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ARTICLE

Hyacinth Macaw (*Anodorhynchus hyacinthinus*) nests in a mosaic of protected areas in Carajás and surrounding areas, state of Pará, Brazil

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ABSTRACT: Natural history studies can provide information that can be used in species conservation and management. The present study provides information about the nests and nest sites of Hyacinth Macaws (*Anodorhynchus hyacinthinus*) in a mosaic of protected areas in Carajás and surrounding areas in the Amazon region of the state of Pará, Brazil. Data were collected during four expeditions conducted in 2007, 2008, 2013 and 2014. A total of 66 tree cavities were monitored, and 28 of these were used by Hyacinth Macaws. In addition, 38 breeding events were recorded (some nests were active in multiple seasons), and 17 eggs and 33 nestlings were observed. Environmental variables for the 24 cavities that were actively used by Hyacinth Macaws were evaluated. Most of the nest cavities were located in *Sterculia* sp. trees (86.6%) and in open areas (*e.g.*, near pastures). Nesting tree and cavity measurements were variable, but the mean diameter at breast height of the trees containing Hyacinth Macaw nest cavities was larger than that reported from other regions, such as the Pantanal. The present study describes the unique ecology and life history of Hyacinth Macaws in Carajás, for which information is scarce. This information will facilitate the conservation and management of Hyacinth Macaws and can be used locally for environmental education.

KEY-WORDS: breeding ecology, endangered bird, hollow-nesting bird, Psittacidae, *Sterculia* sp.

INTRODUCTION

The Hyacinth Macaw *Anodorhynchus hyacinthinus* is the largest member of the Psittacidae and has suffered major population declines over the last 30 years (BirdLife International 2016). The species is classified as "Endangered" in CITES Appendix I and as "Vulnerable" by the IUCN (BirdLife International 2018), owing to illegal trade, local hunting, and habitat loss (Mittermeier *et al*. 1990, Guedes 1993, Snyder *et al.* 2000). The species was once widely distributed in Brazil, yet most of the remaining individuals occur in three major regions. Current populations can be found in the eastern Amazon (Tocantins and Pará states), in central Brazil (Maranhão, Piauí, Bahia, Tocantins, Goiás, Mato Grosso, and Minas Gerais states), and in the Pantanal (Mato Grosso and Mato Grosso do Sul states; BirdLife International 2016); the latter region contains the largest remaining population (Munn *et al*. 1987, Guedes *et al.* 2008, Pivatto *et al*. 2008, BirdLife International 2016).

Although long-term studies of Hyacinth Macaws have been conducted in the Pantanal region (Guedes 1993, Antas 2004, Guedes 2009), little is known about the population status, breeding ecology, or life-history of the species in other locations (Snyder *et al.* 2000, Dornas *et al*. 2013). Vegetation structure and composition differ in the three main areas where Hyacinth Macaws occur, and consequently, resource availability varies (Presti *et al*. 2015). Furthermore, given the current trends of land use in the Amazon Forest, with high rates of deforestation and habitat loss, it is necessary to understand the ecological requirements of Hyacinth Macaw in the Amazon region.

One region in the Amazon, Serra dos Carajás, is a complex of protected areas in the locality between the Xingu and Tocantins Rivers that harbors a permanent breeding population of Hyacinth Macaws, which may be the largest in the Amazon region (Presti *et al*. 2009, Rosa 2016). The region is mostly covered by tropical rainforest, with dense populations of large trees, including *Sterculia* spp., *Euxylophora paraensis*, Brazil Nut Trees,

Bertholletia excelsa, and *Parkia* spp, that are important for the nesting of the local Hyacinth Macaw population (Presti *et al.* 2009, Rosa 2016). However, despite the importance of Serra dos Carajás to the maintenance of Hyacinth Macaw populations, little is known about its ecological requirements in the region (Presti *et al.* 2009). Accordingly, the aim of the present study was to describe the ecology and life-history of Hyacinth Macaws in the mosaic of protected areas in the Amazon region of Carajás, state of Pará, Brazil.

METHODS

Study area

We conducted surveys in the mosaic of protected areas in Carajás and the surrounding private properties, southeast of Pará (06º00'S; 50º30'W, Fig. 1). Carajás contains six protected areas: three National Forests (FLONA), one indigenous reserve, one Environmental Protected Area (APA), and one Biological Reserve, which together form a large forest fragment of ~12,000 km^2 (Martins *et al.* 2012). The vegetation in the region can be divided in two main categories: dense and open tropical rainforest (known locally as "Floresta Ombrófila Densa" and "Floresta Ombrófila Aberta"), which covers the majority of the area, and Savanna (metalophylic vegetation, known locally as *canga*; Martins *et al.* 2012). We monitored three sites within the region, site 1: Rio Itacaiúnas; site 2: Canaã dos Carajás; and site 3: FLONA Itacaiúnas.

Site 1 was located between FLONA Carajás and FLONA Tapirapé-Aquiri. There were six vegetation types in the area: a) dense tropical rainforest, which features epiphytes and arboreal strata reaching 35 m, as well as highly dense understory strata; b) lowland open tropical rainforest; c) open tropical rainforest, which is characterized by the presence of palm trees, including Babassu Palm (*Orbignya phalerata*); d) open tropical forest with lianas; e) riparian forest, which features fast-growing vegetation, few canopy trees, intermediate strata with palm trees, and a high density of woody and herbaceous lianas; and f) savannas (ICMBio 2009).

Site 2 was located in the southernmost part of FLONA Carajás and the surrounding properties. Five municipalities are adjacent to the mosaic of protected areas in Carajás: Marabá, Parauapebas, Canaã dos Carajás, Água Azul do Norte, and São Félix do Xingu. The main economic activities of the region are livestock rearing and agriculture (Palheta-da-Silva 2004, Coelho *et al.* 2008), and the major threats to the protected areas are deforestation, wildfires, and mining. Although this area was extensively cleared for livestock and agriculture, the site contained large flocks of Hyacinth Macaws (Presti *et al.* 2009).

Site 3 was located in the northern area of FLONA Itacaiúnas and the surrounding properties. The site was highly modified and included many private properties

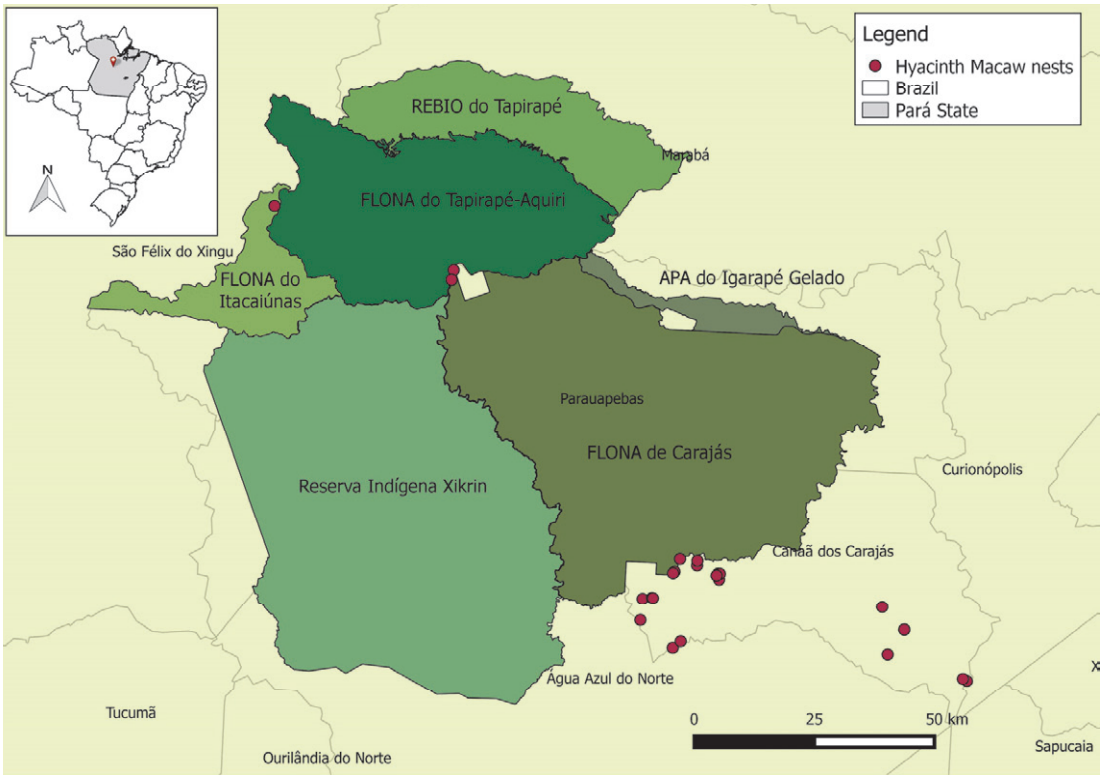

Figure 1. Hyacinth Macaw *Anodorhynchus hyacinthinus* nests monitored in a mosaic of protected areas and surroundings. Green areas represent the six protected areas in Carajás.

and pastures, and the FLONA contained large numbers of cattle. Natural vegetation cover was only observed on slopes and uneven terrain (G.F.S., pers. obs.).

Data collection

We conducted four approximately 30-day-surveys in the study area, in 2007, 2008, 2013, and 2014. We monitored each site from one up to four times between September and October of each year, resulting in a total of 458 h of fieldwork (visits at site 1 in 2013 and 2014 was 96 h; at site 2 in 2007, 2008, 2013 and 2014 was 338 h; and at site 3 in 2013 was 24 h). Expeditions depended on availability of boats, 4WD vehicles, and authorized teams. As such, site 2 that included several farms and readily accessible roads, was visited more frequently than the other two sites.

Bird sampling

Fieldwork involved searching for and describing cavities used by Hyacinth Macaws. We used tracks, creeks, and roads inside the properties to approach potential nesting trees, and information from local inhabitants was also important in locating nests. Only cavities that contained macaws or signs of the presence of Hyacinth Macaw, such as bite marks or remnant pieces of food, feathers, or feces, were monitored (Guedes 1993, Guedes & Seixas 2002). We classified the cavities as active (containing eggs or nestlings), inactive (without breeding activity at the time of the survey, but active in other seasons, either before or after the current season), or potential (without breeding activity, but with signs of Macaw presence).

We monitored cavities that contained stingless bees (*Trigona* sp.) but we did not monitor cavities that contained Honey Bees (*Apis mellifera*) or were otherwise inaccessible, due to structural issues (main trunk broken), even if the cavities had been previously active or Hyacinth Macaws were observed nearby. Some nest cavities were used for more than one season, and each observation of breeding activity was considered and counted as a breeding event.

We accessed cavities using climbing and rappelling techniques (Guedes 1993, Guedes & Seixas 2002). If nesting trees and cavities were active during at least one breeding season, 10 environmental variables were measured for each nesting tree and nest cavity (Table 1). We counted the number of eggs and nestlings. We collected environmental variables for 24 nesting trees, except for diameter at breast height (DBH), which was measured for 20 nesting trees.

Data analysis

Descriptive statistics (mean and standard deviation, SD) were calculated for the environmental variables collected

Table 1. Nest tree and cavity variables measured for trees containing Hyacinth Macaw nests at three sites in the mosaic of protected areas in Carajás, Pará state, Brazil.

Variable		Description
Nest tree	Species	Tree species in which nest cavity was located.
	Tree height	Height of nesting tree (m), measured from the entrance of the nest to the ground using a measuring tape; the entrance to the top of the tree was estimated visually. Both measurements were summed.
	Cavity height	Height of the cavity entrance (m), measured from the entrance of the nest to the ground using a measuring tape.
	DBH	Diameter at breast height (cm), measured as the circumference of the tree at breast height using a measuring tape.
	Location	Location of the nesting tree: open area, edge of the forest, or forest interior (> 5 m from the edge, Guedes 1993).
Nest cavity	Entrance width	Entrance width (cm), measured from lateral edges of the cavity with a ruler.
	Entrance height	Entrance height (cm), measured from the top edge to the bottom edge of the cavity using a ruler.
	Cavity width	Width of the cavity (cm), measured from the entrance to the back wall of the cavity using a ruler.
	Cavity depth	Depth of the cavity (cm), measured from the bottom edge of the entrance to the cavity floor using a ruler. This measurement was not taken for all nests.
	Origin	Most likely origin of cavity: broken branch, fungal action, or other birds (*e.g.*, members of the Picidae family).

at the active nest cavities. The relationship between tree and cavity height was evaluated using Pearson's correlation. All statistical analyses were performed using R version 3.1.1 (R Core Team 2014).

RESULTS

We monitored a total of 66 potential cavities in 2007, 2008, 2013, and 2014. Of these, 28 were actively used by Hyacinth Macaws (Fig. 1). Eight cavities were active more than once, with six used for two breeding seasons and two used for three breeding seasons, and the other 20 nests were only used for a single breeding season. In total, 38 breeding events were recorded (Table 2).

We recorded cavities in 10 tree species, whereas breeding events were only recorded in seven (Table 3). At site 1, we registered nest cavities in five tree species, with breeding events only observed in *Cariniana* sp. and *Parkia* sp. At site 2, we registered nest cavities in six tree species, mostly (86.6%) in *Sterculia* sp. (likely *S. pruriens*), and all the cavities recorded at site 3 were found in *B. excelsa* (Table 3).

Most of the nests (87.5%, n = 21) were located in

Table 2. Nest cavities, breeding events, eggs, and nestlings of Hyacinth Macaws in the mosaic of protected areas in Carajás, Pará state, Brazil, registered during surveys in 2007, 2008, 2013 and 2014. Cavities: total number of cavities monitored; inaccessible: number of cavities with Hyacinth Macaws nearby but which could not be monitored due to the presence of Honey Bees (*Apis mellifera*) or due to the main trunk being broken; stingless bees: number of cavities with stingless bees; Other species: number of other bird species breeding in or using the cavity; *n* active cavities: cavities with eggs or nestlings; and breeding events/eggs/nestlings: number of breeding events, eggs, and nestlings per year/survey and total. (-) Not monitored in that season.

Site (effort)	Cavities	Inaccessible (trunk/*Apis*)	Stingless bees	Other species	*n* active cavities	Breeding events/eggs/nestlings				
						Total	2007	2008	2013	2014
Site 1 - Rio Itacaiúnas (2013 - 2014, 96 h)	17	0/0	0	0	2	2/2/1	-	-	1/0/1	1/2/0
Site 2 – Canaã dos Carajás (2007 to 2014, 338 h)	45	8/2	2	1	25	35/15/30	9/0/9	12/4/12	7/2/6	7/9 /3
Site 3 – FLONA Itacaiúnas (2013, 24 h)	4	3/0	0	0	1	1/0/2	-	-	1/0/2	-
Total	66	13	2	1	28	38/17/33	9/0/9	12/4/12	9/2/9	8/11/3

Table 3. Tree species containing Hyacinth Macaw cavities (active, inactive, and potential; see Methods for details) in the mosaic of protected areas in Carajás, Pará state, Brazil.

Species	Local name	Site 1	Site 2	Site 3	No. cavities	No. breeding events
Bagassa guianensis	Tatajuba	1	-	-	1	0
Bertholletia excelsa	Castanheira-do-Pará	5	-	4	9	1
Cariniana sp.	Estopeira	1	-	-	1	1
Ceiba pentandra	Sumaúma		1	-	1	1
Euxylophora paraensis	Amarelão	8	-	-	8	0
Helicostylis tomentosa	Inharé	-	1	-	1	0
Parkia aff. *gigantocarpa*	Fava-grande	-	1	-	1	1
Parkia sp.	Faveiro	2	1	-	3	1
Schizolobium sp.	Paricá	-	2	-	2	1
Sterculia sp.	Axixá	-	39	-	39	32
Total		17	45	4	66	38

open areas, and the remaining 4.2% (*n* = 1) and 8.3% (*n* = 2) of the nests were located at the forest edge or in the forest interior, respectively. At site 2, which contained most of the monitored cavities, 95.2% (*n* = 20) of the cavities were located in open areas (*i.e.*, pasture). In addition, most of the cavities (70.9%, *n* = 17) had originated from broken branches, and the remaining cavities (29.1%, *n* = 7) originated from the effects of fungi or bird activity. At site 2, 76.1% of nest cavities originated from broken branches.

We collected environmental variables for 24 of the 28 nest cavities. Tree height ranged from 17 to 38 m, and cavity height ranged from 7.5 to 28.8 m, whereas entrance width varied between 10 and 51 cm and entrance height varied between 17 and 137 cm (Table 4). Cavity height was positively correlated with tree height (r = 0.57, P = 0.010) and DBH (r = 0.48, P = 0.048), and entrance width was correlated with entrance height (r = 0.53, P = 0.010).

A total of 17 eggs (four in 2008, two in 2013, and 11 in 2014) and 33 nestlings (9 in 2007, 12 in 2008, 9 in 2013, and 3 in 2014) were observed during the study. The median clutch size was 2 eggs per nest, and the number of nestlings varied from 1 to 2 per nest. Furthermore, competition for cavities was observed in 4 situations and involved 5 additional species, namely Honey Bees, stingless bees (*Trigona* sp.), Red and Green Macaws (*Ara chloroptera*), Scarlet Macaws (*Ara macao*), and Collared Forest Falcons (*Micrastur semitorquatus*).

DISCUSSION

In the present study in the Carajás region, the nest cavities of Hyacinth Macaws were predominantly located in *Sterculia* sp. trees. This finding agrees with a previous report by Presti *et al.* (2009), who found that *S. pruriens* was the preferred tree species for Hyacinth Macaws nesting in Canaã dos Carajás. In the Pantanal region, most Hyacinth Macaw nests are found in Panama Trees (*S. apetala*; 94% in south Pantanal, 91% in north Pantanal, and 86% in the Poconé sub-region; Guedes 1993, Pinho 1998, Pinho & Nogueira 2003, Antas *et al.* 2010). Although other species, including *E. paraensis* and *B. excelsa,* also exhibited indications of being used by Hyacinth Macaws, there were no or few breeding events recorded in these species. However, other tree species have been reported to contain Hyacinth Macaw nest cavities at other locations. For example, in Pantanal, Hyacinth Macaw nest cavities were recorded in *Albizia niopioides*, *Albizia inundata*, Pacara Eearpod Trees *Enterolobium contortisiliquum*, and *Vitex cymosa.* In a central region of Brazil, Hyacinth Macaws were found to occasionally use nest cavities in palm trees, including Moriche Palm *Mauritia vinifera* (Munn *et al.* 1987, Antas *et al.* 2010). Because Hyacinth Macaws depend on softwood trees and pre-existing cavities to breed, the presence of trees with cavities suitable for breeding is vital for the persistence of Hyacinth Macaw populations (Presti *et al.* 2009). Additional studies are needed to evaluate the availability of nesting trees and nest cavities in these regions.

Most nest cavities we recorded in our study were located in open areas, frequently in grazed areas. This has also been reported for Hyacinth Macaws in the Carajás region (Presti *et al.* 2009). Hyacinth Macaws may choose to use open areas to optimize a variety of factors, such as visibility, food accessibility, and ease of mobility, since Hyacinth Macaws are relatively large-bodied (Pinho & Nogueira 2003, Presti *et al.* 2009). Nonetheless, forested environments seem to be more suitable for Macaws than cleared areas (Conrado 2015). Hyacinth Macaws may tolerate a certain level of landscape degradation at locations near forested areas and may use cleared areas for breeding activities since cleared areas have improved visibility (Guedes 1993, Conrado 2015). The forested areas in Carajás play an important role in maintaining the Hyacinth Macaw population in the area, as these areas provide breeding and feeding resources, thereby allowing the macaws to use the surrounding areas, including degraded, grazed, and cleared areas (Conrado 2015). Therefore, the conservation of Carajás protected areas is vital to the conservation of the local Hyacinth Macaw population.

Table 4. Characteristics of active Hyacinth Macaw nests (*n* = 24) in the mosaic of protected areas in Carajás, Pará state, Brazil.

Variable	Mean ± SD	Min	Max
Tree height (m)	25.9 ± 5.7	17.0	38.0
Cavity height (m)	16.8 ± 4.9	7.5	28.8
Entrance width (cm)	20.9 ± 10.4	10.0	51.0
Entrance height (cm)	48.1 ± 35.7	17.0	137.0
Cavity width (cm)	61.2 ± 21.9	33.0	110.0
Cavity depth (cm)	34.8 ± 53.8	0.0	270.0
Diameter at breast height (cm)	366.1 ± 243.8	205.0	995.0

Most of the cavities documented in Carajás originated from broken branches. This has also been reported for Hyacinth Macaws in north Pantanal (81% of cavities SESC RPPN [Private Natural Heritage Reserve] and Pirizal, in Poconé sub-region). However, the trend was not observed in south Pantanal (Nhecolândia), where fungi, together with termites and ants, were responsible for the formation of 56% of cavities (Guedes 1993, Pinho & Nogueira 2003, Antas *et al*. 2010). The availability of cavities is greater in old-growth forests (Mannan *et al*. 1980), and the greater cavity availability may allow Macaws to use cavities produced directly by decay processes and mechanical damage and to avoid infected cavities (Cockle *et al*. 2012). The conservation of well-structured forests with high cavity availability is crucial for the persistence of Hyacinth Macaws in the wild (Cockle *et al*. 2012).

The mean height of nesting trees was higher in Carajás than that reported for other regions (north Pantanal SESC: 18.7 ± 3.3 m; Poconé sub-region: 16.3 ± 4.3 m, and south Pantanal/Nhecolândia: 14.3 ± 2.0 m; Guedes 1993, Pinho & Nogueira 2003, Antas *et al*. 2010). The same pattern was observed for mean cavity height, which was higher in Carajás than in north Pantanal SESC (9.6 ± 2.2 m), the Poconé sub-region (5.8 ± 6.9 m), and south Pantanal/Nhecolândia (7.9 ± 2.0 m, Guedes 1993, Antas *et al*. 2010). Because cavity height was positively correlated with tree height in the present study, the higher mean heights of nesting trees and cavities are likely a consequence of the structure of the Carajás forest itself, which includes dense and tall vegetation (Antas *et al*. 2010, Martins *et al.* 2012).

Nest cavity features may have significant effects on nest success and survival (Britt 2011). Cavities maintain a microclimate and protect eggs and chicks from extreme weather and predation (Britt 2011). DBH was greater in Carajás than other regions, likely due to forest structure. Hyacinth Macaws will use any available cavities that are large enough to hold nestlings. *Sterculia apetala* trees, for instance, must attain a DBH of 60 cm or greater in order to shelter Hyacinth Macaw nestlings (Santos-Jr. *et al*. 2007). Although the physical structure of nest cavities is important, other factors, such as the availability of food and water, and predator detection, may also influence the use of specific trees by Hyacinth Macaws (Sedgwick & Knopf 1992, Antas *et al*. 2010).

Some nest cavities were active during more than one breeding season in Carajás. Similarly, 30% of the cavities in south Pantanal and Nhecolândia were used more than once (Guedes 2004). This could indicate fidelity to the breeding site. Because of their size, large Macaws may have fewer suitable available cavities and exhibit moderate nest-site fidelity (Britt 2011). Further studies that mark individual Hyacinth Macaws should be conducted to evaluate the nest fidelity of the species.

Competition for cavities was observed in Carajás, as previously reported for other sites in Pantanal (Guedes 1993, Pinho & Nogueira 2003, Guedes 2009, Antas *et al*. 2010). Interspecific cavity competitors may be twice as likely to cause nest failure, when compared to predation (Britt 2011). Although Rio Itacaiúnas (site 1) is a preserved area, deforestation can become an issue in other sites, since it may reduce the number of cavities in the area. Secondary cavity-nesters, such as Hyacinth Macaws, depend on pre-existing cavities, and a limitation in this resource can negatively influence populations (Cornelius *et al*. 2008). Hyacinth Macaws may share cavities with stingless bees (*Trigona* sp.), but never with Honey Bees, which are aggressive and do not tolerate the presence of Macaws in their cavities. Stingless bees, however, may also become competitors over time, as the hive grows and makes the cavity unsuitable for Macaws (Guedes 1993 & 2004, Santos-Jr. *et al.* 2007).

Most of the surveys in the present study were conducted in October. However, the nest cavities were observed with eggs and nestlings in different stages of development, which indicated asynchrony in the breeding activity of Hyacinth Macaws. This finding is in agreement with previous studies in Carajás (Presti *et al*. 2009), but not in the Pantanal, in which a synchronous breeding pattern was observed (Guedes 1993 & 2009). The Psittacidae family is characterized by a marked hatching asynchrony (Vigo *et al.* 2011) and environmental factors, such as rain, temperature, and food resource availability may contribute to the asynchrony observed in Carajás (Presti *et al*. 2009) but not in other regions.

The clutch size observed in the present study was similar to that reported from the Pantanal region (Guedes 1993, Antas *et al*. 2010), where most nests contain two eggs and one chick. Factors, such as food availability, cavity availability, the ability of male macaws to feed nestlings, and competition may influence clutch size (Guedes 1993, Renton 2004, Djerdali *et al*. 2008, Antas *et al*. 2010). Furthermore, long-lived species, such as Hyacinth Macaws, generally experience higher adult survival rates and have smaller clutch sizes (Britt 2011).

The present study provides relevant ecological information about Hyacinth Macaws in the Amazon region, for which information of the species is scarce. Surveys in this region are financially and logistically challenging. Therefore, the data presented here represents an important contribution and is expected to facilitate conservation efforts. Understanding key ecological factors, such as nesting tree species, nest distribution, and nest characteristics, has implications for the conservation of the species. Knowing which tree species to preserve and where to best preserve them may be vital to the conservation of Hyacinth Macaws in the region. In

addition, the information provided by the present study may contribute to the development of environmental education activities, which can promote a better understanding of the ecological needs of the Hyacinth Macaw and, thereby, promote its conservation.

The presence of Hyacinth Macaw breeding cavities in the mosaic of protected areas in Carajás and the surrounding areas and the characteristics of these cavities are important for our understanding of the ecological requirements of Hyacinth Macaws in the Amazon region. Hyacinth Macaws have a highly specialized niche, and the limited availability of suitable cavities within breeding sites may reduce local populations to critical levels, thereby affecting their local persistence (Guedes 1993, Johnson *et al*. 1997, Guedes & Seixas 2002). Because habitat degradation is a major threat to many animal species, including Hyacinth Macaws (Johnson *et al*. 1997), land use in Carajás represents a major threat to the viability of the local Hyacinth Macaw population. As such, basic ecological information, such as that presented here, will facilitate local conservation efforts.

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