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ARTICLE

Bird molting and breeding in an area undergoing re-vegetation in the Atlantic Forest of southeastern Brazil

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ABSTRACT: Molting and breeding cycles are high-energetic costs events, and usually synchronized and temporally well defined in tropical avian communities. However, in degraded and/or undergoing restoration areas, environmental stresses, such as forest fragmentation and restriction of food resources, could locally change these patterns. This study aims to analyze molting and breeding in a bird assembly in an undergoing re-vegetation area in the Atlantic Forest of southeastern Brazil. By mist netting, we searched for evidence of molting of flight feathers and presence of brood patch in captured birds. We also recorded three environmental variables (temperature, rainfall, and photoperiod) to test whether they affect those events. We sampled 85 individuals from 36 species. The breeding cycle started in July and peaked in November and December. The molting period was between July and April of the next year and peaked in January and February. Molting and breeding events were related to temperature. The overlap between these events was of 11% (n = 9). Our data suggest that molt and breeding times are in accordance to other studies where the climate is more seasonal, yet more studies are necessary to investigate those biological cycles and their possible alterations due to environmental degradation.

KEY-WORDS: fragmentation, mist nets, overlap, reproduction, restoration.

INTRODUCTION

Migration, molting, and reproduction are the life cycle events of birds that demand the highest energy expenditure (Foster 1974, Marini & Durães 2001), and an evolutionary strategy to reduce these costs would be to reduce their temporal overlap (Clark 2004, Newton 2009, Jahn *et al*. 2017). Yet, individuals of many tropical species undergo molting and breeding events with some overlap (Marini & Durães 2001, Piratelli 2012). This may be related, in comparison to their temperate counterparts, to reduced physiological demands (Foster 1974, Wingfield 2005), such as fewer eggs (Martin *et al*. 2000), gonad size reduction (Hau *et al.* 2010), and an extended molting period (Ryder & Wolfe 2009; but see Silveira & Marini 2012).

Many abiotic factors are thought to influence the timing of molting and breeding in the Neotropical region. Minor changes in photoperiod (*e.g.* increasing the duration of daytime) may cause shifts in behavior, and trigger the development of brood patch and gonads, and an increase in brain activities of areas related to song (Dawson *et al*. 2001, Chandola-Saklani *et al*. 2004, Dawson 2013). Another influence is the availability of food resources, which is needed to supply energy intake (Hemborg & Lundberg 1998) and, in some cases, may be closely related to local precipitation and temperature (*e.g.* Repenning & Fontana 2011). Seasonal forests have a marked climatic seasonality, with a rainy season in a larger food supply (Pennington *et al*. 2009), and a dry season with more limited resources (Araújo-Filho 2009), which may affect bird behavior and physiology (*e.g.* Ryder & Wolfe 2009).

Forest degradation and fragmentation are changes that may cause stress in birds (Lens *et al*. 1999), mainly due to restrictions in food supply and suitable breeding sites (Ford *et al.* 2001). Animals respond to stress with endocrine changes, affecting physiological processes that, if they persist for a long time, can negatively affect survival, reproduction, and resistance to diseases (Boonstra 2004, Romero 2004, Lundberg 2005). Thus, nutritionally deficient birds could have their breeding affected by lack of nutrients for their maintenance and for egg production (Mauget *et al.* 1994).

Many areas are globally undergoing forest restoration as an alternative to minimize the impacts of forest fragmentation (Crouzeilles *et al.* 2016), aiming to recover the original structure and functionality of the ecosystems (SER 2004). Although there are several studies on bird molting and breeding in Brazil (*e.g.* Piratelli *et al.* 2000, Mallet-Rodrigues 2005, Silveira & Marini 2012, Araujo *et al.* 2017), to our knowledge, there are no molting studies that have been done in areas undergoing forest restoration. Such studies may help elucidate periods related to molting and breeding cycles in relation to environmental factors that may interfere with these processes in sites under severe forest fragmentation (Laurance *et al.* 2002, Gastauer *et al*. 2015).

Here we aimed to determine bird molting and breeding periods and whether these events overlap in an area under a restoration program in the Atlantic Forest of southeastern Brazil. We expect little or no overlap between those events, by the patterns already described in assemblages of birds in the Atlantic Forest (*e.g.* Marini & Durães 2001, Maia-Gouvêa *et al.* 2005) and by the high energy demand requirements involved. We predicted that these events are related to such environmental variables as photoperiod, rainfall and temperature.

METHODS

Study area

This research was carried out at Fazenda São Luiz in the region of Itu, state of São Paulo, Brazil (23°14'15.18''S; 47°24'3.29''W; Fig. 1), with an area of 526 ha. The land use in the past was defined by intensive coffee crops from 1940 to 1980, then by pasturelands until 2007, when the restoration program began, resulting in small isolated fragments of native vegetation. The restored area has 386 ha, which planting age ranges from 4 to 11 years. The planting was carried out randomly in alternating lines composed of pioneer and secondary species, with spacing of 2 × 3 m between the lines. Some of the most common tree species are *Schinus terebinthifolius* Raddi, *Cytharexyllum myrianthum* Cham., *Guazuma ulmifolia* Lam., *Machaerium nyctitans* (Vell.) Benth and *Cedrela fissilis* Vell (Gagetti *et al.* 2016). The predominant vegetation is Semideciduous Seasonal Forest with a transition to Cerrado (Brazilian savanna). It is characterized by marked climatic seasonality in rainfall, and trees may lose 20 to 50% of their leaves in the dry season (Araújo-Filho 2009). The climate is humid temperate of the Cwa type, according to Köppen system, being characterized by dry winters and hot summer, with average rainfall of 56 mm and 160 mm, respectively (Alvares *et al*. 2013). The rainy season occurs from October to March, followed by the dry season, from April to September (Cepagri 2017).

Molting and breeding periods

We mist-netted birds from May 2016 to April 2017 to detect the periods of molting and breeding. We used seven to nine mist nets (36 mm, 12 × 3 m) placed 5 m from the edge of two restored areas, the first with 6 (4.22 ha), and the second with 8 years (8.39 ha) after initial restoration process. The total capture effort was 45,631 (h/m^2), with an average of 30 h in 3 days of capture per month, mostly in the second fortnight. The nets were open at dawn, closed in the hottest part of the day (noon), and then reopened until dusk.

We investigated only the flight feathers molting, by the presence of sheathed feathers and by the difference in length compared to other feathers (Fig. 2). We recognized individuals in active molt as those simultaneously replacing at least one feather on both sides of the tail and on both wings (Marini & Durães 2001).

We considered an individual as being in breeding condition by the presence of a brood patch, defined by loss of contour feathers in the ventral region or by hypervascularization in this area (Jones 1971). We used a ranking system varying from stages 1 to 5 to verify the degree of brood patch development (IBAMA 1994, Fig. 3). Despite the breeding period is not restricted to the egg laying period, we used this event as evidence of

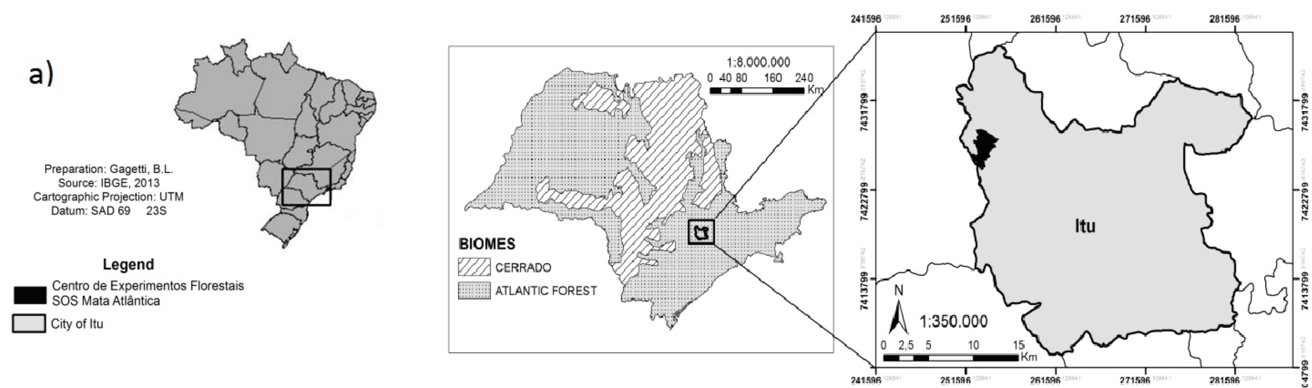

Figure 1. Location of *Centro de Experimentos Florestais SOS Mata Atlântica* in the region of Itu, state of São Paulo, southeastern Brazil. (Modified from Gagetti *et al.* 2016 with permission from the authors).

breeding. Sexual maturity of each individual was checked by plumage characteristics and/or color of the gape. All individuals considered as young were excluded from the analyses.

The overlap of molting and breeding was defined by evidence of both events in the same individual, *e.g.* if a bird had brood patch at any stage of development (stages 1–5) and was in molting, we considered it to be overlapping breeding and molt.

Environmental variables

We retrieved regional data on monthly means of temperature and rainfall from *Centro Integrado de Informações Agrometeorológicas* (Ciiagro 2017), and values of photoperiod through the website Golden Hour Calculator (http://www.b-roll.net/goldenhour/generate.php). We collected information on time of sunrise and sunset for each day of each month of sampling. Thus, we

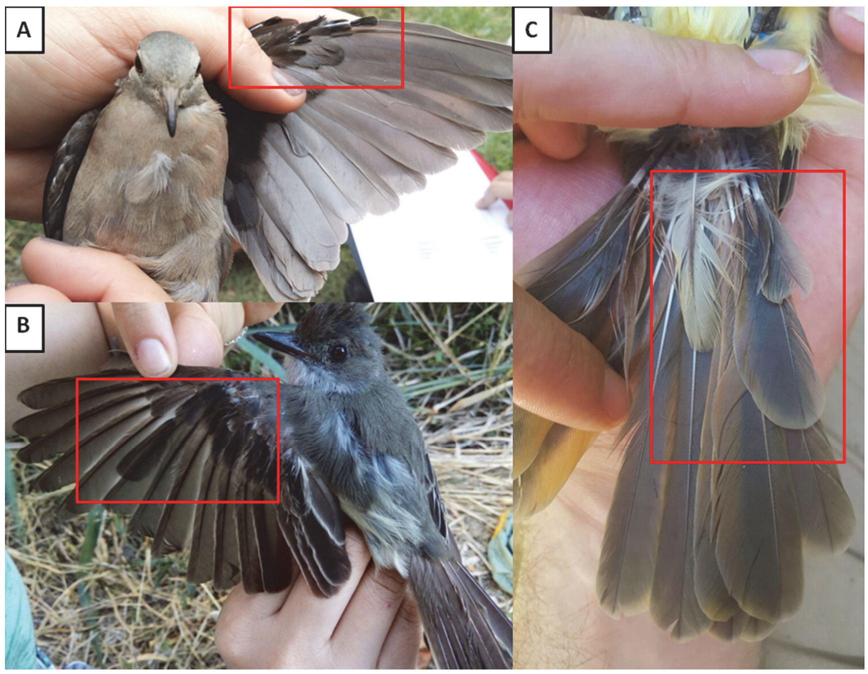

Figure 2. Captured individuals with flight feather molt from May 2016 to April 2017 in the region of Itu, state of São Paulo, southeastern Brazil. (**A**) *Columbina talpacoti*, left wing; (**B**) *Myiarchus swainsoni*, left wing; (**C**) *Myiarchus tyrannulus*, tail. Photo author: Paulo Andrade.

Figure 3. Stages (scores) of brood patch development of captured birds. (**A**) Score 1; (**B**) Score 2; (**C**) Score 3; (**D**) Score 4; (**E**) Score 5. Photo authors: Daniele Moreno and Paulo Andrade.

calculated the total number of minutes per day and the monthly average, with the sum of the minutes per day divided by the number of days in the month.

Data analysis

We determine the molting and breeding periods using percentage of the number of individuals in molting and breeding condition recorded in each month of sampling, and we tested for molt-breeding overlap using a Chi-square test.

We tested the collinearity of predictor variables (photoperiod, temperature, and rainfall) by VIF (Variance Inflation Factor). We used VIF = 3 to find a set of explanatory variables without collinearity, taking one variable at a time and recalculating FV values, repeating the process until FV values were less than 3. As temperature and photoperiod were collinear, we excluded photoperiod from the analyses. Then, we used binomial Generalized Linear Models - GLM to check for any relation of temperature and rainfall with molt and breeding. All analyses were run in the software R 3.4.1 (R Core Team 2017).

RESULTS

We captured 85 birds, 8 of which were recaptured. These individuals represent 36 species and 14 families (Table 1), mostly passerines (n = 28; 77.7%). July and August had the largest number of captured birds (n = 26; 33.7%). The most-captured species were *Turdus leucomelas* Vieillot, 1818 (n = 7; 9.1%), *Tachyphonus coronatus* (Vieillot, 1822) (n = 6; 7.8%) and *Tiaris fuliginosus* (Wied, 1830) (n = 6; 7.8%).

Breeding, molting and overlap

We captured 59 individuals in breeding condition. The breeding period lasted from July to February, and the highest number of individuals with a brood patch (n = 19; 32.2%) was sampled in September and October, most in early stages of development. Individuals with fully-developed brood patches were more common from November to December (n = 6, Fig. 4).

We sampled 9 birds with flight feathers molting, from July to April, with a higher incidence in January and February (n = 5; 55.5%, Fig. 5). From those, 6 were molting wings, one its tail feathers and 2, both wings and tail. All 9 individuals exhibited molt-breeding overlap (about 11%; see Table 1). Overlap was more common from January to April (n = 7; 77.7%). Therefore, some birds may present reproductive activities regardless they are also molting (χ^2 = 3.94, df = 1, P = 0.05).

Environmental variables

We found that both molt and breeding are related to temperature (P < 0.001 for both). While none of these two response variables (*i.e.* molt or reproduction) were influenced by rainfall (P = 0.84 and P = 0.34, respectively).

DISCUSSION

Breeding, molting and overlap

Our findings are in accordance to previous studies carried out in the Atlantic Forest, that breeding period lasts from August to April, peaking in November (Marini & Durães 2001, Mallet-Rodrigues 2005, Piratelli 2012). The molting season in our study was similar to others in the same biome, from September to May, peaking

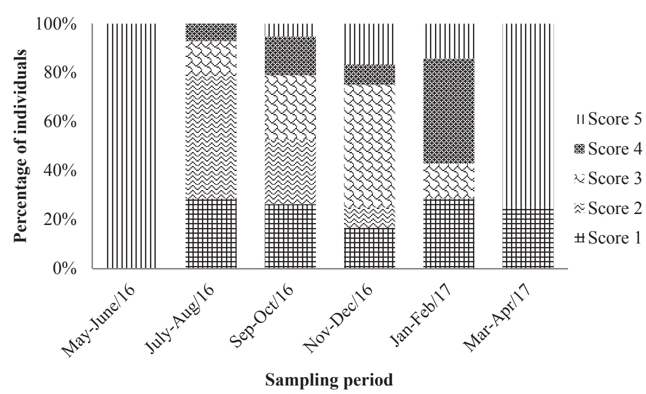

Figure 4. Percentage of individual birds captured with different scores of brood patch development from May 2016 to April 2017 in the region of Itu, state of São Paulo, southeastern Brazil. Score 0: nonexistent brood patch; Score 1: developing brood patch; Scores 2 and 3: brood platch in maximum development, active; Scores 4 and 5: reduction and disappearance of the brood patch (IBAMA 1994).

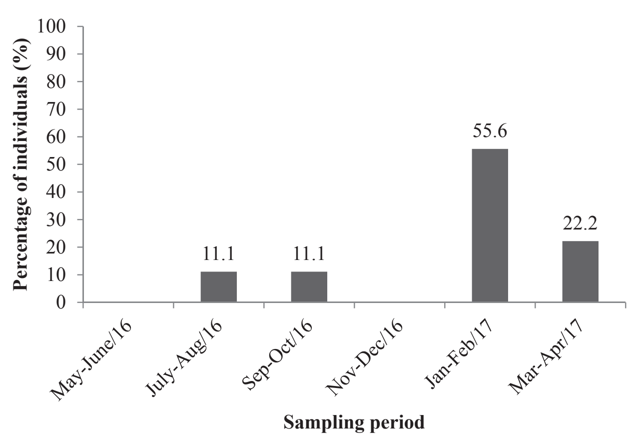

Figure 5. Percentage of individual birds molting flight feathers from May 2016 to April 2017 in the region of Itu, state of São Paulo, southeastern Brazil.

Table 1. Bird families and species captured (nomenclature follows Piacentini *et al*. 2015). Columns represent number of total captures, number of individuals captured molting flight feathers or with a brood patch and number of individuals with both events, from May 2016 to April 2017 in the region of Itu, state of São Paulo, southeastern Brazil.

Taxon	Captures	Molting	Brood patch	Overlap
Columbidae Leach, 1820				
Columbina talpacoti (Temminck, 1810)	2	1	2	1
Leptotila verreauxi Bonaparte, 1855	6	2	4	1
Leptotila rufaxilla (Richard & Bernard, 1792)	1	1	1	1
Cuculidae Leach, 1820				
Piaya cayana (Linnaeus, 1766)	2	1	2	0
Tapera naevia (Linnaeus, 1766)	1	0	1	0
Bucconidae Horsfield, 1821				
Malacoptila striata (Spix, 1824)	1	1	1	1
Picidae Leach, 1820				
Picumnus temminckii Lafresnaye, 1845	1	0	0	0
Veniliornis spilogaster (Wagler, 1827)	1	0	1	0
Thamnophilidae Swainson, 1824				
Thamnophilus doliatus (Linnaeus, 1764)	1	0	1	0
Thamnophilus caerulescens Vieillot, 1816	2	1	2	1
Furnariidae Gray, 1840				
Synallaxis frontalis Pelzeln, 1859	2	1	2	0
Rhynchocyclidae Berlepsch, 1907				
Leptopogon amaurocephalus Tschudi, 1846	3	0	2	0
Tolmomyias sulphurescens (Spix, 1825)	1	0	1	0
Tyrannidae Vigors, 1825				
Myiopagis viridicata (Vieillot, 1817)	1	0	1	0
Myiarchus swainsoni (Cabanis & Heine, 1859)	1	1	1	1
Myiarchus ferox (Gmelin, 1789)	3	0	3	0
Myiarchus tyrannulus (Statius Muller, 1776)	2	1	1	1
Pitangus sulphuratus (Linnaeus, 1766)	2	0	0	0
Myiodynastes maculatus (Statius Muller, 1776)	3	0	3	0
Megarynchus pitangua (Linnaeus, 1766)	1	0	1	0
Cnemotriccus fuscatus (Wied, 1831)	1	0	1	0
Lathrotriccus euleri (Cabanis, 1868)	1	0	1	0
Vireonidae Swainson, 1837				
Cyclarhis gujanensis (Gmelin, 1789)	2	0	2	0
Turdidae Rafinesque, 1815				
Turdus leucomelas Vieillot, 1818	7	0	6	0
Turdus amaurochalinus Cabanis, 1850	1	0	0	0
Passerellidae Cabanis & Heine, 1850				
Zonotrichia capensis (Statius Muller, 1776)	1	0	1	0
Parulidae Wetmore, Friedmann, Lincoln, Miller, Peters, van Rossem, Van Tyne & Zimmer 1947				
Basileuterus culicivorus hypoleucus Bonaparte, 1850	3	0	2	0
Myiothlypis flaveola Baird, 1865	2	2	2	0

Taxon	Captures	Molting	Brood patch	Overlap
Thraupidae Cabanis, 1847				
Tangara sayaca (Linnaeus, 1766)	4	1	3	1
Tangara cayana (Linnaeus, 1766)	1	0	0	0
Volatinia jacarina (Linnaeus, 1766)	2	1	1	1
Coryphospingus cucullatus (Statius Muller, 1776)	2	0	2	0
Tachyphonus coronatus (Vieillot, 1822)	4	0	3	0
Tiaris fuliginosus (Wied, 1830)	6	0	1	0
Thlypopsis sordida (d'Orbigny & Lafresnaye, 1837)	2	0	1	0
Cardinalidae Ridgway, 1901				
Cyanoloxia glaucocaerulea (d'Orbigny & Lafresnaye, 1837)	1	0	0	0

from January to April (Bugoni *et al.* 2002, Repenning & Fontana 2011, Piratelli 2012). Following previously described patterns (*e.g.* Poulin *et al.* 1992, Silveira & Marini 2012) the incidence of molting was higher right after the breeding season.

There are some general patterns about molt-breeding overlap that can be identified across studies. It is widespread in the Neotropics (Foster 1975, Piratelli *et al.* 2000, Marini & Durães 2001, Rohwer *et al.* 2009, Piratelli 2012, Silveira & Marini 2012, Jahn *et al.* 2017) and can occur in tropical regions around the world (Payne 1969, Ralph & Fancy 1994, Verea *et al.* 2009, Moreno-Palacios *et al.* 2013, Pyle *et al.* 2016). We found that molting and breeding events had a higher overlap than in other studies in the Atlantic Forest in south, southeastern and central regions of Brazil (*e.g.* Marini & Durães 2001, Repenning & Fontana 2011, Piratelli 2012). However, considering that the number of overlapping individuals that we captured was lower, which prevents us from generalizing our findings, but this is the first step with results on bird phenology in restoration areas of the Atlantic Forest.

All individuals earlier described as having overlap were passerines (Marini & Durães 2001, Piratelli 2012, Araujo *et al.* 2017), while here we also sample four non-passerine birds (three doves and one puffbird; Table 1). We also sampled bird families reported in previous studies (*e.g.* Thraupidae, Thamnophilidae and Tyrannidae - Marini & Durães 2001, Araujo *et al.* 2017). However, only one species was the same reported in previous similar studies (*Thamnophilus caerulescens* Vieillot, 1816) (Marini & Durães 2001) molting in temperate regions takes about 40–70 days to complete, while tropical birds have a slower metabolism, taking an average of 120 days to complete molting, increasing energy demand when overlapping with breeding (Silveira & Marini 2012). The replacement of feathers demands time, energy and nutrients (Lindström *et al.* 1993), thus, overlapping molt and breeding may only occur in periods of high resource availability (Poulin *et al.* 1992). Although many birds can overlap molt and breeding (Payne 1969, Marini & Durães 2001, Piratelli 2012), the energy costs involved can be translated into tradeoffs. A feather growth rate of up to 40% slower has already been described, with more than twice the time spent in feeding, reducing by half the time for feathers care, and feathers quality and flight speed as well, increasing risks of predation (Echeverry-Galvis & Hau 2013).

The longer the duration of molting, the greater the frequency of overlap with breeding (Johnson *et al.* 2012). A slower molt reduces the gaps between flight feathers and the risk of predation, ensuring an improvement in feathers quality and allowing more energy to be directed towards immunological resistance (Hedenström & Sunada 1999). Foster (1974) suggests that molt-breeding overlap in tropical regions may occur due to extended breeding periods and more potential re-nesting; this may maximize birds' reproductive output in areas where nesting success is low, as fragmented landscapes (Rodrigues *et al.* 2018), which is the case of our study area.

Environmental variables

We found relationship between temperature and patterns of molting and breeding. It is known that both temperature and rainfall define the period of molting worldwide (Poulin *et al.* 1992, Piratelli *et al.* 2000, Tyson & Preston-Whyte 2000, Repenning & Fontana 2011, Piratelli 2012, Ndlovu *et al.* 2017). Data relating temperature and rainfall to reproduction are conflicting (*e.g.* Poulin *et al.* 1992, Piratelli *et al.* 2000, Repenning & Fontana 2011, Piratelli 2012, Araujo *et al.* 2017), since there is no agreement between them.

We observed some overlap between molting and breeding. We recommend long-term studies to evaluate how reforestation programs can be optimized to provide suitable habitats for birds, enabling them to perform their biological cycles and reducing the environmental stress inherent in degraded areas. If one of the main goals of ecological restoration is to rescue ecosystem functions, providing bird habitat quality may reflect well-defined biological rhythms, increasing the success of recolonization by those species.

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