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SHORT COMMUNICATION

Effects of rainfall on bird reproduction in a semi-arid Neotropical region

Liana Monique Paiva Cavalcanti[1], **Luciana Vieira de Paiva**[2] & **Leonardo Fernandes França**[2*]

[1] *Pós Graduação em Ecologia e Conservação, Departamento de Ciências Animais, Universidade Federal Rural do Semi-Árido. Avenida Francisco Mota 572, 59625-900 Mossoró, RN, Brazil.*
[2] *Departamento de Ciências Animais, Universidade Federal Rural do Semi-Árido. Avenida Francisco Mota 572, 59625-900 Mossoró, RN, Brazil.*
[*] *Corresponding author. E-mail: franca_lf@ufersa.edu.br*

ABSTRACT. In semi-arid ecosystems, birds commonly use rainfall as a reliable environmental cue to adjust the timing and strength of their reproductive activity. Here we evaluate this hypothesis for a community of birds in the Caatinga (the semi-arid region of northeastern Brazil), using brood patch information and nest abundance. Sampling occurred every 14 days between September 2012 and August 2013 (brood patch), and every three or four days during the reproductive period (nests). Abundance of brood patches and nests were correlated, and all brood patches were recorded between March and July (4.5 to 5.0 months). We recorded three peaks of brood patch abundance: the first 28 days after the first rains, the second 14 days after the second rainfall peak, and the third synchronously with the third rainy period. These results indicate that intra-annual variation in local rainfall has the potential to account for variations in the timing and intensity of reproduction in the studied birds.

KEY WORDS. Breeding period, brood patches, Caatinga, nests.

In semi-arid ecosystems, relations between bird reproduction and rainfall seasonality have been reported as strongly intermeshed, and associated with short-term responses to variations in precipitation (Ahumada 2001, Illera & Díaz 2006, Dean et al. 2009). In such environments, annual fluctuations in water regime and food availability act as environmental cues to set the timing and intensity of reproductive effort (Zann et al. 1995, Ahumada 2001, Illera & Díaz 2006, Salgado-Ortiz et al. 2009). In some cases, food availability acts as a direct environmental cue (Salgado-Ortiz et al. 2009), but most of the time, the annual rainfall regime is the most important factor. This is especially true in birds, since rainfall is a highly reliable indicator of the availability of high-quality food (Mezquida & Marone 2003, Houston 2013). Scheuerlein & Gwinner (2002) stated that environmental cues, for instance rain, are able to influence, and in some cases determine, the timing of breeding, especially in highly unpredictable environments such as semi-arid ecosystems.

The Caatinga is an area of some 800,000 km^2 of dry tropical forest in northeastern Brazil (Sampaio 1995). Although it is semiarid, extensive areas within the region receive relatively large quantities of rain (750 to 1000 mm) (Nimer 1972). However, the average annual temperature is high (~27°C), while rainfall is both highly restricted in time (all within a period of around three months) and very unpredictable (e.g., annual variation from 360 to 1340 mm) (Prado 2003), so that the Caatinga shares characteristics with more arid areas (Blasco et al. 2000). Most publications on the birds of the region are restricted to inventories, so that there is very little available on the ecology of individual species (review in Albuquerque et al. 2012). Some studies have suggested a link between the timing of Caatinga bird breeding and that of the rainy season (Telino-Jr et al. 2005), but no assessments are available for the quantitative relationship between rainfall, reproductive period and reproductive intensity. In other environments with climates similar to the Caatinga, two hypotheses have received strong support: (1) the timing of breeding is dependent on seasonal rains (Illera & Díaz 2006), and therefore that reproduction occurs mainly or entirely in the rainy season (Cox et al. 2013); (2) that the length and intensity of reproductive effort is adjusted depending on the volume and distribution of rainfall during the breeding season (Illera & Díaz 2006, Salgado-Ortiz et al. 2009). Our study aims to evaluate aspects related to these two hypotheses, using a study design with short intervals between samples (14 days). Here we assume that the timing and intensity of the reproductive period of the avian assemblage will be dependent on the rains.

The Caatinga region studied, known as the Depressão Sertaneja Setentrional, is characterized by formations of trees and shrubs, and an average annual rainfall that ranges from 400 to

800 mm (Velloso et al. 2002). The study area (5°11”S, 37°20”W) consists of semi-preserved fragments (primary or secondary vegetation, ~300 ha) and areas of cultivation (anthropogenic). Data collection occurred in areas of native vegetation, which comprised either forests with trees of up to 10 m in height, or more open areas dominated by shrubs. Both areas had dense undergrowth. A record of six years of precipitation demonstrates the unpredictability of local rainfall, with intense and uni-modal seasons (2007-2008 – 1012 mm, 2008-2009 – 1505 mm, 2010-2011 – 973 mm), weak and bimodal (2009-2010 – 321 mm, 2012-2013 – 492 mm), and a severe drought period (2011-2012 – 245 mm) (Source: INMET – Instituto Nacional de Meteorologia, Mossoro Station A318).

To obtain brood patch records, we captured birds in the semi-preserved areas every 14 days, with sampling occurring on two consecutive days (n = 24 capture occasions, September 2012 to August 2013). In each day we use one transect to capture the birds. At each we placed 12 mist nets (18 x 3 m, 19 mm mesh), spaced 50 m apart, along 600 m. These were opened at 5:00 a.m. and left open for five hours. All captured birds were identified and marked with coded metal bands (provided by the Centro Nacional de Pesquisa e Conservação de Aves Silvestres CEMAVE/ICMBio). Recording brood patches has proved to be an efficient indicator of reproductive investment (Cox et al. 2013) and, despite the recognized relationship between the brood patch stages and reproductive stages (Redfern 2010), studies similar to ours have preferred to group the various active stages for statistical analysis (Cox et al. 2013).

We collected nest abundance data as an additional indicator variable of reproductive periodicity. Nests were located through active search every three to four days between the beginning of February and the end of June. At each located nest, the incubating bird was identified and the nest was then monitored until it became inactive. Data on nest abundance were considered as secondary information, because they were not obtained in a temporally systematized way (i.e., using a standardized search time of hours/person), and because nest searching took place over a shorter period than did recording brood patches.

Reproductive variables considered during the study were: (1) percentage of birds with brood patch, calculated on each capture occasion as a function of the total number of individuals captured, and (2) average daily number of active nests, calculated from the number of active nests in the seven days before and after each mist-netting event. We analyzed the data according to: (i) the total number of species, and (ii) the food guild of each species. We used existing dietary information on the species captured (based on: Moojen et al. 1941, Schubart 1965, Motta-Júnior 1990, Poulin et al. 1993, Gomes et al. 2008) to establish the following feeding guilds: pure insectivores, insectivores-frugivores, insectivores-granivores, granivores and omnivores. Rainfall data were obtained from a publicly-available database belonging to the INMET (Mossoro Station A318, http://www.inmet.gov.br/portal/index.php?r = estacoes/estacoesautomaticas).

We used a Pearson linear correlation with a 0.5 significance level to correlate both the temporal abundance of nests and brood patches, and brood patches and the accumulated rainfall of 14 days prior to each mist-netting session.

During the study 67 bird species from 20 families were captured. We recorded 31 species with brood patch (n = 126 patch records, 807 individuals, in 1016 captures, Appendix 1). Of the remaining 36 species, 77.8% had less than 10 individuals captured in mist nets. We recorded 24 species with nests (n = 66 nests), and individuals of eight of these were also captured while bearing a brood patch (Appendix 1). Of the 16 species recorded only from nests, five were not captured with mist nets during the reproductive period, 10 were captured less than five times and only one – *Columbina passerina* (Linnaeus, 1758), Columbidae = 14 – was captured frequently.

The reproductive period studied was marked by three peaks of brood patch records and occurred between March 2nd and July 20th (Fig. 1). The duration of the brood patch peaks was at least 42 days (March 2nd and April 13th), 14 days (May 11th and May 25th) and 14 days (June 22nd and July 6th). The breeding season lasted 141 days (between peaks of brood patch) and 156 days (between start and end of the patch records). The period of greatest abundance of brood patches (March 2nd to June 8th) was strongly correlated with the abundance of nests ($r^2 = 0.81$, $t_8 = 5.00$, $p = 0.002$, Fig. 2).

All birds encountered in reproductive condition were recorded between March and July (Fig. 1). The proportion of individuals with brood patches and the cumulative rainfall 14 days (n = 23) were correlated when patch appearance was given a time lag of 14 days in relation to the appearance of the rains

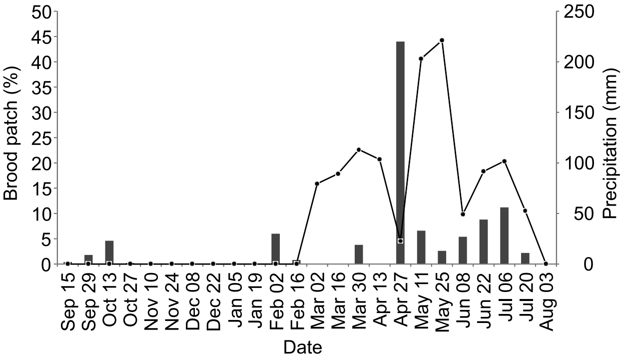

Figure 1. Occurrence of brood patches (●) and accumulated precipitation (bars). Percentage of individuals with brood patches was calculated per netting event and based on the number of captures. Precipitation was calculated based on the interval of 14 days between the netting sessions. Sampling occurred between September 15, 2013 and August 03, 2014. Source of rainfall data: Instituto Nacional de Meteorologia, Mossoro Station, A318, located ~3 km from the study area.

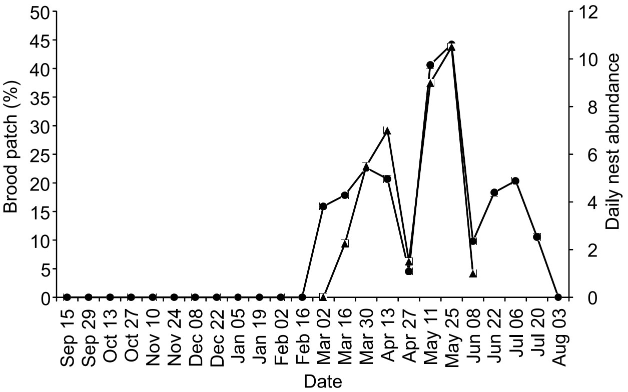

Figure 2. Occurrence of brood patches (●) and nests (▲) in the Caatinga area studied. The percentage of individuals with brood patches was calculated every netting session as a function of the number of captures. Daily nest abundance (average) calculated from the number of active nests in the seven days before and after each netting session.

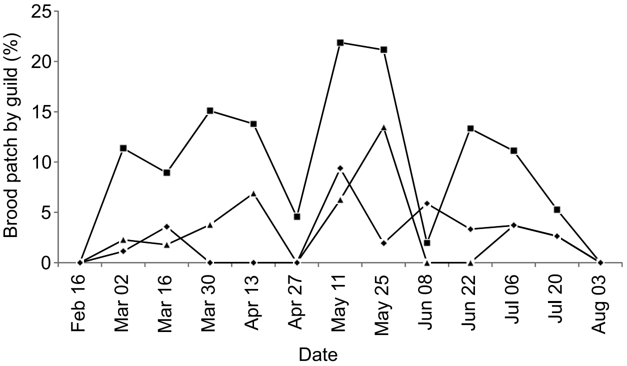

Figure 3. Occurrence of brood patches in purely-insectivorous (■), insectivorous-frugivorous (▲) and insectivorous-granivorous (◆) species. Percentage of individuals with brood patches calculated per netting session based on number of captures.

($r^2 = 0{:}36$, T = 3.46, df = 21, p = 0.002). The onset of the first peak of brood patch abundance (March 2nd) occurred 28 days after the first period of intense rainfall (February 2nd). The beginning of the second and largest brood patch abundance peak (May 11th) occurred after 14 days of unusually high rainfall (April 27th). Finally, the third peak in brood patch abundance peak occurred synchronously with the third period of increased rain (June 22nd to July 6th).

Among the five categories of food-guilds considered, pure-insectivorous were the most highly represented in the sample (47% of the species, 55% of brood patch records). The insectivorous-frugivorous and insectivorous-granivorous guilds together accounted for 31% of all records. The brood patch abundance peaks were evident for pure-insectivorous. The same pattern appears also to have occurred with other insectivores (Fig. 3), but small sample size for the two other guilds did not allow an evaluation of the temporal data.

The strong correlation between data of brood patches and nests, combined with only a partial overlap of species sampled in these two data sets, underscored the interspecific nature of the temporal patterns of reproduction established for the studied birds. While this set of results did not confirm the brood patch as a good reproductive effort indicator (e.g., Cox et al. 2013), it did not yield any evidence to disprove this assumption.

Brood patches appeared only for a period of some 4.5 to 5.0 months, a range similar to that recorded in other Caatinga area where the brood patches sampling occurred at monthly intervals (Ruiz-Esparza 2010). Restricting reproductive activity to narrow windows is a commonly observed strategy in bird communities from semiarid environments from South Africa and Australia (Yomtov 1987, Dean et al. 2009), and similar reports are found for bird populations elsewhere in semiarid South America – e.g., *Poospiza torquata* (d'Orbigny & Lafresnaye, 1837), Thraupidae, 4.5 months (Mezquida & Marone 2003), and *Setophaga petechia bryanti* (Ridgway, 1873), Parulidae, 3.5 months (Salgado-Ortiz et al. 2009). In this type of environment, rainfall is often used as short-term signal for regulation of the avian reproductive period (Ahumada 2001, Hau 2001, Houston 2013), and length and intensity of reproductive activity may be closely tied with that of the rainy season (Illera & Díaz 2006). It appears plausible that such an association between bird breeding season and rainy season could also occur in the Caatinga area studied. The current data indicates a potential seasonal pattern for the study area. However, its confirmation depends on the provision of multiple annual replicates.

Some studies that have evaluated Caatinga bird assemblies mention the association between reproduction and rainy season (Nascimento et al. 2000, Telino-Jr et al. 2005, Roos et al. 2006, Ruiz-Esparza 2010), but none had the specific aim of conducting a temporally accurate analysis to quantitatively characterize the relationship. Our records, apart from pointing to a potential restriction of the reproductive period to the rainy season in the study region, provide evidence for a possible association between the intensity of reproduction (as measured by the abundance of brood patches and nests) and the intensity of immediate rainfall (measured by accumulated rainfall). More specifically, this included multiple brood patch abundance peaks within the breeding season and a time lag of ~14 days between patch appearance and rain onset. Insectivorous birds in arid environments have been shown to reduce or increase reproductive activity depending on the annual rainfall volume (Lloyd 1999). Similar to our findings, some species in a South African arid-zone were also able to begin their reproductive cycles after low volumes of rain (Lloyd 1999), while for populations of Darwin's finches, reproductive intensity varied within the season in response to intermittent rains (Grant & Boag 1980). Our initial results indicate that such a fine-tuned relationship between rainfall and abundance of breeding birds is also likely to occur in the studied Caatinga area.

The presence of several reproductive peaks with different intensities and rain-linked time lag may have occurred because of variations in availability of arthropods, an important food source of the majority of the bird species in the study (diet analysis – e.g., Motta-Júnior 1990, Gomes et al. 2008), and common food source for many frugivorous and granivorous birds during the breeding season (Poulin et al. 1992). In arid and semi-arid environments the effects of precipitation on the primary production are direct and strong (Grant & Grant 1989, Lloyd 1999), and this trigger the seasonality in the arthropods abundance (Poulin et al. 1992, Ahumada 2001, Houston 2013). In some cases, this two-step relationship generates a time lag of one to two months between rain and increased arthropod abundance (Poulin et al. 1993, Illera & Díaz 2006, Houston 2013). Such relationships make precipitation a reliable environmental cue for birds, allowing them to predict the future availability of food and so determine their reproductive period (Hau 2001, Leitner et al. 2003). Our preliminary report of a relationship between the periodicity of rains and brood patches indicates that this context is also potentially valid for the Caatinga.

Based on historical ornithological studies in the Caatinga (Albuquerque et al. 2012), the hypotheses raised here can be considered a first assessment, a study designed to evaluate the relationship at a temporally fine scale. According to the current results, these hypotheses deserve to be the subject of further evaluated using long-term studies.

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Appendix 1. Species recorded with some indication of reproductive activity during the study. List shows reproductive records, local occurrence form, and feeding guild for each species. We used a '+' sign to show the number of brood patches and the number of nests in species recorded with both indications of reproductive activity.

Species	Record of reproductive evidences		Occurrence*	Feeding guild**
	Kind	Number		
Coccyzus melacoryphus Vieillot, 1817	brood patch	19	resident	insectivores
Lanio pileatus (Wied, 1821)	patch + nest	15 + 2	resident	insectivores; granivores
Tolmomyias flaviventris (Wied-Neuwied, 1831)	patch + nest	11 + 1	resident	insectivores
Myiopagis viridicata (Vieillot, 1817)	brood patch	9	resident	insectivores; frugivorous
Columbina talpacoti (Temminck, 1810)	patch + nest	2 + 6	resident	granivores
Mimus saturninus (Lichtenstein, 1823)	nest	8	resident	omnivores
Cyclarhis gujanensis (Gmelin, 1789)	brood patch	7	resident	omnivores
Euscarthmus meloryphus Wied-Neuwied, 1831	brood patch	7	resident	insectivores
Formicivora melanogaster Pelzeln, 1868	brood patch	7	resident	insectivores
Paroaria dominicana (Linnaeus, 1758)	nest	7	resident	insectivores; granivores
Turdus rufiventris Vieillot, 1818	patch + nest	2 + 4	resident	omnivores
Hemitriccus margaritaceiventer (Orbigny & Lafresnaye, 1837)	brood patch	6	resident	insectivores
Todirostrum cinereum (Linnaeus, 1766)	nest	6	resident	insectivores
Coereba flaveola (Linnaeus, 1758)	patch + nest	4 + 1	resident	insectivores; frugivorous
Pachyramphus polychopterus (Vieillot, 1818)	patch + nest	3 + 1	migratory	insectivores
Turdus amaurochalinus Cabanis, 1850	patch + nest	1 +3	migratory	omnivores
Casiornis fuscus P.L. Sclater & Salvin, 1873	brood patch	4	resident	insectivores
Veniliornis passerinus (Linnaeus, 1766)	brood patch	4	resident	insectivores
Columbina minuta (Linnaeus, 1766)	nest	4	resident	granivores
Columbina picui (Temminck, 1813)	nest	4	resident	granivores
Empidonomus varius (Vieillot, 1818)	nest	4	migratory	insectivores; frugivorous

Continues

Appendix 1. Continued.

Species	Record of reproductive evidences		Occurrence*	Feeding guild**
	Kind	Number		
Pitangus sulphuratus (Linnaeus, 1766)	nest	4	resident	omnivores
Cnemotriccus fuscatus (Wied-Neuwied, 1831)	brood patch	3	resident	insectivores
Myiarchus tyrannulus (Statius Muller, 1776)	brood patch	3	resident	insectivores; frugivorous
Thamnophilus capistratus Lesson, 1840	brood patch	3	resident	insectivores
Vireo olivaceus (Linnaeus, 1766)	patch + nest	1 + 1	migratory	omnivores
Celeus flavescens (Gmelin, 1788)	brood patch	2	resident	insectivores; frugivorous
Taraba major (Vieillot, 1816)	brood patch	2	resident	insectivores
Volatinia jacarina (Linnaeus, 1766)	brood patch	2	resident	insectivores; granivores
Eupsittula cactorum (Kuhl, 1820)	nest	2	resident	frugivorous
Cyanocorax cyanopogon (Wied-Neuwied, 1821)	nest	2	resident	omnivores
Tangara sayaca (Linnaeus, 1766)	nest	2	resident	omnivores
Elaenia flavogaster (Thunberg, 1822)	brood patch	1	resident	insectivores; frugivorous
Elaenia parvirostris Pelzeln, 1868	brood patch	1	migratory	insectivores; frugivorous
Myiodynastes maculatus (Statius Muller, 1776)	brood patch	1	resident	omnivores
Nystalus maculatus (Gmelin, 1788)	brood patch	1	resident	insectivores; granivores
Phaeomyias murina (Spix, 1825)	brood patch	1	resident	insectivores; frugivorous
Piculus chrysochloros (Vieillot, 1818)	brood patch	1	resident	insectivores
Picumnus limae E. Snethlage, 1924	brood patch	1	resident	insectivores
Sakesphorus cristatus (Wied-Neuwied, 1831)	brood patch	1	resident	insectivores
Sittasomus griseicapillus (Vieillot, 1818)	brood patch	1	resident	insectivores
Columbina passerina (Linnaeus, 1758)	nest	1	resident	granivores
Icterus pyrrhopterus (Vieillot, 1819)	nest	1	resident	insectivores; frugivorous
Nemosia pileata (Boddaert, 1783)	nest	1	nondescript	insectivores; granivores
Sporophila albogularis (von Spix, 1825)	nest	1	resident	granivores
Tyrannus melancholicus Vieillot, 1819	nest	1	resident	insectivores; frugivorous
Vanellus chilensis (Molina, 1782)	nest	1	resident	insectivores

*Classification of occurrence from Silva et al. (2003), Olmos et al. (2005), and unpublished information from the Laboratory of Animal Population Ecology. **Classification of guilds from Moojen et al. (1941), Schubart et al. (1965), Motta-Junior (1990), Poulin et al. (1993), and Gomes et al. (2008).