicus* (Family Cyperaceae), *Solanum glaucophyllum* (Solanaceae), *Senecio* spp. (Asteraceae), and *Typha* spp. (Typhaceae), and by smaller patches of native woodlands comprised mostly of *Celtis ehrenbergiana* (Cannabaceae) in the higher areas (Vervoorst 1967). About 70% of the area is used for cattle production, with land crops covering 20% (Codesido & Bilenca 2011) and the remaining land consisting in deep water bodies, tree plantations, dunes, salt marshes, and urban areas (Baldi & Paruelo 2008).We conducted our study in October–November 2015, which comprises the peak of the breeding season for most bird species (de la Peña 2015). Within an area of approximately 80,000 ha, we sampled roads representing the three types of roads present in the area. Sampled road types were: unpaved roads of local use (three roads), one paved road of one-lane per side that connects General Madariaga city with Las Armas town, and one paved road of two-lanes per side that connects General Madariaga city with Pinamar city. All these roads could be considered as transects, being the mean distance among transects' midpoints 20.4 km (range: 6.2–26.5 km). Road types have different speed limits (two-lanes per side: 110 km/h, one-lane per side: 100 km/h, unpaved: 60 km/h). In addition, road types could have different traffic intensity in terms of vehicles per unit of time. The two-lanes per side probably has the highest amount of vehicles per unit of time since it connects two cities and leads to one of the most important touristic spots along the coast of Buenos Aires province. We further considered the potential differences among road types from a birds' perspective (see Statistical analysis), since it has been reported that traffic-related factors such as noise can affect bird distribution and behavior (Seiler 2001, Kociolek *et al.* 2011).

Along each road we selected points at random distances from the beginning of the sampling section of the road (one-lane per side: *n* = 30 points, two-lanes per side: *n* = 30, unpaved: *n* = 30), being the minimum distance between neighbour points 400 m. Then, in each point we established one sampling plot, which was a fragment of roadside borders of 200-m length that was centred in the point and comprised the area between the edge of the road, either right or left, and the fence of its adjacent field. Since the width of our roadside borders had a range of 6.0–45.6 m, the area of our sampling plots varied between 0.12 and 1.08 ha.

Bird sampling

In each sampling plot, we performed bird surveys using 10-min point counts, during the first 4 h after sunrise and in good weather conditions (Bibby 2000). Sampling plots were divided in two 100-m length subplots, and each of two observers recorded every bird seen or heard in one subplot, disregarding those birds flying above the plot. We considered that there was minimal need to account for detection probability given the high visibility in these roadside borders mainly constituted by grassland, and because each observer recorded individuals at a maximum distance of 50 m (Smucker *et al.* 2005). To increase the accuracy of abundance estimations, we surveyed each plot twice (one visit during October and the other one during November), and the maximum number of individuals recorded for each species was considered the species' abundance. Later, we classified species by their nesting sites (de la Peña 2015). We only considered in further analyses the abundance of those grassland birds that build their nests directly on the ground, or very close to the ground on clumps of grasses (de la Peña 2015), hereafter designated as "ground nesting birds". We also noted which of these ground nesting bird species are considered as grassland obligates (Azpiroz & Blake 2009). Scientific nomenclature was in accordance with South American Classification Committee (SACC–American Ornithologists' Union, Remsen-Jr. *et al.* 2019).

Vegetation sampling

In each sampling plot, we estimated local vegetation cover based on three transects perpendicular to the road, separated by 75 m. One observer (D. Depalma) measured the length of intersection of each vegetation type (see below) on each transect, by walking along the transect using a measuring tape (Matteucci & Colma 1982). When there was no accessibility (*e.g.*, wetlands), the length of intersection of vegetation types was measured with a rangefinder (Redfield® Raider™ 550). Then we expressed the lengths of intersection as percentages. Finally, in every plot, for each vegetation type we used the average of the three transects. The perpendicular orientation of transects allowed us to account for the vegetation gradient present in roadside borders.

Vegetation types consisted of short grass (areas consisting mainly in grasses shorter than 30 cm), tall grass (grassland of 30–80 cm height dominated by the exotic pasture *Festuca arundinacea* –with low presence of *Bromus catharticus*, *Dactylis glomerata*, *Triticum aestivum*, *Nassella neesiana*, *Avena sativa* and *Phalaris minor*), Pampa grass (individuals of the native grass *Cortaderia selloana* of 0.7–2 m height), dicotyledoneous (grassland of 30–80 cm height dominated by exotic flowering plants with non-negligible presence of native flowering plants), wetland vegetation (*S. californicus* and *Typha* spp.), water, native trees (*C. ehrenbergiana* and *Scutia buxifolia*) and exotic trees (mainly *Populus* spp.). All flowering plants were classified into the finest level possible, and thus we determined that exotic flowering plants belonging to the family Brassicaceae represented 55% of the total flowering plants, and plants belonging to the native species *Matricaria chamomila* represented 32%. We also counted individual trees within the entire area of each sampling plot. In all statistical analyses, the number of trees was incorporated instead of tree cover, since it may be a more accurate variable to measure in linear fragments (McDonald & Johnson 1995; Table 1). The number of trees has been also mentioned as one of the major factors influencing bird richness and abundance in field borders (Hinsley & Bellamy 2000).

In addition, while measuring vegetation cover at plot scale, we described the cover of surrounding fields. Later, we estimated the cover of surrounding fields in satellite images of November 2015 (Image© 2017 Digital Globe, source: Google® Earth™) with Google Earth Pro Software (Sullivan 2009). Validating the images with our observations recorded in the field, we measured the percentage of short grassland, seminatural grassland, native woodland, exotic woodland, and modified land within a 200-m radius circular area around each plot (Table 1). Short grassland consisted in extremely short grass intensively grazed or mowed. Seminatural grassland consisted in tall grass often moderately disturbed by grazing. Modified land consisted in crops (mainly maize and soy), stubble, and human settlements. Finally, native woodland consisted in groups of trees mainly composed by *C. ehrenbergiana* and *S. buxifolia*, and exotic woodland were composed by at least 80% of exotic trees (mostly *Eucalyptus* spp., Table 1). We considered the percentage of seminatural grasslands as available habitat for grassland birds, and the percentage of native and exotic woodlands and modified land as potential sources of predators.

Artificial nests experiment

Artificial nests carry a certain bias since their visual signals (absence of parental activity) and chemical signals differ from those of natural nests, and thus they may underestimate or overestimate the actual predation risk, according to nest type and predator community composition (Thompson & Burhans 2004). However, they provided us a possibility to evaluate the relationship

Table 1. Characteristics of roadside borders of the Argentine Pampas. Frequencies of occurrence and mean value ± standard deviation per sampling plot are shown. Ranges are in parentheses.

Vegetation type	Frequency of occurrence (%)	Value per plot
Roadsides		
Short grass (%)	86.6	10.8 ± 10.5 (0–39.5)
Tall grass (%)	70	32.7 ± 28.5 (0–95.8)
Pampa grass (%)	47.7	5.7 ± 10.1 (0–48.5)
Dicotyledonous (%)	82.2	5.4 ± 6.9 (0–32.9)
Wetland (%)	72.2	21.4 ± 21.8 (0–87)
Native trees (*n*)	55.5	7.4 ± 14.5 (0–71)
Exotic trees (*n*)	5.5	1.4 ± 7.6 (0–50)
Total trees (*n*)	58.8	8.8 ± 17.4 (0–89)
Surrounding fields		
Seminatural grassland (%)	46.6	12.3 ± 17.2 (0–72.1)
Short grass (%)	60	2.7 ± 23.9 (0–81.2)
Wetland (%)	76.6	14.4 ± 15.1 (0–52.8)
Modified land (%)	44.4	8.6 ± 14.3 (0–55.4)
Native woodland (%)	43.3	1.3 ± 2.6 (0–11.5)
Exotic woodland (%)	22.2	0.6 ± 1.4 (0–6.5)
Total woodland (%)	66.6	2.5 ± 3.8 (0–24.19)

between predation risk and environmental variables through a field experiment, controlling for nest location, clutch size and differences in parental activity around the nest (Thompson & Burhans 2004). In addition, we were able to identify types of predators by the marks left on artificial eggs (Zanette & Jenkins 2000). Within a representative subsample of 60 plots (*i.e.*, one-lane per side: *n* = 20, two-lanes per side: *n* = 20, unpaved: *n* = 20), we placed one artificial nest made of hemp on the ground. To resemble the nesting sites of ground nesting birds, all nests were located beneath a clump of tall grass, therefore equally sheltered. Monitoring was performed every four days until predation occurred or during 16 days, which encompassed the approximate duration of laying plus incubation periods of most ground nesting passerines (de la Peña 2015). The artificial nest (10.5 cm diameter × 5.5 cm depth) was always placed in the center of the 200 m of the plot, beneath the first clump of tall grass encountered by walking from the road into the roadside border. We used this method instead of selecting fixed locations because, due to the presence of wetlands within most roadsides, many locations were unsuitable for nest placement (Table 1). In each nest, we put two quail eggs (*Coturnix coturnix*): one natural egg and the other filled with paraffin and tied to the nest by a nylon thread (Svagelj *et al.* 2003). We considered the removal and/or break of at least one of the eggs as a predation event. When predation was detected, nests were immediately removed and no longer monitored. After monitoring, we observed the natural and the paraffin-filled eggs and looked for marks. We interpreted the marks based on the criteria used by Cozzani & Zalba (2012) to identify ground nest predators in Buenos Aires province. Thus, we considered incisor marks on the paraffin-filled egg as predation by small mammals, while bigger and deeper teeth marks, and horseshoe shape marks on the natural egg were considered as predation by medium-sized mammals. Likewise, unique, deep marks on the paraffin-filled egg were considered as predation by birds, and the presence of two marks separated by a distance of 0.9 cm was considered predation by ophidians.

Statistical analysis

All statistical analyses were conducted using the R environment (R Core Team 2019). We evaluated the relationship between total abundance of ground nesting birds and environmental variables using a Generalized Linear Mixed Model (GLMM) with the “glmadmb” function of the “glmmADMB” package (Bolker *et al.* 2012). Since overdispersion occurred when adjusting the model to a Poisson distribution, we solved this problem by using a Negative Binomial distribution. We accounted for potential interdependencies among plots belonging to the same road type by incorporating “road type” as a random factor. Furthermore, since plots along unpaved roads were grouped in three different roads, we incorporated the random factor “road identity” nested within road type. The dependent variable in the model was total abundance of ground nesting birds. We considered nine candidate independent variables measured at plot scale: the percentage (%) of short grass, tall grass, dicotyledonous, Pampa grass, wetland vegetation and water, the number of native trees, the number of exotic trees, and the number of total trees. We also considered five candidate independent variables of surrounding fields (200-m radius): available habitat for grassland birds (percentage of seminatural grassland), and sources of predators (percentage of native woodland, percentage of exotic woodland, percentage of total woodland and percentage modified land). Since sampling plots had different widths, we incorporated plot area as an offset, which specifies an *a priori* known component to be included in the linear predictor during fitting (Crawley 2012).

We evaluated the support for predictor variables by information theoretic procedures (Burham & Anderson 2002), using the "MuMIn" package (Bartoń 2013). We used Akaike's information criterion corrected for small sample size (AIC_c). In order to improve the parsimony (in terms of model parameters) of the global model, and to avoid generating an excessively large set of models based on sample size which could lead to spurious results (Grueber *et al.* 2011), we only incorporated relevant parameters. In order to define relevant parameters, we first built 14 univariate models, each of them having one candidate independent variable as the only predictor. We incorporated to the global model only those variables that lowered the AICc in more than 2 units relative to the null model. Those variables were the percentage of tall grass within roadsides and the number of native trees within roadsides (the correlation between these two variables was not significant). In addition, we also included the interaction between both variables. We considered models with all possible combinations of the three final predictor variables and ranked them by their AIC_c. Finally, we obtained parameter estimates by averaging models with a $\Delta AIC_c < 4$ from the best model, and calculated 95% confidence interval limits of parameter estimates (Grueber *et al.* 2011).

To test the effects of environmental variables on artificial nests' survival we used a mixed Cox proportional hazards model (Cox 1972) with the "coxme" package (Therneau & Therneau 2018). This model is an extension of survival analysis similar to a logistic regression, and is able to evaluate the relationship between independent variables and the rate of occurrence of predation (Santabárbara *et al.* 2016). As with the model of bird abundance, we accounted for potential interdependencies among plots belonging to the same road and road type by incorporating the random factor "road identity" nested within the random factor "road type". The dependent variable was composed of the survival time (days) and the occurrence of predation (0 or 1). The coefficient of an independent variable indicates its relationship with the occurrence of predation: a positive coefficient means that the variable is positive associated with the occurrence of predation. Coefficients were calculated by the partial maximum likelihood method. Likewise, for every independent variable the model estimates a Hazard Ratio (HR). A HR > 1 indicates that the variable is positively associated with the probability of predation, while a HR < 1 indicates the opposite. We considered nine candidate independent variables measured at plot scale: the percentage (%) of short grass, tall grass, dicotyledonous, Pampa grass, wetland vegetation and water, the number of native trees, the number of exotic trees, and the number of total trees. We also considered four candidate independent variables of surrounding fields (sources of predators within the 200-m radius): percentage of native woodland, percentage of exotic woodland, percentage of total woodland, and percentage of modified land.

To improve the parsimony of a potential global model, we first built one univariate mixed model to test the effect of each independent variable on survival separately, in order to further incorporate relevant parameters only. The only independent variable that had a significant effect on survival was "distance to road". We checked the assumptions about the linear functional form of the independent variables and hazards proportionality (*i.e.*, the ratio of the survival rates remaining constant through time; Santabárbara *et al.* 2016). To accomplish this, we deleted two nests belonging to the two-lanes per side road that impeded the linear functional form of the variable "distance to road". These nests (*i.e.*, outliers) were removed from all the analyses.

RESULTS

Bird abundance

We made 2832 records of 84 species using roadside borders. Amongst them, 1083 individuals (38.2%) belonging to 13 species (15.5%) were ground nesting species (Appendix I). Seven of these species are considered grassland obligates (*Leistes superciliaris*, *Anthus correndera*, *Sicalis luteola*, *Embernagra platensis*, *Vanellus chilensis*, *Nothura maculosa* and *Rynchotus rufescens*; Appendix I). As shown by the GLMM, ground nesting birds' abundance was positively associated with the percentage of tall grass within roadsides, and negatively associated with the number of native trees within roadsides (Table 2).

Survival of artificial ground nests

Of the 60 artificial nests we set out, 31 were predated within the 16-day period (one-lane per side: *n* = 10, two-lanes per side: *n* = 10, unpaved: *n* = 11). Thus, artificial nest survival was 48.3%. According to the criteria used by Cozzani & Zalba (2012), 43.7% of predated nests (14 nests) exhibited small mammal marks, 15.6% (5 nests) were predated by medium sized-mammals, 9.4% (3 nests) were predated by birds and 3.1% (1 nest), by ophidians (Fig. 1). In 25% of nests (8 nests), we could not identify the predator, since in five cases the artificial egg had non identifiable marks (Fig. 1), and in three cases it had been removed. In such situations, we could not identify the predator using the natural egg either, since it had been removed in four nests, and it exhibited unidentifiable marks in the remaining nests.

Moreover, during field work we detected potential mammalian predators: *Galictis cuja* (Order Carnivora), *Conepatus chinga* (Order Carnivora), *Cavia aperea* (Order Rodentia) and *Didelphis albiventer* (Order Didelphimorphia). We also detected potential ophidian predators: *Liophis poecilogyrus* and *Liophis anomalus* (Order Squamata). Likewise, we recorded potential avian predators during bird surveys: *Caracara plancus*, *Milvago chimango*, *Chroicocephalus maculipennis*, *Circus buffoni* and *Guira guira* (Appendix I).

As shown by the results of mixed univariate Cox regressions, only distance to road had a significant effect on nest survival. The probability of nest predation was

Table 2. Candidate Generalized Linear Mixed Models with factors influencing the abundance of grassland ground nesting bird species in roadside borders of the Argentine Pampas, listed in decreasing order of importance. Only those models with a $\Delta AIC_c < 4$ from the best model and the null model are included. Averaged estimates of parameters are shown in the second part of the table. Those parameters whose 95% Confidence Intervals excluded 0 are in bold. K: number of parameters. TGR: tall grass of roadsides; NTR: native trees of roadsides; TGR*NTR: interaction term. SE: unconditional Standard Error. CI: 95% Confidence Interval.

Candidate models	**K**	**Log-likelihood**	**AIC_c**	**ΔAIC_c**	**Weight**
TGR + NTR	6	-262.22	537.5	0	0.58
TGR	5	-264.39	539.5	2.04	0.21
TGR + NTR + TGR*NTR (Global model)	7	-262.1	539.6	2.13	0.2
Null model	4	-268.91	546.3	8.83	0.01

Model averaging	**Estimate**	**SE**	**CI**	**Relative importance**
TGR	**0.247**	**0.07**	**0.097, 0.397**	**1**
NTR	**-0.092**	**0.07**	**-0.229, -0.005**	**0.79**
TGR*NTR	0.001	0.02	-0.073, 0.119	0.2

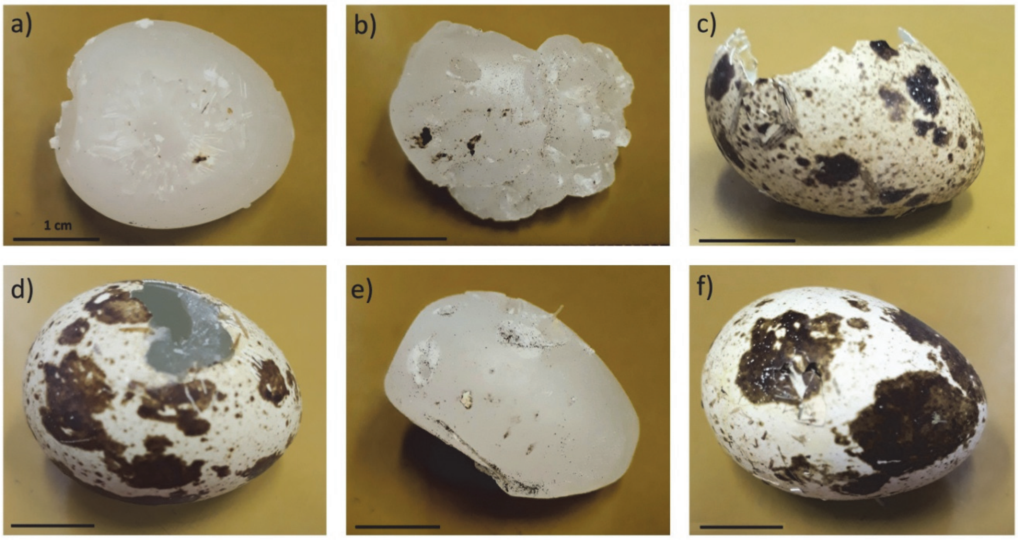

Figure 1. Predated natural and paraffin-filled *Coturnix coturnix* eggs on roadside borders of the Argentine Pampas. Examples of marks produced by small-sized mammals' incisors (**A**), medium-sized mammals' teeth marks (**B**), a horseshoe-shaped mark produced by a medium-sized mammal (**C**), one unique bird's beak mark (**D**), two marks produced by an ophidian predator (**E**) and one unidentifiable mark (**F**).

positively associated with the distance to road ($P < 0.05$; Table 3, Fig. 2). Nevertheless, the probability of nest predation also exhibited a marginal positive association with the number of native trees within roadsides ($P = 0.05$, Table 3).

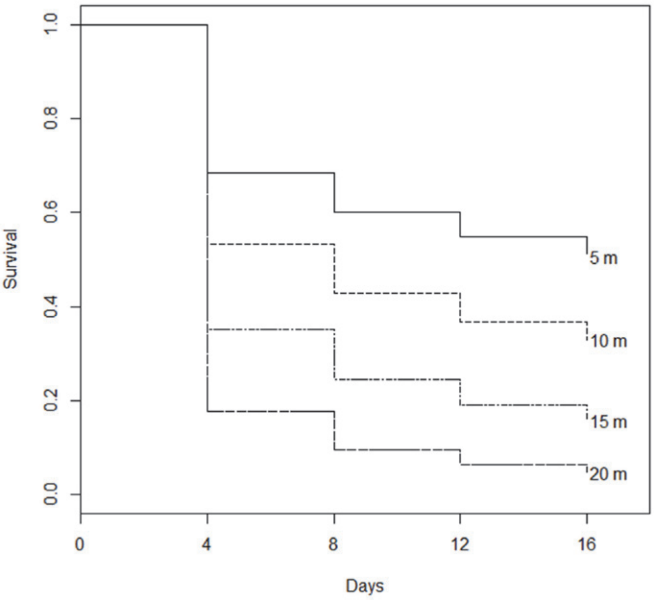

Figure 2. Expected survival curves for artificial nests located at different distances to the road in roadside borders of Argentine Pampas. Survival curves were built by fitting a mixed Cox proportional hazards model with distance to the road as the predictor variable. Predicted survival for nests located at 5, 10, 15 and 20 m from the road are shown.

DISCUSSION

In order to assess the suitability of roadsides for ground nesting birds in one modified grassland of the Argentine Pampas, we evaluated the influence of roadside factors and surrounding field factors on bird abundance, and on the predation of artificial nests. We found that bird abundance was positively associated with tall grass cover of roadsides and negatively associated with the number of native trees of roadsides, while evidence of predation decreased with proximity of nests to the road.

Regarding bird abundance, our results indicate that tall grass cover of roadsides favors their use by ground nesting birds, while the number of native trees reduces it. Similarly, it has been previously reported that ground nesting birds of the Pampas such as *Sicalis luteola* use grassy field margins more frequently than margins with trees (Leveau & Leveau 2011). In another study of birds inhabiting field margins of the Argentine Espinal region, authors found that while total bird density increased with the number of trees, the density of some ground nesters decreased (Di Giacomo & Lopez-de-Casenave 2010). In this sense, it is possible that tall grass increase the amount of escape cover and nest concealment for most ground nesters considered in our study (Isacch & Martínez 2001, Davis 2005), while native trees in the proximities imply higher rates of nest predation and parasitism (Flaspohler *et al.* 2001, Patten *et al.* 2006, Pietz *et al.* 2009). It is not clear why only native trees, rather than total trees,

Table 3. Factors influencing predation of artificial nests in roadside borders of Argentine Pampas, tested by Mixed Cox Logistic Regression models. Regression coefficient and hazard ratio for the predictor variable of each of the univariate models are shown. Significant predictor variables ($P < 0.05$) are in bold.

Univariate model	Coefficient	*P*-value	Hazard ratio
Short grass	0.005	0.57	1.01
Tall grass	-0.005	0.41	0.99
Pampa grass	0.014	0.5	1.01
Dicotyledonous	-0.036	0.27	0.96
Wetland vegetation	0.007	0.43	1.01
Water	-0.005	0.73	0.99
Native trees	0.02·	0.05	1.02
Exotic trees	-0.02	0.37	0.97
Total trees	0.006	0.41	1.01
Distance to road	**0.102***	**0.02**	**1.11**
Modified land	< -0.001	0.21	0.99
Native woodland	0.028	0.71	1.02
Exotic woodland	0.105	0.37	1.11
Total woodland	< -0.001	0.97	0.99

* $P < 0.05$
· $P < 0.1$

were negatively associated with bird abundance. One explanation is that native trees attract more predators than exotic trees. For example, in the Pampas, insectivorous birds usually prefer to forage on native trees than on exotic ones (Cueto & Lopez-de-Casenave 2002). Therefore, native trees could attract some insectivorous birds that predate nests opportunistically, and thus represent an additional predation pressure. Another explanation is that native trees were more abundant than exotic ones in roadsides (Table 1) and formed continuous lines along field fences, which could provide more shelter to predators, and be perceived by sharp edges by birds (Fletcher & Koford 2003, Weldon & Haddad 2005).

Unlike local vegetation of roadsides, the cover of surrounding fields did not relate with bird abundance. On the one hand, the lack of associations between bird abundance and the cover of seminatural grasslands in the landscape could suggest that during the breeding season birds travel short distances to fulfill their requirements, and forage within nest proximities rather than using surrounding alternative habitats (Robinson *et al.* 2004, Vickery *et al.* 2009). On the other hand, the lack of associations between abundance and sources of predation such as woodlands and modified lands could be related to the characteristics of our study area. Also in the flooding Pampa, Pretelli *et al.* (2018) found no negative effect of agriculture on the abundance of grassland specialist birds inhabiting grassland remnants, probably because in this region agriculture is often mixed with short grasses and pastures. In contrast, they did report a negative effect of a continuous forest matrix around grassland remnants on bird abundance, although our study area did not exhibit a forest matrix but rather small scattered patches of woodland, which could be perceived differently by birds.

Regarding nest predation, most marks left on artificial nests belonged to mammals. A high frequency of predation by mammals in our nests is consistent with other studies, which compared nest predation at different heights and reported that mammals were the most frequent predators of ground nests (Söderström *et al.* 1998, Colombelli-Négrel & Kleindorfer 2009). As proposed for other habitat strips within modified landscapes, these roadsides could serve as corridors for mammals, which could predate nests in an opportunistic manner as they travel (Meunier *et al.* 1999, Conover *et al.* 2011).

Additionally, predation mostly due to mammals could explain the striking negative relationship between proximity to the road and the probability of predation. These animals are usually affected by the presence of roads (Seiler 2001, Benítez-López *et al.* 2010). Moreover, recent researches about animals killed by collisions in Argentine roads found dead individuals of some of the mammalian predators we detected during this study such as *Didelphis albiventer*, *Galictis cuja* and *Cavia aperea* (Attademo *et al.* 2011, Bauni *et al.* 2017). Therefore, it is possible that mammals do not prefer to forage in road proximities, but rather move along the road, parallel to it (Forman & Alexander 1998, Meunier *et al.* 1999).

Nevertheless, the success of real nests may be influenced by additional factors. Real nests might not be exposed to the same predation pressures as artificial nests (Thompson & Burhans 2004), and artificial nests can underestimate predation by birds due to the lack of parental activity (Söderström *et al.* 1998, Flaspohler *et al.* 2001). Thus we cannot reject based on our results the possibility that nest predation may be causing the negative relationship between bird abundance and native trees, and that native trees may have a significant, rather than marginal, positive effect on nest predation. During bird surveys, we detected avian predators perching on trees in roadsides (Appendix I), and trees could offer them lookouts during the predation of real nests (Flaspohler *et al.* 2001).

Another explanation, although not excluding, would be that the negative association between grassland birds and native trees is actually the result of a higher risk of nest parasitism near trees (Patten *et al.* 2006, Pietz *et al.* 2009). Within the Pampas, nest parasitism by the generalist brood parasite *Molothrus bonariensis* is one of the major causes of egg losses for nesting birds, due to the punctures performed on the host's eggs during inspection visits (Massoni & Reboreda 2002). However, this icterid might not be able to break the thick shell of quail eggs (Svagelj *et al.* 2003). Likewise, it might not visit artificial nests frequently, since parasites' behavior is usually based on parental activity around the nest (Wilson *et al.* 1998). The monitoring of real nests would be necessary in order to test the potential implications of native trees for nest predation and parasitism. In addition, real nest monitoring could also clarify the effect of road proximity on ground nest success. Although our artificial nests were less likely to be predated in road proximities, chicks of natural nests that hatch and fledge closer to roads may be more exposed to collisions (Kociolek *et al.* 2011).

In summary, this paper highlights that roadside borders of the flooding Pampas are inhabited by a wide range of grassland bird species, including several grassland obligates, and their conservation value could be increased with the application of appropriate managements. Such managements should consider the importance of tall grass for ground nesting birds, as well as the negative effects of native trees on their abundance. Future studies that involve the monitoring of real nests are necessary in order to elucidate the potential effects of native trees, distance to the road, and other environmental variables on ground nest success.

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APPENDIX I

Birds recorded using roadside borders of the Argentine Pampas (n = 90 sampling plots). In every plot, the maximum abundance of each species recorded across samplings (October and November) was used. Total individuals of each species summed those detected over the 90 sampling plots. (*) Grassland ground nesting species. (**) Grassland obligates.

Order, Family, Species	Total individuals	Presence (%)	Mean abundance
TINAMIFORMES			
Tinamidae			
*Rhynchotus rufescens**, **	27	22.22	0.03
*Nothura maculosa**, **	7	7.77	0.07
ANSERIFORMES			
Anhimidae			
Chauna torquata	1	1.11	0.01
Anatidae			
Dendrocygna viduata	1	1.11	0.01
Callonetta leucophrys	4	2.22	0.04
Spatula versicolor	15	7.77	0.16
Anas georgica	2	1.11	0.02
Anas flavirostris	4	3.33	0.04
Netta peposaca	3	2.22	0.03
PODICIPEDIFORMES			
Podicipedidae			
Rollandia rolland	4	2.22	0.04
Podilymbus podiceps	2	2.22	0.02
Podiceps major	1	1.11	0.01
COLUMBIFORMES			
Columbidae			
Patagioenas picazuro	10	8.88	0.11
Zenaida auriculata	63	36.66	0.7
Columbina picui	3	2.22	0.03
CUCULIFORMES			
Cuculidae			
Guira guira	25	5.55	0.27
GRUIFORMES			
Aramidae			
Aramus guarauna	1	1.11	0.01
Rallidae			
Pardirallus maculatus	1	1.11	0.01
Pardirallus sanguinolentus	15	13.33	0.16
Porphyriops melanops	2	2.22	0.01
Fulica rufifrons	3	2.22	0.03
Fulica armillata	6	2.22	0.06
Fulica leucoptera	4	4.44	0.04
APODIFORMES			
Trochilidae			
Chlorostilbon lucidus	8	3.33	0.08

Order, Family, Species	Total individuals	Presence (%)	Mean abundance
CHARADRIIFORMES			
Charadriidae			
*Vanellus chilensis** **	2	1.11	0.02
Recurvirostridae			
Himantopus mexicanus	2	1.11	0.02
Laridae			
Chroicocephalus maculipennis	29	5.55	0.32
Gelochelidon nilotica	1	1.11	0.01
SULIFORMES			
Phalacrocoracidae			
Phalacrocorax brasilianus	1	1.11	0.01
PELECANIFORMES			
Ardeidae			
Ardea alba	2	2.22	0.02
Egretta thula	1	1.11	0.01
ACCIPITRIFORMES			
Accipitridae			
Elanus leucurus	1	1.11	0.01
Rostrhamus sociabilis	21	14.44	0.23
Circus buffoni	5	3.33	0.05
Rupornis magnirostris	1	1.11	0.01
PICIFORMES			
Picidae			
Colaptes melanochloros	1	1.11	0.01
Colaptes campestris	2	2.22	0.02
FALCONIFORMES			
Falconidae			
Caracara plancus	24	16.66	0.26
Milvago chimango	27	24.44	0.3
PSITTACIFORMES			
Psittacidae			
Myiopsitta monachus	62	18.88	0.68
PASSERIFORMES			
Furnariidae			
Furnarius rufus	32	25.55	0.35
Phleocryptes melanops	90	37.77	1
Leptasthenura platensis	2	2.22	0.02
Phacellodomus striaticollis	23	2.22	0.25
Anumbius annumbi	25	21.11	0.31
Limnoctites sulphuriferus	35	24.44	0.38
Synallaxis albescens	3	1.11	0.03

Order, Family, Species	Total individuals	Presence (%)	Mean abundance
Tyrannidae			
Serpophaga nigricans	8	7.77	0.08
Serpophaga subcristata	1	1.11	0.01
Pseudocolopteryx flaviventris	61	38.88	0.67
Tachuris rubrigastra	8	5.55	0.08
Pyrocephalus rubinus	14	10	0.15
Hymenops perspicillatus	144	74.44	1.6
Satrapa icterophrys	7	6.66	0.07
Machetornis rixosa	2	2.22	0.02
Pitangus sulphuratus	57	35.55	0.63
Tyrannus melancholicus	17	13.33	0.18
Tyrannus savana	64	37.77	0.71
Hirundinidae			
Progne tapera	9	6.66	0.1
Progne chalybea	3	3.33	0.03
Tachycineta leucorrhoa	24	20	0.26
Hirundo rustica	128	28.88	1.42
Troglodytidae			
Troglodytes aedon	25	22.22	0.27
Cistothorus platensis	1	1.11	0.01
Polioptilidae			
Polioptila dumicola	5	4.44	0.05
Turdidae			
Turdus rufiventris	5	5.55	0.05
Mimidae			
Mimus saturninus	14	10	0.15
Motacillidae			
*Anthus correndera**, **	3	3.33	0.03
Fringillidae			
Spinus magellanicus	9	6.66	0.1
Passerellidae			
*Zonotrichia capensis**	378	96.66	4.2
Icteridae			
*Leistes superciliaris**, **	1	1.11	0.01
Molothrus bonariensis	219	73.33	2.43
Amblyramphus holosericeus	19	12.22	0.21
Agelaioides badius	58	16.66	0.64
Agelasticus thilius	152	56.66	1.68
Pseudoleistes virescens	222	72.22	2.46
Thraupidae			
Sicalis flaveola	28	15.55	0.31
*Sicalis luteola**, **	526	85.55	5.84
Sporophila caerulescens	8	5.55	0.08

Order, Family, Species	**Total individuals**	**Presence (%)**	**Mean abundance**
*Embernagra platensis**, **	111	65.55	1.23
Poospiza nigrorufa	64	45.55	0.71
*Donacospiza albifrons**	6	5.55	0.06
Paroaria coronata	1	1.11	0.01
Pipraeidea bonariensis	5	3.33	0.05

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ARTICLE

Three bird species new to Brazil from the Serra da Mocidade, a remote mountain in Roraima

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ABSTRACT: From 15 January to 06 February 2016, we conducted an expedition to the Serra da Mocidade, a remote and previously unexplored mountain range in extreme northern Amazonian Brazil. There we encountered three bird species never before documented in Brazilian territory: *Grallaria guatimalensis* (Grallariidae) was photographed, audio recorded, video recorded and a single specimen collected; *Catharus aurantiirostris* (Turdidae) was similarly documented and a series of specimens collected; and a single individual of *Parkesia motacilla* (Parulidae) was photographed. All were found in the understory of montane forest at 1000–1550 m elevation. We interpret each of these as most likely representing a regularly occurring population on Mocidade. However, each had probably been overlooked in Brazil for a different reason and represents a distinct distributional pattern. Adding these novelties to Brazil's previously published total of 1919 species clearly expresses the country's position among the most bird-rich in the world, perhaps the richest, and suggests that further exploration of Brazil's Amazonian mountains will yield more discoveries.

KEY-WORDS: Amazonia, *Catharus aurantiirostris*, *Grallaria guatimalensis*, montane forest, *Parkesia motacilla*, tepui avifauna.

INTRODUCTION

The number of bird species documented within Brazilian territory has grown considerably in recent years, as reported regularly by the *Comitê Brasileiro de Registros Ornitológicos* (CBRO - Brazilian Bird Records Committee; Piacentini *et al.* 2015). There are basically three ways by which an avifauna may increase over time: the discovery of new species, taxonomic revision (elevating subspecies to species level), or simply by documenting the presence of species known from other countries but never before found in the one in question. Brazil is clearly a current hotspot for the discovery of new species (see Whitney & Cohn-Haft 2013), and 15% of the twenty species added in the last country-wide revision were species new to science (Piacentini *et al.* 2015). Similarly, recent taxonomic revisions have led to the splitting of widespread species into numerous more restricted-range ones (*e.g.*, Rodrigues *et al.* 2013, Rego *et al.* 2014, Lopes & Gonzaga 2016), including 75% of the latest increase. This is especially prevalent in the Amazon, where the enormous territorial extent and presence of numerous areas of endemism within Brazil are likely to continue to produce major revisions in taxonomy and increases in total species numbers for some time to come.

The third mode, documenting range extensions into Brazil, is currently the least common, accounting for only 10% of recent additions (Piacentini *et al.* 2015). Such discoveries are of course most likely near international borders and for species that are especially difficult to identify or that occupy habitats still poorly explored within the country. Amazonian montane forests (above 1000 m a.s.l.) have barely been studied within Brazil (Novaes 1965, Dickerman & Phelps-Jr. 1982, Borges *et al.* 2014). They are found in a region known as "Pantepui", a complex of ancient sandstone table-top mountains (called "tepuis") and other geologically distinct mountains, located in southern and eastern Venezuela, Guyana, Surinam, and adjacent parts of Brazil (Mayr & Phelps-Jr. 1967). Based predominantly on studies from Venezuela (see references in Mayr & Phelps-Jr. 1967 and in Hilty 2003), these montane forests are known to have an avifauna distinct from that of the Amazonian lowlands and with a high degree of endemism. Outside of Venezuela, there have been only a few recent ornithological studies in Guyana (Braun *et al.* 2003, Robbins *et al.* 2007) and Suriname (Zyskowski *et al.* 2011); most montane habitat on the Brazilian side of these countries' borders remains unexplored (but see Borges *et al.* 2014). Thus, the mountains of northern Brazil are likely places to find bird species previously undetected in the country.

METHODS

Our expedition to the Serra da Mocidade, a remote and previously unexplored mountain range in the state of Roraima in extreme northern Amazonian Brazil (Fig. 1), took place from 15 January to 06 February 2016, including surveys around two camps: "Camp 1" at 600 m a.s.l. and "Camp 2" at 1000 m a.s.l. We spent 12 days working above 1000 m elevation (1°42'N; 61°47'W), with trails accessing a peak over 1700 m a.s.l. A multidisciplinary group of colleagues conducted inventories of a variety of animal, plant, and mineral groups, mostly to be reported elsewhere after more detailed analyses. However, one immediate and striking result of the expedition was the documentation of three bird species not previously recognized in the Brazilian avifauna. Here, we present this documentation and discuss briefly the relevance of each case, including the possible population and conservation status of these species in Brazil.

RESULTS AND DISCUSSION

Scaled Antpitta (*Grallaria guatimalensis*)

On 29 January 2016, Cohn-Haft, Naka, and Marcos Amend encountered a single individual of *Grallaria guatimalensis*. It was first seen perched on a large rock in a stream below a small waterfall at just over 1000 m elevation. From there it hopped out of sight under an overhanging boulder and then reappeared in the adjacent understory, moving in a seemingly tame and undisturbed fashion on or near the ground. It was subsequently collected (see Appendix I for specimen data). A second individual was encountered by Leite on 31 January, some 2 km away in a dry-bottom ravine at about 1300 m elevation, after repeated "trolling" with playback at different sites, using other recordings from northern South America. The bird responded by vocalizing (see XC461791 at xeno-canto.org) and approaching. It finally revealed itself in the fork of a trunk, 3 m above ground, where it remained for some

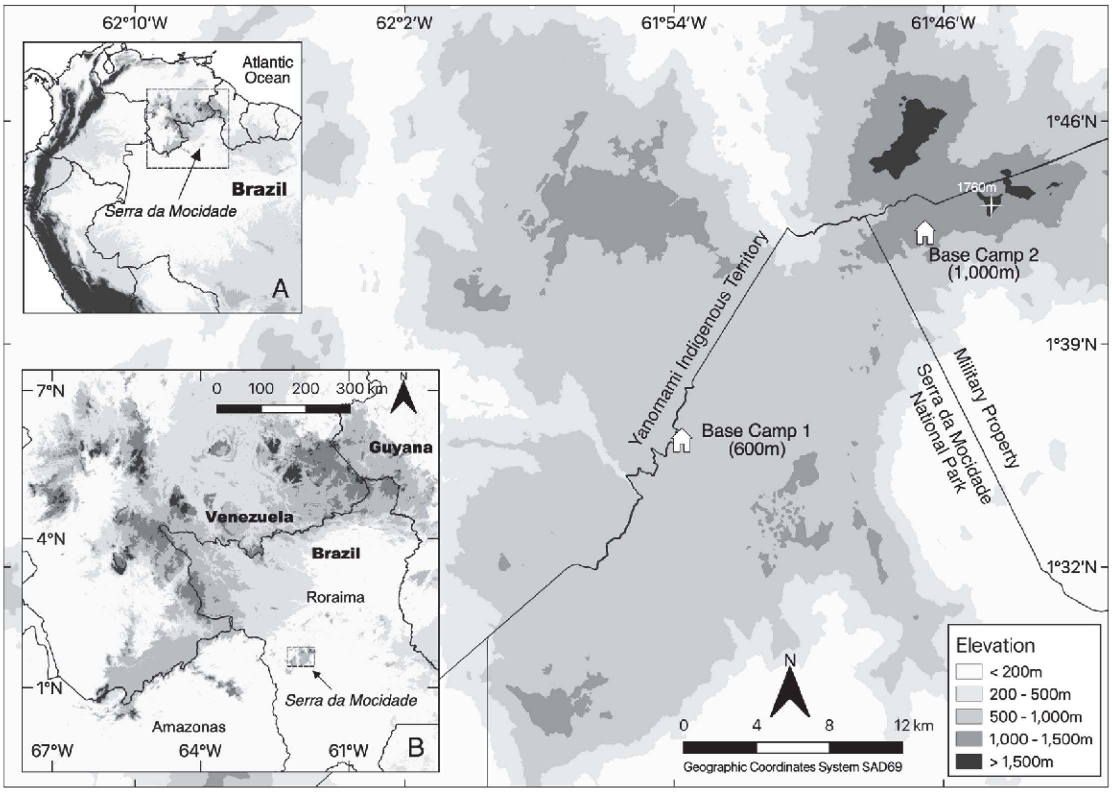

Figure 1. The Serra da Mocidade mountain range in the context of northern South America (inset A, where square delimits area detailed in inset B) and of Pantepui (inset B, where dashed square delimits that part of the Serra detailed in the main figure), showing elevational ranges above sea level. All the species mentioned here were found near Base Camp 2 and trails between camp and the 1760 m peak to the east.

10 min and was photographed (Fig. 2) and filmed (see IBC1570323 at hbw.com/ibc/), before dropping to the ground and moving out of sight.

This species is known from forest understory in montane areas (mostly 500–2500 m) over an extensive distribution in Central America and northern South America, including the Andes and tepuis (Greeney 2018). Nine subspecies are currently accepted, showing considerable variation in size and coloration (Krabbe & Schulenberg 2016). The only subspecies recognized from Pantepui, *G. g. roraimae*, is poorly known with local but probably widespread occurrence in the region (Braun *et al.* 2003, Hilty 2003). Although we have not yet had an opportunity to compare carefully our specimen, photographs, or recordings to others, the gray crown and overall orangey ventral coloration of the birds on Serra da Mocidade jibe with characteristics described for the expected subspecies, *G. g. roraimae* (Greeney 2018). Molecular studies of the species across its range are currently in course (Gustavo Bravo, pers. comm.) and suggest that more than one species-level taxon is involved.

Figure 2. Scaled Antpitta (*Grallaria guatimalensis*) at approximately 1300 m elevation on the Serra da Mocidade. Photo author: Gabriel Leite.

Although an earlier reference to its presence in Brazil (Mayr & Phelps-Jr. 1967) was shown to be the result of misidentification (Mallet-Rodrigues & Pacheco 2003), this species' occurrence in the country was to be expected, considering its widespread distribution elsewhere in Pantepui (Hilty 2003). Our observations represent a range extension of some 280 km (Fig. 3) and suggest that the Brazilian Pantepui comprises an important part of this taxon's range. The scarcity of detections (only two) during the expedition could be a result of little vocal activity at this time of year or of local rarity. Even if the species is uncommon locally, rather than merely difficult to detect as we suspect, the overwhelmingly intact state of montane forests in the region should sustain natural population densities. This corroborates a "Least

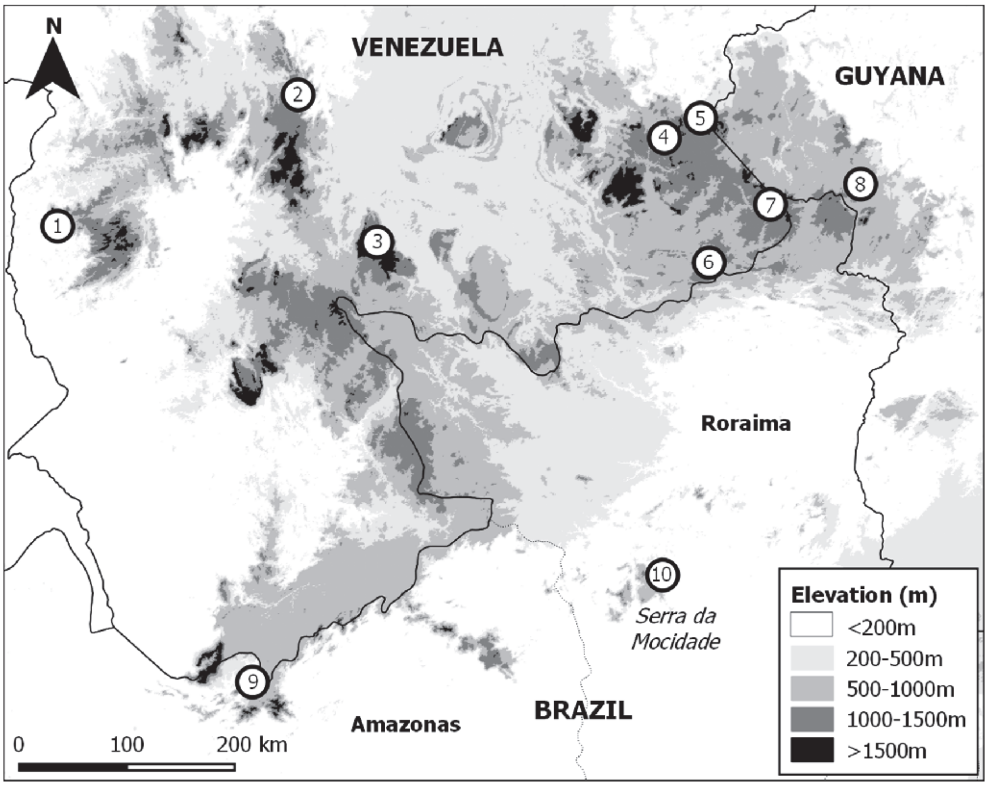

Figure 3. Known localities of the tepui endemic *Grallaria guatimalensis roraimae*, the only subspecies of Scaled Antpitta known from Pantepui. Numbers refer to localities as follows: 1) Cerro Paraque (Mayr & Phelps-Jr. 1967, Greeney 2018), 2) Cerro Tabaro (Hilty 2003), 3) Cerro Jaua (Hilty 2003), 4) Ptari-tepui (Hilty 2003), 5) Sierra de Lema (Hilty 2003, Klaiber 2015), 6) Paurai-tepui (Crease 2011), 7) Mount Roraima (Chapman 1931, Braun *et al.* 2003), 8) Mount Ayanganna (Milensky *et al.* 2016), 9) Sierra Imeri (Mayr & Phelps-Jr. 1967), 10) Serra da Mocidade (this study).

Concern" threat status for the species in Brazil, as already recognized globally (BirdLife International 2019). In the absence of any prior common name in Portuguese, we propose *Tovacuçu-do-tepui*, "Tovacuçu" being the name used generically in Brazil for the other resident *Grallaria* species.

Orange-billed Nightingale-Thrush (*Catharus aurantiirostris*)

Laranjeiras first observed this species on 16 January 2016. While cutting a trail through unbroken forest along a slope at about 1400 m elevation, he heard an unfamiliar vocalization which he imitated whistling. An individual of this species approached, perching calmly on a horizontal branch, 2 m above ground in lightly shaded understory, dense with slender bamboos (*Chusquea* spp.). Shortly afterwards, along the same trail and in similar habitat, another individual was observed, perched near the ground, showing the same quiet and inconspicuous behavior. Over the following weeks, members of our ornithological team observed this species daily, frequently singing, moderately responsive to playback, and present in considerable numbers at different points between 1100 and 1550 m a.s.l., especially but not exclusively where bamboo dominated the understory. In general, we encountered single individuals (at most two) at any given spot, and they seemed to be more or less continuously distributed through the forest in preferred habitat. We obtained numerous photos (Fig. 4; see also WA3461246 at wikiaves.com.br) and recordings of vocalizations (see XC461792, XC493456, XC493458, XC493459 at xeno-canto.org), and we collected a series of nine specimens (see Appendix I for specimen data).

Figure 4. Orange-billed Nightingale-Thrush (*Catharus aurantiirostris*) from the Serra da Mocidade, showing brown crown typical of those populations found nearest in northern Venezuela and eastern Colombia. Photo author: Anselmo d'Affonseca.

The occurrence of *C. aurantiirostris* in the Serra da Mocidade is intriguing. As in *G. guatimalensis*, this species is resident in montane areas (mostly 600–2900 m) in Central America and northern South America, where a total of 11 subspecies are recognized (Collar 2016). However, unlike the antpitta, this thrush was completely unknown from the Pantepui region. Serra da Mocidade is almost 1000 km from the nearest reported site of occurrence, in northern Venezuela (Collar 2016), and in the intervening area there are hundreds of kilometers of seemingly suitable montane habitat in the Venezuelan tepuis, some of which at least have been reasonably well studied (Fig. 5). We find it unlikely that the species could have been overlooked at other sites if it were as common and conspicuous as we found it at Mocidade.

Several alternative hypotheses might explain this gap. One is that the population we found is only temporarily present, the result of an as yet, undocumented seasonal migration from the Andes into the tepuis. In this case, the species may indeed be present throughout the intervening areas, but perhaps was not detected elsewhere due to surveys at the wrong times of year. The species is known to migrate elsewhere, at least short distances up and down slopes (Collar 2016). The presence of moderate or heavy fat in two of the nine specimens is consistent with migratory behavior, considering that most resident Amazonian birds show little or no fat accumulation (Johnson *et al.* 2012). However, the variability in fat stores among the specimens, with four having trace or little fat, is more difficult to explain. Although it seems unlikely to us that such annual migrants throughout the tepuis would have passed unnoticed elsewhere, documenting the presence or absence of this species on Mocidade at other times of year would be illuminating, as would searches for it on other nearby mountains at the same time of year. We found no unambiguous evidence of breeding, such as nesting or breeding-condition adults (based on size and state of gonads and lack of brood patches) or fledglings (based on overall plumage and molt pattern, lack of gapes and of bursae, moderate to complete skull ossification), and so we cannot eliminate the possibility of a migrant, non-breeding population.

Another possibility is that we stumbled onto a temporary or new population during a rare and irregular incursion or colonization event, not likely to be repeated and as such never before documented. Although we also cannot rule out this possibility, much more information over longer periods and more locations would be necessary to demonstrate witnessing such a rare event. Considering how poorly studied even the best-known Amazonian sites are, let alone remote Amazonian mountains, we are inclined to interpret events during this and other expeditions as typical of normal, regularly occurring phenomena until proven to the contrary.

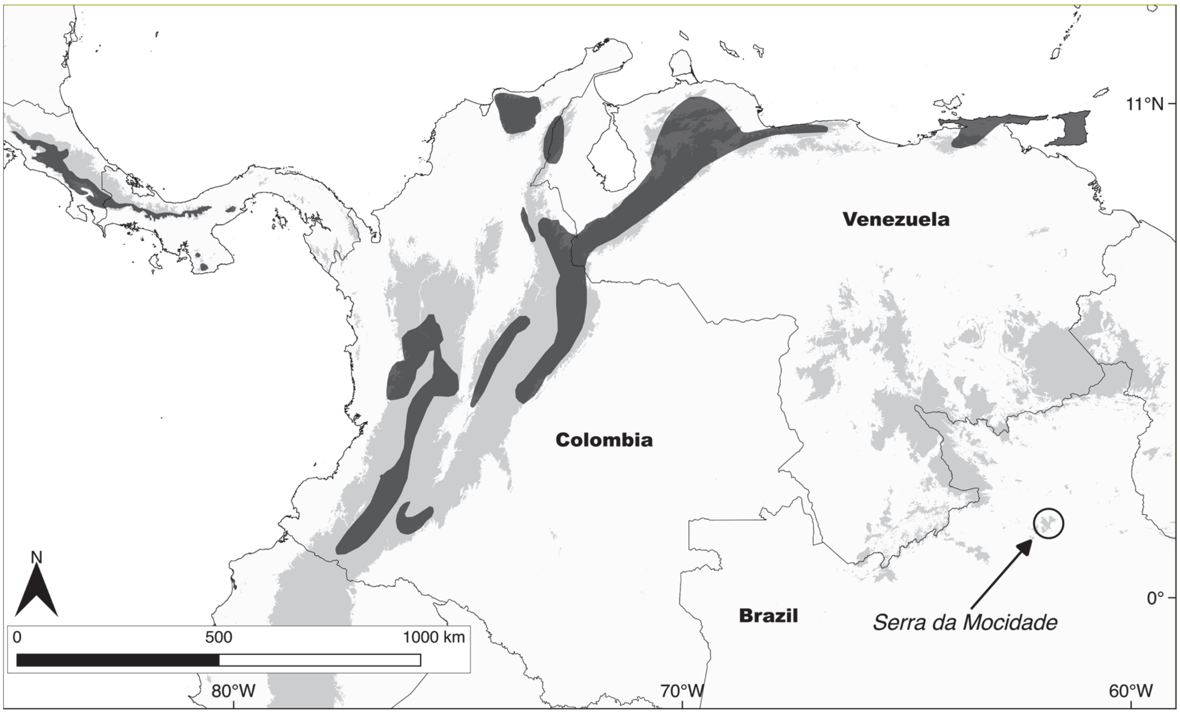

Figure 5. Distribution of *Catharus aurantiirostris* as previously known (black polygons, from xeno-canto.org, based on BirdLife International 2016) and at Serra da Mocidade (black circle), superimposed on highland areas (gray areas, above 600 m elevation) of Central America and northern South America. Note large distributional gap in the Pantepui highlands north and west of Mocidade.

Finally, and what we believe to be the most likely explanation for the presence of *C. aurantiirostris* in our study area, is that indeed the species colonized Mocidade without colonizing other localities within Pantepui, or was once present more widely but went locally extinct elsewhere and persisted on Mocidade, presumably because of this mountain range's large size and distance from other mountains, where extinction factors for whatever reason did not affect Mocidade. Active singing, fairly uniform spacing among individuals, and the tendency to approach after playback all suggest to us a resident population of territorial individuals or pairs, albeit not breeding at the time of our expedition. Documenting reproduction at the site should be a priority of future expeditions to help settle the question of the status of this population.

Phenotypic similarity of these birds (Fig. 4) to descriptions of several populations found at the nearest known localities (Collar 2016) does not permit taxonomic conclusions without direct comparison among specimens. Genetic studies underway (Matthew Halley, pers. comm.) should help elucidate the origin, age, and taxonomic status of the Mocidade population as well as permit identification of demographic processes relevant to diversification within this polytypic species.

As a Portuguese common name, we propose *Sabiazinho-de-bico-laranja*, meaning "small orange-billed thrush". If the Mocidade population should prove to be a distinct species, then we would suggest calling it *Sabiazinho-da-Mocidade*. Furthermore, we suggest that this diminutive noun form, *sabiazinho*, be used for all *Catharus* thrushes in recognition of their smaller size and different plumage patterns compared with *Turdus* spp., which are called *sabiás* in Portuguese.

Assuming that this thrush occurs throughout Mocidade in appropriate habitat, then even if it only occurs on Mocidade, within Brazil, it should nevertheless have a significantly large population. Regardless of taxonomic status, and despite the relatively small total area of montane habitat on Serra da Mocidade (about 100 km^2 above 1100 m), there is no evidence of threat, or even human presence, in its purported range. Thus, we suggest this species be categorized as "Least Concern" at the national level, consistent with its global listing (BirdLife International 2019). However, we also recognize that this scenario could rapidly change under new environmental conditions due to climate change. The Brazilian state of Roraima is witnessing more often and more dramatic droughts related to "El Niño Southern Oscillation" events (Cochrane & Schulze 1998, Fonseca *et al.* 2017), and wild fires now often spread across large portions of the state. It is not unthinkable that a couple of severe droughts could allow the arrival of fire into Mocidade, despite its current relatively humid environment and lack of human presence (Fonseca *et al.* 2017). Therefore, while we believe these populations do not face an imminent threat, the very limited suitable area for this species in the country (~100 km^2) could be a cause of concern in the near future.

Louisiana Waterthrush (*Parkesia motacilla*)

On 01 February 2016, while actively photographing birds, d'Affonseca-Neto observed an unfamiliar passerine along a flat and relatively straight stretch of a narrow (3–5 m wide), shallow (10–50 cm deep), fast-moving stream at 1050 m a.s.l. The bird appeared to be foraging for small arthropods while hopping through overhanging branches and roots less than 1 m above the stream. During the few minutes that the bird was present, d'Affonseca-Neto took pictures at fairly close range (Fig. 6), which we identified later that day as *P. motacilla*. On the following days, we made repeated unsuccessful attempts to relocate the bird, including using mist nets along the stream.

The long supercilium, which is narrower and faintly buffy anterior to the eye, white and increasingly wide posterior to the eye, is a diagnostic feature relative to *P. noveboracensis* (Sibley 2012), a very similar-looking species known elsewhere in Brazil. Other useful marks include the predominantly white ventral ground color, unstreaked throat and undertail coverts, strong and continuous dark line bordering throat, and subtly contrasting buffy tone to lower flanks. The overall pattern of ventral streaking, with relatively sparse, broad streaks, forming two roughly parallel lines along the lower flanks is also characteristic. Finally, an interesting feature proposed by Roeder & Moores (2007), of primary projection (beyond tertials) roughly equal to tertial projection (beyond the greater coverts) in *P. motacilla* (as opposed to much shorter relative primary projection in *P. noveboracensis*), is also upheld in this individual (Fig. 6).

To our knowledge, this is the first documented record of Louisiana Waterthrush in Brazil or from the Pantepui region, and one of the few records from anywhere in South America. The species mostly winters in Central America and the Caribbean, but may be regular in extreme northern Venezuela (Hilty 2003, Mattsson *et al.* 2009). It is of course impossible to know if our single observation represents a very rare occurrence, or if lack of coverage and lack of familiarity with the species' identification are responsible for overlooking what could be a regular wintering population. Its only congener, the Northern Waterthrush (*P. noveboracensis*), is itself an uncommon but regular winterer in northern Brazil, including elsewhere during this same expedition (see below). Careful attention by observers to diagnostic marks separating the two (see above) may lead to more correct identifications in the future.

In the breeding range, the two waterthrushes separate by habitat, *P. noveboracensis* on slack water, beaver ponds and lakesides, *P. motacilla* along small, fast-running, forested streams with cut banks and exposed roots (Mattsson *et al.* 2009, Whitaker & Eaton 2014), much like where our observation was made. Consistent with this, most of our observations of *P. noveboracensis* in South America (unpub. data) have been along large lowland rivers or in mangrove swamps. Our one record of that species during the Serra da Mocidade expedition was at a lower site (Base Camp 1, 600 m a.s.l.; Fig. 1), along a flat stretch of the Rio Pacu, considerably larger, slower, and more exposed to the sun than the stream where *P. motacilla* appeared. If this habitat distinction persists on the wintering grounds as our observations suggest, and if *P. motacilla* does occur regularly in northern South America, then it is likely to be found most in montane areas and, in Brazil, to be restricted to Pantepui. Thus, it is best treated as either an extralimital vagrant or a regular migrant of least conservation concern in Brazil, consistent with its global status (BirdLife International 2019). We propose the Portuguese name *Abana-rabo-da-serra*, meaning "montane tail-wagger". Consistent with that and in recognition of the distinctive tail wagging behavior in this genus, we also propose changing the Portuguese name of *P. noveboracensis* from *Mariquita-*

Figure 6. Two angles of the Louisiana Watertrush (*Parkesia motacilla*) found on the Serra da Mocidade, showing many of the diagnostic features (see text), separating this species from its only congener, the Northern Waterthrush (*P. noveboracensis*). Photo author: Anselmo d'Affonseca.

boreal (which could be applied equally to virtually all of the migrant warblers from North America) to *Abana-rabo-da-baixada*.

Final considerations

Along with its neighbors, Colombia and Peru, Brazil is among the three countries with the greatest diversity of birds in the world. However, the counts vary considerably, especially depending on taxonomy, about which there is rarely complete consensus. Attempts to list the species of these countries applying a uniform taxonomic scheme across them come up with different totals and rankings: Colombia 1877 species, Peru 1855, Brazil 1809 (BirdLife International 2017); Colombia 1851, Brazil 1818, Peru 1802 (Avendaño *et al.* 2018, Pacheco & Agne 2019, Plenge *et al.* 2018, respectively, using Remsen-Jr. *et al.* 2019). However, Brazil's ornithological records committee (Piacentini *et al.* 2015) lists 1919 species for the country, reflecting numerous taxonomic splits not yet adopted globally. With the addition of the three species reported here and others reported elsewhere (CBRO, in prep.), Brazil's total avifauna rises to 1938 species (not including splits). Brazil's total avifauna rises to 1922 species. Similar in-country efforts in Colombia to compile that country's avifauna report totals of 1909 (Avendaño *et al.* 2017) and 1937 (Donegan *et al.* 2016), suggesting minimal difference between Brazil and Colombia using current knowledge and similar taxonomic approaches. Based on sheer geographic area, Brazil (roughly eight and seven times greater than Colombia and Peru, respectively) is indeed likely to contain the highest bird diversity of any country.

Finding, in a single expedition, three species new to the already rich Brazilian avifauna, all possibly of regular occurrence in the region, demonstrates just how little is known about Amazonian montane birds. We made a comparable sampling effort at a lower elevation site (600 m, Base Camp 1) during the same trip, with no species new for Brazil (but with several range, habitat, and elevation extensions, to be presented elsewhere). This suggests that indeed it is the montane fauna per se, and not just any previously unexplored Amazonian site, that especially needs work.

Each of the three novelties represents a different pattern of occurrence that might help direct future research. As was the case with *G. guatimalensis*, there are still several resident bird species in the tepuis of Venezuela that have not yet been confirmed in Brazil, including *Polytmus milleri* and *Grallaricula nana* (Naka *et al.* 2006). North American migrants, like *P. motacilla*, with a preference for montane wintering grounds in northern South America, include *Contopus sordidulus*, still awaiting confirmation in Brazil, and *Setophaga cerulea*, recently confirmed (Farias & Dapaz 2019). Most resident Andean bird species are not known from the tepuis, and predicting which of these might actually have isolated populations somewhere in Amazonian Brazilian mountains, as appears to be the case with *C. aurantiirostis*, is much more difficult. However, there are other cases of predominantly Andean birds also known from few or single Pantepui localities; examples include *Dysithamnus leucostictus* (Zyskowsky *et al.* 2011) and *Phyllomyias zeledoni* (Wetmore & Phelps-Jr. 1956, Hilty 2003). Further additions to the Brazilian avifauna, thus, are a likely side effect of continued research in Amazonian mountains. We believe this intriguingly understudied realm deserves increased attention.

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APPENDIX I

Specimen data of birds collected on Serra da Mocidade, Brazil.

Grallaria guatimalensis — one specimen (data translated from Portuguese of specimen label): Instituto Nacional de Pesquisas da Amazônia (INPA) number 5005, tissue A-19796, female (ovary 8 × 6 mm; oviduct 3 mm wide, convoluted; ova minute), no bursa, skull 100% ossified, stomach containing arthropod parts (saved), 75 g, iris dark brown, maxilla blackish brown, mandible grayish beige with darker tip, toes and tarsi dull pale pink, little fat, no body or tail molt, primary 1 molting both sides, collector Mario Cohn-Haft, preparator Gisiane R. Lima number 3265.

Catharus aurantiirostris — nine specimens, summarized: INPA 5016-5024. Five males (24.5–32 g; left testes 2 × 1–4 × 3 mm; skulls 75–100% ossified; trace [1 individual], little [3], moderate [1] fat), three females (22–27.5 g; ovaries 6 × 4–8 × 5 mm, oviduct convoluted [2], straight [1], ova minute; skull 50–95% ossified; little [2] and heavy [1] fat), and one unidentified sex (27 g; gonads not found; skull 95% ossified; fat not noted). Stomach contents (saved): arthropod parts (6) and fruit fragments (2). None with bursa or any feather molt. Tissues: A-19754, A-19763, A-19793, A-19813, A-19828, A-19848, A-19869, A-19901, A-19909. All were prepared by Gisiane R. Lima, after collection by various team members.

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ARTICLE

The Tocantins-Araguaia Basin as a migratory route and a wintering area of *Falco peregrinus* (Aves, Falconidae)

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ABSTRACT: The Peregrine *Falco peregrinus*, is an Nearctic migrant to Brazil where its status in central Brazil is still poorly known. Herein we present a compilation of records of the species from the state of Tocantins and comment on its use of a wintering site in the state of Goiás. These records show that the Tocantins-Araguaia River Basin is a migration route for the species, and therefore a mid-continental migration route through the interior of South America.

KEY-WORDS: Araguaia River, bird of prey, Brazil central, Cerrado Biome, migratory bird, North-South Railroad, Tocantins River.

INTRODUCTION

The Peregrine Falcon *Falco peregrinus* Tunstall, 1771, is one of the most well studied birds in the world (Ferguson-Lees & Christie 2001, White *et al.* 2013) occurring on every continent except Antarctica. Some subspecies perform long migrations and can travel more than 14,000 km between wintering and breeding areas (Sick 1997, Fuller *et al.* 1998, Mestre 2007, Goodrich & Smith 2008).

In South America at least three migratory routes of *F. peregrinus* are known: two coastal and one continental (Fuller *et al.* 1998). In coastal routes, individuals of *F. peregrinus* follow the Pacific or Atlantic coasts, making use of urban centers and coastal environments as stopover sites to the southeastern and southern portion of Brazil, northern Argentina and Uruguay, which comprise their wintering areas. The continental route passes through the interior of the Amazon region, following river basins until reaching the Pantanal through central-west, southeast and southern Brazil, northern Argentina and Uruguay (Fuller *et al.* 1998, Erize *et al.* 2006, Mestre 2007).

In Brazil, the species has been recorded between September and April, mostly in the south, southeast and northeastern coasts (Silva-e-Silva 1996, Sick 1997, Mestre 2007). Migrant populations show great fidelity to their routes, stopover sites and wintering sites and may use the same wintering sites for several consecutive years (Silva-e-Silva 1996, Sick 1997, Drummond 2010, White *et al.* 2013).

Although there is much published information about migratory movements of the Peregrine Falcon, there is little information about the individuals that remain in Brazil during the wintering period, especially in the central portion of the country, where the species is under-recorded. Therefore, the aim of this study is present a synthesis of *F. peregrinus* records for the states of Tocantins and Goiás, central Brazil, demonstrating that the Tocantins-Araguaia River Basin is a migratory route of the species.

METHODS

The *F. peregrinus* records for the states of Tocantins and Goiás occurred in two ways: sightings and compilation of records. Sightings were conducted in the urban area of Goiânia, capital of the state of Goiás, between 2016 and 2018, and from January to April 2019, and in the region with natural vegetation and pastures under the influence of the North-South Railway (NSR), in the rural area of the municipality of Oliveira de Fátima, central portion of the state of Tocantins, during fieldwork between 20 to 25 March 2019.

The compilation of records of *F. peregrinus* was obtained from the citizen science platforms WikiAves (wikiaves.com.br) and eBird (ebird.org), which are publicly and freely accessible (Lees *et al.* 2014). The compiled records are presented by the accession number on these respective platforms. However, some records were kindly provided through requests to other ornithologists or birdwatchers (Table 1). The compiled records were mapped, assuming the geographic distribution of *F. peregrinus* as presented by White *et al.* (2019).

RESULTS

On 22 March 2019, at 17:30 h, T.D. sighted a *F. peregrinus* perched on a dry branch on a medium-sized tree top (between 10 and 15 m high) on the borders of the North-South Railroad (NSR), municipality of Oliveira de Fátima, central region of the state of Tocantins (10°41'S; 48°48'W). Given the small size of the individual, it was assumed to be a male (Fig. 1). The region is located within the Cerrado Biome, 90 km from the right bank of the Tocantins River. The vegetation was composed of a mosaic of fragments of semideciduous seasonal forests, "Cerradão" gallery forest and Cerrado *sensu strictu*, interspersed with pastures intended for livestock. This record shows to be the first documented of the species in Tocantins.

Reports of the occurrence of *F. peregrinus* in the state of Tocantins are remarkably scarce compared with the numerous records of the species in other regions of Brazil (Mestre 2007). While in cities, such as São Paulo, Recife and Porto Alegre, it is possible to count different pairs or individuals in the same wintering period (Pereira *et al.* 2006, Mestre 2007), in Tocantins there have been no more than four sightings of the species. These are in chronological order: in April 2006, a female was spotted atop a large dry tree on the banks of the Araguaia River, on the edge of Cantão State Park (Dornas & Pinheiro 2011). Between 18–22 November 2010, Brito *et al.* (2016) mention a sighting in the region of Presidente Kennedy, north central Tocantins, in areas of transitional Cerrado-Amazon (semideciduous-ombrophilous) forests near power transmission line towers. On 07 November 2015, another sighting was reported by Marcelo Barbosa (eBird list S25770349) in Lagoa da Confusão municipality, in a circular and naturally fragmented forest formation, locally called "ipuca", adjacent to rice fields and a few kilometers from the Javaés River and Bananal Island, at the western portion of Tocantins.

T.J. and E.F.S. conducted a regular series of observations of *F. peregrinus* in the urban area of Goiânia, capital of the state of Goiás, between 2016 and 2018, and from January to April 2019. Sightings of this species at the top of buildings in the urban center of Goiânia from 27 October 2017 to 20 March 2018, demonstrated the perennial use of this urban complex during wintering period (Table 1).

At the end of the austral spring, on 20 November 2018, the species was again detected by T.J. on the same perch on top of buildings in Goiânia city center. Sighting of the species on these buildings continued until 25 December 2018. After that date, no further sighting and/or photographic records were shared on citizen science platforms. T.J. observed a female *Falco rufigularis* sharing the same perch used by *F. peregrinus*, from December 2018 through January 2019. Apparent interspecific competition, or even frequent harassment by *F. rufigularis* (mobbing behavior), forced *F. peregrinus* to find another hunting and resting perch.

However, on 20 February 2019, E.F.S. spotted an individual on another building tower in the urban center of Goiânia. The individual used this perch for three consecutive days. In the evening it was catching bats, returning to the same perch to consume the prey. The same perch was used in 2016, when E.F.S. documented the individual at the same time of the year (Table 1; WA2125588). The E.F.S. sighting point (16°42'06''S;

Figure 1. Male *Falco peregrinus* registered on the banks of the North-South Railroad, in Oliveira de Fátima, Tocantins state, Brazil. Photo author: Túlio Dornas.

Table 1. Compiled records of *Falco peregrinus* for the state of Goiás, Brazil, through sightings and media deposited on the Wikiaves database.

Date (dd/mm/yyyy)	Autor	Municipality	Source	Coordinates
19/04/2019	Jayrson Araújo	Goiânia	WA3338803	16°48'S; 49°16'W
22/02/2019	Estevão F. Santos	Goiânia	Sighting	16°42'S; 49°17'W
21/02/2019	Estevão F. Santos	Goiânia	Sighting	16°42'S; 49°17'W
20/02/2019	Estevão F. Santos	Goiânia	Sighting	16°42'S; 49°17'W
25/12/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
14/12/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
13/12/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
12/12/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
10/12/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
29/10/2018	André Siade	Anápolis	WA3161421	16°19'S; 48°56'W
25/10/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
24/10/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
23/10/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
20/10/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
20/03/2018	Igor Oliveira	Goiânia	WA2918299	16°36'S; 49°17'W
04/02/2018	André De Lucca	Goiânia	Sighting	16°37'S; 49°15'W
30/01/2018	Tiago Junqueira	Goiânia	Sighting	16°40'S; 49°16'W
26/01/2018	Igor Oliveira	Goiânia	WA2861801	16°40'S; 49°16'W
30/12/2017	Matheus dos Santos	Goiânia	WA2829930	16°40'S; 49°16'W
23/12/2017	Kennedy Road	Goiânia	WA2823841	16°40'S; 49°16'W
22/12/2017	Kelrene Lara	Goiânia	WA2858406	16°40'S; 49°16'W
13/12/2017	Ivo Zecchin	Goiânia	WA2814435	16°40'S; 49°16'W
30/10/2017	André Mendonça	Goiânia	WA2757513	16°40'S; 49°16'W
30/10/2017	Márcia Bessa	Goiânia	WA2823575	16°40'S; 49°16'W
27/10/2017	Jayrson Oliveira	Goiânia	WA2759201	16°40'S; 49°16'W
27/10/2017	Marcelo Dionísio	Goiânia	WA2766727	16°40'S; 49°16'W
26/10/2017	Marcelo Dionísio	Goiânia	WA2753124	16°40'S; 49°16'W
24/10/2017	Tiago Junqueira	Goiânia	WA2749446	16°40'S; 49°16'W
25/12/2016	Rodolfo P. Oliveira	Rio Verde	WA2412786	17°47'S; 50°52'W
25/12/2016	Rodolfo P. Oliveira	Rio Verde	WA2412785	17°47'S; 50°52'W
30/10/2016	Geraldo Morais	Aparecida de Goiânia	WA2353219	17°49'S; 49°14'W
14/02/2016	Estevão F. Santos	Goiânia	WA2125588	16°42'S; 49°17'W
15/03/2013	Rafael Pedra	Itumbiara	WA909996	18°24'S; 49°13'W
15/03/2013	Rafael Pedra	Itumbiara	WA909995	18°24'S; 49°13'W

Date (dd/mm/yyyy)	Autor	Municipality	Source	Coordinates
31/10/2012	Felipe Zenha	Aparecida do Rio Doce	WA1913644	18°17'S; 51°08'W
05/04/2012	Juliano Mafra	Corumbaíba	WA1027528	18°23'S; 48°39'W
05/04/2012	Juliano Mafra	Corumbaíba	WA616728	18°23'S; 48°39'W
07/02/2010	Tiago Junqueira	Itumbiara	WA546620	18°15'S; 48°53'W
30/11/1999	Milton Melo	Itumbiara	WA907270	18°24'S; 49°13'W

49°17'10''W) is located just over 3 km from the T.J. perch (16°40'55''S; 49°16'10''W). After the last E.F.S. sighting of 20 February 2019, only one additional record was made for Goiânia on citizen science platforms (WA3338803). It was assumed that the species would stay in mid-March and April 2019 in Goiânia, before it returns to the Northern Hemisphere.

Between 1999 and 2013 in southern Goiás, there are at least six records of the species between the cities of Itumbiara and Corumbaíba, near the banks of the Paranaíba River, in November, February, March and April (Table 1). Although there is no synthesis of records with better temporal representativeness, it is remarkable that *F. peregrinus* used this southern region of Goiás for prolonged periods during the wintering period.

DISCUSSION

Although some maps show the southern center of Goiás as a wintering area of the species, apparently the result of cartographic artifact due to the delimitation of polygons of occurrence of the species in Brazil, evidence of *F. peregrinus* wintering in the state of Goiás was not known previous to this work. The region has been assumed to be a zone of passage or stopover site for the species (Erize *et al.* 2006, White *et al.* 2019). Our systematic monitoring and the compilation of records from citizen science platforms for the state of Goiás strongly confirm that both the city of Goiânia and the southern portion of Goiás are wintering sites of *F. peregrinus* in central Brazil.

Therefore, the *F. peregrinus* records for Tocantins and Goiás explains the use of the Tocantins-Araguaia River Basin as a migratory route by the species, which apparently has a preference for the areas near and adjacent to the two large rivers of the region (Fig. 2). The migratory movements resulting from the sightings of Dornas & Pinheiro (2011) and the documented records presented in this study in municipality of Oliveira de Fátima coincide with the species returning to the Northern Hemisphere to start the next reproductive period (White *et al.* 2013). This migration route is reinforced by records at Fazenda Fartura, on 02 and 03 February 2014, on the left bank of the Araguaia River, in the state of Pará (Ariane Gouvea, eBird lists S50980498 and S51300295).

On the other hand, the record presented by Brito *et al.* (2016) in November 2010 in the region of Presidente Kennedy and at the "ipuca" forest fragment in Lagoa da Confusão (Marcelo Barbosa, eBird list S25770349), in November 2015, reveal the use of the region as a stopover site for the species in its migration to the southernmost regions. The use of the Araguaia Valley and Bananal Island region is further reinforced by records of the species in São Félix do Araguaia, Mato Grosso, on the left bank of the Araguaia River, on 30 November 2008 (Bradley Davis, eBird list S14459547).

Other records made in south of Pará state: Marabá, (Silva-e-Silva 1996), Canaã dos Carajás, (WA1523550), Santana do Araguaia (Somenzari *et al.* 2011), Paragominas (Lees *et al.* 2012); and Maranhão state: Sambaíba (Tatiana Pongiluppi, eBird List S41906604), support this trajectory through central Brazil as migratory route of the species, demonstrating arrival at the end of the southern winter towards the south of the continent, with a later return towards the Northern Hemisphere in late Austral Summer. It is assumed that this route via central Brazil, using the Tocantins-Araguaia Basin, has been used by individuals during the wintering period in the Goiás region, especially in Goiânia, as previously presented.

A behavioral characteristic of *F. peregrinus* in its migratory movements is the use of landscape macroelements as references in their flights (White *et al.* 2013). Goodrich & Smith (2008) point out that some species of migratory birds of prey use riverbeds as a guide in their migration. However, in the migration route along central Brazil, in addition to the use of riverbeds, we hypothesized that *F. peregrinus* uses the newly built North-South Railroad (NSR) as a macroelement in the landscape to aid migration. The NSR is a Brazilian longitudinal railroad, expected to be 4155 km long when it is completed and designed to connect the southern and northern ends of the country, as well as the main east-west projected railroads in different regions of the country (Valec 2018). The stretch of tracks already completed and in partial operation consist of almost 1600 km between the region of Anápolis, in Goiás, and Açailândia, in

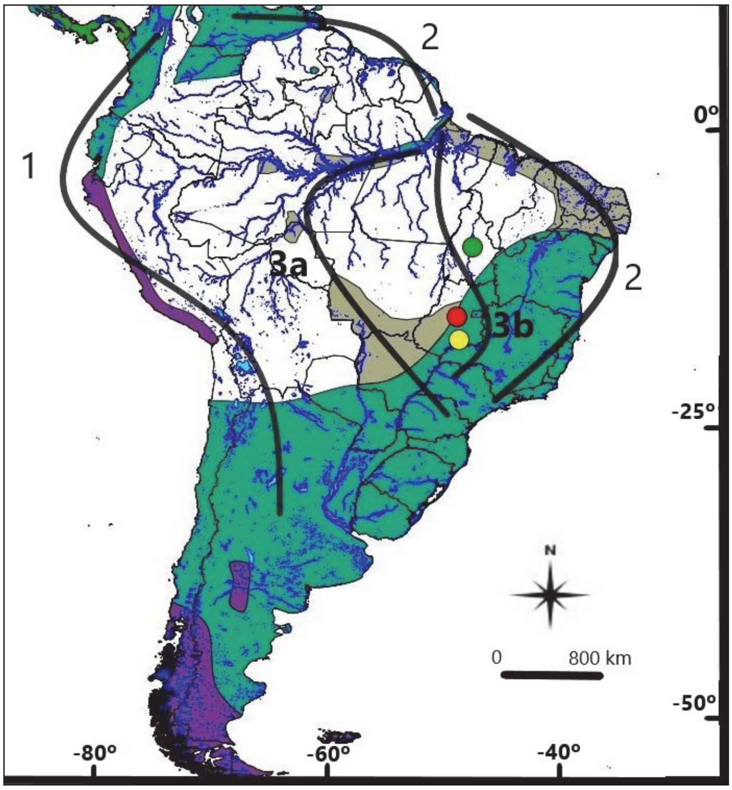

Figure 2. Known wintering areas (green polygon), wintering areas updated (beige polygon – records from the Wikiaves portal, Mestre 2007 and this survey) and the migratory routes of *Falco peregrinus*: **1**) Pacific Coast Route; **2**) Atlantic Coast Route; and **3**) Continental Route, **3a**) Amazonia-Pantanal Route and **3b**) Central Brazil Route. Locations: Oliveira de Fátima, Tocantins (green circle); Goiania, Goiás (red) and Itumbiara, Goiás (yellow). Purple polygon indicates resident populations.

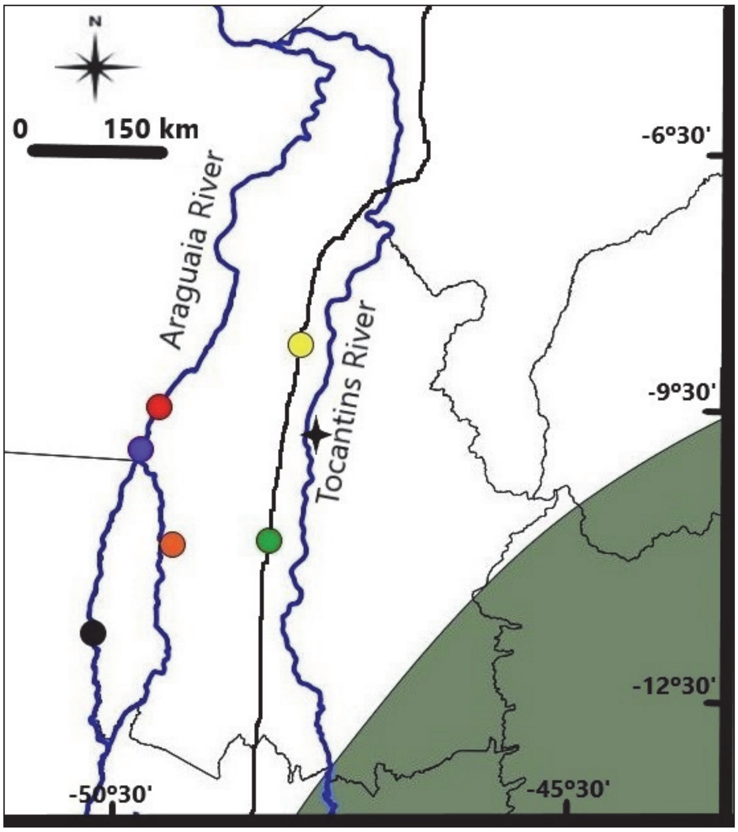

Figure 3. Localities of registration of *Falco peregrinus* in Tocantins state and the west banks of the Araguaia River, in Pará and Mato Grosso states. Green point: Oliveira de Fátima, Tocantins; yellow: Presidente Kennedy, Tocantins; orange: Lagoa da Confusão; red: Parque Estadual do Cantão; blue: Fazenda Fartura, Pará state; black: São Félix do Araguaia, Mato Grosso state. The black star is Palmas city. The black line is NRS railroad route. The green spot shows part of the wintering area recognized by White *et al.* (2019).

Maranhão, crossing the north-center of Goiás, all of the state of Tocantins and part of Maranhão (Valec 2018).

In the rainy season, between November and April, it was found that the railroad edges, especially near streams and rivers, concentrate an abundance of different bird species, including passerines, small doves, parrots and ducks. This accumulation of water marginally to the railroad, attracting the birds in a remarkable way, as observed at a several points in the fieldwork by the authors, was analogous to the ecological role played floodplains and riparian forests along large rivers. At the time of record, 20 minutes before nightfall, the presence of vocally restless passerines (*Turdus leucomelas*, *Saltator maximus* and *Ramphocelus carbo*), parrots and columbids (*Brotogeris chiriri* and *Columbina talpacoti*, respectively) signaled a possible falcon attack before their sleeping perch, however aborted due to our approach and presence.

Similarly, the role played by large rivers as a macroelement of the landscape, where potential prey for *F. peregrinus* concentrate due to the inherent biological characteristics of these environments, can also be attributed to the railroad. The NSR is an almost linear north-south line, similar to the routes used by the species during its migratory movements through central Brazil. Thus, *F. peregrinus* would have a projected landscape view of a large longitudinal section, at least 1600 km, and 100 m wide on average.

The use of highways as macroelements is also possible. However, we did not search or sample areas of influence of local highways. We assume that the structure of the highways appears to be different, besides they do not have the same linear route as the NRS, the intense and continuous traffic of vehicles could prevent a systemic use of the marginal roadside by Peregrine Falcon. Moreover, we suggest that the earthworks system applied to the NRS railroad is different than the highways, providing in the railroad a greater retention of water from streams, forming frequent and extensive flooding along the route, implying greater abundance and availability of prey in the railroad than on the highways.

We also believe that the species may be found in the future in the urban limits of Palmas city (Fig. 3). The emergence of large buildings and urban characteristics of large Brazilian megacities, such as Goiânia, São Paulo and Recife, together with large flocks of Feral Pigeons (*Columba livia*) and/or parrots such as *B. chiriri* and *Eupsittulla aurea*, may support our prediction.

However, the confirmation of all these assumptions will depend on more systematic studies and programs to monitor prey along the railway and highways line and in the urban boundaries of Palmas city. The growth in birdwatching can reduce the time needed to receive information about these assumptions, given the massive contribution that citizen science platforms, mostly supplied by birdwatchers, offered to this synthesis presented.

Therefore, we conclude that these records consolidate the Tocantins-Araguaia River Basin as a migration route of *F. peregrinus*, confirming definitively that the central portion of Brazil is a wintering site of the species. Finally, it is worth mentioning the importance of Brazil in the global maintenance of this emblematic bird of prey, especially regarding the migrant subspecies that are established in South America.

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