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Efeitos da poluição sonora nas características do canto e na fisiologia das aves

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RESUMO GERAL

Aeroportos são fonte de ruídos extremos, que geram incômodos no nosso dia a dia e podem desencadear patologias em seres humanos e outros seres vivos. Nas aves, o ruído gera dificuldades para a comunicação e reduções no sucesso reprodutivo, estando entre as causas para a redução populacional de espécies sensíveis. Neste trabalho, avaliamos o impacto do ruído de três aeroportos brasileiros na estrutura da comunidade de aves, no comportamento de canto e na condição fisiológica das aves que se encontram no entorno das pistas. Nas três regiões estudadas (Brasília, Campinas e Salvador), realizamos capturas com redes de neblina e gravações automáticas nas áreas aeroportuárias e em áreas silenciosas. Áreas de ambiente aeroportuário apresentaram menor riqueza de espécies e menores índices de diversidade α. Também encontramos menor similaridade (diversidade β) entre ambientes aeroportuários do que entre áreas estudadas em uma mesma região (aeroporto *vs*. controle), não sustentando a hipótese de homogeneização biótica das áreas perturbadas do estudo. Dentre as 15 espécies que tiveram o horário de início do coro matutino avaliado, *Elaenia chiriquensis* e *Neothraupis fasciata* apresentaram antecipações no horário de início, enquanto *Camptostoma obsoletum*, *Troglodytes musculus* e *Zonotrichia capensis* apresentaram atrasos no horário de início do coro matutino. As demais espécies não apresentaram mudança significativa. A mudança no início do coro matutino em ambiente ruidoso se mostrou relacionada ao tamanho das populações analisadas, sendo que espécies capazes de antecipar o coro matutino apresentaram populações maiores, enquanto espécies que atrasaram o coro matutino apresentaram populações menores em ambiente aeroportuário. Dentre as 19 espécies que tiveram a condição fisiológica avaliada por meio das concentrações de corticosterona nas penas (CORT_P), *Cyclarhis gujanensis* e *Turdus rufiventris* apresentaram níveis aumentados, enquanto *Troglodytes musculus* e *Coryphospingus cucullatus* apresentaram níveis reduzidos de CORT_P em ambiente aeroportuário. As demais espécies não apresentaram mudanças significativas. De acordo com o “Modelo de Escopo Reativo”, ambos os desvios de concentração representam condições anormais e prejudiciais aos indivíduos, caracterizando condições de estresse crônico. Assim, os dados obtidos neste estudo mostram que o ruído aeroportuário representa um obstáculo à manutenção das comunidades, ao comportamento de canto no coro matutino e às condições fisiológicas de algumas espécies de aves, gerando evidências de que o ruído extremo pode afetar diferentes espécies de diferentes formas, constituindo-se um risco para a avifauna.

Palavras-chave: Aeroporto, coro matutino, diversidade, estresse, riqueza, ruído

INTRODUÇÃO GERAL

O ruído é um dos principais limitantes da comunicação acústica, e pode ser definido como qualquer som indesejado que possa interferir na percepção de sinais sonoros biologicamente relevantes (Brumm and Slabbekoorn 2005; Gil and Brumm 2013). Apesar de muitos ambientes naturais possuírem seus próprios ruídos, produzidos pela biota e ambiente físico (e.g. cachoeiras, riachos), ambientes urbanos são singularmente caracterizados por ruídos indesejados, como o tráfego de veículos. A grande maioria dos ruídos antrópicos é caracterizada por sons de baixa frequência, que sobrepõem e mascaram os sons produzidos nesta faixa de frequência.

O ruído pode ser prejudicial à saúde e bem-estar de seres humanos, gerando aumento da pressão sanguínea, aumento da secreção de catecolaminas, redução na qualidade do sono, dificuldade de concentração e aumento de erros diários (Smith and Stansfeld 1986; Stansfeld and Matheson 2003; Stansfeld et al. 2005; Jarup et al. 2008; Júnior et al. 2012). Em outros animais, o ruído é responsável por diversas mudanças comportamentais, o que já foi confirmado por meio de vários estudos. Por exemplo, a sépia (*Sepia officinalis*) muda seus padrões de sinalização de cor quando exposta a *playback* de ruído (Kunc et al. 2014). O pato-arlequim (*Histrionicus histrionicus*), a cabra das montanhas rochosas (*Oreamnos americanus*), e o pardal (*Passer domesticus*) aumentam a frequência de comportamento de alerta quando expostos a ruído de aviões, helicópteros e rodovias (Goldstein et al. 2005; Goudie 2006; Meillère et al. 2015). Caranguejos (*Carcinus maenas*) e peixes (*Phoxinus phoxinus*) exibem interrupções nos padrões de forrageamento quando expostos a ruído de embarcações (Wale et al. 2013; Voellmy et al. 2014). Baleias jubarte (*Megaptera novaeangliae*) mudam a complexidade de sua vocalização durante a atividade de embarcações (Sousa-Lima et al. 2002). O chapim-real (*Parus major*), quando forrageando próximo a aeroportos, aumenta sua vigilância e reduz sua atividade alimentar durante os picos de ruído de aeronaves (Klett-Mingo et al. 2016).

Os sinais vocais representam uma importante forma de comunicação para as aves, sendo utilizados para transmitir e adquirir informações cruciais. Porém, para que a comunicação acústica seja eficiente, é necessário que o som seja capaz de se propagar do emissor até o receptor (Patricelli and Blickley 2006). As aves utilizam esses sinais em diferentes contextos: escolha de parceiro, coordenação das atividades reprodutivas, defesa de território, alimentação da prole, chamados de alarme na presença de um predador, e até mesmo formação de bandos interespecíficos (mistos) (Catchpole and Slater 2008). A comunicação vocal possui diversas vantagens sobre outros tipos de comunicação, podendo ser utilizada à distância sem a necessidade do contato visual, e podendo ser utilizada em condições atmosféricas em que outros tipos de mensagem não poderiam ser transmitidas (Bradbury and Vehrencamp 1998). Apesar das vantagens associadas à comunicação vocal, várias restrições podem limitar sua eficiência. A poluição sonora é uma das restrições que possuem forte efeito negativo sobre a eficiência da comunicação vocal das aves, trazendo potenciais consequências negativas ao *fitness* (aptidão) (Habib et al. 2007; Schroeder et al. 2012) de indivíduos de espécies que não conseguem se adaptar a essas mudanças.

Características acústicas do canto das aves são moldadas por fatores ambientais que determinam a adaptação dos sinais em resposta às pressões seletivas ecológicas (Slabbekoorn 2004). Sabemos que algumas espécies de aves podem alterar seu canto e seu comportamento de vocalização sob condições de ruído, a fim de facilitar a comunicação, por exemplo, aumentando a frequência mínima do canto em ambientes urbanos (Slabbekoorn and Boer-Visser 2006; Halfwerk and Slabbekoorn 2009; Nemeth and Brumm 2009; Bermúdez-Cuamatzin et al. 2011; Tolentino et al. 2018). Essas mudanças reduzem a sobreposição espectral e por consequência, reduzem o mascaramento acústico pelo ruído urbano. Além disso, aves, como muitos outros vertebrados, podem aumentar a amplitude de sua vocalização quando confrontados com ambientes ruidosos, tornando-se desta forma menos afetados pelo mascaramento do sinal acústico (Brumm and Todt 2002). Outra forma de lidar com o ruído é cantar quando os níveis de ruído estão mais baixos (Fuller et al. 2007). Nos arredores de aeroportos, por exemplo, aves que cantam mais cedo podem reduzir a sobreposição do canto com o período de atividade das aeronaves, compensando assim a reduzida janela de período sem ruído de aeronaves (Gil et al. 2014; Dominoni et al. 2016; Sierro et al. 2017). Adicionalmente, as espécies podem aumentar a redundância dos sinais que emitem, aumentando as chances de que a mensagem seja transmitida através do ambiente ruidoso (Brumm and Slater 2006; Sierro et al. 2017).

Apesar das mudanças vocais que já foram confirmadas em vários estudos, nem todas as espécies são capazes de mudar seu sinal acústico em ambientes ruidosos, e esta ausência de adaptabilidade pode forçar espécies com canto menos plástico a procurar áreas mais adequadas à transmissão do seu sinal acústico (Francis et al. 2011a). Além disso, o ruído também impacta a qualidade da reprodução das aves, gerando reduções no sucesso de ninhos, no tamanho de ninhada, nas taxas de crescimento dos ninhegos e no sucesso de eclosão dos ovos (Halfwerk et al. 2011; Hayward et al. 2011; Fairhurst et al. 2013; Strasser et al. 2013; Kleist et al. 2018). Tais consequências negativas à reprodução levam também à diminuição no número de espécies capazes de se reproduzir em determinadas áreas (Francis et al. 2009), explicando reduções populacionais, e perdas de riqueza e diversidade nas comunidades de aves de ambientes ruidosos (Reijnen et al. 1995; Bayne et al. 2008; Slabbekoorn and Ripmeester 2008; Francis et al. 2009; Barber et al. 2010). As espécies que permanecem em áreas ruidosas enfrentam ainda modificações fisiológicas resultantes do estresse ao qual estão sujeitas, gerando indivíduos com penas de menor qualidade, pior condição corporal e sistema imune deficiente (Ruiz et al. 2002; Lattin et al. 2011; Zhang et al. 2011; Chávez-Zichinelli et al. 2013).

Neste trabalho, nosso objetivo é avaliar os impactos gerados pela atividade aeroportuária brasileira sobre a avifauna, com foco na estrutura das comunidades, no comportamento de canto e nas alterações fisiológicas dos indivíduos. A compreensão deste processo e das pressões que geram as adaptações das aves possui implicações importantes para a conservação deste grupo, nos permitindo predizer como as aves se ajustam ao desenvolvimento urbano. Ao final, apresentamos possíveis medidas mitigadoras ao impacto da atividade aeroportuária, com objetivo de incitar maiores discussões sobre o assunto e de auxiliar na criação de ferramentas para abrandar os efeitos desta atividade.

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CAPÍTULO 1- Mudanças na comunidade de aves devido ao ambiente aeroportuário

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ABSTRACT

Airport environments are affected by several anthropogenic modifications, including fragmented and degraded habitats, intense air pollution and extreme noise, all of which are known to represent threats to biodiversity. The aim of our study was to identify changes in avian communities associated with this anthropic habitat. We used mist-nets and Automatic Recording Units (ARU) to capture and record bird species in three Brazilian airports, and in three silent control sites. We characterized studied sites in terms of landscape structure, noise and light levels, and evaluated avian community structure using species richness, and α and β diversity indexes. Avian communities presented higher species richness and higher α diversity in silent control sites than in airport environments. Higher similarity of avian communities occurred between sites within the same geographic region. We found landscape composition similarities among all airport-affected sites and among all silent control sites, with higher levels of noise and higher levels of artificial light in airport-affected sites. The reduced species richness found in disturbed sites reinforces accumulating evidence indicating that urbanization processes lead to impoverished faunas. However, results do not point to biotic homogenization, as 60% of species found in disturbed sites also characterize the associated undisturbed sites. This implies that airport environments surrounded by native vegetation are largely populated by urban-adapted species in common with local avian communities, rather than by specialized species that adapt to this habitat at a wider geographical scale.

Key-words: Automatic recording units, beta diversity, Brazil, noise.

INTRODUCTION

Building and operating airports are human industrial activities associated with negative changes in the surrounding natural environment, resulting in two critical threats to biodiversity. The first one is habitat fragmentation and degradation, and the second one is extreme noise levels. Habitat fragmentation is characterized by the loss of continuous large extensions of natural habitats and the subsequent isolation of patches (Fahrig 2003) due to clearance for agriculture, cattle raising (O'Dea and Whittaker 2007), opening of roads, and other human-driven modifications. While habitat degradation includes reduced quality of patches. It is well known that habitat fragmentation and degradation processes are responsible for great losses in biodiversity (Saunders et al. 1991; Mac Nally et al. 2000; Baillie et al. 2004), including changes in species composition (turnover) and the loss of area-sensitive species (Boulinier and Nichols 2001; Antunes 2005; Banks-Leite et al. 2010; Felinks et al. 2011).

Many of these negative consequences are characterized by Allee effects, which typically imply negative population growth under a certain population density threshold (Stephens and Sutherland 1999), resulting in non-random species local extinction, and community homogenization. Biota homogenization embodies a conservation issue, as the process is characterized by the replacement of several unique endemic species by few widespread species, reducing diversity (McKinney and Lockwood 1999). Human disturbances can be considered the main driver of the process, and a reason for reduced β diversity among disturbed areas (Proppe et al. 2013).

Studies have found that noise from various sources is also responsible for changes in animal community and population aspects for a great diversity of animal taxa. For example, the noise produced by gas compressor stations resulted in reduced pairing success in ovenbirds (*Seiurus aurocapilla*) (Habib et al. 2007), as well as reduced density for several bird species in boreal forests in Canada (Bayne et al. 2008), all of which presumably were unable to deal successfully with noise. At chronic noise levels, species can either avoid the noisy area, or remain in the area, with the possible negative consequences linked to this decision (Habib et al. 2007). In New Mexico, an experimental study conducted near natural gas fields where noise-producing compressors work continuously, found a reduction in overall species richness, and also detected changes in community structure, although some species adapted well to the noise and showed increased nest success (Francis et al. 2009). In particular, the balance between community services provided by birds was compromised: seed dispersal was drastically reduced whereas pollination increased near noisy sites (Francis et al. 2012).

In addition to community and population changes, behavioral modifications can also be associated with noise exposure in a wide array of animal groups. For example, the common cuttlefish (*Sepia officinalis*) exhibits changes in color signaling patterns due to exposure to noise playbacks (Kunc et al. 2014). Harlequin ducks (*Histrionicus histrionicus*), mountain goats (*Oreamnos americanus*), and house sparrows (*Passer domesticus*) show increased levels of alert behavior when exposed to aircraft, helicopter and traffic noise (Goldstein et al. 2005; Goudie 2006; Meillère et al. 2015). Shore crabs (*Carcinus maenas*) and European minnows (*Phoxinus phoxinus*) exhibit disrupted foraging patterns when exposed to ship noise playbacks (Wale et al. 2013; Voellmy et al. 2014), while humpback whales (*Megaptera novaeangliae*) present changes in vocalization complexity during boating activity (Sousa-Lima et al. 2002). Finally, great tits (*Parus major*), when feeding close to airport environments, increase vigilance and decrease feeding activity during aircraft noise peaks (Klett-Mingo et al. 2016).

Birds use acoustic communication in different ways in their daily life, including activities associated with mating, territory defense, predator avoidance and parent-offspring communication (Catchpole and Slater 2008). Studies on birds have focused on structural changes in vocalizations and singing behavior as noise-coping strategies. The most commonly observed strategies are increases in singing period (Sierro et al. 2017), anticipations in singing time (Fuller et al. 2007; Arroyo-Solís et al. 2013; Nordt and Klenke 2013; Dominoni et al. 2016), increases in song amplitude (Cynx et al. 1998; Brumm and Todt 2002; Schuster et al. 2012; Nemeth et al. 2013), reductions in song duration (Slabbekoorn and Boer-Visser 2006), increases in signal redundancy (Brumm and Slater 2006), and increases in minimum frequency (Slabbekoorn and Peet 2003; Wood and Yezerinac 2006; Rios-Chelen et al. 2012; Parris and MacCarthy 2013). Such strategies are not restricted to birds, and have also been reported in mammals (Sousa-Lima et al. 2002; Rabin et al. 2003), frogs (Hanna et al. 2014) and insects (Lampe et al. 2012).

Typical airport noise patterns are characterized by a constant high amplitude noise in the low frequency ranges and strong, sudden peaks of high amplitude noise in a broad range of frequencies (Smith 1989; Sierro et al. 2017) (e.g., aircrafts landing and taking off; Fig.1). Airport noise is considered a threat to human health (Stansfeld and Matheson 2003; Stansfeld et al. 2005), and is known to induce behavioral changes in birds (Kershner and Bollinger 1996; Gil et al. 2014; Dominoni et al. 2016; Klett-Mingo et al. 2016; Sierro et al. 2017). Thus, it is also expected that airport noise attaining levels above 50 dB can have adverse effects upon biodiversity (Croci et al. 2008; Proppe et al. 2013), as such noise intensities can be harmful for most studied species (Shannon et al. 2016).

In the present study, our objective was (1) to characterized study areas in terms of landscape composition, noise and light levels, and (2) to test for differences between bird communities in airport-affected versus silent sites (control) in Brazil. We expected that airport-affected sites would present (a) higher degree of urbanization and habitat degradation, higher levels of noise and light when compared to silent control sites; (b) reduced species richness when compared to its respective control silent site; and (c) biotic homogenization among the airport-affected sites.

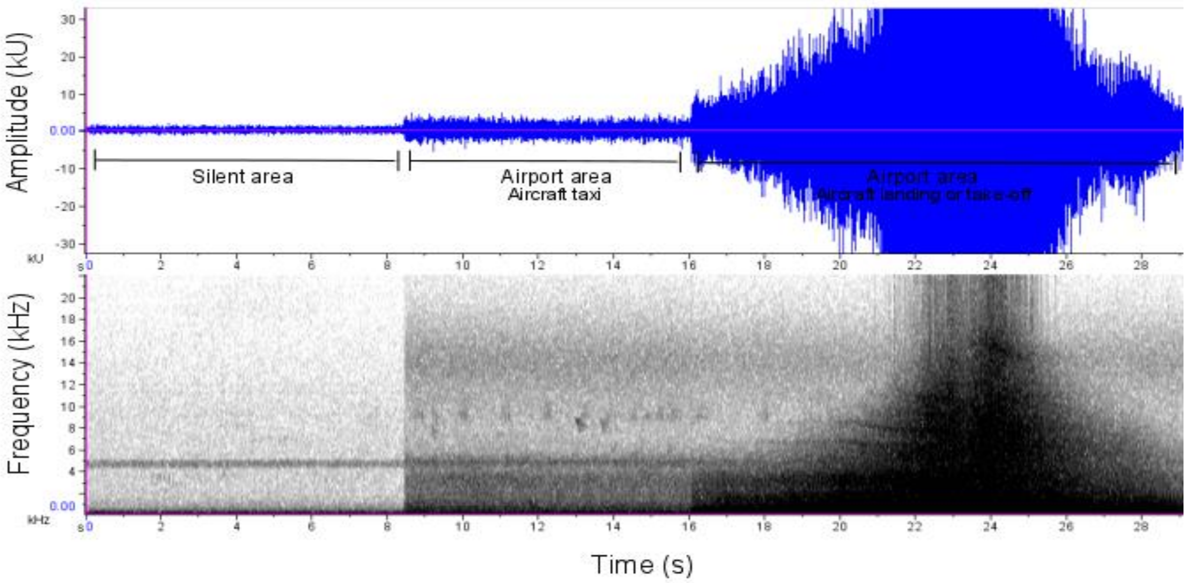

Fig 1 Airport noise characterization. First audio segment shows silent control site background noise; second segment shows airport-affected site during aircraft taxing; and third segment shows airport-affected site during aircraft landing or take-off. All segments are from São Paulo state, on December 8th 2014 at 0531 h.

METHODS

Study sites

We selected three Brazilian airports, based on their high aircraft activity and availability of native vegetation around the lanes. For each airport-affected site, we selected a matched silent control site, with similar vegetation structure, at distances ranging from 8 to 17 km from the corresponding airport. Studied airports are Presidente Juscelino Kubitschek International Airport (AIR_Bras: 15°52'19.4"S 47°55'11.9"W) in Brasília (DF), Viracopos International Airport (AIR_Camp: 23°00'24.4"S 47°08'30.0"W) in Campinas (São Paulo state) and Luís Eduardo Magalhães International Airport (AIR_Sal: 12°54'42.8"S 38°19'44.2"W) in Salvador (Bahia state). For each of these airports we chose the following silent control sites: “Parque Nacional de Brasília” (DF) (CONT_Bras: 15°43'18.1"S 47°58'14.4"W), a private farm named “Fazenda Santa Maria” (SP) (CONT_Camp: 23°05'53.2"S 47°07'49.8"W), and a residential area with large protected areas named “Condomínio Buscavida” (BA) (CONT_Sal: 12°51'30.0"S 38°16'08.0"W) (Fig. 2).

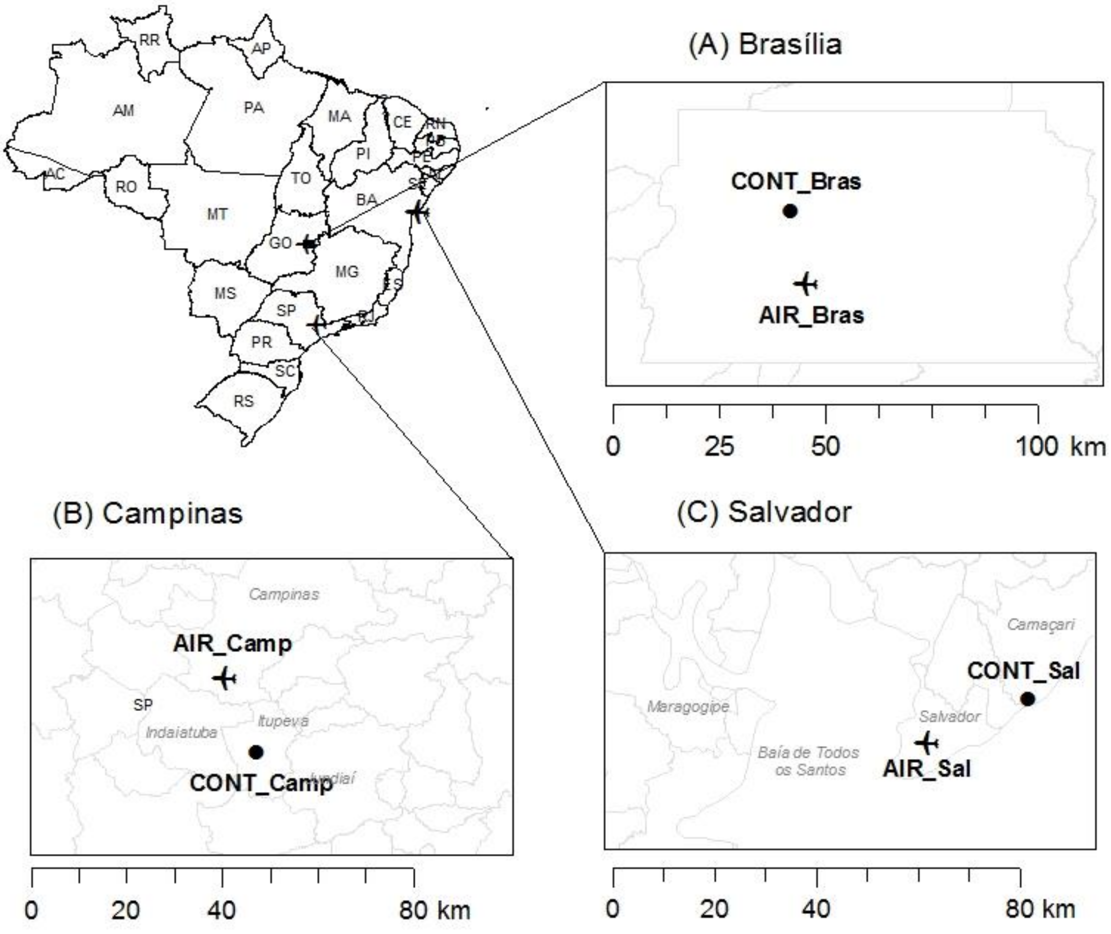

Fig 2 Airport-affected sites (AIR_Bras, AIR_Camp and AIR_Sal) and silent control sites (CONT_Bras, CONT_Camp, CONT_Sal) in Brazil used in the current study.

Most published studies concerning airport environments are limited to grassland areas immediately around flight lanes (e.g. Kershner and Bollinger 1996, Blackwell and Wright 2006). Here, we sampled forested areas affected by aircraft noise around airport flight lanes (around 250 m from lanes). The studied airport-affected sites are managed by airport administration companies (INFRAMÉRICA in Brasília, Aeroportos Brasil in Campinas, and INFRAERO in Salvador) or belong to the Brazilian Air force (Salvador only).

Bird captures and recordings

We conducted fieldwork between September and December 2014, and from November 2015 to January 2016. We used both mist-net captures and automatic recording units (ARU: SONGMETER SM2+; Wildlife Acoustics 2007-2011) to identify species in each studied site. These are complementary methods, allowing the detection of a higher number of species, since both methodologies have limitations. The mist-net methodology is limited in terms of bird size and flying behavior (Bibby et al. 1992), while the ARU methodology is restricted to vocal species, and requires knowledge of bird vocalizations. The use of ARUs for monitoring avian diversity is a developing technology, proven to be efficient in open areas (Alquezar and Machado 2015).

Using mist-nets we sampled a total of 10 mornings at each airport-affected site and at each silent control site in Campinas and Salvador (total of 500 mist-net hours per site), and a total of 13 mornings at each site in Brasilia (total of 650 mist-net hours) (See Supplementary Material for mist-nets geographic coordinates). In airports, mist-nets were set at a maximum distance of 250 m from flight lanes, and in control sites, they were set without restrictions. At each morning, we set a group of 10 nets, keeping them open for 5 hours per morning (total of 3300 mist-net hours). All captured birds were identified and banded with numbered metal bands provided by the Brazilian bird-banding agency (CEMAVE-ICMBio).

Automatic recordings (ARU) were programmed to work between -120 min before civil sunrise until 90 min after civil sunrise (civil sunrise: time when sun center is 6 degrees below the horizon; www.timeanddate.com). Recordings were conducted in bouts of one minute followed by one inactive minute, totaling 106 min per morning, and programmed at a sample rate of 44.1 kHz, and 16 bits in stereo mode. ARUs were placed in 12 points in airport-affected and in silent control sites in Brasília and Campinas (total 48), with a minimum distance of 250 m between recorders' points. In Salvador, ARUs were placed in 10 points in airport-affected and in silent control sites (total 20), since in this site the ground surface available around the airport was smaller than in the other airports (See Supplementary Material for ARUs geographic coordinates). Recorders were placed on tree branches approximately 2-4 m from the ground, and remained at the same spots for two consecutive days. We listened to a total of 14,416 hours, and identified species by their song.

Site characterization

In order to characterize the study areas in terms of their surface composition, and evaluate landscape changes associated to airports, we classified landscapes components as: (1) Native vegetation, including several vegetation types such as cerrado *sensu stricto*, gallery forest, *vereda* (marshes) *Caatinga* (dry forest) and dunes; (2) Modified vegetation, including naked soil, pasture, crop and coconut plantation; (3) Urbanization, including urban structures (e.g. houses, buildings and roads) and airport lanes; and (4) Water, including rivers, mangroves, lakes and ocean.

Using GoogleEarth (Google inc. 2017), we selected the points where automatic recorders were installed within each site (as detailed above), and determined the central positions around which mist-net had been placed. To classify the overall landscape, we created a contour around each of these points, with a 2 km radius (buffer area) using ArcGis (ESRI 2009), and joined the resulting contour areas within the same site to create a single surface. Afterwards, we manually classified landscape structure within these surfaces.

Noise levels

To estimate noise levels, we used a subset of the recordings from ARUs. Microphones and recorders were calibrated using a pure tone of known amplitude, before being placed in the field. We selected one 1-min recording every 6 min, from -120 min before civil sunrise until 90 min after civil sunrise. Recordings containing rain, high levels of wind, human interference and clipping due to the high amplitude noise levels of aircrafts were excluded from analysis or replaced with another 1-min recording within the 6 min analyzed. We used recordings of one morning for each sampled point, considering 10 sampling points per site.

We conducted analyses of the recordings with the *PAMGuide* package (Merchant et al. 2015) in R 3.3.2 (R Development Core Team 2016) to obtain sound level estimates. In the *PAMGuide* package, we used the following settings: TOL metric, 44.100 for window length, -36 for mic sensibility, 24 for mic gain, and 30 for time-averaging spectra (Welch) creating 4 measurements for each 1-min file. We used TOL metric (1/3-octave band levels), in which frequency is spaced logarithmically, and doubles every three 1/3-octave bands. According to Merchant et al. (2015), this metric has higher resolution at lower frequencies, where anthropogenic noise is concentrated. Noise levels were analyzed considering two perspectives: noise level amplitude in different frequency bands; and mean noise amplitude in different sites.

To compare amplitude values of noise levels in airport-affected sites and silent control sites for different frequency bands, we used a mixed linear model (LMM) (random factors = (1|Point), (1|Region) and (1|Day:Time)), followed by a chi-square test to find the treatment significance. All amplitude values were log transformed for normality data correction. We analyzed differences in the following frequency bands: 100 Hz, 501.1 Hz, 1000 Hz, 1995.2 Hz, 3162.2 Hz, and 5011.8 Hz. These particular bands were selected because they represent different parts of acoustic space exhibiting either sounds produced by the biota (biophony: Pijanowski et al. 2011, i.e. from about 2000 to 5000 Hz) and/or sounds produced by aircrafts (technophony: Towsey et al. 2014, i.e. concentrated below 2000 Hz).

To determine the difference in mean amplitude noise level between pairs of sites within the same region we used a LMM (random factor = (1|Point) and (1|Day:Time)) for each pair. We considered only values within 1000 to 2000 Hz frequency band, representing technophony, with a high contribution of anthropophony and a low one of biophony. As described in Joo et al. (2011), we considered technophony as the mean amplitude (PSD: power spectrum density) between these frequencies.

Light levels

We installed *Sky Quality Meters* LU-DL (Unihedron, Ontario, Canada) in five points within each study site to measure mean sky light intensity (i.e. sky darkness). The device remained in place for two consecutive days at the same spot to measure sky darkness, allowing us to determine light pollution levels during the night. We standardized time by civil sunrise time in each site, and used a LMM (random variable = (1|Point), (1|Day:Time) to compare values of sky darkness at night (-120 to -60 minutes before sunrise) between regions and pairs of sites. We included the variables “region”, “treatment”, and the interaction “region:treatment” in the model. Values of sky darkness were transformed using Box-cox for normality data correction, as available in the *AID* package (Asar et al. 2016). We also ran a post-hoc test to identify statistical significance of differences between sites, using *lsmeans* package (Lenth, 2016).

Species richness, α and β diversity

We used richness estimators to evaluate species richness of each studied site, using accumulation curves to determine sampling efficiency. Richness estimators allowed us to compare data obtained using different methods and sampling efforts (Magurran 2004). Here, we used the nonparametric estimator Chao 2, based upon presence/absence data, which is an adaptation from Chao 1 (Chao 1987), based on abundance data. Chao 2 uses the number of species that occurs in a single sample, and those that occur in two samples (Magurran 2004). The accumulation curves were built as a function of sampling effort (Colwell and Coddington 1994). All values were obtained using the *fossil* package (Vavrek 2015) in R 3.3.2 (R Development Core Team 2016).

Alpha (α) diversity is a measure of local diversity, and indicates heterogeneity or equitability (not homogeneous) of species composition at a given site. We used the Shannon-Wiener Index, which confers higher importance to rare species and considers abundance, providing an interpretation beyond the simple number of species (Whittaker 1972; Keylock 2005). Abundance values were obtained from captures and recordings, the latter based upon the number of days that a species is recorded per study site (i.e. frequency of records, Alquezar and Machado *in prep*). The Shannon-Wiener Index was calculated using *Vegan* package (Oksanen et al. 2017) in R 3.3.2 (R Development Core Team 2016).

We used the β diversity index to evaluate differences in species composition between sites (Whittaker 1972). Airport-affected sites are more degraded and subjected to human interference than are control sites; we thus expected species composition among the former to be more similar than when compared with control silent sites (i.e., evidence of homogenization). This analysis of dissimilarity provides an indication of two contrasting aspects of diversity: species spatial turnover and nestedness of communities ($\beta_{SOR} = \beta_{SIM} + \beta_{NES}$) (Baselga 2010). Species turnover is the replacement of some species by others, due to differences in habitat characteristics, geographic and historical aspects (Qian et al. 2005; Baselga et al. 2007). Nestedness, on the other hand, represents the tendency of less diverse communities to include a subset of species from species-rich communities in the same region (Wright and Reeves 1992), and is considered a non-random effect. The dissimilarity analysis used here is a Sorensen-based multiple-site index and all formulas can be found in Baselga (2010). Analyses were done in R 3.3.2 (R Development Core Team 2016) using *betapart* package (Baselga et al. 2017).

RESULTS

Bird captures and recordings

Pooling all studied sites, and using data from both mist-net captures and ARU methodology, we registered 154 species, belonging to 18 bird orders. For the order Passeriformes, 23 families were represented. The mist-net technique yielded 100 species, while the ARU methodology yielded 119 species, with 65 species in common for the two methods (species list available in Supplementary Material) .

Site characterization

In general, airport-affected sites presented higher proportions of the landscape class “urbanization” than silent control sites, while the latter had higher proportions of the class “native vegetation” (Table 1). Sites located in the Brasília region had the highest sampled area extension (AIR_Bras and CONT_Bras), and also the highest values for proportion of native vegetation, with very well preserved cerrado *sensu stricto* vegetation and some gallery forests. Sites from the other two regions presented similar total sampled area extension (AIR_Camp, CONT_Camp, AIR_Sal and CONT_Sal). The vegetation in AIR_Camp exhibits remnants of the Cerrado biome (Ferreira et al. 2007) and is much degraded, mostly composed by grassy areas and few trees. The original vegetation in CONT_Camp was Atlantic forest, but due to forest clearing for cattle and buffalo grazing, sampled points were in areas of grass with a few trees preserved for shade. The vegetation in AIR_Sal and CONT_Sal is a mixture of Caatinga vegetations, with some forested areas, and dunes with a few smaller trees.

Table 1 Total area (ha) and percentage of landscape classes within each study site (see text for site acronyms).

Site	Total area (ha)	% Native vegetation	% Modified vegetation	% Urbanization	% Water
AIR_Bras	4144.14	37.09	22.25	40.57	0.09
CONT_Bras	3723.89	91.97	8.03	0.00	0.00
AIR_Camp	3229.06	9.33	46.47	43.72	0.48
CONT_Camp	2735.86	39.20	56.40	2.36	1.94
AIR_Sal	2794.39	21.20	16.65	49.11	13.04
CONT_Sal	2938.38	34.16	12.70	19.34	33.80

Noise levels

Airport-affected sites had higher levels of noise amplitude in all the analyzed frequency bands compared with silent control sites, and the larger differences occurred in frequency bands 501.1 and 1000 Hz (Table 2). Within pairs of sites, noise amplitude at 1000 to 2000 Hz frequency band was higher in airport-affected than in silent control sites, for all regions: Brasília: estimate = -0.297, SE = 0.02, $X^2 = 173.1$, df = 1, $p < 0.001$; Campinas: estimate = -0.253, SE = 0.02, $X^2 = 94.34$, df = 1, $p < 0.001$; and Salvador: estimate = -0.167, SE = 0.04, $X^2 = 15.43$, $p < 0.001$ (Table 3 and Fig. 3).

Table 2 Results obtained in separate LMMs for each frequency band, comparing values of noise amplitude (dB) between airport-affected and silent control sites. Values of model estimate and standard error (SE), X^2 and *p* value (df = 1 for all tests).

Frequency	Airport dB (mean±sd)	Control dB (mean±sd)	Estimate	SE	X^2	*p* value
100 Hz	65.0 ± 8.5	53.5 ± 7.3	-0.191	0.01	93.29	<0.001
501.1 Hz	60.1 ± 8.3	45.0 ± 5.8	-0.283	0.02	184.33	<0.001
1000 Hz	55.7 ± 8.6	41.2 ± 4.2	-0.293	0.02	209.74	<0.001
1995.2 Hz	49.2 ± 8.8	40.7 ± 4.3	-0.176	0.01	100.04	<0.001
3162.2 Hz	48.8 ± 8.9	43.8 ± 5.1	-0.106	0.01	40.93	<0.001
5011.8 Hz	50.5 ± 9.3	46.7 ± 7.7	-0.071	0.02	8.17	0.03

Table 3 Values for minimum, mean and maximum amplitudes (Min amp, Mean amp and Max amp, respectively; dB=decibels) for each study site, between -100 before and 90 min after civil sunrise, between 1000 and 2000 Hz frequency band.

Site	Min amp (dB)	Mean amp (dB) ± sd	Max amp (dB)
CONT_Bras	35.30	38.29 ± 2.47	54.11
AIR_Bras	38.20	52.05 ± 8.02	86.01
CONT_Camp	36.29	41.67 ± 3.45	60.97
AIR_Camp	40.82	54.12 ± 8.81	92.17
CONT_Sal	36.48	43.01 ± 3.84	70.21
AIR_Sal	37.62	51.48 ± 8.86	92.17

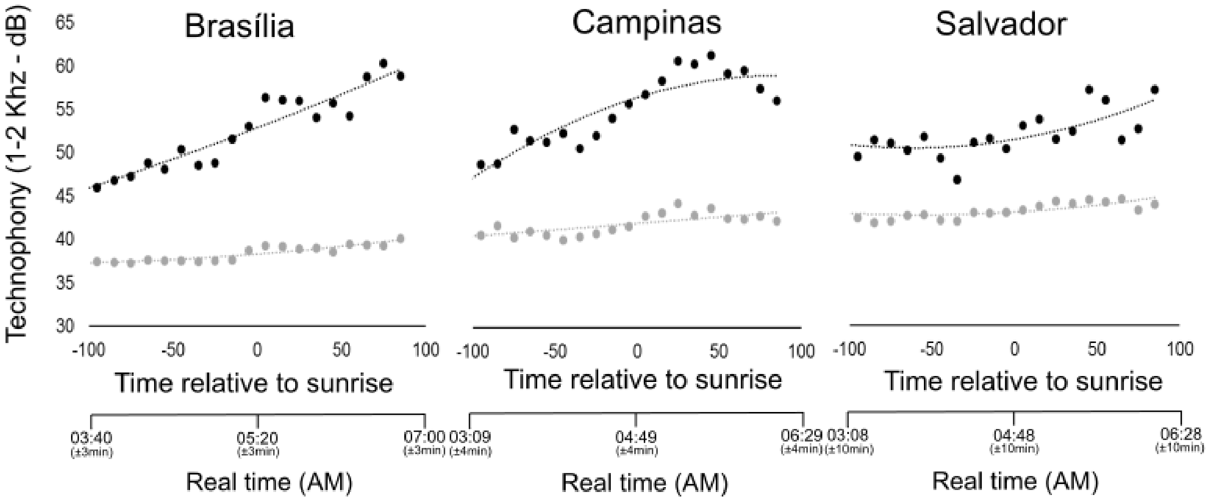

Fig 3 Mean amplitude levels (dB) for technophony (1-2 Khz) in airport-affected sites (black) and silent control sites (gray), for each region, between -100 min before and 90 min after civil sunrise.

Light levels

Airport-affected sites presented lower sky darkness compared with control sites using pooled data from the three regions (LMM: estimate = 0.718, SE = 0.24, X^2 = 8.59, df = 1, p = 0.003), and the interaction between site and treatment also showed a significant relationship (X^2 = 10.50, df = 2, p = 0.005). The general pattern is for higher luminosity levels in airport-affected sites, although the post-hoc test indicates that the difference between airport and silent control site in Campinas is stronger than in the other regions (BRAS: estimate = -0.718, df = 86, t.ratio

= -2.93, p = 0.004; CAMP: estimate = -1.469, df = 84, t.ratio = -5.78, p < 0.001; SAL: estimate = -0.311, df = 86, t.ratio = -1.19, p = 0.23) (Fig. 4).

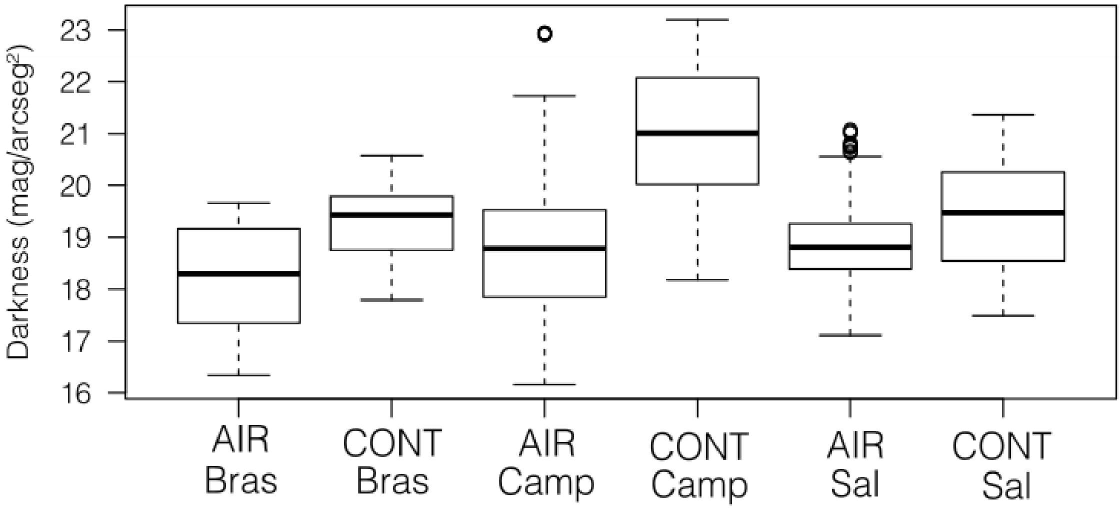

Fig 4 Mean values of sky darkness for all studied sites. AIR_Bras (18.29 mag/arcseg²), CONT_Bras (19.21 mag/arcseg²), AIR_Camp (18.79 mag/arcseg²), CONT_Camp (21.00 mag/arcseg²), AIR_Sal (18.93 mag/arcseg²) and CONT_Sal (19.45 mag/arcseg²).

Species richness, α and β diversity

In the three regions, airport-affected sites presented lower species richness than silent control sites. According to richness values estimated by Chao 2 (Table 4), this pattern would be maintained with an increase of sampling effort (Fig. 5). The region with the highest species richness was Brasília, which was more intensely sampled in terms of mist-net effort. However, the sites with highest α diversity were CONT_Camp and CONT_Sal (Table 4).

Considering the 154 species recorded, 13 were found in all airport-affected and control sites (*Aramides cajaneus*, *Cyclarhis gujanensis*, *Camptostoma obsoletum*, *Caracara plancus*, *Elaenia flavogaster*, *Furnarius rufus*, *Megascops choliba*, *Nyctidromus albicollis*, *Nyctibius griseus*, *Rupornis magnirostris*, *Turdus leucomelas*, *Troglodytes musculus*, and *Vanellus chilensis*), and 36 were restricted to only one site (24 in silent control sites, and 12 in airport-affected sites). Sixty-seven species were registered in either two or three sites, and of these only three were restricted to silent control sites (*Anthrostomus rufus*, *Patagioenas cayannensis*, and *Tangara cayana*), and a single species was restricted to airport-affected sites (*Donacobius atricapillus* – probably because the habitat required by species were available only in AIR_Camp).

Table 4 Data summary of species richness for each site according to each methodology (Mist-nets, ARU and Both/Total), number of individuals captured in mist-nets, number of sampling units in each methodology, estimated species richness with Chao 2 estimator ± standard deviation, and α Diversity Index (Shannon-Wiener).

Site	Method	Observed richness	No. of individuals	No. of samples	Estimated richness	α Diversity Index
CONT_Bras	Net	40	272	13	74.5±9.6	
	ARU	63		23	70.0±2.8	
	Total	88		36	129.8±9.5	3.684
AIR_Bras	Net	43	244	13	61.3±5.3	
	ARU	61		24	79.2±6.0	
	Total	86		37	118.3±7.8	3.643
CONT_Camp	Net	33	134	10	65.4±10.0	
	ARU	69		24	78.3±3.5	
	Total	80		34	100.5±6.0	3.876
AIR_Camp	Net	26	151	10	63.5±13.0	
	ARU	53		24	55.2±1.3	
	Total	60		34	68.0±3.1	3.504
CONT_Sal	Net	38	181	10	45.2±2.9	
	ARU	60		20	72.1±4.7	
	Total	75		30	83.9±3.3	3.877
AIR_Sal	Net	29	189	10	78.0±18.6	
	ARU	46		20	52.7±2.8	
	Total	56		30	70.4±3.1	3.310

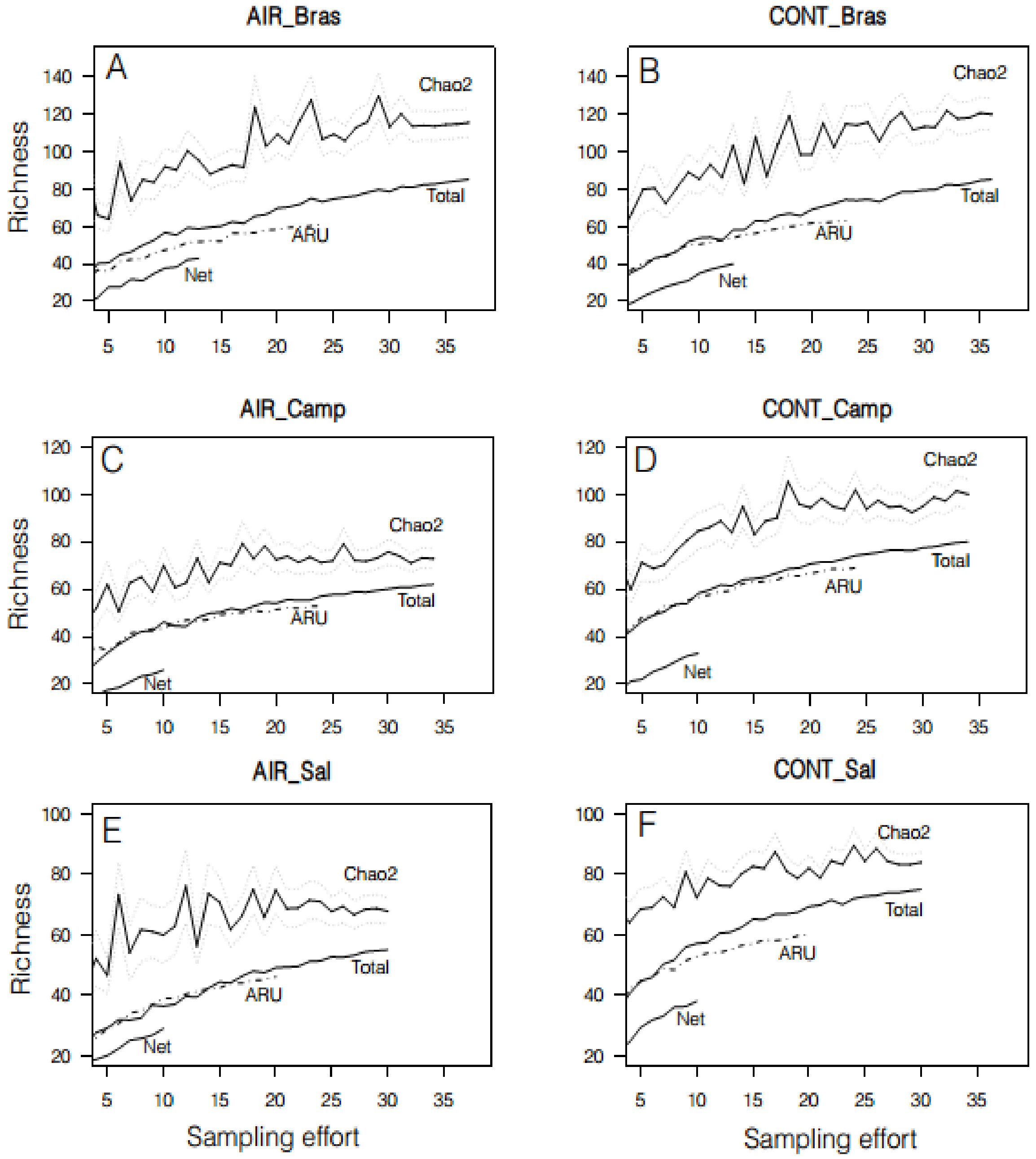

Fig 5 Estimated species richness obtained by Chao 2, total observed species richness, species richness obtained with ARU methodology and species richness obtained with mist-net methodology, based on sampling effort. AIR_Bras: Brasília airport-affected site; CONT_Bras: Brasília silent control site; AIR_Camp: Campinas airport-affected site; CONT_Camp: Campinas silent control site; AIR_Sal: Salvador airport-affected site and CONT_Sal: Salvador silent control site.

Pairs of studied sites in the same region (airport-affected *vs.* silent control sites) shared a higher number of species than sites in different regions. CONT_Bras and AIR_Bras had 65 shared species (59% of 109 species in the region), CONT_Camp and AIR_Camp had 53 shared species (61% of 87 species in the region), and CONT_Sal and AIR_Sal had 48 shared species (57% of 83 species in the region) (Table 5).

Table 5 Number of shared and non-shared species between pairs of sites. Left: number of shared species between pairs of sites. The values in the main diagonal are total number of species in each site. Right: number of non-shared species between pairs of sites. For example: AIR_Bras site has 21 species that are not present in CONT_Bras, and CONT_Bras has 23 species that are not present in AIR_Bras.

	Shared Species						**Non-shared Species**					
	CONT_Bras	AIR_Bras	CONT_Camp	AIR_Camp	CONT_Sal	AIR_Sal	CONT_Bras	AIR_Bras	CONT_Camp	AIR_Camp	CONT_Sal	AIR_Sal
CONT_Bras	**88**						0	21	32	20	38	30
AIR_Bras	65	**86**					23	0	28	21	36	26
CONT_Camp	48	52	**80**				40	34	0	7	33	25
AIR _Camp	40	39	53	**60**			48	47	27	0	42	28
CONT _Sal	37	39	42	33	**75**		51	47	38	27	0	8
AIR _Sal	26	30	31	28	48	**56**	62	56	49	32	27	0

Cluster analysis on the Sorrensen index of dissimilarity ($\beta_{SOR} = \beta_{SIM} + \beta_{NES}$) yielded three different clusters, based upon sub-clusters of paired sites, suggesting that sites within the same region are more similar despite the differences in anthropic pressure (Fig. 6). The highest dissimilarity values occurred between the sites in Salvador and all other sites. The component of β_{SOR} with the highest importance was β_{SIM}, which is the species turnover component. The β_{NES} component represents species nestedness between sites, and indicated a different relationship between the sites, tending to cluster airport-affected sites and control sites separately, although the separation was not perfect. However, this component presented lower weight for total β_{SOR} (See Supplementary Material for β values).

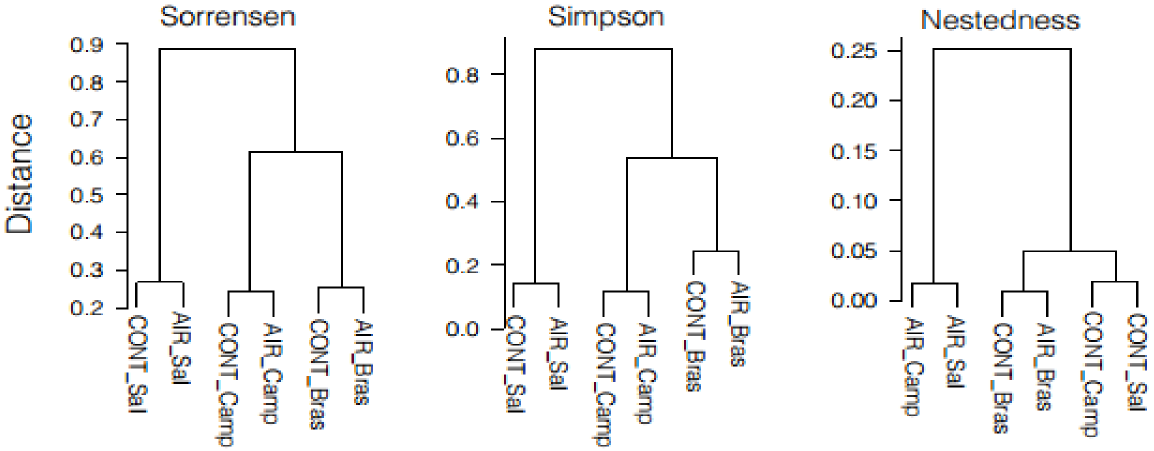

Fig 6 Sites clustered by βSorrensen, βSimpson and βNestedness index of dissimilarity, based on Ward D2 criteria.

DISCUSSION

Avian communities presented higher species richness and higher α diversity in silent control sites, as we had predicted. Additionally, dissimilarity analyses showed higher similarity between sites in the same geographic region (β_{SOR} and β_{SIM}), and some degree of similarity between airport-affected sites (β_{NES}). However, results do not point to biotic homogenization, as 60% of species found in disturbed sites also characterize the associated undisturbed sites. The studied airport-affected sites comprise higher proportions of urbanization and lower proportions of native vegetation when compared with silent control sites. They are also more disturbed by aircraft noise (technophony) and by artificial light. These elements characterize an intensely modified environment, still occupied by the native fauna.

The higher species richness and α diversity values in silent control sites found in our study are similar to results found in other studies, where more preserved areas sustain a higher number of species, including sensitive and unique species, and sites disturbed by degradation, urbanization, and noise, present lower species richness (Perillo et al. 2017). Due to the biological urbanization process (Møller 2013), disturbed sites occasionally also have the potential to sustain a high number of species (Brawn et al. 2001), but usually result in communities composed of more generalist and opportunistic species (Blair 1996; Bonier et al. 2007; Patón et al. 2012).

Species singing in broader frequency ranges may be more successful in noisy environments than species singing in narrow frequency bands (Francis 2015). Those singing at higher ranges of frequency might also have an advantage over those singing in lower ranges of frequency (Proppe et al. 2013). Communication of the latter category is more easily masked by anthropogenic noise, and these species are rarely able to increase song minimum frequency to avoid the masking (Hu and Cardoso 2010). This is probably the reason why *A. rufus* (center frequency ± 1590 Hz) and *P. cayannensis* (center frequency ± 516 Hz) were not found in airport-affected sites, since their songs are in very low ranges of frequency (500 to 1600 Hz). However, this would not explain why *T. cayana* was never recorded in airport-affected sites, since their song frequency is relatively high (center frequency ± 7400 Hz). Species presence or absence is not the only important element to be considered, since declining species abundance in noisy places has also been associated with bird song minimum frequency (Proppe et al. 2013; Francis 2015). As proposed by Proppe et al. (2013), selective pressure associated with low frequency band in urban areas might be contributing toward losses of diversity and biota homogenization.

Our data showed losses of diversity in the airport-affected sites, although we are unable to discriminate among the relative contributions of fragmentation, degradation, and noise effects towards these patterns. Our results show that species composition found in airport-affected sites is strongly influenced by the available regional species pool, as sites within the same region share 57-61% of their avifauna, and presented lower values of dissimilarity. Additionally, differences in species composition between sites are more influenced by species replacement than by species nestedness. This means that there is a group of species that is common between sites, but that there is another group that is represented either by species that have been lost in the urbanization process because of their sensitivity to the novel attributes of airport-affected habitats (urban avoiders), or by species that have been added because of their generalism and opportunism (urban adapters) (Croci et al. 2008; Baselga 2010).

Ambient characteristics, such as landscape composition, noise levels and light intensity are important factors defining species behavior and community composition. High proportions of native vegetation are important to maintain native avifauna (Barrantes et al. 2011), but modified vegetation may also represent a target environment for birds (Brawn et al. 2001), since they can have increased resource availability (Marzuluff 2001) in the form of human-produced seeds and introduced fruits. Increased noise levels are restrictive to some species, diminishing their ability to communicate (Grade and Sieving 2016), and simultaneously reducing habitat quality for breeding and survival (Halfwerk et al. 2011; Schroeder et al. 2012). Light levels are naturally variable, yielding clues about day duration and seasons, and regulating organisms' biological cycles (Dawson et al. 2001). Interferences in the amount of natural light can generate behavioral modifications, including the amounts of time spent singing (Miller 2006; Kempenaers et al. 2010; Da Silva and Kempenaers 2017) and sleeping (Sun et al. 2017), in addition to disturbing hormonal cycles (de Jong et al. 2016; Ouyang et al. 2017).

Airport environments are commonly composed of very urbanized landscapes, but the presence of native and modified vegetation around the studied airports allowed us to observe the effect of these modifications, in addition to the extreme noise conditions. The high amplitude noise, concentrated in the lower frequency bands, justified the choice of study sites. On the other hand, the deliberated choice of airport sampling points where light poles were not available was not enough to eliminate a higher light level that could influence bird behavior (Kempenaers et al. 2010; Nordt and Klenke 2013).

In summary, we have shown that the studied airport-affected sites exhibit similar disturbances in terms of landscape composition, noise and light intensity. Studied airport-affected sites exhibited, relative to control sites, changes in species composition and reduced species richness, associated with habitat fragmentation, disturbance and noise pollution. Our results do not point towards biotic homogenization, however, since species composition in disturbed sites was dependent upon regional pools. Here we show that airport-affected environments are not suitable areas for bird species conservation, even in cases where vegetation is highly preserved around lanes. However, we advice that native vegetation shall be maintained, in order to soften the noise and air pollution produced by the airports.

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SUPPLEMENTARY MATERIAL 1. Geographic coordinates for mist-nets.

	AIR_Bras					**CONT_Bras**			
	Latitude	*Longitude*	*Month and day*	*Year*		*Latitude*	*Longitude*	*Month and day*	*Year*
1	15° 52' 59.5" S	47° 56' 03.0" W	Sep 22nd and 23th	2014	**1**	15° 43' 51.5" S	47° 57' 25.8" W	Sep 29th and 30th 2014	2014
2	15° 52' 44.0" S	47° 56' 42.6" W	Sep 24th and 25th	2014	**2**	15° 43' 24.8" S	47° 56' 24.4 " W	Oct 1st and 2nd 2014	2014
3	15° 52' 36.0" S	47° 56' 36.8" W	Sep 26th and 27th	2014	**3**	15° 43' 51.8" S	47° 57' 55.4" W	Oct 4th and 5th 2014	2014
4	15° 52' 35.1" S	47° 54' 17.0" W	Oct 17th and 18th	2015	**4**	15° 43' 01.7" S	47° 57' 38.9" W	Nov 20th and 21st	2015
5	15° 52' 58.8" S	47° 55' 18.84" W	Oct 22nd and 23th	2015	**5**	15° 43' 41.6" S	47° 57' 02.1" W	Nov 23th and 24th	2015
6	15° 53' 03.7" S	47° 56' 04.7" W	Oct 24th and 25th	2015	**6**	15° 44' 30.9" S	47° 57' 52.7" W	Nov 27th	2015
7	15° 52' 54.8" S	47° 55' 07.5" W	Nov 13th	2015	**7**	15° 44' 02.3" S	47° 57' 19.5" W	Nov 29th and 30th	2015

	AIR_Camp					**CONT_Camp**			
	Latitude	*Longitude*	*Month and day*	*Year*		*Latitude*	*Longitude*	*Month and day*	*Year*
1	23° 00' 11.5" S	47° 08' 14.7" W	Nov 26th and 27th	2014	**1**	23° 05' 49.9" S	47° 07' 28.8" W	Nov 15th and 16th	2014
2	23° 00' 01.4" S	47° 08' 29.3" W	Nov 28th	2014	**2**	23° 05' 50.9" S	47° 07' 49.9" W	Nov 17th and 18th	2014
3	22° 00' 06.2" S	47° 08' 20.8" W	Nov 29th and 30th	2014	**3**	23° 05' 50.7" S	47° 08' 00.3" W	Nov 19th and 20th	2014
4	22° 59' 56.3" S	47° 09' 001.7" W	Dec 03th	2014	**4**	23° 05' 14.5" S	47° 07' 51.5" W	Nov 21st and 22nd	2014
5	23° 00' 16.2" S	47° 08' 03.5" W	Dec 05th and 06th	2014	**5**	23° 04' 54.2" S	47° 08' 32.3" W	Dec 15th and 16th	2014
6	22° 59' 53.2" S	47° 09' 06.5" W	Dec 08th and 09th	2014					

	AIR_Sal					**CONT_Sal**			
	Latitude	*Longitude*	*Month and day*	*Year*		*Latitude*	*Longitude*	*Month and day*	*Year*
1	12° 54' 28.2" S	38° 19' 36.9" W	Dec 18th	2015	**1**	12° 51' 13.6" S	38° 15' 55.8" W	Dec 12th	2015
2	12° 54' 19.3" S	38° 19' 10.8" W	Dec 19th and 20th	2015	**2**	12° 51' 49.6" S	38° 16' 29.4" W	Dec 13th and 14th	2015
3	12° 54' 11.4" S	38° 19' 16.8" W	Dec 21st	2015	**3**	12° 51' 40.5" S	38° 16' 15.4" W	Jan 03th and 04th	2016
4	12° 54' 25.6" S	38° 19' 55.5" W	Dec 23th	2015	**4**	12° 51' 25.7" S	38° 15' 07.7" W	Jan 08th	2016
5	12° 54' 19.3" S	38° 19' 19.0" W	Jan 14th	2016	**5**	12° 51' 26.3" S	38° 15' 51.9" W	Jan 10th and 11th	2016
6	12° 54' 18.0" S	38° 18' 42.0" W	Jan 16th and 17th	2016	**6**	12° 51' 21.3" S	38° 16' 23.1" W	Jan 21st and 23th	2016
7	12° 54' 31.4" S	38° 20' 04.4" W	Jan 23th and 24th	2016					

SUPPLEMENTARY MATERIAL 2. Geographic coordinates for Automatic Recording Units.

	AIR_Bras			**CONT_Bras**	
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	15° 52' 44.2" S	47° 56' 44.5" W	1	15° 43' 44.8" S	47° 57' 13.7" W
2	15° 53' 02.3" S	47° 56' 19.7" W	2	15° 43' 45.8" S	47° 57' 32.7" W
3	15° 52' 34.1" S	47° 56' 09.0" W	3	15° 43' 50.6" S	47° 57' 24.6" W
4	15° 53' 01.6" S	47° 56' 05.7" W	4	15° 43' 41.5" S	47° 56' 50.9" W
5	15° 52' 36.0" S	47° 56' 22.1" W	5	15° 43' 54.2" S	47° 57' 48.8" W
6	15° 52' 59.1" S	47° 55' 46.0" W	6	15° 43' 45.4" S	47° 56' 34.2" W
7	15° 52' 36.5" S	47° 56' 33.4" W	7	15° 43' 55.7" S	47° 58' 07.3" W
8	15° 52' 56.8" S	47° 56' 49.9" W	8	15° 43' 52.0" S	47° 56' 21.5" W
9	15° 52' 34.6" S	47° 56' 41.2" W	9	15° 43' 48.3" S	47° 58' 00.7" W
10	15° 53' 03.3" S	47° 56' 42.6" W	10	15° 43' 57.6" S	47° 56' 19.9" W
11	15° 52' 44.2" S	47° 56' 44.5" W	11	15° 43' 15.4" S	47° 57' 49.4" W
12	15° 53' 03.9" S	47° 56' 29.1" W	12	15° 44' 04.0" S	47° 56' 07.4" W

	AIR_Camp			**CONT_Camp**	
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	22° 59' 54.5" S	47° 09' 05.7" W	1	23° 05' 49.0" S	47° 08' 00.5" W
2	23° 00' 07.7" S	47° 08' 09.9" W	2	23° 05' 11.2" S	47° 08' 04.3" W
3	22° 59' 48.8" S	47° 09' 01.8" W	3	23° 05' 53.3" S	47° 07' 54.6" W
4	23° 00' 16.2" S	47° 08' 06.9" W	4	23° 05' 22.6" S	47° 08' 01.3" W
5	22° 59' 57.0" S	47° 08' 24.6" W	5	23° 05' 59.7" S	47° 07' 50.3" W
6	23° 00' 20.5" S	47° 07' 59.1" W	6	23° 05' 32.1" S	47° 08' 01.8" W
7	23° 00' 01.5" S	47° 08' 16.2" W	7	23° 05' 53.2" S	47° 07' 19.7" W
8	23° 00' 23.0" S	47° 07' 43.9" W	8	23° 04' 51.9" S	47° 08' 31.4" W
9	23° 00' 04.6" S	47° 08' 22.2" W	9	23° 05' 56.1" S	47° 07' 07.0" W
10	22° 59' 48.6" S	47° 08' 37.6" W	10	23° 05' 01.6" S	47° 08' 37.2" W
11	23° 00' 10.2" S	47° 08' 15.7" W	11	23° 05' 41.4" S	47° 07' 21.0" W
12	22° 59' 38.2" S	47° 08' 50.5" W	12	23° 04' 57.5" S	47° 08' 46.8" W

	AIR_Sal			**CONT_Sal**	
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	12° 54' 27.4" S	38° 19' 36.6" W	1	12° 51' 40.4" S	38° 16' 14.2" W
2	12° 54' 18.3" S	38° 19' 21.6" W	2	12° 51' 47.1" S	38° 16' 29.4" W
3	12° 54' 28.6" S	38° 20' 01.7" W	3	12° 51' 36.0" S	38° 16' 06.1" W
4	12° 54' 31.1" S	38° 20' 10.9" W	4	12° 51' 50.4" S	38° 16' 19.1" W
5	12° 55' 17.5" S	38° 20' 23.0" W	5	12° 51' 35.6" S	38° 15' 57.6" W
6	12° 55' 00.5" S	38° 19' 45.1" W	6	12° 51' 24.7" S	38° 15' 50.5" W
7	12° 54' 40.6" S	38° 20' 34.0" W	7	12° 51' 08.1" S	38° 15' 53.9" W
8	12° 55' 02.2" S	38° 20' 14.1" W	8	12° 51' 16.3" S	38° 15' 48.7" W
9	12° 54' 21.7" S	38° 18' 27.2" W	9	12° 51' 22.7" S	38° 16' 22.5" W
10	12° 54' 18.5" S	38° 18' 46.9" W	10	12° 51' 20.4" S	38° 16' 30.9" W

SUPPLEMENTARY MATERIAL 3. Species lists (scientific names and common names based on Brazilian Council for Ornithological Registers (Piacentini et al. 2015), with indication of occurrence of species at specific sites, and which method registered the species: (NET) captures with mist-nets, or (ARU) automatic recording units.

	ORDER/Family/*Species*	**Common Name**	**AIR_Bras**	**CONT_Bras**	**AIR_Camp**	**CONT_Camp**	**AIR_Sal**	**CONT_Sal**	**Method**
	TINAMIFORMES								
	Tinamidae								
1	*Crypturellus parvirostris*	Small-billed Tinamou	x	x	x				ARU
2	*Rhychotus rufescens*	Red-winged Tinamou	x	x		x		x	ARU
3	*Nothura maculosa*	Spotted Nothura	x						ARU
	GALLIFORMES								
	Cracidae								
4	*Ortalis araucuan*	East Brazilian Chachalaca					x	x	ARU
	PELECANIFORMES								
	Ardeidae								
5	*Syrigma sibilatrix*	Whistling Heron	x			x			ARU
	Threskiornithidae								
6	*Mesembrinibis cayennensis*	Green Ibis		x	x	x			ARU
7	*Theristicus caudatus*	Buff-necked Ibis	x	x					ARU
	ACCIPITRIFORMES								
	Accipitridae								
8	*Rostrhamus sociabilis*	Snail Kite	x	x					ARU

9	*Rupornis magnirostris*	Roadside Hawk	x	x	x	x	x	x	NET/ARU
	GRUIFORMES								
	Rallidae								
10	*Aramides cajaneus*	Gray-necked Wood-Rail	x	x	x	x	x	x	ARU
11	*Mustelirallus albicollis*	Ash-throated Crake					x		ARU
	CHARADRIIFORMES								
	Charadriidae								
12	*Vanellus chilensis*	Southern Lapwing	x	x	x	x	x	x	ARU
	COLUMBIFORMES								
	Columbidae								
13	*Columbina passerina*	Common Ground-Dove						x	NET
14	*Columbina minuta*	Plain-breasted Ground-Dove					x		NET
15	*Columbina talpacoti*	Ruddy Ground-Dove	x		x	x	x	x	NET/ARU
16	*Columbina squammata*	Scaled Dove				x	x	x	NET/ARU
17	*Patagioenas picazuro*	Picazuro Pigeon	x	x	x	x		x	ARU
18	*Patagioenas cayennensis*	Pale-vented Pigeon				x		x	ARU
19	*Leptotila rufaxilla*	Gray-fronted Dove			x	x	x	x	NET/ARU
20	*Leptotila verreauxi*	White-tipped Dove			x	x			NET
	CUCULIFORMES								
	Cuculidae								
21	*Crotophaga ani*	Smooth-billed Ani	x		x	x	x	x	NET/ARU
22	*Guira guira*	Guira Cuckoo				x			ARU
23	*Tapera naevia*	Striped Cuckoo	x	x		x			ARU
	STRIGIFORMES								
	Strigidae								

24	*Megascops choliba*	Tropical Screech-Owl	x	x	x	x	x	x	NET/ARU
25	*Bubo virginianus*	Great Horned Owl		x					ARU
26	*Glaucidium brasilianum*	Ferruginous Pygmy-Owl	x			x	x	x	ARU
27	*Athene cunicularia*	Burrowing Owl			x	x	x	x	ARU
	NYCTIBIIFORMES								
	Nyctibiidae								
28	*Nyctibius griseus*	Common Potoo	x	x	x	x	x	x	ARU
	CAPRIMULGIFORMES								
	Caprimulgidae								
29	*Antrostomus rufus*	Rufous Nightjar				x		x	ARU
30	*Nyctidromus albicollis*	Common Pauraque	x	x	x	x	x	x	NET/ARU
31	*Hydropsalis parvula*	Little Nightjar	x	x		x			NET/ARU
32	*Hydropsalis maculicaudus*	Spot-tailed Nightjar	x	x					NET
	APODIFORMES								
	Trochilidae								
33	*Phaethornis pretrei*	Planalto Hermit				x			NET
34	*Eupetomena macroura*	Swallow-tailed Hummingbird	x	x			x	x	NET/ARU
35	*Colibri serrirostris*	White-vented Violetear	x	x					NET
36	*Chlorostilbon lucidus*	Glittering-bellied Emerald		x					NET
	GALBULIFORMES								
	Bucconidae								
37	*Nystalus chacuru*	White-eared Puffbird	x	x					ARU
38	*Nystalus maculatus*	Spot-backed Puffbird	x	x			x	x	NET/ARU
	PICIFORMES								
	Ramphastidae								

39	*Ramphastos toco*	Toco Toucan	x	x	x	x			ARU
	Picidae								
40	*Picumnus pygmaeus*	Spotted Piculet					x	x	NET/ARU
41	*Picumnus albosquamatus*	White-wedged Piculet	x	x		x			ARU
42	*Melanerpes candidus*	White Woodpecker			x	x		x	ARU
43	*Veniliornis passerinus*	Little Woodpecker	x						NET
44	*Veniliornis mixtus*	Checkered Woodpecker		x					NET
45	*Colaptes campestris*	Campo Flicker	x	x	x	x			ARU
46	*Dryocopus lineatus*	Lineated Woodpecker				x			NET
47	*Campephilus melanoleucos*	Crimson-crested Woodpecker	x	x		x			ARU
	CARIAMIFORMES								
	Cariamidae								
48	*Cariama cristata*	Red-legged Seriema	x	x	x	x			ARU
	FALCONIFORMES								
	Falconidae								
49	*Caracara plancus*	Southern caracara	x	x	x	x	x	x	ARU
50	*Milvago chimachima*	Yellow-headed Caracara	x			x			ARU
51	*Herpetotheres cachinnans*	Laughing Falcon	x	x		x		x	ARU
52	*Falco sparverius*	American Kestrel				x			NET
53	*Falco femoralis*	Aplomado Falcon				x			ARU
	PSITTACIFORMES								
	Psittacidae								
54	*Diopsittaca nobilis*	Red-shouldered Macaw		x					ARU
55	*Eupsittula aurea*	Peach-fronted Parakeet	x	x	x	x			ARU
56	*Forpus xanthopterygius*	Blue-winged Parrotlet			x	x	x	x	NET/ARU

57	*Brotogeris chiriri*	Yellow-chevroned Parakeet	x	x					ARU
58	*Amazona aestiva*	Turquoise-fronted Parrot	x	x		x			ARU
	PASSERIFORMES								
	Thamnophilidae								
59	*Formicivora grisea*	White-fringed Antwren					x	x	NET/ARU
60	*Herpsilochmus atricapilus*	Black-capped Antwren		x					ARU
61	*Thamnophilus doliatus*	Barred Antshrike			x	x			NET/ARU
62	*Thamnophilus torquatus*	Rufous-winged Antshrike		x	x				NET/ARU
63	*Thamnophilus ambiguus*	Sooretama Slaty-Antshrike					x	x	ARU
64	*Thamnophilus caerulescens*	Variable Antshrike	x	x		x			NET/ARU
	Melanopareiidae								
65	*Melanopareia torquata*	Collared Crescentchest	x	x					ARU
	Dendrocolaptidae								
66	*Lepidocolaptes angustirostris*	Narrow-billed Woodcreeper	x	x				x	NET/ARU
	Furnariidae								
67	*Furnarius rufus*	Rufous Hornero	x	x	x	x	x	x	NET/ARU
68	*Pseudoseisura cristata*	Caatinga Cacholote					x	x	NET/ARU
69	*Phacellodomus rufifrons*	Rufous-fronted Thornbird	x					x	ARU
70	*Phacellodomus ruber*	Greater Thornbird	x						ARU
71	*Synallaxis frontalis*	Sooty-fronted Spinetail	x	x	x	x			NET/ARU
72	*Synallaxis albescens*	Pale-breasted Spinetail		x					NET/ARU
73	*Synallaxis spixi*	Spix’s Spinetail			x	x			NET
	Pipridae								
74	*Antilophia galeata*	Helmeted Manakin	x	x					NET
	Tityridae								

75	*Pachyramphus polychopterus*	White-winged Becard	x	x					NET
	Rhynchocyclidae								
76	*Tolmomyias flaviventris*	Yellow-breasted Flycatcher					x	x	NET
77	*Todirostrum cinereum*	Common Tody-Flycatcher	x	x	x	x	x	x	NET/ARU
78	*Hemitriccus margaritaceiventer*	Pearly-vented Tody-tyrant		x			x	x	NET/ARU
	Tyrannidae								
79	*Camptostoma obsoletum*	Southern Beardless-Tyrannulet	x	x	x	x	x	x	NET/ARU
80	*Elaenia flavogaster*	Yellow-bellied Elaenia	x	x	x	x	x	x	NET/ARU
81	*Elaenia parvirostris*	Small-billed Elaenia		x					NET
82	*Elaenia mesoleuca*	Olivaceous Elaenia	x						NET
83	*Elaenia cristata*	Plain-crested Elaenia	x	x		x		x	NET/ARU
84	*Elaenia chiriquensis*	Lesser Elaenia	x	x	x	x		x	NET/ARU
85	*Elaenia obscura*	Highland Elaenia	x						NET
86	*Suiriri suiriri*	Suiriri Flycatcher	x	x					NET/ARU
87	*Phaeomyias murina*	Mouse-colored Tyrannulet		x	x	x			NET/ARU
88	*Serpophaga subcristata*	White-crested Tyrannulet			x				NET
89	*Myiarchus swainsoni*	Swainson's Flycatcher	x	x	x	x		x	NET/ARU
90	*Myiarchus tyrannulus*	Brown-crested Flycatcher		x	x	x		x	NET/ARU
91	*Pitangus sulphuratus*	Great Kiskadee	x		x	x	x	x	NET/ARU
92	*Myiodynastes maculatus*	Streaked Flycatcher			x	x			NET
93	*Megahyncus pitagua*	Boat-billed Flycatcher			x	x	x	x	NET/ARU
94	*Myiozetetes similis*	Social Flycatcher					x	x	NET/ARU
95	*Tyrannus melancholicus*	Tropical Kingbird	x		x	x	x	x	NET/ARU
96	*Empidonomus varius*	Variegated Flycatcher	x		x	x		x	NET/ARU
97	*Myiophobus fasciatus*	Bran-colored Flycatcher	x	x	x	x			NET/ARU

98	*Fluvicola nengeta*	Masked Water-Tyrant					x	x	NET
99	*Cnemotriccus fuscatus*	Fuscous Flycatcher			x	x			NET
100	*Lathrotriccus euleri*	Euler’s Flycatcher		x					NET
101	*Xolmis cinereus*	Gray Monjita	x						ARU
	Vireonidae								
102	*Cyclarhis gujanensis*	Rufous-browed Peppershrike	x	x	x	x	x	x	NET/ARU
103	*Hylophilus amaurocephalus*	Gray-eyed Greenlet				x	x	x	NET/ARU
104	*Vireo chivi*	Chivi Vireo	x	x		x	x	x	NET/ARU
	Corvidae								
105	*Cyanocorax cristatelus*	Curl-crested Jay	x	x	x	x			ARU
	Hirundinidae								
106	*Stelgidopteryx ruficollis*	Southern Rough-winged Swallow				x	x		NET/ARU
107	*Progne tapera*	Brown-chested Martin		x	x				ARU
	Troglodytidae								
108	*Troglodytes musculus*	Southern House Wren	x	x	x	x	x	x	NET/ARU
109	*Pheugopedius genibarbis*	Moustached Wren						x	ARU
	Donacobiidae								
110	*Donacobius atricapilla*	Black-capped Donacobius			x		x		ARU
	Polioptilidae								
111	*Polioptila plumbea*	Tropical Gnatcatcher					x	x	NET/ARU
112	*Polioptila dumicola*	Masked Gnatcatcher	x	x					ARU
	Turdidae								
113	*Turdus leucomelas*	Pale-breasted Thrush	x	x	x	x	x	x	NET/ARU
114	*Turdus rufiventris*	Rufous-bellied Thrush	x	x		x	x	x	NET/ARU
115	*Turdus amaurochalinus*	Creamy-bellied Thrush	x	x					NET

	Mimidae								
116	*Mimus gilvus*	Tropical Mockingbird					x	x	NET/ARU
117	*Mimus saturninus*	Chalk-browed Mockingbird	x	x	x	x			NET/ARU
	Motacilidae								
118	*Anthus lutescens*	Yellowish Pipit	x			x			ARU
	Passerellidae								
119	*Zonotrichia capensis*	Rufous-collared Sparrow	x	x	x	x			NET/ARU
120	*Ammodramus humeralis*	Grassland Sparrow	x	x	x	x	x		NET/ARU
	Parulidae								
121	*Geotlhypis aequinoctialis*	Masked Yellowthroat	x	x					NET/ARU
	Icteridae								
122	*Icterus pyrrhopterus*	Variable Oriole						x	NET
123	*Gnorimopsar chopi*	Chopi Blackbird	x	x			x	x	NET/ARU
	Thraupidae								
124	*Neothraupis fasciata*	White-banded Tanager	x	x				x	NET/ARU
125	*Schistochlamys melanopis*	Black-faced Tanager	x						NET
126	*Schistochlamys ruficapillus*	Cinnamon Tanager						x	NET
127	*Tangara sayaca*	Sayaca Tanager	x		x	x	x	x	NET/ARU
128	*Tangara palmarum*	Palm Tanager					x	x	NET/ARU
129	*Tangara cayana*	Burnished-buff Tanager		x		x		x	NET/ARU
130	*Nemosia pileata*	Hooded Tanager			x	x	x		NET
131	*Sicalis flaveola*	Safron Finch					x	x	NET/ARU
132	*Hemithraupis guira*	Guira Tanager	x	x	x	x		x	NET/ARU
133	*Volatinia jacarina*	Blue-black Grassquit	x	x	x	x	x		NET/ARU
134	*Coryphospingus pileatus*	Pileated Finch	x				x	x	NET/ARU

135	*Coryphospingus cucullatus*	Red-crested Finch		x	x	x			NET/ARU
136	*Tachyphonus rufus*	White-lined Tanager		x			x	x	NET
137	*Dacnis cayana*	Blue Dacnis		x				x	NET
138	*Coereba flaveola*	Bananaquit	x	x	x		x	x	NET/ARU
139	*Sporophila plumbea*	Plumbeous Seedeater		x					NET
140	*Sporophila nigricollis*	Yellow-bellied Seedeater	x	x		x			NET/ARU
141	*Sporophila caerulescens*	Double-collared Seedeater		x					NET
142	*Sporophila leucoptera*	White-bellied Seedeater	x						NET
143	*Emberizoides herbicola*	Wedge-tailed Grass-Finch	x	x	x	x			ARU
144	*Saltatricola atricollis*	Black-throated Saltator	x	x					ARU
145	*Saltator maximus*	Buff-throated Saltator		x					NET
146	*Saltator similis*	Green-winged Saltator		x	x	x		x	NET/ARU
147	*Thlypopsis sordida*	Orange-headed Tanager			x		x	x	NET/ARU
148	*Cypsnagra hirundinacea*	White-rumped Tanager	x	x				x	ARU
	Fringilidae								
149	*Euphonia chlorotica*	Purple-throated Euphonia	x	x	x	x			NET/ARU
	Passeridae								
150	*Passer domesticus*	House Sparrow	x						NET
	Non-identified								
151	No ID – Passeriforme (*recording available under request*)							x	ARU
152	No ID – Passeriforme (*recording available under request*)							x	ARU
153	No ID – Psittacidae (*recording available under request*)			x			x	x	ARU
154	No ID – Thamnophilidae (*recording available under request*)							x	ARU
			86	88	60	80	56	75	

SUPPLEMENTARY MATERIAL 4. Values of Sorrensen index of dissimilarity (β_{SOR}), Simpson index of dissimilarity (β_{SIM}) and Nestedness index of dissimilarity (β_{NES}) for pairs of sites.

		CONT_Bras	AIR_Bras	CONT_Camp	AIR_Camp	CONT_Sal
AIR_Bras	**β_{SOR}**	**0.252**				
	β_{SIM}	0.244				
	β_{NES}	0.008				
CONT_Camp	**β_{SOR}**	**0.428**	**0.373**			
	β_{SIM}	0.400	0.350			
	β_{NES}	0.028	0.023			
AIR_Camp	**β_{SOR}**	**0.459**	**0.465**	**0.242**		
	β_{SIM}	0.333	0.350	0.116		
	β_{NES}	0.126	0.115	0.126		
CONT_Sal	**β_{SOR}**	**0.546**	**0.515**	**0.458**	**0.511**	
	β_{SIM}	0.506	0.480	0.440	0.450	
	β_{NES}	0.039	0.035	0.018	0.061	
AIR_Sal	**β_{SOR}**	**0.638**	**0.577**	**0.544**	**0.517**	**0.267**
	β_{SIM}	0.535	0.464	0.446	0.500	0.142
	β_{NES}	0.103	0.113	0.097	0.017	0.124

CAPITULO 2 – Mudanças no coro matutino da comunidade de aves em resposta ao ruído aeroportuário

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Species plasticity in a noisy world: changes in dawn chorus onset time in tropical airports

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ABSTRACT

Airport noise interferes with acoustic communication in birds living in proximity to airports. Since dawn chorus in birds iniciate roughly when airports start to operate, a way in which birds can reduce this interference is by shifting their singing to a period when airport noise is less intense, typically by advancing their onset singing time to avoid the most acoustically busy hours of the morning. We investigated whether birds presented advances in dawn chorus onset by using automated recording units to sample dawn choruses in three airports and three control sites in Brazil. We found that dawn chorus times were not globally affected by exposure to airport noise. However, changes in dawn chorus onset were highly variable and species-specific. Dawn chorus onset was advanced in two, and delayed in three species. An estimate of population size differences (song occurrence) between control and airport sites was the main predictor of changes in onset time, as advances were associated to bigger populations, and delays in onset time were associated to smaller populations in airport sites. Additionally, advances in dawn chorus were positively associated to a longer duration of the singing period, while delays were associated to a shorter singing period. The direction of changes in dawn chorus were not explained by species´ song frequency, eye-size, degree of urbanity, potential noise decrease, and light increase in airports. Our results therefore suggest that changes in dawn chorus onset behavior are linked to each species intrinsic characteristics and to population’s ability to persist in noise environments.

Key-words: ARU; Brazil; song occurrence; Passeriformes, resilience.

INTRODUCTION

Natural selection in response to a complex combination of environmental factors is responsible for continuously shaping animal behavior (Candolin and Wong 2012). Additionally, wild animals need to adjust to anthropogenic changes in the environment that may potentially affect their behavior and fitness. In the case of birds, anthropogenic noise interferes with acoustic communication, which is used in various life-history contexts, from mate attraction to territory defense and parent-offspring communication (Catchpole and Slater 2008). Urban environments have introduced many unnatural elements that can explain a suite of behavioral and physiological modifications found in numerous bird species. These changes include singing at unusual times of the day and night in large cities or modifications in several song characteristics including frequency and duration (Partecke et al. 2004; Fuller et al. 2007; Kempenaers et al. 2010; Nordt and Klenke 2013; Spoelstra and Visser 2013).

Two of the most obvious urban challenges that may contribute to altered singing behavior are noise and light. The differential contributions of these two elements, although difficult to tease apart (Bergen and Abs 1997; Nordt and Klenke 2013), have been shown to modify acoustic signals in urban environments (Fuller et al. 2007; Nemeth and Brumm 2010; Nordt and Klenke 2013). Noise imposes an important constraint in communication by limiting the acoustic space of signaling birds and by reducing the probability that the signal will reach its intended receptor (Wiley 2013). On the other hand, increased light levels enhance the possibility that birds will intensify their nocturnal activity levels, impacting circadian sleep cycles and affecting behavior (Kempenaers et al. 2010).

The dawn chorus is characterized by a peak of bird vocal activity that starts approximately 30 to 60 min before sunrise, mostly during the breeding season, and in which different bird species show specific timings for their first song of the day (Staicer et al. 1996). Both individual singing rates and number of species singing reach a maximum in this period of the morning, and then typically decrease as light intensity increases. At this point, many singing birds initiate other daily activities that interfere with intense singing, and reduce their singing rate (Burt and Vehrencamp 2005). Singing at dawn is often more intense, versatile and complex than later during the day. Some species have specific dawn songs that are only produced at dawn (Staicer et al. 1996; Leger 2005). During the rest of the day, these species produce either different songs (e.g. *Elaenia chiriquensis*) or very simple calls (e.g. *Coryphospingus cucullatus* and *Neothraupis fasciata*) (Staicer et al. 1996).

Numerous hypotheses have been proposed to elucidate this pattern of singing activity at dawn, usually as a result of species-specific studies. Convergent selective pressures may explain this pattern of dawn singing to a large extent (Staicer et al. 1996), although different species have evolved behaviors that are specific to their life history. For example, some studies propose that territorial defense at this time of the day is important because of a possible higher probability of territorial take-overs by floater males (Kacelnik and Krebs 1982; Amrhein et al. 2004; Kunc et al. 2005). Another hypothesis suggests that singing at dawn may be a consequence of excessive energy reserves stored during the night (MacNamara et al. 1987; Hutchinson 2002). Finally, it has also been proposed that singing at this time is logical because light conditions are insufficient for foraging but are suitable for social acoustic communication (Kacelnik 1979; Kacelnik and Krebs 1982). This would explain why increased luminosity is a key determinant in the timing of bird singing (Berg et al. 2006; Nordt and Klenke 2013). In addition, some studies suggest that microclimatic characteristics at dawn enhance acoustic transmission efficiency (Henwood and Fabrick 1979; Brown and Handford 2003). Thus, singing during the dawn chorus appears to be a type of vocal performance of broad taxonomic relevance, although the significance of the different hypotheses that have been proposed require additional research.

Anthropogenic noise generated by traffic, industries and airports is mainly concentrated in low frequency bands, masking the frequency range which is mostly used by birds (Rheindt 2003). Airport noise is an extreme type of noise pollution, with high amplitude in a wide spectrum of frequencies, and is usually predictable in timing, given its dependency upon scheduled flights. In some cases, birds living near airports have been shown to be able to anticipate their dawn chorus to avoid early morning aircraft peak traffic periods (Gil et al. 2014; Dominoni et al. 2016; Sierro et al. 2017). Thus, it appears that at least some species can flexibly adjust their singing periods to avoid the interference of anthropogenic noise and increase signal detectability in noisy environments. Those that are not able to adjust their behavior must be more susceptible to effects of noise in population dynamics, as some species in noisy places can face reduced pairing success (Habib et al. 2007), as well as reduced population density (Bayne et al. 2008). At chronic noise levels, species can either avoid, or remain in the noisy area, with the possible negative consequences linked to this decision (Habib et al. 2007).

Here, we test the hypothesis that bird populations living in airport surroundings exhibit higher flexibility in morning song onset time when compared with the corresponding species populations living in silent sites, to avoid the interference caused by aircraft traffic. We consider species that sing early in the morning, including those that sing before sunrise (typically described as dawn chorus) as well as those that initiate singing after civil sunrise (i.e., when the sun center is 6 degrees below the horizon) (Dominoni et al. 2016). We have two general predictions: (I) individuals of a given species living in noisy sites will initiate their dawn chorus earlier than individuals of the same species living in silent sites (Gil et al. 2014; Dominoni et al. 2016); (II) differences between species in the direction and strength of change (advances or delays) should be explained by a suite of modulators, namely: (a) population size (song occurrence): we expect established large populations (adapters) to show greater advances than small populations (avoiders) (Francis et al. 2009); (b) song frequency: we expect birds with lower frequencies to show greater advances (Rheindt 2003; Francis et al. 2011b); (c) degree of urbanity: we expect urban adapter species to show greater advances than urban avoiders (Croci et al. 2008); (d) noise-gain: we expect populations that can achieve more significant reductions in noise levels by an advance in timing, to show greater advances than those in wherein an advance would lead to a less significant reduction in noise levels (Sierro et al. 2017). In addition to these modulators we control for species-specific differences in eye size (Thomas et al. 2002), and site-specific levels of light pollution (Da Silva et al. 2016).

METHODS

Study site

As previously described in chapter one, our field data were collected in three Brazilian airports, which were selected based on their high aircraft activity and availability of native vegetation around the lanes. For each airport-affected site, we selected a silent control site, with similar vegetation structure, at distances ranging from 8 to 17 km from each airport. Studied airports are Presidente Juscelino Kubitschek International Airport (AIR_Bras: 15°52'19.4"S 47°55'11.9"W) in Brasília (Distrito Federal), Viracopos International Airport (AIR_Camp: 23°00'24.4"S 47°08'30.0"W) in Campinas (São Paulo state) and Luís Eduardo Magalhães International Airport (AIR_Sal: 12°54'42.8"S 38°19'44.2"W) in Salvador (Bahia state). For each of these airports we chose the following silent control sites: “Parque Nacional de Brasília” (DF) (CONT_Bras: 15°43'18.1"S 47°58'14.4"W), a private farm named “Fazenda Santa Maria” (SP) (CONT_Camp: 23°05'53.2"S 47°07'49.8"W), and a residential area with large protected areas named “Condomínio Buscavida” (BA) (CONT_Sal: 12°51'30.0"S 38°16'08.0"W) (See Figure 2 in Chapter One).

Ambient noise and light measurements

We measured noise levels by transforming sound files acquired with automatic recording units (ARU) SONGMETER SM2+ (Wildlife Acoustics 2007-2011) into sound level measurements, using TOL metric (1/3-octave band levels). Analyses showed that all airport-affected sites had higher levels of noise amplitude, with the larger differences found in bands 501.1 Hz (Linear Mixed Model (LMM): estimate = -0.283, $p < 0.001$) and 1000 Hz (LMM estimate = -0.293, $p < 0.001$). The paired sites in Brasília presented the highest differences in noise levels at 1000 to 2000 Hz frequency band (Brasília: LMM estimate = -0.297, $p < 0.001$; Campinas: LMM estimate = -0.253, $p < 0.001$; and Salvador: LMM estimate = -0.167, $p < 0.001$). Mean amplitude levels for the three airport-affected sites between -100 and 90 min after sunrise at 1000 to 2000 Hz frequency band (52.55dB ±sd 8.20) is approximately 28% higher than the mean amplitude levels found in the silent control sites (40.99 dB ±sd 3.52) (for analyses details, see chapter one).

We measured light levels with *Sky Quality Meters* LU-DL device (Uniedrom, Ontario, Canada) at night to estimate the amount of artificial light at each locality. In general, airport-affected sites are more affected by artificial lighting (LMM Estimate = 0.828, $p = 0.001$), and the highest difference between airport-affected sites and silent control sites was found in the Campinas region (Brasília: LMM estimate = -0.828, $p = 0.001$; Campinas: LMM estimate = -1.325, $p < 0.001$; Salvador: LMM estimate = -0.259, $p = 0.04$). Mean night sky darkness in airport-affected sites between -120 and -60 min after sunrise (18.17 mag/arcseg^2 ±sd 0.99) is approximately 5% lower than night sky darkness in silent control sites (19.21 mag/arcseg^2 ±sd 0.77) (for analyses details, see Chapter One).

Recordings

We used ARUs to record the birds' dawn chorus. They were programmed to record from 2 hours before civil sunrise (-120 min) until 1 hour after civil sunrise (60 min), alternating periods of 1 min of recording and 1 min of inactivity. Recorders were set in custom-made harnesses and hung from branches at a height of 1–3 m (Gil et al. 2014). As sunrise timing is different in the different airport regions, we standardized time by civil sunrise, such that "0" is the time when the sun´s center is 6 degrees below the horizon (Time and Date AS ; Miller 2006; Nordt and Klenke 2013). ARUs worked in stereo mode, at a sample rate of 44.1 Khz and 16 bits.

Study sites were sampled during the breeding season for each region, when birds have higher vocal activity. Recorders were installed simultaneously in the paired sites (airport and control) within each region, to avoid possible seasonality effects (see Nordt and Klenke (2013)). In Brasília, we placed recorders in 12 points in the airport-affected site, and 12 points in the silent control site, between October 10th and 29th of 2014. In Campinas, we placed recorders in 12 points in the paired sites between December 4th and 19th of 2014. In Salvador, we had a smaller area available in the airport-affected site, so we placed recorder in 10 points in each site between December 19th of 2015 and January 16th of 2016. Each recording point was located at least 250 m from other points and was sampled during two to three consecutive mornings. Points in airport-affected sites were at a maximum distance of 300 m from airport lanes (See Supplementary Material 1 for recorders geographic coordinates).

We used Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY) for simple visualization and listening of recordings. For each 1-min file, we identified species by song. For statistical analysis, we considered only species that were recorded in at least eight sampled points per control and treatment sites, regardless of the number of mornings.

For statistical analyses, we contemplated three population variables (dawn song onset, duration of singing period, and song occurrence), three species-specific variables (song frequency, eye size, and urbanity), and three environmental variables (actual noise difference, potential noise reduction, and light increase), defined as follows. **Dawn chorus onset**: time at which each species started singing in each area (considering the period between -120 to 60 min in relation to civil sunrise). For each species, we averaged the times of the first and second songs in each sampled morning, for a more robust determination of dawn song onset (Sierro et al. 2017). This was included in the model as standardized effect difference between airport-affected and silent control sites (i.e. Hedge's *d*; Nakagawa and Cuthill (2007)), where positive values indicate species singing earlier and negative values species singing later in airports-affected relative to silent control sites. **Duration of singing period**: how much of the morning period was acoustically used by each species. We took the first and last song of each species in each morning and calculated the duration of singing activity (in minutes). This was included in the model as the standardized effect difference between airport-affected and silent control sites (i.e. Hedge's *d*; Nakagawa and Cuthill (2007)), where positive values indicate species singing for shorter periods in airports relative to control sites, and negative values indicate species singing for longer periods in airports relative to control sites. **Song occurrence**: at a large extend, this index represents a proxy for population size in each site. To determine song occurrence, we divided the number of mornings in which the species was detected by song (maximum of 2 mornings per point) by the number of mornings sampled in each site (Joo et al. 2011). This was included in the model as an index (Song occurrence airport/control), where values above 1 represent higher song occurrence in airports, and values below 1 represent lower song occurrence in airports than in control site (see Supplementary Material 2). **Song frequency**: the acoustic space occupied by each species. We selected 5 recordings of each species and used Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY) to measure the acoustic parameters of a total of 20 songs from each species, using an FFT of 1024. We measured the peak (dominant) frequency, which is the frequency concentrating the most amplitude (energy) (See Thesis Supplementary Material). **Eye-size:** species eye size, which is known to be related to the time of species-specific timing of dawn chorus onset (Thomas et al. 2002). Eye-size was measured in Image J program (U. S. National Institutes of Health, USA) using rule-scaled pictures of captured live birds (Alquezar et al *unpublished*). This variable was corrected for species body weight, so the values included in the model are residuals of a linear regression (adjusted $r^2 = 0.86$, $F_{1,24} = 165.9$, $p < 0.001$). **Urbanity**: degree of association of each species to urban environments. We collected data on species occurrence in Brazil using eBird database (eBird 2017) and ran models taking into account detection probabilities to determine the difference in occupancy between urban and natural areas. For models, we used the value of the Z statistic as a representation of the degree of urbanity for each species, where positive Z values are associated with species that exhibit some degree of preference for urban habitats while negative values are associated with species that exhibit some degree of avoidance of urban environments (See Thesis Supplementary Material). **Actual noise difference**: difference in noise amplitude in the airport, considering the time of dawn chorus onset at the airport and at the control site. This means: if a given species would sing at the airport-affected site at the time that it sings in silent control site, what is the difference in noise amplitude that it achieves? Actual noise difference = [Noise airport (dawn chorus time: airport)] - [Noise airport (dawn chorus time: control)]. **Potential noise reduction**: reduction in the amount of noise that a species would experience by starting its dawn chorus 20 min earlier in airport, which is a standard advance time found in previous studies (Gil and Lluisia *in prep.*). Which means: if a given species sings at the airport-affected site 20 min earlier than it sings in silent control site, what would be the reduction in noise amplitude that it would achieve? Potential noise reduction = [Noise airport (dawn chorus time: control – 20 min)] - [Noise airport (dawn chorus time: control)]. **Light increase**: the difference in light intensity between airport-affected and silent control sites at the same time. Which means: if a given species sings at the airport-affected site at the same time that it sings in silent control site, what would be the increase in light intensity? Light increase = [Darkness control (time: control)] - [Darkness airport (time: control)] (see Supplementary Material 3).

Statistical analyses

Statistical analyses were performed in R version 3.3.2 (R Development Core Team 2016), and significance was considered for $p < 0.05$. All data on time of dawn chorus onset was normalized using boxcox transformation, and re-scaled due to negative values, before applying normalization. We ran a linear mixed model (LMM) (random factors = (1|Point)) using the dataset for all regions, and all species that were registered in at least eight sample points of each treatment (Airport *vs.* Control). The interaction between variables "Treatment" and "Species" was included as explanatory, and the significance value (*p*) was calculated with a post-hoc analysis of deviance (type 3). We assessed species-specific responses by testing whether individuals singing in airport-affected sites changed their dawn chorus onset in relation to individuals singing in silent control sites. We ran separate LMM for each species (random factors = (1|Point) and (1|Region)), and calculated significance value (*p*) through a post-hoc analysis of deviance (type 3). To run these analyses we used packages "*AID*" (Asar et al. 2016), "*lme4*" (Bates et al. 2015), and "*car*" (Fox and Weisberg 2011).

Subsequently, using a LMM (random factors = (1|Region) and (1|Species)) we tested whether dawn chorus onset time (represented by standardized effect difference) can be explained by population (song occurrence), species-specific (song frequency, eye size, and urbanity), and environmental characteristics (potential noise reduction and light increase). We evaluated populations' responses in each region, considering that song occurrence, noise and light differ among regions. We used the "dredge" and "model average" functions to summarize the best models results, ranking models by Akaike's Information Criteria (AICc) and considering models within $\Delta AIC < 3$. Data were normalized using log transformation, followed by scaling. To run these analyses we used additional packages "*MuMIn*" (Barton 2016), and "*AICcmodavg*" (Mazerolle 2016).

RESULTS

We obtained dawn chorus onset data in airports and control sites for 15 species (Order Passeriformes), some of which occurred in all three regions, while others occurred in either one or two regions (Brasília, Campinas and Salvador). We found a significant interaction effect between treatment and species (post-hoc Anova: $X^2 = 62.65$, df = 14, $p < 0.001$) (Table 1), which means that species present different changes of dawn chorus onset in the airport conditions. This result led us to investigate individual species response (Engqvist 2005).

Two species anticipated dawn chorus onset in noisy sites: the lesser elaenia (LE- *Elaenia chiriquensis* ±14.6 min earlier) and the white-banded tanager (WBT- *Neothraupis fasciata* ±8.8 min earlier). Three species presented a significant delay, with later singing onset times in noisy sites: the southern beardless-tyrannulet (SBT- *Camptostoma obsoletum* ±10.1 min later), the southern house wren (SHW- *Troglodytes musculus* ±16 min later), and the rufous-collared sparrow (RCS- *Zonotrichia capensis* ±12.6 min later). The remaining ten species presented no significant changes (Fig. 1 and Table 1).

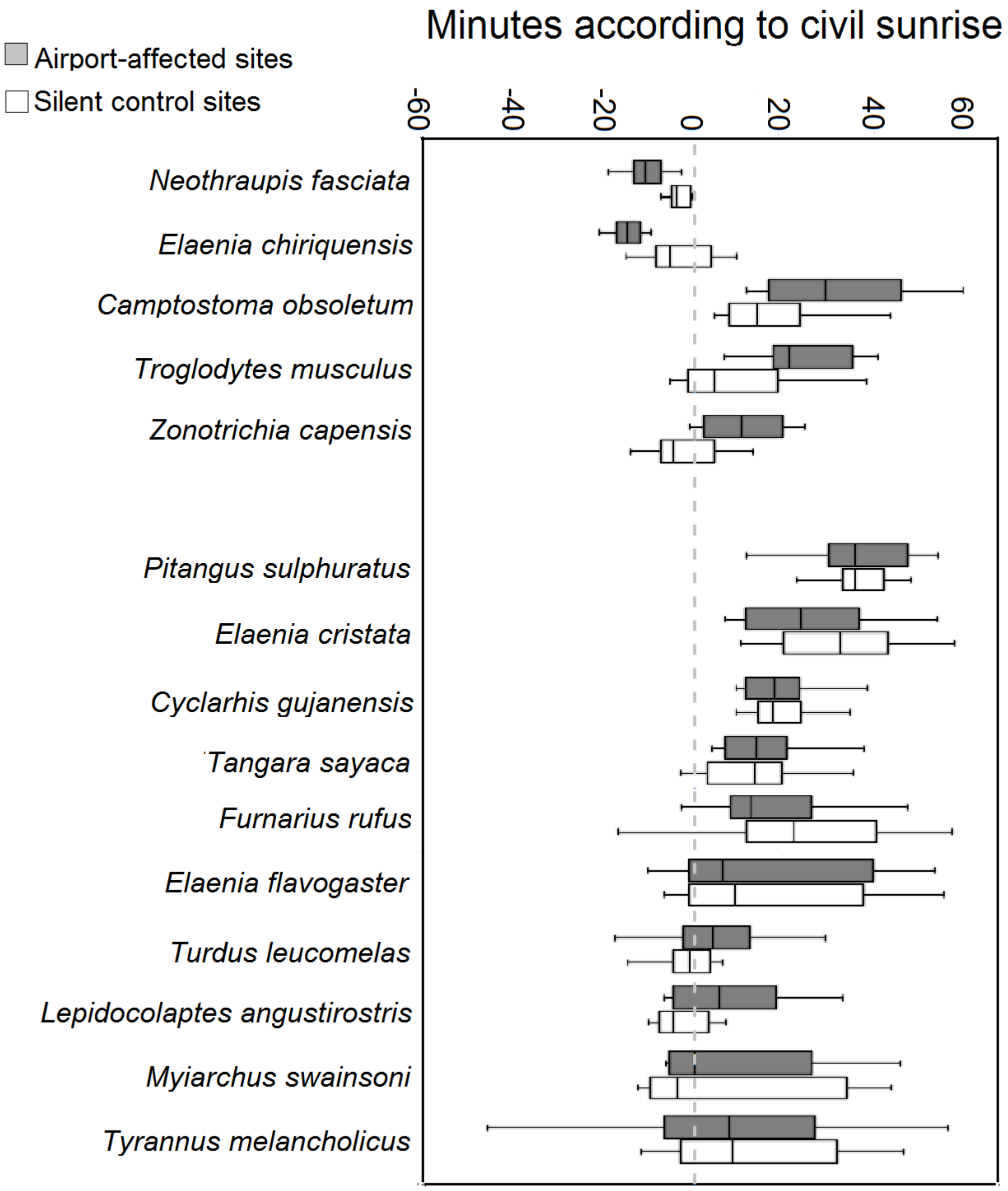

Fig 1. Mean dawn chorus onset for 15 bird species, in airport-affected sites (gray) and silent control sites (white). The first two species (*N. fasciata* and *E. chiriquensis*) advanced dawn chorus onset in airports; the next three species (*C. obsoletum*, *T. musculus* and *Z. capensis*) presented significant delays in dawn chorus onset in airports. The remaining ten species showed no differences in dawn chorus onset between airport and control sites.

Table 1. Linear mixed model values for all species together, and for individual species, including dawn chorus onset estimates from models, chi-square values (X^2), standard error, degrees of freedom and p values for intercept and treatment (control). Region refers to populations included in sample (B=Brasília, C=Campinas, S=Salvador, and ALL=all regions), and (1|region) or/and (1|point) indicates which variables were used as random variables for each species-specific model. Additionally, mean values of dawn chorus onset time for 15 species (in minutes), for airport-affected (airport mean) and silent control sites (control mean), including sample size (N: number of points) and number of repetitions per mornings (rep). Species are presented in phylogenetic order.

							Airport		**Control**	
	Estimate	**SE**	**X^2**	**df**	**p value**	**Region**	**mean**	**N (rep)**	**mean**	**N (rep)**
All species (Treatment * Species) + (1|point)										
Intercept	0.295	0.13	4.68	1	0.03					
TreatControl	0.544	0.24	4.94	1	0.02					
Species	--	--	307.20	14	<0.001					
Treat*Species	--	--	65.02	14	<0.001					
1. *Lepidocolaptes angustirostris* (1|point)						B	6.37	12 (24)	-1.87	13 (24)
Intercept	-0.256	0.22	1.346	1	0.24					
TreatControl	0.572	0.31	3.395	1	0.06					
2. *Furnarius rufus* (1|region)+(1|point)						C, S	15.03	17 (34)	25.58	17 (26)
Intercept	0.303	0.20	2.242	1	0.13					
TreatControl	-0.497	0.27	3.239	1	0.07					
3. *Camptostoma obsoletum* (1|region)+(1|point)						ALL	29.07	10 (14)	16.75	20 (33)
Intercept	-0.274	0.30	0.826	1	0.36					
TreatControl	0.921	0.29	9.583	1	0.001					
4. *Elaenia flavogaster* (1|region)+(1|point)						ALL	9.91	14 (23)	16.00	14 (22)
Intercept	0.220	0.25	0.755	1	0.38					
TreatControl	-0.174	0.35	0.235	1	0.62					
5. *Elaenia cristata* (1|region)+(1|point)						B, S	23.07	12 (23)	30.97	19 (36)
Intercept	0.284	0.19	2.067	1	0.15					
TreatControl	-0.517	0.31	2.660	1	0.10					
6. *Elaenia chiriquensis* (1|region)+(1|point)						B, C	-15.29	14 (34)	-0.69	12 (23)

Intercept	0.613	0.23	6.768	1	0.009					
TreatControl	-0.999	0.31	9.921	1	0.001					
7. *Myiarchus swainsoni* (1|region)+(1|point)						B, C	1.88	10 (17)	7.22	15 (31)
Intercept	0.296	0.48	0.373	1	0.54					
TreatControl	0.122	0.40	0.088	1	0.76					
8. *Pitangus sulphuratus* (1|region)+(1|point)						C, S	36.95	20 (44)	36.19	15 (32)
Intercept	0.034	0.32	0.011	1	0.91					
TreatControl	0.051	0.27	0.035	1	0.85					
9. *Tyrannus melancholicus* (1|region)+(1|point)						ALL	4.97	20 (41)	10.33	14 (21)
Intercept	0.304	0.26	1.343	1	0.24					
TreatControl	-0.179	0.33	0.278	1	0.59					
10. *Cyclarhis gujanensis* (1|region)+(1|point)						ALL	20.56	14 (25)	18.19	22 (43)
Intercept	-0.081	0.40	0.041	1	0.83					
TreatControl	0.446	0.27	2.656	1	0.10					
11. *Troglodytes musculus* (1|region)+(1|point)						B, C	24.30	11 (20)	8.23	23 (46)
Intercept	-0.243	0.31	0.603	1	0.43					
TreatControl	0.802	0.25	9.620	1	0.001					
12. *Turdus leucomelas* (1|region)+(1|point)						ALL	4.00	20 (36)	-1.03	24 (44)
Intercept	-0.130	0.25	0.257	1	0.61					
TreatControl	0.455	0.23	3.850	1	0.05					
13. *Zonotrichia capensis* (1|point)						C	10.48	11 (22)	-3.08	12 (23)
Intercept	-0.490	0.17	7.587	1	0.04					
TreatControl	1.087	0.26	17.248	1	<0.001					
14. *Neothraupis fasciata* (1|region)+(1|point)						B, S	-10.08	12 (25)	-1.22	10 (20)
Intercept	1.132	0.56	3.992	1	0.04					
TreatControl	-1.004	0.24	16.336	1	<0.001					
15. *Tangara sayaca* (1|region)+(1|point)						C, S	12.18	21 (45)	13.41	17 (32)
Intercept	0.055	0.21	0.069	1	0.79					
TreatControl	-0.022	0.28	0.006	1	0.93					

According to model selection based on populations, changes in dawn chorus onset were significantly explained by differences of song occurrence (population size) between airport-affected and silent control sites (Table 2 and Fig. 2; Post-hoc Anova: $X^2 = 30.73$, df = 1, $p<0.0001$), whereas none of the other predictors were retained in the final models. As predicted, species that advanced dawn chorus onset presented higher song occurrence in airport-affected sites than in silent control sites, suggesting bigger populations in noisy sites. On the other hand, species that delayed dawn chorus onset had lower song occurrence in airport-affected sites, suggesting smaller populations in noisy areas. Other selected models presented ΔAIC > 3 and were not considered as suitable explanations for dawn chorus onset changes. The variables "actual noise difference" and "duration of singing period" were not included in the model selection since they are highly correlated with dawn chorus onset time: birds that sing earlier achieve higher noise reductions ($r = 0.95$; $t = 16.14$; df = 24; $p <0.001$), and birds that sing earlier presented longer duration of singing period ($r = -0.84$; $t = -7.86$; df = 24; $p <0.001$) (Fig. 3).

Table 2. Model selection results (LMM) for dawn chorus onset (standardize effect difference) as response variable, including intercept estimate (Int), estimates for variables: song occurrence, song frequency, corrected eye size, urbanity, potential noise reduction and light increase; degrees of freedom, values for corrected and delta Akaike's information criteria and model weight (Random variables: Species and Region). Only the first six best models are presented.

Int	**Occur**	**Song**	**Eye**	**Urban**	**Noise**	**Light**	**df**	**AICc**	**ΔAIC**	**Weight**
-1.29e-16	0.749						5	68.8	0.00	0.582
-8.54e-17	0.745		0.248				6	71.9	3.08	0.125
1.72e-05	0.787			-0.162			6	73.0	4.17	0.072
2.93e-15	0.776	-0.154					6	73.1	4.30	0.068
-1.33e-16	0.748					-0.089	6	73.9	5.15	0.044
5.58e-03	0.737				-0.009		6	74.2	5.41	0.039

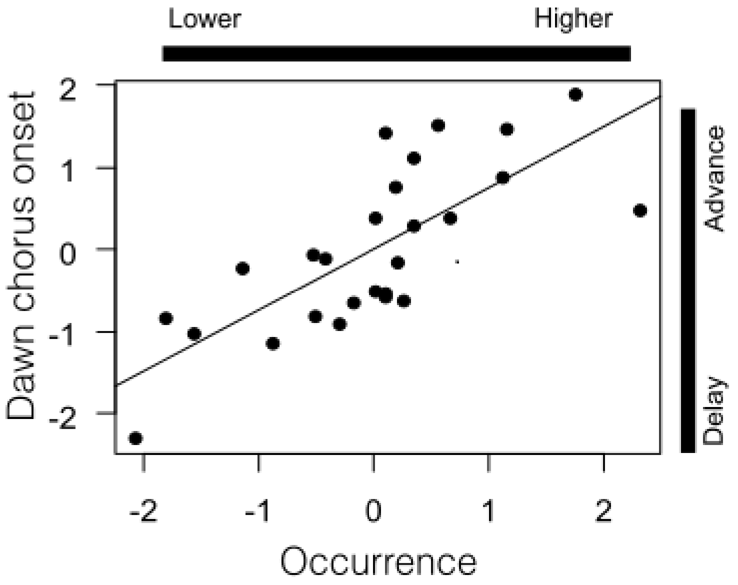

Fig 2. Relationship between dawn chorus onset changes (standardized effect difference) and song occurrence (index) for 26 pairs of populations (15 species), both normalized by boxcox. Dawn chorus values below 0 indicate delays and values above 0 indicate advances in dawn chorus onset in airport-affect sites. Occurrence values below 0 indicate lower song occurrence, and values above 0 indicate higher song occurrence.

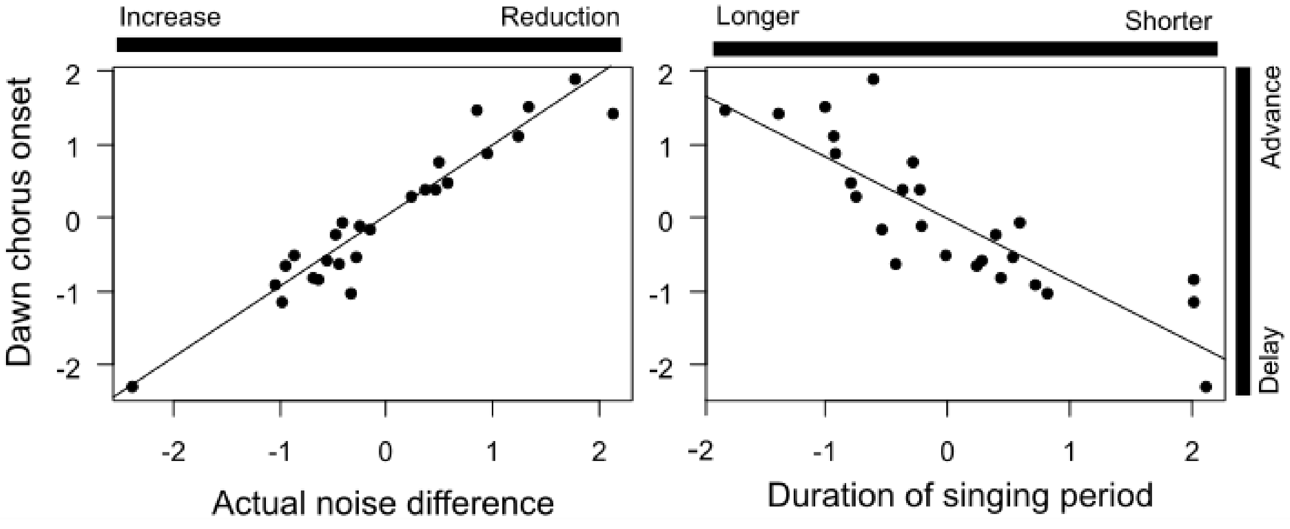

Fig 3. Correlation of dawn chorus onset time (standardized effect difference) with actual noise difference in left and with duration of singing period (standardized effect difference) in right, all normalized by boxcox. Tendency line obtained by linear regression.

DISCUSSION

Our results show that species-specific dawn chorus onset times were not globally affected by exposure to airport noise. We found that responses to airport-noise was species-specific: out of 15 studied species, two presented advances and three presented delays in their dawn chorus onset time in the airport-affected sites. In addition, populations that advanced their timing presented longer song choruses during the morning. When we analyzed differences in detail, we find that these divergent results were related to species differences in population size (song occurrence), probably related to their susceptibility to extreme noise.

Contrary to our main hypothesis, the majority of evaluated species did not show higher song plasticity in the expected direction (advances). And, although the earlier the species sang the higher the amount of noise it was able to avoid, we found that song chorus advance was not explained by the amount of noise that a given species would avoid by singing 20 min earlier at that site. This is in contrast to a previous study in which seasonal differences in song advance were explained by differences in the overlap of natural song routines with airport traffic noise (Sierro et al. 2017). The significant interaction between treatment and species shows that species respond differently, as previously found in a recent study (Dominoni et al. 2016). When we analyzed species separately, we found that five of 15 species presented changes in their dawn chorus onset, including advances and delays. Although such a result could be expected due to random patterns, previous studies have found that species-specific differences could be explained by the species´ skill in dealing with noisy conditions. Results from these studies have found: earlier dawn song in two of six studied species when experimentally exposed to noise (Arroyo-Solís et al., 2013); increased time spent singing near airports in two of 10 species (Gil et al., 2014); earlier dawn songs in five of 10 species near airports (Dominoni et al., 2016); and temporal shifts of song in different directions in four of 19 species, when experimentally exposed to noise (Proppe and Finch, 2017).

However, in contrast to other studies, we were able to associate the changes in dawn chorus onset with population conditions. Species that advanced the most in airport-affected sites and had longer choruses also had higher song occurrence (probably due to larger population size). This suggests that species that show advances are those that show a better adaptation to urbanized airport conditions. These species seem to be successfully dealing with noise, increasing their singing period and showing adaptive changes in timing that reduce their exposure to noise during the dawn chorus. Similar results were found for two flycatchers in North America in relation to modifications of song characteristics; the grey flycatcher (*Empidonax wrightii*) showed no changes in vocal frequency but declined in occupancy, while the ash-throated flycatcher (*Myiarchus cinerascens*) showed an increase in vocal frequency, but no changes in occupancy (Francis et al. 2010). Those populations that show the opposite pattern, that is, song delays with respect to the control populations, are characterized by lower song occurrence, and possible smaller population sizes. Thus, these species may not be able to adapt to extreme levels of noise, and may be facing difficulties in maintaining reproduction (Francis et al. 2009), or may be avoiding noisy sites due to species-specific characteristics (Francis 2015).

The duration of dawn singing is possibly as important for birds as the onset time of dawn chorus (Dominoni et al. 2016). The relationship found between dawn chorus onset, species song occurrence and duration of singing period could also be a result of higher species density leading to higher competition between individuals (Goretskaia 2004). As a result, birds would show earlier dawn choruses, and increase the period spent singing as a result of intra-specific competition. However, increases in singing period duration, activity (song redundancy) and song duration have been reported in noisy sites as strategies to reduce acoustic interference (Brumm and Slater 2006; Díaz et al. 2011; Gil et al. 2014; Yang and Slabbekoorn 2014; Sierro et al. 2017). In addition, singing in noise conditions above 70-80 dB threshold has been shown to be disadvantageous (Cynx et al. 1998; Díaz et al. 2011). Thus, we propose that our results are better explained by populations’ ability to deal with noisy environments, and not by intra-specific competition.

Exposure to noise may result in changes in population dynamics, a fact previously shown in various studies for different types of noise. Noise-generating compressor stations, for example, are responsible for a considerable reduction in bird density (Bayne et al. 2008), and this is also the case for some bird populations exposed to traffic noise along roadside habitats in Canada (Proppe et al. 2013). Changes in population dynamics in airport surroundings can be a consequence of long-term effects on the species’ fitness, since noise can affect avian breeding success (Dominoni et al. 2016). Noise interferes with the breeding process due to noise masking, reducing pairing success (Habib et al. 2007), clutch size and fledgling success (Halfwerk et al. 2011). These effects bring about a reduction in the number of species able to breed in noisy sites (Francis et al. 2009). Thus, bird populations that survive in noisy areas may be benefiting from their behavioral plasticity (Gil et al. 2014).

Overall, we found no association of song peak frequency, species eye-size, species urbanity, potential noise reduction and light increase to the species ability to deal with studied noisy environment. Studies investigating the impact of noise in birds’ dawn chorus onset usually indicate light as a possible confounding factor, since artificial light is a major factor leading birds to start their daily activity earlier (Dominoni et al. 2014; de Jong et al. 2016), to increase nocturnal vigilance (Yorzinski et al. 2015), to advance breeding period (Kempenaers et al. 2010; Dominoni et al. 2013), and to advance dawn chorus onset (Miller 2006; Dominoni et al. 2013; Ki and Cho 2014; Da Silva et al. 2016). However, light was not retained as an important predictor of song onset in our study. We suggest two possible explanations: 1) incidence of artificial light was not very strong in our studied sites (5% higher in airport-affected sites than in silent control sites); and 2) light effects in tropical regions are weaker than in temperate regions (Dorado-Correa et al., 2016), where variations in civil sunrise time (±1 hour in the tropics and ±3 hours in temperate regions), and seasonal variation in day length (±1.9 hours in tropics and ±5.8 hours in temperate regions) are much stronger.

In summary, we have shown species-specific advances and delays in dawn chorus onset, related to noise in airport-affected sites. Advances in dawn chorus onset (expected behavior) occurred in airport populations of larger size than those in silent control sites, and delays in dawn chorus onset (unexpected behavior) occurred in apparently declining populations. These results suggest that changes in dawn chorus onset are related to populations' ability to deal with noise exposure.

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SUPPLEMENTARY MATERIAL 1. Geographic coordinates for Automatic Recording Units.

Aeroporto de Brasília (AIR_Bras)			Parque Nacional de Brasília (CONT_Bras)		
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	15° 52' 44.2" S	47° 56' 44.5" W	1	15° 43' 44.8" S	47° 57' 13.7" W
2	15° 53' 02.3" S	47° 56' 19.7" W	2	15° 43' 45.8" S	47° 57' 32.7" W
3	15° 52' 34.1" S	47° 56' 09.0" W	3	15° 43' 50.6" S	47° 57' 24.6" W
4	15° 53' 01.6" S	47° 56' 05.7" W	4	15° 43' 41.5" S	47° 56' 50.9" W
5	15° 52' 36.0" S	47° 56' 22.1" W	5	15° 43' 54.2" S	47° 57' 48.8" W
6	15° 52' 59.1" S	47° 55' 46.0" W	6	15° 43' 45.4" S	47° 56' 34.2" W
7	15° 52' 36.5" S	47° 56' 33.4" W	7	15° 43' 55.7" S	47° 58' 07.3" W
8	15° 52' 56.8" S	47° 56' 49.9" W	8	15° 43' 52.0" S	47° 56' 21.5" W
9	15° 52' 34.6" S	47° 56' 41.2" W	9	15° 43' 48.3" S	47° 58' 00.7" W
10	15° 53' 03.3" S	47° 56' 42.6" W	10	15° 43' 57.6" S	47° 56' 19.9" W
11	15° 52' 44.2" S	47° 56' 44.5" W	11	15° 43' 15.4" S	47° 57' 49.4" W
12	15° 53' 03.9" S	47° 56' 29.1" W	12	15° 44' 04.0" S	47° 56' 07.4" W

Aeroporto Viracopos (AIR_Camp)			Fazenda Santa Maria (CONT_Camp)		
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	22° 59' 54.5" S	47° 09' 05.7" W	1	23° 05' 49.0" S	47° 08' 00.5" W
2	23° 00' 07.7" S	47° 08' 09.9" W	2	23° 05' 11.2" S	47° 08' 04.3" W
3	22° 59' 48.8" S	47° 09' 01.8" W	3	23° 05' 53.3" S	47° 07' 54.6" W
4	23° 00' 16.2" S	47° 08' 06.9" W	4	23° 05' 22.6" S	47° 08' 01.3" W
5	22° 59' 57.0" S	47° 08' 24.6" W	5	23° 05' 59.7" S	47° 07' 50.3" W
6	23° 00' 20.5" S	47° 07' 59.1" W	6	23° 05' 32.1" S	47° 08' 01.8" W
7	23° 00' 01.5" S	47° 08' 16.2" W	7	23° 05' 53.2" S	47° 07' 19.7" W
8	23° 00' 23.0" S	47° 07' 43.9" W	8	23° 04' 51.9" S	47° 08' 31.4" W
9	23° 00' 04.6" S	47° 08' 22.2" W	9	23° 05' 56.1" S	47° 07' 07.0" W
10	22° 59' 48.6" S	47° 08' 37.6" W	10	23° 05' 01.6" S	47° 08' 37.2" W
11	23° 00' 10.2" S	47° 08' 15.7" W	11	23° 05' 41.4" S	47° 07' 21.0" W
12	22° 59' 38.2" S	47° 08' 50.5" W	12	23° 04' 57.5" S	47° 08' 46.8" W

Aeroporto de Salvador (AIR_Sal)			Condomínio Buscavida (CONT_Sal)		
	Latitude	*Longitude*		*Latitude*	*Longitude*
1	12° 54' 27.4" S	38° 19' 36.6" W	1	12° 51' 40.4" S	38° 16' 14.2" W
2	12° 54' 18.3" S	38° 19' 21.6" W	2	12° 51' 47.1" S	38° 16' 29.4" W
3	12° 54' 28.6" S	38° 20' 01.7" W	3	12° 51' 36.0" S	38° 16' 06.1" W
4	12° 54' 31.1" S	38° 20' 10.9" W	4	12° 51' 50.4" S	38° 16' 19.1" W
5	12° 55' 17.5" S	38° 20' 23.0" W	5	12° 51' 35.6" S	38° 15' 57.6" W
6	12° 55' 00.5" S	38° 19' 45.1" W	6	12° 51' 24.7" S	38° 15' 50.5" W
7	12° 54' 40.6" S	38° 20' 34.0" W	7	12° 51' 08.1" S	38° 15' 53.9" W
8	12° 55' 02.2" S	38° 20' 14.1" W	8	12° 51' 16.3" S	38° 15' 48.7" W
9	12° 54' 21.7" S	38° 18' 27.2" W	9	12° 51' 22.7" S	38° 16' 22.5" W
10	12° 54' 18.5" S	38° 18' 46.9" W	10	12° 51' 20.4" S	38° 16' 30.9" W

SUPPLEMENTARY MATERIAL 2. Values of dawn chorus onset time, duration of singing period and song occurrence (population characteristics) in silent control sites, airport-affected sites and respective standardized effect difference (Hedge *d*) and index of song occurrence (air/cont). Values refer to 26 pairs of populations from 15 species in three regions (Brasília, Campinas and Salvador).

		Dawn chorus onset			**Duration of singing period**			**Song occurrence**		
Species	**Region**	**Cont**	**Air**	**Effect**	**Cont**	**Air**	**Effect**	**Cont**	**Air**	**Index**
Camptostoma obsoletum	BRAS	13.85	22.71	-0.796	15.38	24.44	-0.475	0.750	0.667	0.889
Camptostoma obsoletum	CAMP	23.83	43.00	-1.395	6.00	33.54	-2.201	0.542	0.292	0.538
Camptostoma obsoletum	SAL	10.88	16.50	-1.262	14.00	34.40	-1.118	0.500	0.150	0.300
Cyclarhis gujanensis	CAMP	22.38	33.20	-1.018	11.20	34.09	-2.090	0.917	0.208	0.227
Cyclarhis gujanensis	SAL	12.89	17.40	-0.656	41.16	47.56	-0.793	0.900	0.950	1.056
Elaenia chiriquensis	BRAS	-0.70	-17.14	1.188	251.84	89.81	1.453	0.917	0.958	1.045
Elaenia cristata	BRAS	27.64	23.70	0.274	34.26	29.83	0.206	0.958	0.958	1.000
Elaenia flavogaster	CAMP	7.79	13.88	-0.342	22.29	39.75	-0.706	0.667	0.292	0.438
Elaenia flavogaster	SAL	30.38	4.50	1.559	39.83	28.80	0.500	0.250	0.600	2.400
Furnarius rufus	CAMP	30.38	13.28	0.919	35.29	15.86	0.872	0.583	0.708	1.214
Furnarius rufus	SAL	20.77	14.73	0.276	43.54	42.67	0.036	0.450	0.650	1.444
Lepidocolaptes angustirostris	BRAS	-1.88	6.38	-0.638	37.83	42.17	-0.204	0.958	0.958	1.000
Myiarchus swainsoni	BRAS	-2.71	0.94	-0.160	33.71	52.40	-0.863	0.833	0.583	0.700
Neothraupis fasciata	BRAS	-2.86	-10.08	1.229	64.32	12.80	1.872	0.500	0.917	1.833
Pitangus sulphuratus	CAMP	36.00	45.14	-0.756	33.04	26.95	0.271	0.792	0.917	1.158
Pitangus sulphuratus	SAL	36.29	29.48	0.616	51.70	50.67	0.092	0.900	1.000	1.111

Tangara sayaca	CAMP	9.43	17.12	-0.713	31.39	41.55	-0.524	0.917	0.958	1.045
Tangara sayaca	SAL	21.00	5.42	0.715	51.22	32.00	0.844	0.500	0.900	1.800
Troglodytes musculus	BRAS	-0.56	33.25	-3.906	20.00	189.48	-1.835	0.958	0.167	0.174
Troglodytes musculus	CAMP	18.71	22.06	-0.211	69.13	67.19	0.027	0.875	0.667	0.762
Troglodytes musculus	SAL	19.00	-4.11	1.260	122.13	30.91	0.896	0.550	0.750	1.364
Turdus leucomelas	CAMP	1.26	10.00	-0.991	26.47	41.00	-0.690	1.000	0.708	0.708
Turdus leucomelas	SAL	-5.00	-1.89	-0.269	49.68	38.82	0.401	0.850	0.950	1.118
Tyrannus melancholicus	CAMP	12.00	4.95	0.370	51.44	31.00	0.739	0.250	0.750	3.000
Tyrannus melancholicus	SAL	9.67	5.00	0.180	52.82	35.14	0.634	0.700	0.850	1.214
Zonotrichia capensis	CAMP	-3.08	10.48	-1.113	38.83	58.14	-0.998	0.917	0.750	0.818

SUPPLEMENTARY MATERIAL 3. Values of song frequency (species' mean peak frequency), eye size, urbanity (species characteristics), actual noise reduction, potential noise reduction and light increase (environment characteristics), for 26 pairs of populations from 15 species in three regions (Brasília, Campinas and Salvador).

Species	**Region**	**Song frequency**	**Eye size**	**Urbanity**	**Actual noise reduction**	**Potential noise reduction**	**Light increase**
Camptostoma obsoletum	BRAS	3809.22	3.22	-0.108	-0.678	1.502	-0.672
Camptostoma obsoletum	CAMP	3809.22	3.22	-0.108	-0.703	0.989	0.882
Camptostoma obsoletum	SAL	3809.22	3.22	-0.108	-0.214	0.633	-1.018
Cyclarhis gujanensis	CAMP	2861.22	9.78	0.131	-0.436	1.008	0.882
Cyclarhis gujanensis	SAL	2861.22	9.78	0.131	-0.174	0.653	-0.911
Elaenia chiriquensis	BRAS	3213.27	4.60	-0.540	1.2139	1.473	-0.800
Elaenia cristata	BRAS	3496.40	5.94	-0.698	0.304	1.529	-0.392
Elaenia flavogaster	CAMP	3358.60	5.89	0.013	-0.312	1.197	0.873
Elaenia flavogaster	SAL	3358.60	5.89	0.013	1.032	0.828	-0.706
Furnarius rufus	CAMP	2271.06	10.35	0.267	0.756	0.904	0.860
Furnarius rufus	SAL	2271.06	10.35	0.267	0.241	0.732	-0.651
Lepidocolaptes angustirostris	BRAS	2522.79	6.73	0.168	-0.618	1.470	-0.800
Myiarchus swainsoni	BRAS	2412.95	8.85	-0.472	-0.272	1.469	-0.800
Neothraupis fasciata	BRAS	3173.34	7.68	-0.722	0.534	1.468	-0.800
Pitangus sulphuratus	CAMP	3409.15	15.83	0.156	-0.293	0.831	0.887
Pitangus sulphuratus	SAL	3409.15	15.83	0.156	0.324	0.887	-0.535

Tangara sayaca	CAMP	5887.18	8.31	0.254	-0.382	1.176	0.873
Tangara sayaca	SAL	5887.18	8.31	0.254	0.588	0.734	-0.658
Troglodytes musculus	BRAS	3898.64	4.49	0.044	-2.580	1.473	-0.800
Troglodytes musculus	CAMP	3898.64	4.49	0.044	-0.151	1.055	0.862
Troglodytes musculus	SAL	3898.64	4.49	0.044	0.807	0.714	-0.651
Turdus leucomelas	CAMP	2375.59	14.95	0.046	-0.478	1.282	0.915
Turdus leucomelas	SAL	2375.59	14.95	0.046	-0.091	0.474	-0.903
Tyrannus melancholicus	CAMP	6070.09	10.53	0.155	0.372	1.143	0.851
Tyrannus melancholicus	SAL	6070.09	10.53	0.155	0.162	0.621	-1.048
Zonotrichia capensis	CAMP	4043.92	5.90	-0.337	-0.759	1.339	0.966

CAPITULO 3- Resposta hormonal das aves (corticosterona) ao ruído de aeroportos

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Avian stress responses to airport noise as measured by feather corticosterone concentration

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ABSTRACT

Noise represents a threat to human and wildlife health, triggering physiological and behavioral challenges to individuals living close to sources of extreme noise. We evaluated the physiological response of 19 bird species living in three Brazilian airport surroundings, and compared levels of corticosterone deposited on feathers to those of birds living in silent control sites in similar landscapes. The interaction between feather corticosterone ($CORT_f$) concentration and species identity was significant, indicating that the $CORT_f$ response to noise is very species-specific. We found significant changes of $CORT_f$ concentration in four species, as two of them (*Cyclarhis gujanensis* and *Turdus rufiventris*) presented increased levels and two species (*Troglodytes musculus* and *Coryphospingus cucullatus*) presented reduced levels of $CORT_f$ in airport-affected sites. The remaining 15 species presented no significant changes. We also found no relationship between changes in $CORT_f$ concentration among species-specific characteristics (song frequency and degree of urbanity) or population characteristics (occurrence and body condition). Disruptions in physiological response, in both directions, are considered pathological signals of disturbances. When the HPA axis presents either super stimulation or down regulation, consequences for individuals are generally associated to jeopardized fitness, survival, and/or immunity. Although a species-specific response, noise is capable of disrupting animal health, representing a challenge for species conservation in a world that is continuously increasing human noise production.

Key-words: Aircraft, birds, Brazil, hormones, physiology.

INTRODUCTION

Urban development, roads, industries and airports are sources of a great amount of noise, resulting in health challenges for many noise-sensitive organisms. Airports produce an extreme type of noise that threatens human health by increased risk of hypertension, psychological and sleep disturbances, increased catecholamine secretion, and impaired cognitive performance in children (Stansfeld and Matheson 2003; Stansfeld et al. 2005; Nunes and Slatter 2006; Jarup et al. 2008; Finegold 2010; Floud et al. 2013). In birds, anthropogenic noise has been associated with reduced individual and population fitness, including decreases in the number of nesting species (Francis et al. 2009), reduced nest success (Hayward et al. 2011; Strasser et al. 2013), higher nest predation rate (Crino et al. 2011), smaller clutch size (Halfwerk et al. 2011), and reduced hatching success (Kleist et al. 2018). However, different species vary in their responses to noise, so that some of them are more likely to abandon noisy areas (Francis 2015), while others are less susceptible to noise disturbance (e.g *Passer domesticus*, Angelier et al. (2016)).

Birds rely strongly on vocal communication for the maintenance of social interactions, mate attraction, adult-offspring communication, territory defense, and group cohesion (Hultsch and Todt 1982; Kunc et al. 2005; Wood and Yezerinac 2006; Catchpole and Slater 2008). Noise greatly masks the frequency bands most used by birds, disrupting communication and reducing birds' ability to perceive predators and assess other risky situations (Quinn et al. 2010; Klett-Mingo et al. 2016). Additionally, enduring exposure to noise can in some situations induce chronic stress condition in birds (Kleist et al. 2018).

Stress can be defined as a set of behavioral and physiological responses that help an individual restore systemic homeostasis when exposed to noxious stimuli, such as predator exposure, shortage of food resources, competition, and unfavorable climatic conditions, among other possibilities (Buchanan 2000; Romero 2004; Costantini 2008; Dantzer et al. 2014). Physiological responses to stressors are usually measured through concentrations of glucocorticoid hormones in blood stream (Sapolsky et al. 2000; Romero 2004); in birds, corticosterone (CORT) is the hormone analogous to cortisol in mammals. CORT release is induced by the hypothalamic-pituitary-adrenal (HPA) axis, which controls responses to stressful events and regulates the metabolic processes involved in system restauration (Sapolsky 1992; Lendvai et al. 2013). When threats are occasional, CORT release helps individuals to deal with risky situations (Wingfield and Kitaysky 2002). However, when noxious stimuli is continuous, the stress response can become detrimental in terms of the individual's breeding activities, survival and cognitive ability (Sapolsky et al. 2000; Kitaysky et al. 2003).

Due to ambiguities in the use and misinterpretation of the concept of stress in the literature, Romero et al. (2009) proposed the "Reactive Scope Model" to summarize the several physiological responses associated to exposure to noxious stimuli, based on a previous model proposed by McEwen and Wingfield (2003). The model presents four levels of physiological responses, involving a normal reactive scope (points 1 and 2 below) and pathological effects (3 and 4 below), using the concepts of homeostasis (maintenance of physiological stability) and allostasis (physiological mechanisms that maintain the homeostasis). (1) Predictive Homeostasis: changes in hormones levels due to predictable changes, such as circadian and seasonal variations; (2) Reactive Homeostasis: changes due to unpredictable and short-term changes (which we usually called acute stress), such as predator exposure and food shortage; (3) Homeostatic Overload: changes that exceed the normal reactive scope and cause physiological disruption (usually called chronic stress), with hormones levels above the reactive homeostasis range; and (4) Homeostatic Failure: changes that cause physiological disruption and death, with hormone levels below the predictive homeostasis range.

Hormone measurements include baseline and stress-induced levels of CORT. Baseline level measurements are those conducted without external interferences while measurement of stress-induced levels of CORT are those done under external interference when the individual is under acute stress, including contexts of bird manipulation (Partecke et al. 2006) and food restriction (Patterson et al. 2014). There are several ways to measure CORT levels, including instantaneous measures (e.g. blood and saliva samples) reflecting hormone levels in a restricted and specific period, and integrated measures (e.g. feces, urine, fur, feathers) reflecting CORT levels that have been produced and/or deposited during a lengthier period of time (Sheriff et al. 2011).

The technique for extraction and measurement of feather corticosterone ($CORT_f$) was described in 2008 (Bortolotti et al. 2008) and is still not fully explored, but has been extensively used in the last few years. CORT metabolites are deposited in feathers during growth, when feather structures are being irrigated by blood (Jenni-Eiermann et al. 2015). When feather growth is finished, the keratinized tissue preserves the stored CORT (Bortolotti et al. 2008), where it remains stable for several years, resisting to heat and freezing (Bortolotti et al. 2009a). $CORT_f$ represents a long-term hormone assessment, is less invasive than blood measurements, not influenced by researcher bird manipulation, and is considered a promising technique for studies in avian stress physiology and conservation (Bortolotti et al. 2009a; Sheriff et al. 2011; Fairhurst et al. 2013; Dantzer et al. 2014).

Some studies have tested whether $CORT_f$ reflects plasmatic CORT ($CORT_p$) levels. In Bortolotti et al. (2008), $CORT_f$ levels was correlated with stress-induced, but not baseline $CORT_p$ levels in adult red-legged partridges (*Alectoris rufa*), experimentally submitted to a stress-inducing protocol. In another example, adult European starlings (*Sturnus vulgaris*) given subcutaneous CORT capsules presented higher $CORT_f$ levels than individuals that were not supplemented with the hormone (Lattin et al. 2011). However, in this latter study, different sections of the feather did not represent the exact period of hormone increase, and feathers were of lower quality when grown under higher hormone levels. In fact, recent studies that have examined the relation between plasmatic and feather CORT levels (Fairhurst et al. 2013; Patterson et al. 2014) leads to the important conclusion that CORT_f typically does not represent the exact values of CORT_p, since it reflects cumulative exposures to different levels of CORT. Consequently, CORT_f can be considered as a long-term record of the HPA activity (Bortolotti et al. 2008; Bortolotti et al. 2009b; Fairhurst et al. 2013; Romero and Fairhurst 2016).

Animal responses to stressful conditions have been studied and reviewed by many authors, but the field has yet to achieve a consensus with respect to the expected direction of physiological responses (see reviews on acute response *vs*. fitness: Breuner et al. (2008), baseline levels *vs*. fitness: Bonier et al. (2009), glucocorticoids *vs*. conservation issues: Busch and Hayward (2009), glucocorticoids *vs*. urbanity: Bonier (2012), and chronic stress Dickens and Romero (2013)). However, a pattern of higher levels of baseline and fecal CORT has been found across vertebrate taxa for individuals exposed to urban disturbance (Dantzer et al. 2014).

Only nine studies have evaluated the link between noise pollution and CORT levels in birds, and most of them have evaluated stress responses based on a capture-restraint protocol (Wingfield et al. 1982), evaluating baseline and stress-induced levels of CORT in plasma, or only baseline levels assessed from feces samples (Table 1). These studies do not show a clear pattern for birds´ stress response to noise disturbance. A few studies suggest that species that are more common in cities exhibit no changes in baseline CORT levels and/or no changes in body condition compared to the same species in quiet areas (e.g. song sparrow (*Melospiza melodia*): Grunst et al. (2014); house sparrow (*Passer domesticus*): Angelier et al. (2016); house wren (*Troglodytes aedon*): Davies et al. (2017)). Conclusions based on the remaining studies are ambiguous, because baseline and stress-induced levels of CORT in urban birds were either higher or lower than in birds in silent areas (Crino et al. 2011; Hayward et al. 2011; Blickley et al. 2012; Crino et al. 2013; Strasser et al. 2013; Kleist et al. 2018). Thus, we

Table 1. Summary of papers relating noise to altered levels of CORT. All studies were conducted during the breeding season.

Type of noise	Species	Age Sex	Tissue	Type of response	Response (CORT)	Other	Reference
Traffic (real road)	Mountain white-crowned sparrow (*Zonotrichia leucophrys*)	7 days old	Blood	Baseline Stress-induced	Higher Higher	Bigger nestlings Higher predation	Crino et al 2011
Motorcycle (experimental)	Northern spotted owl (*Strix occidentalis*)	Adult Male	Feces	Baseline	Higher	Decreased reproductive success	Hayward et al 2011
		Adult Female			Lower	Compromised nutrition	
Industrial/trucks (experimental)	Greater sage-grouse (*Centrocercus urophasianus*)	Adult Male	Feces	Baseline	Higher	Reduced attendance to leks	Blickley et al 2012
Traffic (experimental)	Mountain white-crowned sparrow (*Zonotrichia leucophrys*)	5 days old	Blood	Baseline Stress-induced	Null Lower	Better body condition	Crino et al 2013
Traffic (real road)	American kestrel (*Falco sparverius*)	Adult Female	Blood	Baseline	Higher	Nest abandonment	Strasser and Heath 2013
Urban noise (real city)	Song sparrow (*Melospiza melodia*)	Adult Male	Blood	Baseline Stress-induced	Null Lower	Higher feather quality Higher density in city	Grunst et al 2014
Traffic (experimental)	House sparrow (*Passer domesticus*)	9 days old	Blood	Baseline Stress-induced	Null Null	No changes in body condition	Angelier et al 2016
Traffic (experimental)	House wren (*Troglodytes aedon*)	Adult	Blood	Baseline Stress-induced	Higher Null	No changes in body condition	Davies et al 2017
Natural gas fields (real)	Western bluebird (*Sialia Mexicana*)	Adult Female	Blood	Baseline	Lower	Lower hatching success Reduced body condition	Kleist et al 2018
	Mountain bluebird (*Sialia currucoides*)	12 days old		Baseline	Lower		
	Ash-throated flycatchers (*Myiarchus cinerascens*)			Stress-induced	Higher		

continue having a paltry understanding of how different species deal with noise at a physiological level.

Here, we test the hypothesis that birds living in airport environments are exposed to more stressful stimuli than birds living in silent sites. We used measurements of corticosterone in feathers to evaluate differences in $\mathrm{CORT_f}$ concentration, and predicted that birds in airport areas subjected to chronic stress would exhibit lower body condition and smaller population size, and that species with lower song frequency and lower affinity to urban environments would be more susceptible to noise and thus more likely to be chronically stressed. Chronic stress is here defined as lower or higher levels of corticosterone in airport-affected sites in relation to control sites (standard concentration), according to the Reactive Scope Model (Romero et al. 2009).

METHODS

Study sites

As previously described in chapter one, our field data were collected in three Brazilian airports, selected based on their high aircraft activity and availability of native vegetation around the lanes. For each airport-affected site, we selected a silent control site, with similar vegetation structure, at distances ranging from 8 to 17 km from each airport. Studied airports are Presidente Juscelino Kubitschek International Airport (AIR_Bras: 15°52'19.4"S 47°55'11.9"W) in Brasília (DF), Viracopos International Airport (AIR_Camp: 23°00'24.4"S 47°08'30.0"W) in Campinas (São Paulo state) and Luís Eduardo Magalhães International Airport (AIR_Sal: 12°54'42.8"S 38°19'44.2"W) in Salvador (Bahia state). For each of these airports we chose the following silent control sites: “Parque Nacional de Brasília” (DF) (CONT_Bras: 15°43'18.1"S 47°58'14.4"W), a private farm named “Fazenda Santa Maria” (SP) (CONT_Camp: 23°05'53.2"S 47°07'49.8"W), and a residential area with large protected areas named “Condomínio Buscavida” (BA) (CONT_Sal: 12°51'30.0"S 38°16'08.0"W) (See Fig 2 in Chapter One).

Ambient noise and light measurements

We measured noise levels by transforming sound files acquired with automatic recording units (ARU) SONGMETER SM2+ (Wildlife Acoustics 2007-2011) into sound level measurements, using TOL metric (1/3-octave band levels). Analyses showed that all airport-affected sites had higher levels of noise amplitude, with the larger differences found in bands 501.1 Hz (Linear Mixed Model (LMM): estimate = -0.283, p < 0.001) and 1000 Hz (LMM estimate = -0.293, p < 0.001). The paired sites in Brasília presented the highest differences in noise levels in the 1000 Hz band (Brasília: LMM estimate = -0.297, p < 0.001; Campinas: LMM estimate = -0.253, p < 0.001; and Salvador: LMM estimate = -0.167, p < 0.001). Mean amplitude levels for the three airport-affected sites between -100 and 60 min after sunrise at 1000 to 2000 Hz frequency band (52.55dB ±sd 8.20) is approximately 28% higher than the mean amplitude levels found in the silent control sites (40.99 dB ±sd 3.52)
(for analyses details, see chapter one).

Field data collection

We captured birds with mist nests during their breeding seasons: in Brasília during October/2014 and November/2015; in Campinas during November-December/2014; and in Salvador during December/2015-January/2016. In airports, mist-nets were set at a maximum distance of 250 m from flight lanes, and in control sites, they were set without restrictions. We standardized samplings using 10 mist-nets, during 10 mornings in each site, opened for 5 hours during the morning. Additionally, we conducted directional captures using isolated nets and a playback stimulus to attract the bird (Fokidis et al. 2009), in order to increase the sample size of specific species, balancing the number of individuals captured in airport and control sites.

Captured birds were banded with numbered metal bands (provided by CEMAVE-ICMBio) and measured (weight, tarsus length, wing length, tail length, and total length). Additionally, we collected two to three feathers from each individual's tail and stored them in identified paper bags for later analysis. In the Cerrado biome, birds molt after the breeding season (Silveira and Marini 2012), thus the collected feathers are representative of $CORT_f$ deposited at the end of the preceding breeding season. All procedures were approved by the University's Ethics Committee (See thesis Supplementary Material).

Feather processing and $CORT_f$ analyses

Each feather was individually weighted and measured for length (excluding calamus), and cut into very small pieces (< 2 mm). For each sample, we used from 1-3 feathers from the same individual, and this material was weighed with a high precision balance to the nearest 0.001 g. As species' feathers are highly variable in length and width, a single feather from *Mimus gilvus* can have 109 mm and 33.3 mg, while a single feather from *Volatinia jacarina* can have 42 mm and 4.4 mg. In this cases in which each individual bird feather material was too small to provide a reliable assay (e.g. *Volatinia jacarina*, *Ammodramus humeralis*, *Troglodytes musculus*), we decided to pool 2-3 individual's material into a single sample (up to 6 feathers). Pooled materials belong to individuals from the same species and from the same site and region. Samples varied between 15 to 35 mg of total weight, and 65 to 400 mm of total length.

We conducted a methanol-based hormone extraction following Bortolotti's protocol (Bortolotti et al. 2008; Bortolotti et al. 2009a), including adjustments suggested by Lattin et al. (2011). The cut-up feather samples were placed in silanized glass tubes (to increase hormone recovery), to which we added 6 ml of methanol (HPLC gradient grade, Prolabo (VWR), Pennsylvania, USA). The samples were then placed in a sonicating water bath at room temperature for 30 min, followed by incubation at 50 ºC overnight (18 hours) in a shaking water bath. We added an additional 2 ml of methanol to the samples, which were quickly centrifuged, and then separated the liquid from feathers using a disposable syringe and a plug of synthetic polyester fiber (0.45 µm) for filtration. The methanol extract was placed in a new silanized glass tube and evaporated in a fume hood using a stream of nitrogen. After complete evaporation, we added 300 µl of steroid free serum (DRG Instruments GmbH, Marburg, Germany), quickly centrifuged the samples, stored the new extracts in plastic tubes, and then froze them at -20 ºC for subsequent CORT analysis.

We ran a corticosterone enzyme immunoassay (EIA) using a CORT specific kit (DRG Instruments GmbH, Marburg, Germany), and read the plates in a Biotek spectrophotometer (Biotek Instruments, Inc, Winooski, Vermont, USA). Absorbance was read at a wavelength of 450 nm. Samples were assayed in duplicates, and $CORT_f$ concentration was averaged from the two samples after regression of the standard curve of each plate.

Intra-assay variation was calculated as the mean variation between duplicates (8.7%, n=642 samples), and inter-assay variation was calculated as the mean of mean variation between lower and higher control concentrations of each plate (12.1%, n = 17 plates). Feather hormone values are expressed as a function of each sample´s total feather length (pg/mm), but were also estimated as a function of each sample´s total mass (pg/mg). Most studies indicate that expressing hormone level in terms of feather length is a more appropriate approach (Bortolotti et al. 2008; Bortolotti et al. 2009a; Jenni-Eiermann et al. 2015), however, some studies still express hormone values in terms of feather mass (Koren et al. 2011; Lendvai et al. 2013). Laboratory analyses were conducted in the Ecophysiology Lab of the Museo Nacional de Ciencias Naturales (Madrid, Spain), from September-November of 2016.

Predictor variables

For our statistical analyses (see section below), we used four predictor variables based on field data from the airport-affected and control sites in the three study regions. **Song occurrence** was used as a proxy for population size in each site. It was estimated based on recordings obtained using automated recording units (ARU) SONGMETER SM2+ (Wildlife Acoustics 2007-2011) installed in the study sites. This value was calculated by dividing the number of mornings that each species was detected in a site by the total number of mornings sampled at the site (Joo et al. 2011). The value was included in the model as a ratio (Song occurrence airport/control), where values below 1 represent higher occurrence in airports than in control sites, and values above 1 represent lower occurrence in airports than in control sites. **Body condition** was estimated from the residuals of a linear regression between body mass and tarsus length (Rubenstein 2007) of captured individuals, and transformed in "standardized effect difference" between airport and control sites (i.e. Hedge's *d*; Nakagawa and Cuthill (2007)), where positive values indicate a better body condition in the airport than in the control site, and negative values the reverse trend. **Song frequency** represents the acoustic space occupied by each species. We selected 5 recordings of each species and used Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY) to measure acoustic parameters from 20 songs, using a fixed FFT of 1024. We measured peak (dominant) frequency for each species, which is the frequency concentrating the most amplitude (energy) (See Thesis Supplementary Material). **Urbanity** represents the degree of association of each species to urban environments. To this end, we collected data on species´ occurrence in Brazil using the eBird database (eBird 2017) and ran models taking into account detection probabilities to determine the difference in occupancy between urban and natural areas (See Thesis Supplementary Material). For the models used here, we used the value of the Z statistic as a representation of the degree of urbanity for each species, where high positive Z values are associated with species that exhibit some degree of preference for urban habitats while low negative values are associated with species that exhibit some degree of avoidance for urban environments (APPENDIX A).

In this study, we did not consider possible differences in $\mathrm{CORT_f}$ concentration due to life stage, seasonal variation, or sex (Bonier et al. 2006; Romero et al. 2006; Crossin et al. 2013). We collected feathers exclusively from adult birds, thus having grown during the same annual time interval for each species. This excludes possible molts due to feather loss occurring through exceptional circumstances, such as in aggressive interactions or accidents. We also disconsidered possible differences related to sex, because the great majority of analyzed species present no sexual dimorphism (exceptions are *Volatinia jacarina* and *Coryphospingus cucullatus*).

Statistical analyses

Statistical analyses were performed in R version 3.3.2 (R Development Core Team 2016), and significance was considered for $p < 0.05$. $\mathrm{CORT_f}$ concentration was normalized by log transformation, and re-scaled. We ran an exploratory linear mixed model (LMM) (random factors = (1|Plate) and (1|Region)), where variables "Treatment", "Species", and their interaction were included as factors, and the significance value (p) was calculated with a post-hoc analysis of deviance (type 3). We assessed species-specific responses by testing whether individuals living in airport-affected sites presented changes in $\mathrm{CORT_f}$ in relation to individuals living in silent control sites. We ran separate LMMs for each species (random factors = (1|Plate) and (1|Region)), and calculated significance values (p) by a post-hoc analysis of deviance (type 3). When species data was relative to a single plate and/or to a single region, we ran simpler linear models with no random structure. To run these analyses we used packages "*AID*" (Asar et al. 2016), "*lme4*" (Bates et al. 2015), and "*car*" (Fox and Weisberg 2011).

Subsequently, using a LMM (random factors = (1|Region) and (1|Species)) we tested whether CORT$_f$ concentration (represented by standardized effect difference) could be explained by population (song occurrence and body condition) and species characteristics (song frequency and urbanity). We evaluated each species´ responses in each region, considering that occurrence and body condition differ among regions. We used the "dredge" and "model average" functions to summarize the best models results, ranking models by Akaike's Information Criteria (AICc) and considering models within ΔAIC < 3. Data were normalized using log transformation, followed by scaling. To run these analyses we used additional packages "*MuMIn*" (Barton 2016), and "*AICcmodavg*" (Mazerolle 2016).

RESULTS

We captured and collected feathers from 1187 individuals within the six sampled sites, totaling 124 species. However, due to reduced sample size for some species, we considered data only for 19 species, totaling 821 analyzed individuals and 643 samples (since we polled some individual's material, as described above). CORT$_f$ concentrations varied from 0.76 ng mm^{-1} to 182.86 ng mm^{-1} (mean = 7.25 ng mm^{-1}; sd = 11.76).

We found a significant difference in the interaction treatment * species (*post-hoc* Anova: $X^2 = 42.63$, df = 18, $p < 0.001$) (Table 2), indicating species-specific differences between treatments. In the species-specific models, two species presented significantly increased CORT$_f$ levels, and two species presented reduced CORT$_f$ levels in the airport-affected sites. The rufous-browed peppershrike (*Cyclarhis gujanensis*; estimate = 0.95; p = 0.01), and the rufous-bellied thrush (*Turdus rufiventris*; estimate = 1.03; p = 0.04) presented increases, while the southern house wren (*Troglodytes musculus*; estimate = -0.43; p = 0.01), and the red-crested finch (*Coryphospingus cucullatus*; estimate = -0.89; p = 0.04) presented

Table 2. Linear mixed model values, including estimates, standard error, chi-square values (X^2), and *p* values for intercept and treatment (airport). Mean CORT_f concentration values are shown for 19 species in airport-affected and silent control sites, including sample size (*N*). Region refers to populations included in the sample (BRAS=Brasília, CAMP=Campinas, SAL=Salvador, and ALL=all regions), and (1|region) or/and (1|plate) indicates which variables were used as random variables for each species-specific model. Species are presented in phylogenetic order.

Linear Mixed Models					**CORT_f concentration (pg mm^{-1})**			
	Estimate	**SE**	X^2	***p* value**	**Airport**	***N***	**Control**	***N***
All								
Intercept	-0.078	0.46	0.002	0.865				
Treatment-Airport	-0.300	0.06	0.403	0.525				
Species	--	--	82.711	<0.001				
Treatment*Species	--	--	42.639	<0.001				
1.*Columbina talpacoti* (ALL) (1|region)								
Intercept	0.571	0.53	1.130	0.288	6.436 ± 1.7	6	10.119 ± 7.2	4
Treatment-Airport	-0.833	0.60	1.895	0.169				
2.*Eupetomena macroura* (SAL) (1|plate)								
Intercept	1.433	1.54	0.857	0.355	3.550 ± 1.3	10	3.477 ± 0.8	8
Treatment-Airport	-0.302	0.36	0.674	0.412				
3.*Synallaxis frontalis* (BRAS and SAL) (1|region)+(1|plate)								
Intercept	-0.348	0.38	0.807	0.369	8.035 ± 5.0	18	5.629 ± 4.1	8
Treatment-Airport	0.581	0.41	1.921	0.166				
4.*Elaenia cristata* (BRAS) (1|plate)								
Intercept	0.160	0.32	0.239	0.625	5.993 ± 3.3	16	7.672 ± 4.3	17
Treatment-Airport	-0.453	0.34	1.730	0.188				
5.*Elaenia chiriquensis* (BSB) (1|plate)								
Intercept	-0.350	0.38	0.842	0.359	5.901 ± 3.5	22	3.922 ± 2.1	37
Treatment-Airport	0.560	0.38	2.142	0.143				
6.*Suiriri suiriri* (BRAS)								
Intercept	-0.584	0.37	-1.555	0.181	6.879 ± 2.3	3	3.927 ± 0.71	4

Treatment-Airport	1.362	0.57	2.375	0.064				
7.Myiarchus swainsoni (BRAS and CAMP) (1|region)+(1|plate)								
Intercept	-0.759	0.70	1.174	0.279	6.934 ± 2.7	10	7.750 ± 5.0	25
Treatment-Airport	-0.192	0.33	0.323	0.570				
8.Pitangus sulphuratus (SAL) (1|plate)								
Intercept	0.084	0.37	0.050	0.823	12.444 ± 12.7	54	9.112 ± 4.9	10
Treatment-Airport	0.207	0.38	0.295	0.587				
9.Cyclarhis gujanensis (1|region)+(1|plate)								
Intercept	-0.252	0.50	0.253	0.615	15.550 ± 11.4	10	6.466 ± 4.3	10
Treatment-Airport	0.950	0.38	6.017	0.014				
10.Troglodytes musculus (ALL) (1|region)+(1|plate)								
Intercept	0.255	0.47	0.290	0.590	13.643 ± 24.3	35	23.274 ± 34.7	32
Treatment-Airport	-0.436	0.18	5.604	0.018				
11.Turdus leucomelas (ALL) (1|region)+(1|plate)								
Intercept	-0.056	0.39	0.020	0.886	4.983 ± 3.3	41	4.199 ± 2.65	31
Treatment-Airport	0.176	0.26	0.442	0.506				
12.Turdus rufiventris (ALL) (1|region)+(1|plate)								
Intercept	-0.397	0.31	1.588	0.208	5.997 ± 1.5	5	4.682 ± 0.9	8
Treatment-Airport	1.032	0.50	4.129	0.042				
13.Mimus gilvus (SAL)								
Intercept	0.716	0.47	1.523	0.188	5.928 ± 1.1	4	7.686 ± 0.9	3
Treatment-Airport	-1.252	0.62	-2.015	0.100				
14.Zonotrichia capensis (CAMP)								
Intercept	-0.064	0.26	-0.243	0.811	8.654 ± 9.1	8	7.162 ± 4.9	17
Treatment-Airport	0.201	0.46	0.431	0.671				
15.Ammodramus humeralis (BRAS and CAMP) (1|region)								
Intercept	0.133	0.47	0.080	0.777	3.435 ± 0.6	5	4.492 ± 3.4	5
Treatment-Airport	-0.266	0.66	0.160	0.689				

16.Tangara sayaca (ALL) (1|region)+(1|plate)								
Intercept	0.260	0.21	1.537	0.215	4.273 ± 2.2	32	5.446 ± 2.9	22
Treatment-Airport	-0.439	0.27	2.593	0.107				
17.Volatinia jacarina (BRAS and CAMP) (1|region)+(1|plate)								
Intercept	-0.323	0.31	1.062	0.303	2.971 ± 1.4	48	2.524 ± 1.1	14
Treatment-Airport	0.483	0.30	2.579	0.108				
18.Coryphospingus cucullatus (CAMP) (1|plate)								
Intercept	0.283	1.06	0.071	0.790	4.777 ± 2.0	20	3.736 ± 1.7	10
Treatment-Airport	-0.895	0.44	3.977	0.046				
19.Coereba flaveola (BRAS and SAL) (1|region)+(1|plate)								
Intercept	0.179	0.24	0.555	0.456	1.787 ± 0.7	10	2.052 ± 0.6	17
Treatment-Airport	-0.483	0.39	1.500	0.221				

decreases in $\mathrm{CORT_f}$. The remaining species presented no significant changes in $\mathrm{CORT_f}$ levels between airport-affected and control sites (Table 2).

We ran additional linear models for each species, using $\mathrm{CORT_f}$ based on feather mass, and correlated estimates from models of $\mathrm{CORT_f}$ based on feather mass *vs*. length. $\mathrm{CORT_f}$ values from both measurements were highly and significantly correlated ($r = 0.96$, $t = 90.32$, df = 624, $p < 0.001$), and the same pattern was observed for the estimates values of models ($r = 0.97$, $t = 18.44$, df = 17, p <0.001). In our analysis, measurements of feather mass are more precise than measurements of feather length, but as they are highly correlated, we chose to present values of feather length to be in accordance with literature (Bortolotti et al. 2009a; Lattin et al. 2011).

In the model selection procedure that explored whether $\mathrm{CORT_f}$ concentrations in the different populations could be explained by population and/or species characteristics, we found that the null model presented the lowest AIC and all other models presented ΔAIC > 3, offering no support for an effect of the tested variables on $\mathrm{CORT_f}$ concentration (Table 3).

Table 3. Model selection results (LMM) for $\mathrm{CORT_f}$ concentration (standardized effect difference) as the dependent variable. Including intercept estimate, body condition (standardized effect difference), song occurrence, song frequency, and urbanity; degrees of freedom, values for corrected (AICc) and delta (ΔAIC) Akaike’s information criteria, and model weight (Random variables: Species and Region). Only the first six best models are presented.

Intercept	**Body condition**	**Occur**	**Song frequency**	**Urbanity**	**df**	**AICc**	**ΔAIC**	**Weight**
0.0355					4	73.4	0.00	0.629
0.0605				0.148	5	77.1	3.73	0.097
0.0401			0.034		5	77.4	3.98	0.086
0.0257		0.158			5	77.5	4.10	0.081
0.0281	0.102				5	78.3	4.89	0.055
0.0632			0.200	0.146	6	81.4	8.05	0.011

DISCUSSION

Stress induced by noise has been investigated in recent years for few bird species, achieving no consensus response so far. Here, we evaluated corticosterone deposited in feathers as a long-term measure of stress response in 19 bird species living in Brazilian airport-affected sites. We found that species´ response to airport noise is variable and species-specific. Exploring individual species, we found that four species exhibited significant changes in $CORT_f$ levels, with changes represented either by lower or higher levels of $CORT_f$ in airport-affected sites. The variables body condition, song occurrence, song frequency, and urbanity did not explain the differences in $CORT_f$ concentration among the populations.

Species-specific responses to noisy environments vary greatly among species (Francis and Barber 2013), presenting a difficult and additional obstacle to determine an expected corresponding physiological response to this disturbance. In our study, the rufous-browed peppershrike (*C. gujanensis*) and the rufous-bellied thrush (*T. rufiventris*) exhibited increased levels of $CORT_f$ in airport-affected areas, showing a typical stress response and matching results from several studies of birds, fishes, and humans in response to noise as a stressor (Evans et al. 2001; Anderson et al. 2011; Crino et al. 2011; Kight and Swaddle 2011; Strasser et al. 2013). This increased hormone level is classified as a stage of homeostatic overload (Romero et al. 2009), which can result in greater individual susceptibility to parasite infections (Bortolotti et al. 2009b) and decreased survival in the wild (Koren et al. 2011).

On the other hand, the southern house wren (*T. musculus*) and the red-crested finch (*C. cucullatus*) presented reduced levels of $CORT_f$ in airport-affected areas. Reductions in CORT concentrations can be observed in individuals experiencing homeostatic failure (Romero et al. 2009), a more severe state of chronic stress, which has also been shown to be related to lower reproductive success (Kleist et al. 2018). For instance, two studies using captive European starlings (*Sturnus vulgaris*), which were exposed to a protocol of several sequential stressful conditions for 18-20 days (e.g. noise, cage disturbance, restrain), found lower basal and stress-induced plasmatic levels of CORT during the stress protocol (Rich and Romero 2005; Cyr et al. 2007). This chronically stressed state also induced body weight reductions in both studies, and hormone basal levels slowly recovered to initial levels after the end of stress protocol. The authors discarded the possibilities of results occurring due to habituation to the stressor and exhaustion, and claimed that the response must be a controlled systemic downregulation of HPA activity (Rich and Romero 2005). The same research group investigated the response to a similar stress protocol for free-living breeding females. They were able to associate the lower basal levels of CORT found in stressed females to lower fledging success (Cyr and Romero 2007). The nestlings reared by these stressed females presented higher levels of stress-induced CORT (restrain protocol), a possibly permanent and deleterious condition for nestlings exposed to higher levels of CORT during development (Love et al. 2005; Saino et al. 2005). Another study also found lower levels of baseline CORT in animals exposed to high levels of urbanization, this time in tree lizards (*Urosaurus ornatus*) (French et al. 2008). The study offered three possible explanations for the reduced baseline CORT levels found: (1) a response of acclimation to a repeated stressor; (2) a real reduction of stress conditions due to higher resource availability; or (3) a state of chronic stress.

Studies reporting no changes or decreases in CORT concentration may be underrepresented in the literature, which could be the reason for the assumption that only increases in CORT are indicative of a stressful condition (Dickens and Romero 2013). As measurements of CORT in feathers represent an integrated measurement of both baseline and stress induced levels of the hormone (Bortolotti et al. 2008), they appear as a more consistent way to assess the natural variation of the hormone. Additional ways to support the conclusion that reduced CORT$_f$ levels may be indicative of chronic stress would be to evaluate changes in body condition, reproductive success, and/or population resilience. However, taking all data together, we found no association between differences in $CORT_f$ concentration (standardized effect difference) and the variables body condition, population size (song occurrence), song frequency, and degree of urbanity.

Based on possible explanations for either increased or reduced levels of CORT concentration (Rich and Romero 2005; French et al. 2008; Romero et al. 2009), we assume that birds that exhibit either of these states are in conditions of chronic stress. Thus, we concur with the assumption that the relationship between stressful disturbances and CORT are less linear and more log-quadratic (Busch and Hayward 2009), as has been found for the relationship between noise disturbance and feather growth and body size (Kleist et al. 2018). For the remaining 15 species that presented no changes in $CORT_f$ concentration between airport-affected and silent control sites, we assume that they are habituated to noise conditions, that is, they perceive noise condition as innocuous and thus ignore it, thereby avoiding physiological disorders (Romero 2009).

Human-caused disturbances to wildlife are increasing continuously and generating several negative effects to their welfare. The study of animal/plant physiological responses to disturbances have been recently named as “conservation physiology” (Wikelski and Cooke 2006), highlighting that populational physiological responses to environmental changes are important symptoms that should suggest clearer guidance to conservation actions (Cooke and O’Connor 2010). Here we have analyzed species that are commonly found in urban environments, but we found indications that they might not be as healthy as could be assumed just because they are able to inhabit disturbed habitats. The results highlight that more sensitive species, usually less able to deal with disturbances, might suffer more severely from human generated stress conditions. Noise is a modern problem that needs more attention from conservation policy makers to allow a more complete protection of wildlife.

CONCLUSIONS

Here we present evidence for chronic stress condition in four species of passerine birds affected by noise pollution in the surroundings of three Brazilian airports. The remaining investigated 15 species present no changes in the hormone stress-indicator and are apparently in good health condition. Population physiological alterations linked to human produced noises are important data to be used in conservation policies, as population health can indicate population viability.

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APPENDIX A. Values of CORT_f concentration and body condition in airport-affected sites and silent control sites, and theirs Hedge *d* effect (standardized effect difference), index of song occurrence (air/cont), song frequency (Hz), and urbanity index (Z value). Values refer to 24 populations of 17 species in three regions (Brasília, Campinas and Salvador).

		CORT_f (pg mm^{-1})			**Body condition**			**Song**	**Song**	
Species	**Region**	Airport	Control	Effect	Airport	Control	Effect	**occurrence**	**frequency**	**Urbanity**
Ammodramus humeralis	BRAS	3.337	5.643	-0.599	0.660	-0.660	0.792	2.000	4153.12	-0.379
Coereba flaveola	SAL	1.663	2.127	-0.125	0.163	-0.148	0.067	1.875	7717.48	0.191
Columbina talpacoti	ALL	6.436	10.120	-0.600	-0.260	0.390	-0.323	0.286	562.500	0.040
Coryphospingus cucullatus	CAMP	4.777	3.654	0.323	0.157	-0.570	0.267	2.182	2429.01	-0.256
Cyclarhis gujanensis	SAL	14.312	5.341	0.758	-0.014	0.021	-0.015	1.056	2580.97	0.131
Elaenia chiriquensis	BRAS	5.902	3.922	0.264	0.211	-0.153	0.051	1.045	2861.21	-0.698
Elaenia cristata	BRAS	5.994	7.672	-0.247	0.072	-0.072	0.035	1.000	3213.27	-0.698
Mimus gilvus	SAL	5.928	7.687	-0.948	0.096	-0.128	0.181	1.800	2926.35	0.089
Myiarchus swainsoni	BRAS	6.968	8.002	-0.104	0.280	-0.132	0.095	0.700	1690.75	0.245
Myiarchus swainsoni	CAMP	6.798	7.503	-0.110	0.409	-0.164	0.235	0.100	1690.75	0.245
Pitangus sulphuratus	SAL	13.233	9.112	0.278	-0.001	0.003	-0.001	1.111	3303.18	0.156
Suiriri suiriri	BRAS	6.880	3.928	0.993	0.544	-0.408	0.430	2.200	3303.18	0.071
Synallaxis frontalis	BRAS	10.748	7.491	0.335	-0.485	0.728	-1.220	0.500	3018.21	0.334
Synallaxis frontalis	CAMP	7.493	4.512	0.571	0.083	-0.581	0.628	1.385	3018.21	0.334
Tangara sayaca	SAL	3.891	5.885	-0.403	0.201	-0.158	0.093	1.800	4008.01	0.254
Tangara sayaca	CAMP	4.474	4.814	-0.082	-0.141	0.330	-0.160	1.045	4008.01	0.254

Troglodytes musculus	CAMP	28.383	54.272	-0.408	-0.171	0.171	-0.093	0.762	5887.18	0.044
Troglodytes musculus	BRAS	11.003	11.172	-0.011	-0.041	0.053	-0.025	0.174	5887.18	0.044
Troglodytes musculus	SAL	3.603	6.800	-0.578	-0.143	0.143	-0.082	1.364	5887.18	0.044
Turdus leucomelas	CAMP	4.324	4.575	-0.042	-0.120	0.074	-0.051	0.708	4200.00	0.046
Turdus leucomelas	SAL	3.685	3.895	-0.048	0.053	-0.059	0.028	1.118	4200.00	0.046
Volatinia jacarina	BRAS	3.157	2.542	0.165	0.103	-0.131	0.053	2.800	6855.70	0.138
Volatinia jacarina	CAMP	2.662	2.422	0.343	0.025	-0.190	0.121	8.000	6855.70	0.138
Zonotrichia capensis	CAMP	9.307	7.202	0.165	-0.556	0.243	-0.189	0.818	3231.65	-0.337

DISCUSSÃO GERAL

1. VISÃO GERAL DA TESE

Através da abordagem de três diferentes aspectos da relação entre aves e o ruído de aeroportos, podemos concluir que espécies e populações respondem de forma diferenciada ao ruído, mas que o ruído pode gerar reduções de diversidade, reduções populacionais, mudanças temporais no coro matutino e estados de estresse crônico em aves que residem próximo a ambiente aeroportuário.

Observamos que os ambientes aeroportuários estudados apresentaram maiores níveis de ruído, maiores níveis de iluminação artificial e maiores proporções de ambientes urbanizados do que as áreas controle, tornando-se ambientes propícios a modificações na estruturação das populações e das comunidades (McKinney 2008; Francis et al. 2009; Duarte et al. 2015), e a modificações comportamentais e fisiológicas nos indivíduos (Schroeder et al. 2012; Chávez-Zichinelli et al. 2013). Nas três regiões estudadas (Brasília, Campinas e Salvador), foi registrado um total de 154 espécies de aves, sendo que a riqueza de espécies e o índice de diversidade α foram menores nos ambientes aeroportuários. Áreas de ambiente aeroportuário apresentaram grau moderado de similaridade entre si em relação à composição de espécies da comunidade, entretanto, as áreas estudadas em uma mesma região apresentaram maior similaridade entre si, do que as áreas dentro de um mesmo tratamento (aeroporto vs. controle). Assim, 60% das espécies encontradas em ambiente aeroportuário correspondem ao conjunto de espécies disponíveis na região estudada, não sustentando a hipótese de homogeneização biótica das áreas perturbadas do estudo (McKinney and Lockwood 1999).

Avaliamos o comportamento de coro matutino de 15 espécies de aves, e encontramos mudanças significativas no horário de início do coro matutino em cinco espécies, sendo que duas espécies anteciparam o início do coro matutino nos aeroportos (*Elaenia chiriquensis* e

Neothraupis fasciata) e as outras três espécies atrasaram o coro (*Camptostoma obsoletum*, *Troglodytes musculus* e *Zonotrichia capensis*). Era esperado que algumas espécies apresentassem antecipação do coro matutino, entretanto, os atrasos aparecem como um comportamento desvantajoso em ambientes onde o ruído possui horário de início previsível. Afim de entender se variáveis populacionais (ocorrência de canto), espécie-específicas (frequência de canto, tamanho do olho e urbanidade) e ambientais (nível de ruído e luz) poderiam explicar esse resultado, analisamos 26 pares de populações relativas às 15 espécies avaliadas previamente. Os resultados indicam a variável "ocorrência de canto" como de maior importância para explicação do padrão. Esta variável representa um "proxy" para tamanho da população em cada área, sendo calculada a partir do número de manhãs em que a espécie foi registrada por gravadores automáticos em cada área. Assim, espécies que iniciaram o coro matutino mais cedo no aeroporto do que na área controle apresentaram uma maior ocorrência nos aeroportos, e espécies que iniciaram o coro matutino mais tarde no aeroporto apresentaram menor ocorrência nos aeroportos. Tal mudança nos tamanhos populacionais foi observada em campo e agora comprovada estatisticamente, indicando que espécies capazes de antecipar seu canto parecem estar lidando com o ruído de forma mais adequada, enquanto aquelas espécies que não conseguem antecipar o horário de canto e ainda apresentam um atraso, parecem ter dificuldade em lidar com o ruído, não sendo capazes de manter sua população estável. Reduções no tamanho das populações em ambiente ruidoso são comuns em espécies que não conseguem adaptar seu comportamento às condições de ruído extremo (Reijnen et al. 1995; Bayne et al. 2008; Francis et al. 2010), e podem ser explicadas por reduções tanto no sucesso de atração de parceiros quanto dos ninhos (Habib et al. 2007; Halfwerk et al. 2011; Hayward et al. 2011; Fairhurst et al. 2013; Strasser et al. 2013; Kleist et al. 2018).

Avaliamos também a resposta fisiológica de 19 espécies em relação às concentrações de corticosterona depositada nas penas ($CORT_f$). Encontramos mudanças significativas em quatro espécies, sendo que nas áreas de aeroportos duas espécies apresentaram níveis aumentados de $CORT_f$ (*Cyclarhis gujanensis* e *Turdus rufiventris*), e as outras duas espécies apresentaram níveis reduzidos de $CORT_f$ (*Troglodytes musculus* e *Coryphospingus cucullatus*). De acordo com o "Modelo de Escopo Reativo" (Romero et al. 2009), níveis acima e abaixo dos valores padrão de concentração de corticosterona de cada espécie (definidos com base nos valores de áreas controle), podem indicar problemas fisiológicos nos indivíduos. A corticosterona depositada nas penas é uma medida integrada do hormônio, representando tanto os valores basais do hormônio, quanto as variações decorrentes de situações adversas enfrentadas pela ave durante o crescimento da pena. Valores mais altos de $CORT_f$ ocorrem em indivíduos com reações que excedem as respostas normais, enquanto valores mais baixos de $CORT_f$ ocorrem indivíduos em situação de falha fisiológica, provavelmente apresentando reação hormonal aquém da reação necessária à manutenção da homeostase do sistema (Romero et al. 2009).

Dentre as espécies estudadas nos capítulos 2 e 3, existe a sobreposição de 9 espécies. A espécie *Troglodytes musculus* (curruíra) foi registrada nos três aeroportos estudados. Apesar de ser uma espécie comumente encontrada em centros urbanos, apresentou atrasos no início do coro matutino, população reduzida em todos os aeroportos, e níveis de corticosterona mais baixos nos aeroportos do que nas áreas controles, indicando sua baixa resiliência a ambientes com ruído extremo. A espécie *Zonotrichia capensis* (tico-tico) foi avaliada apenas no aeroporto de Campinas, pois não foi registrada na região de Salvador, e apesar de bastante abundante em Brasília (27 indivíduos capturados no PNB), sua população é baixíssima dentro do aeroporto de Brasília (1 indivíduo capturado). Essa espécie apresentou atraso no início do coro matutino, redução da população no aeroporto e variação positiva (aumento) não significativa nas concentrações de corticosterona entre aeroporto e área controle. A espécie *Elaenia chiriquensis* (chibum) é migratória e vem para a região central do Brasil (Brasília) para se reproduzir. É uma espécie pouco comum em ambientes urbanizados, e apresentou antecipação do coro matutino, tamanho populacional aumentado, e variação positiva (aumento) não significativa nas concentrações de corticosterona entre aeroporto e área controle. A espécie *Cyclarhis gujanensis* (pitiguari) foi avaliada apenas em Salvador, onde possui maior população. É uma espécie comumente vista em cidades, e não apresentou mudanças no horário de início do coro matutino, entretanto, apresentou níveis mais elevados de corticosterona no aeroporto, indicando fragilidade ao ruído extremo. As demais espécies avaliadas em ambos os capítulos não apresentaram mudanças significativas em nenhum dos dois aspectos avaliados (*Pitangus gujanensis*, *Tangara sayaca*, *Elaenia cristata*, *Turdus leucomelas* e *Myiarchus swainsoni*).

2. RUÍDO AEROPORTUÁRIO E SUAS IMPLICAÇÕES

2.1. Introdução à problemática

O transporte aéreo é amplamente utilizado em todo o mundo, apresentando contínuo crescimento. No Brasil, o número de passageiros apresentou crescimento de 10% ao ano, entre os anos de 2003 e 2014, e deve continuar crescendo em todo o mundo até 2050 (Yosimoto et al. 2016). A aviação possui três principais impactos ecológicos reconhecidos: as colisões com a fauna nos aeródromos; a poluição atmosférica devido aos gases liberados pela queima de combustível das aeronaves; e a poluição sonora gerada pelas turbinas das aeronaves. Este último impacto é um dos maiores entraves para o crescimento da atividade aeroportuária (Antoine and Kroo 2004; Kelly and Allan 2006).

O ruído produzido pelas aeronaves representa um problema de saúde pública, reconhecidamente complexo e de difícil mitigação (INFRAERO 2004). A RBAC 161 (Regulamento Brasileiro de Aviação Civil) define ruído aeronáutico como todo *"ruído oriundo das operações de circulação, aproximação, decolagem, subida, rolamento e teste de motores de aeronaves"*, sendo que grande parte do ruído produzido advém do funcionamento das turbinas e da aerodinâmica do motor, devido às diferenças de temperatura entre os gases liberados e o ar (Rainho 2016). A RBAC 161 também estabelece diretrizes para a elaboração de Planos de Zoneamento de Ruído (PZR) para cada aeródromo, delimitando curvas de ruído de diferentes intensidades (Figura 1). O ruído aeronáutico é medido na escala A, que diminui o peso do ruído de baixa frequência (Nykiel 2009), e é considerado como uma média entre o "nível equivalente de pressão sonora diurna na escala A" (L_{AeqD}) e o "nível equivalente de pressão sonora noturna na escala A" (L_{AeqN}) adicionada de 10 dB (Falzone 1999), gerando o "nível equivalente de pressão sonora média diurna e noturna" (L_{DN}). A emenda Nº 1 da RBAC 161 (ANAC 2013) prevê a delimitação de curvas de ruído de 85, 80, 75, 70 e 65 dB no PZR básico de cada aeródromo.

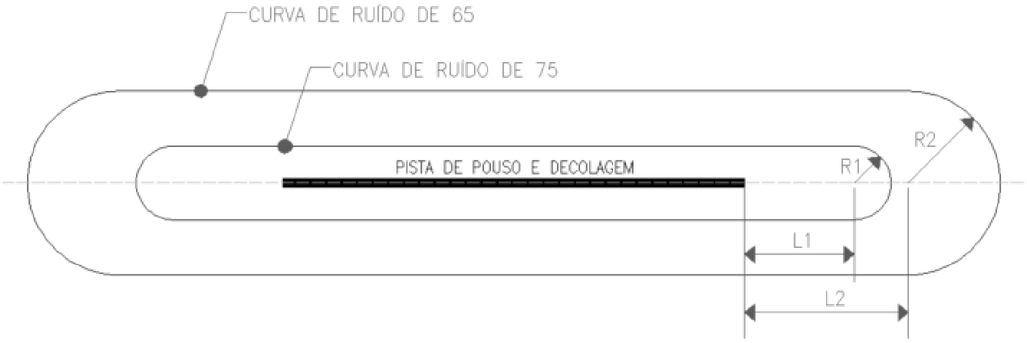

Figura 1. Exemplo de curvas de ruído no entorno da pista de um aeródromo. Imagem de RBAC 161, emenda Nº 1 (ANAC 2013).

Existe uma grande preocupação acerca do impacto do ruído nas áreas vizinhas aos aeródromos, já que este pode gerar desvalorização dos imóveis da área (Feitelson et al. 1996) e uma série de danos à saúde humana, como reduzida capacidade de concentração em crianças em período escolar (Bullinger et al. 1999; Haines et al. 2001; Nunes and Slatter 2006), e distúrbios de sono (CAA 2009; Finegold 2010) que podem levar a hipertensão e doenças cardíacas (Babisch et al. 2013; Floud et al. 2013). De acordo com a Organização Mundial da Saúde (OMS), níveis de ruído acima de 65 dB (na faixa A) podem causar danos à saúde humana, níveis entre 60 e 65 dB (A) podem gerar incômodo moderado, e níveis entre 55 e 60 dB (A) podem gerar incômodo. Já a RBAC 161 permite a ocupação de áreas no entorno de aeródromos que possuam L_{DN} inferior a 65 dB (A), mesmo que este cause incômodo moderado.

2.2. *Situação dos aeroportos estudados*

2.2.1. Aeroporto Internacional de Viracopos (Campinas-SP)

O Aeroporto Internacional de Viracopos é um dos principais terminais de carga do país e é considerado o segundo melhor do mundo em sua categoria (Viracopos Aeroportos Brasil 2018), sendo o aeroporto brasileiro mais central e com maior conexão entre a rede de voos do país (Couto et al. 2015). Em 2017 operou em média 301 voos por dia, e no terminal de cargas foram transportadas em média 16.573 toneladas por mês (Viracopos Aeroportos Brasil 2018). Este aeroporto se encontra sob concessão para a concessionária Aeroportos Brasil desde 2012, que vem realizando obras de ampliação no mesmo. Entretanto, de acordo com notícia veiculada na internet, a concessionária estuda a devolução da concessão para o Governo Federal (Portal G1 Campinas 2017).

Este aeroporto possui grande área habitada em seu entorno, sendo esta uma das maiores preocupações em relação ao ruído, já que as faixas entre 55 e 65 dB L_{DN} afetam cerca de 53.000 pessoas, e cerca de 384.000 pessoas são afetadas por ruído médio, abaixo de 55 dB L_{DN}. O restante das áreas em seu entorno é representado por zonas rurais (Figura 2).

Figura 2. Imagem retirada de documento da ANAC, sobre Análises preliminares de Impacto Ambiental no Aeroporto Internacional de Viracopos (2017). Em verde = isofônica de 55 dB L_{DN}; laranja = isofônica de 60 dB L_{DN}; vermelho = isofônica de 65 dB L_{DN}.

2.2.2. Aeroporto Internacional Deputado Luís Eduardo Magalhães (Salvador – BA)

O Aeroporto Internacional de Salvador é um dos principais aeroportos da região nordeste do país, e apresentou aumento de 265% na movimentação de passageiros entre os anos de 2003 e 2014 (Consórcio Aéreo Brasil 2017). O Aeroporto era administrado pela INFRAERO e em 2015 foi incluído no plano nacional de desestatização, sendo recentemente leiloado e concedido à companhia francesa Vinci Aeroportos Brasil (INFRAERO 2018).

O PZR deste aeroporto só se encontra disponível na forma descritiva (Consórcio Aéreo Brasil 2017), por isso apresentamos apenas a delimitação territorial do aeroporto (Figura 3). O sítio aeroportuário é vizinho à Área de Proteção Ambiental (APA) Lagoas e Dunas do Abaeté, sob administração do Instituto do Meio Ambiente e Recursos Hídricos (INEMA 2018). Segundo a lei Nº 9.985, que cria o Sistema Nacional de Unidades de Conservação (SNUC), APAs (Área de Proteção Ambiental) constituem Unidades de Conservação de Uso Sustentável, *que possuem o objetivo de proteger a biodiversidade biológica, disciplinar o processo de* *ocupação e assegurar a sustentabilidade do uso dos recursos naturais*. No zoneamento ecológico-econômico da APA existem Zonas de Preservação Permanente (ZPP; Figura 4), incluindo uma “Zona de Proteção Visual” que compreende os últimos remanescentes do sistema dunar associado a zonas úmidas, e possui objetivo de preservação do sistema; uma “Zona de Vida Silvestre” que compreende áreas úmidas, lagoas e dunas com vegetação de restinga arbórea e arbustiva em perfeito estado de conservação; e uma “Zona de Uso Específico”, onde também encontramos dunas, muitas lagoas, brejos e alagadiços de enorme importância ecológica, mas que estão destinadas à ampliação do aeroporto (CEPRAM 2002). Para que seja realizada a ampliação, a empresa necessita realizar Estudos de Impacto Ambiental (EIA) e está condicionada às determinações dos órgãos ambientais (CEPRAM 2002; Consórcio Aéreo Brasil 2017). Entretanto, a empresa afirma que não há necessidade e não possui a intenção de ampliar o aeroporto dentro dos próximos 10 anos (Portal G1 Bahia 2017).

O sistema dunar encontrado na lateral deste aeroporto possui alto grau de permeabilidade e contribui para o armazenamento de água no lençol freático e recarga das lagoas (Quartaroli et al. 2007). Além de ser um dos últimos remanescentes do sistema dunar associado a zonas úmidas, esta área abriga espécies de alta relevância ecológica, como o lagarto *Ameivula abaetensis* (Dias et al. 2002). Este sistema é protegido atualmente pelo Parque das dunas, que em 2013 recebeu da UNESCO o título de Reserva da Biosfera da Mata Atlântica, mas ainda assim é ameaçado pela possibilidade de expansão do sítio aeroportuário.

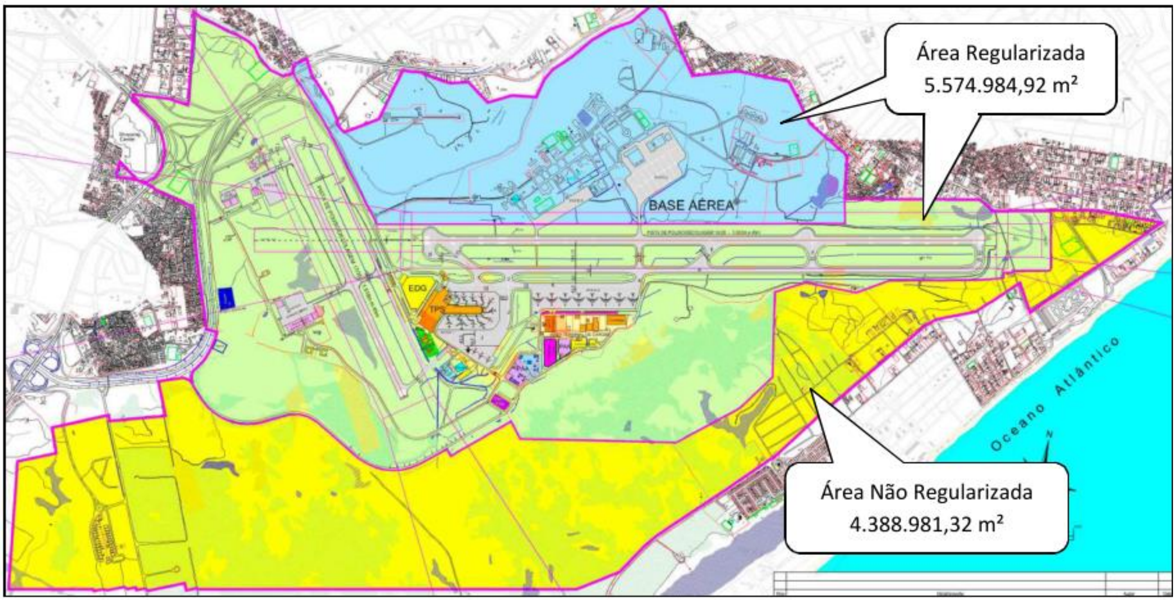

Figura 3. Delimitação territorial das áreas aeroportuárias em Salvador. Imagem retirada de documento do Consórcio Aéreo Brasil (2017). Área em azul = área militar (Base aérea), área em verde = área civil (INFRAERO), e área em amarelo = área pretendida para expansão do aeroporto.

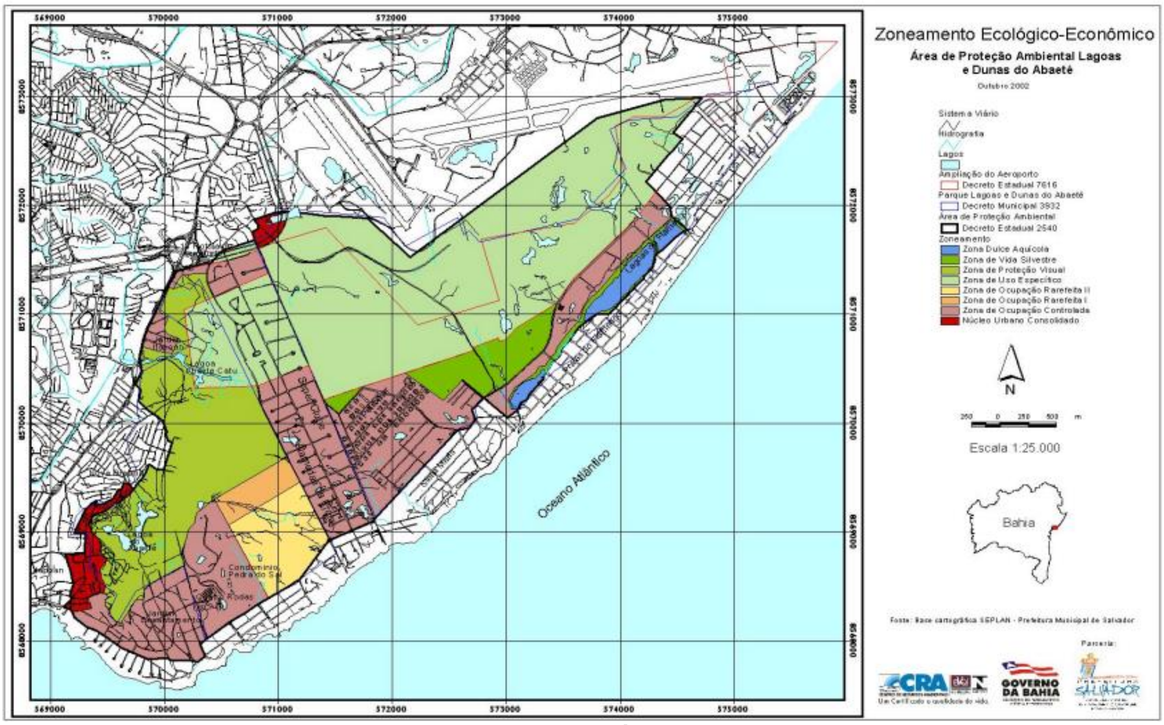

Figura 4. Zoneamento ecológico-econômico da Área de Proteção Ambiental Lagoas e Dunas do Abaeté. Imagem retirada da Resolução Nº 3023 de 20 de setembro de 2002 (CEPRAM 2002). Área em verde musgo à esquerda = Zona de Proteção Visual, área em verde escuro abaixo = “Zona de Vida Silvestre”, e área em verde claro acima = “Zona de Uso Específico”.

2.2.3. Aeroporto Internacional Juscelino Kubitschek (Brasília-DF)

O Aeroporto Internacional Juscelino Kubitschek é o 3º maior do país em movimentação de passageiros, sendo o aeroporto com maior capacidade de pista do Brasil, devido à sua recente ampliação. Sua média atual é de 412 voos por dia, totalizando cerca de 46 mil passageiros/dia (INFRAMÉRICA 2018). Atualmente, é administrado pela empresa Inframérica.

O Aeroporto Internacional de Brasília encontra-se dentro da APA das bacias Gama e Cabeça-de-Veado (Figura 5), junto com as Áreas de Relevante Interesse Ecológico (ARIE) do Capetinga-Taquara, da Granja do Ipê e do Riacho Fundo, além da Reserva Ecológica do IBGE, a Fazenda Água Limpa (UnB), as áreas especiais de proteção do Jardim Zoológico de Brasília e do Jardim Botânico de Brasília, e a Estação Ecológica do Jardim Botânico (IBRAM 2014). Algumas destas áreas pertencem à Reserva da Biosfera do Cerrado (RESBIO).

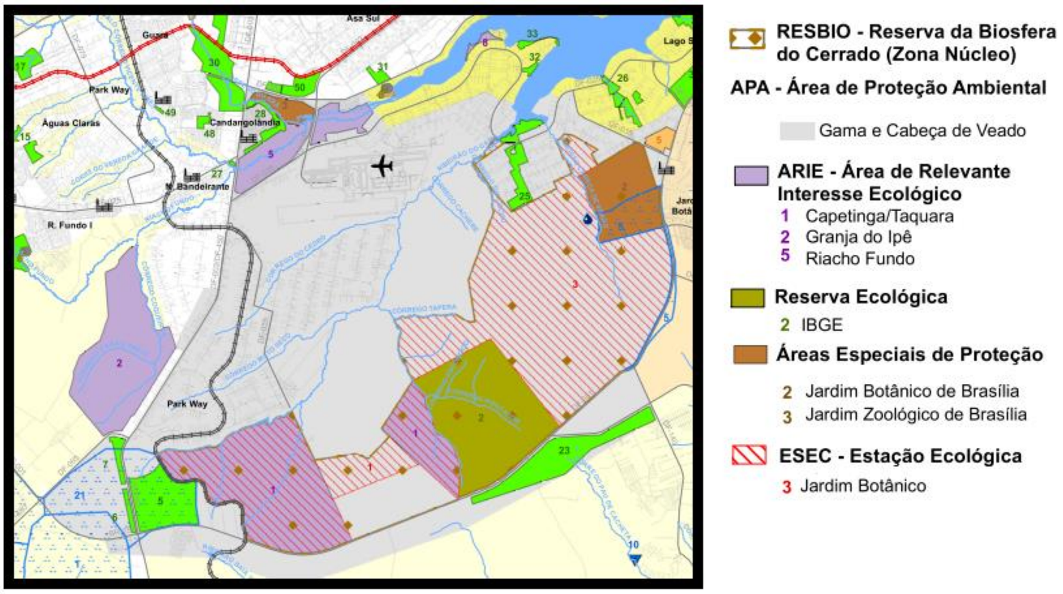

Figura 5. Imagem ampliada do Mapa Ambiental do Distrito Federal, produzido pelo Instituto Brasília Ambiental (IBRAM 2014).

De acordo com o Plano Específico de Zoneamento de Ruído (PZER) deste aeroporto, a curva de ruído que vai de 65 a 70 dB (A) (Figura 6) não vai muito além da área designada como sítio aeroportuário. Entretanto, é de conhecimento público que as zonas residenciais no entorno deste aeroporto encontram-se afetadas pelo ruído do mesmo (Júnior et al. 2012), sendo alvo de petições públicas on-line e de notificações oficiais (Correio Brasiliense 2010). Em 2016, a ANAC emitiu uma análise preliminar de impacto ambiental relacionado à operação das pistas paralelas simultâneas independentes neste aeroporto (ANAC 2016a). De acordo com as imagens apresentadas nesta nota técnica, as linhas de ruído (isofônica) de 55 dB L_{DN} adentram a área designada como RESBIO, sendo o "cenário de operações simultâneas" menos crítico para a reserva do que o "cenário base" (Figura 7). A nota técnica conclui que, apesar de aumento do número de pessoas expostas a níveis de ruído entre 55 e 65 dB L_{DN}, a mudança da configuração do aeroporto não resulta em impacto significativo de ruído aeronáutico, já que essa faixa de ruído não restringe a ocupação da área.

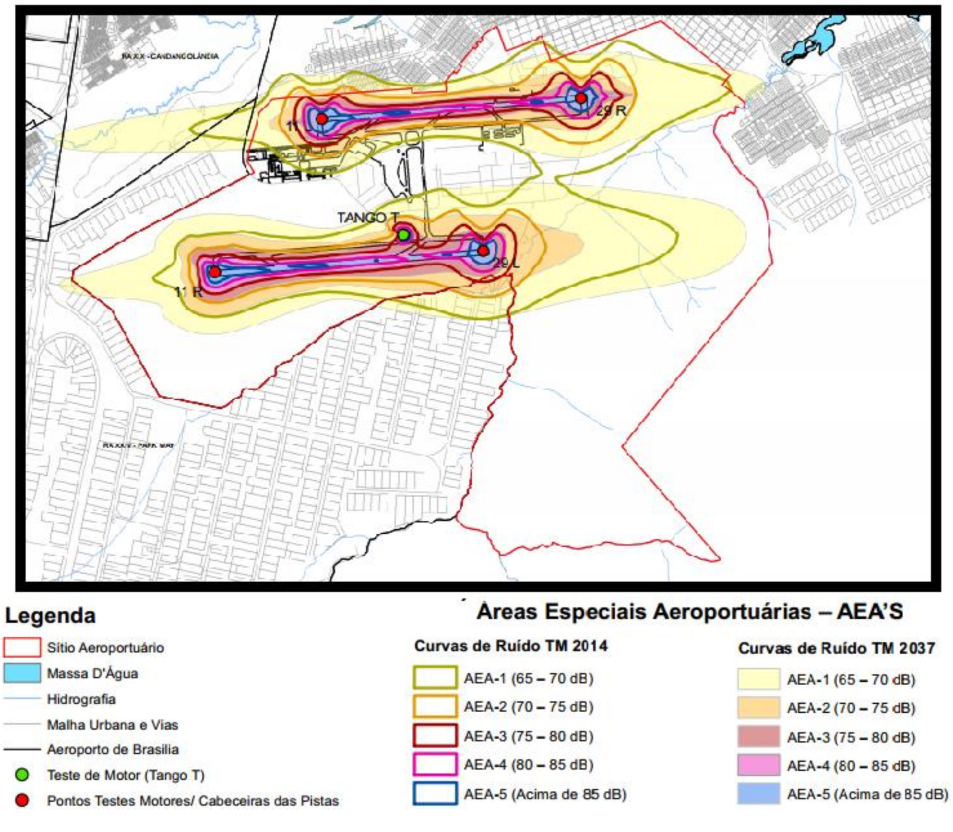

Figura 6. Imagem ampliada do Plano Específico de Zoneamento de Ruído do Aeroporto Internacional de Brasília (Sonora Ambiental).

Este aeroporto inclui em suas rotas de pousos e decolagem, sobrevoos sobre áreas onde está prevista a preservação dos ecossistemas naturais, da biota nativa, inclusive de espécies raras ou ameaçadas de extinção, como determinado no decreto Nº 9.417, que cria a APA das bacias do Gama e Cabeça-de-Veado e dá outras providências (GDF 1986). Dentro desta APA existe uma Unidade de Proteção Integral (Estação Ecológica do Jardim Botânico de Brasília), que possui como objetivo a *preservação da natureza, sendo admitido apenas o uso indireto dos seus recursos naturais* (BRASIL 2000). Segundo o SNUC, em uma Estação Ecológica (EE) tem-se como objetivo central *a preservação da natureza e a realização de pesquisas*, onde não são permitidas alterações que prejudiquem a biodiversidade. O plano de manejo específico desta EE prevê ainda um projeto de conservação de peixes de lagoas temporárias, e um projeto de conservação de emas (*Rhea americana*) (JBB 2010), espécie que se encontra próxima de estar ameaçada de extinção (“Near-Threatened”) na classificação da lista vermelha de espécies ameaçadas (IUCN 2016), tornando o ruído produzido pela atividade aeroportuária incompatível com os projetos previstos. As áreas que integram a Reserva da Biosfera do Cerrado formam uma área contínua e propícia à sobrevivência e reprodução de animais de grande e médio porte, que não possuem grandes chances de sobrevivência em áreas menores. Dentre estas, podemos citar registros de onça-parda (*Puma concolor*), jaguatirica (*Leopardus pardalis*), anta (*Tapirus terrestris*), lobo-guará (*Chrysocyon brachyurus*), cachorro-do-mato (*Cerdocyon thous*), tatu-canastra (*Priodontes maximus*), tamanduá-bandeira (*Myrmecophaga tridactila*), bugio (*Alouatta caraya*), veado-catingueiro (*Mazama gouazoupira*), dentre outros (Juarez 2008; Lima and Saracura 2008; Cardoso and Sant'Anna 2017). Esses mamíferos de médio e grande porte, expostos ao ruído, sofrem suas conhecidas consequências. Muitos desses mamíferos se encontram em estado de vulnerabilidade na lista vermelha de espécies ameaçadas (*T. terrestris, P. maximus*, e *M. tridactila*) (IUCN 2016), e deveriam ser focados com maior atenção pelas leis ambientais, garantindo condições adequadas para sua sobrevivência e reprodução.

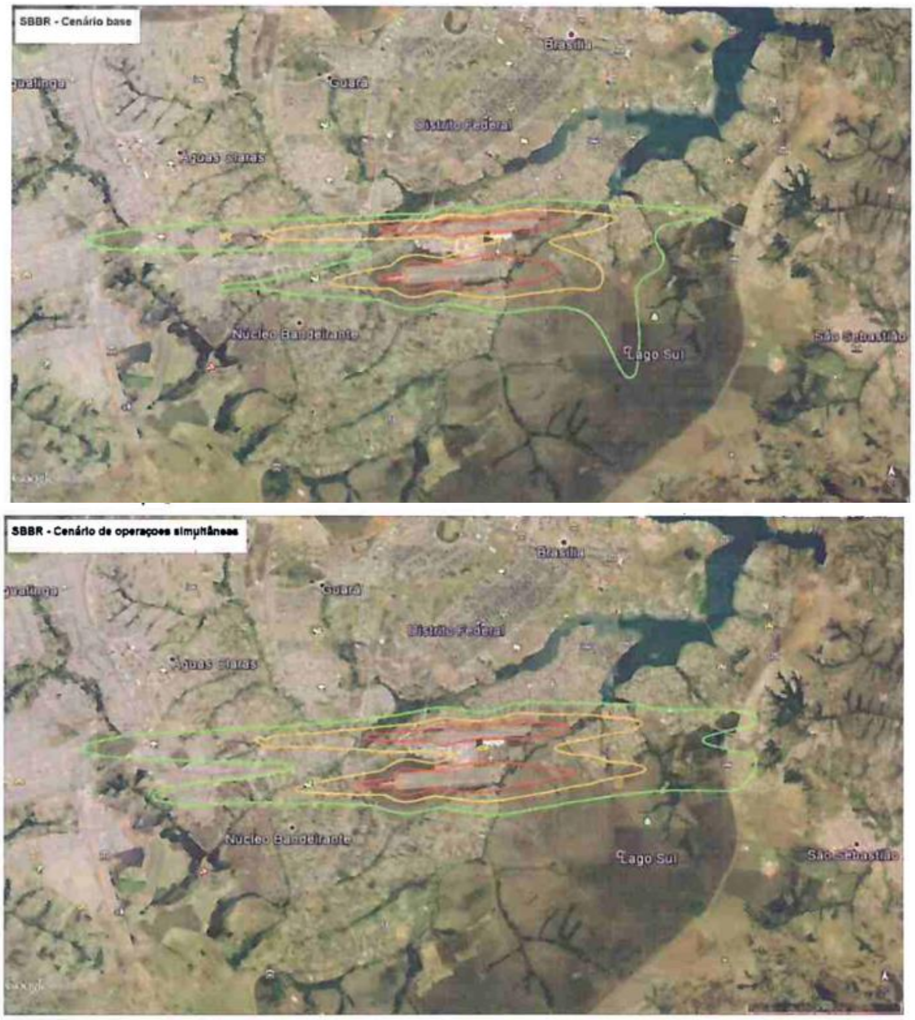

Figura 7. Imagens retiradas da nota técnica 29/2016/SRI. “Cenário base” acima, representa situação anterior às operações paralelas e independentes das pistas, baseado nos movimentos de 01-01-2015 a 10-11-2015. “Cenário de operações simultâneas” abaixo, busca reproduzir as operações paralelas simultâneas independentes, baseado nos movimentos de 01-12-2015 a 27-02-2016. Verde = isofônica de 55 dB L_{DN}; laranja = isofônica de 60 dB L_{DN}; vermelho = isofônica de 65 dB L_{DN}.

2.3. Proteção da fauna

As leis aeroportuárias brasileiras que tangem a fauna incluem apenas a fauna que gera algum risco às aeronaves, já que esta gera um grande custo aos aeroportos, seja por custos associados ao conserto de aeronaves, ou à sequência de atrasos gerada por uma colisão (Allan 2000). O chamado risco de fauna foi alvo de recente regulamentação pelo Conselho Nacional do Meio

Ambiente (CONAMA, 2012) através da lei nº 12.725 e pela Agência Nacional de Aviação Civil (ANAC, 2014) através da Resolução nº 320 de 29 de maio de 2014. A resolução RBAC 164 faz parte do Regulamento Brasileiro da Aviação Civil, e define as medidas a serem tomadas quando qualquer animal é identificado dentro ou no entorno da área operacional do aeródromo, e as medidas mitigadoras de riscos que evitem atração da fauna. A ANAC possui ainda um Sistema de Gerenciamento de Risco Aviário (SIGRA), onde é possível registrar avistamentos e colisões, gerando um grande banco de dados sobre a fauna que apresenta risco para a aviação brasileira. Dentre os animais, as aves representam o grupo com maior número de incidentes, estando o quero-quero (*Vanellus chilensis*), o urubu-de-cabeça-preta (*Coragyps atratus*), o carcará (*Caracara plancus*) e a coruja-buraqueira (*Athene cunicularia*) dentre as espécies com maior número de ocorrências no Brasil (Guedes et al. 2010; de Hoon and de Oliveira 2014; Carvalho et al. 2016). As espécies de passeriformes incluídas neste estudo representam baixo risco em relação a colisões com aeronaves. Considerando as possibilidades e riscos de colisões com aves, dois dos aeroportos avaliados neste estudo (Brasília e Salvador) encontram-se entre os aeroportos com maior número de colisões entre os anos de 2011 e 2012 (Carvalho et al. 2016).

Apesar de não fazer parte do sitio aeroportuário, as áreas vizinhas aos aeroportos, que sejam afetadas pelo ruído, também são de responsabilidade do aeroporto. A RBAC 161 determina como devem ser avaliados os impactos do ruído produzido, e prevê diversas possibilidades de uso do solo no entorno de um aeródromo, como: uso residencial, uso público (presídios, escolas, hospitais, igrejas, serviços governamentais, etc.), uso comercial, uso industrial e de produção, e uso recreacional (estádios, zoológicos, parques de diversão, campos, etc.). Já a NBR 10151 (ABNT 2000), que versa sobre os níveis aceitáveis de ruído, prevê os níveis mais baixos para áreas de sítios e fazendas (40 dB L_{DN} durante o dia e 35 dB L_{DN} durante a noite). Assim, ambas as legislações deixam de fora o controle de ruído que impacte Unidades de Conservação, deixando uma lacuna no que se refere à uma legislação que proteja a fauna de Unidades de Conservação dos ruídos da atividade de aviação, produzidos além do aeródromo.

A vida selvagem brasileira é diariamente ameaçada de formas incontáveis, fruto do crescimento desordenado das cidades, da derrubada de vegetação nativa, da ausência de corredores de fauna adequados, da ausência de passagens para travessia da fauna nas estradas (resultando em milhares de mortes por atropelamento). Assim, a forma mais eficiente de garantir a preservação da fauna nativa se baseia na proteção das Unidades de Conservação (Le Saout et al. 2013), que segundo a Constituição Federal Brasileira, é um direito do cidadão.

De acordo com seu artigo 225:

Todos têm direito ao meio ambiente ecologicamente equilibrado, bem de uso comum do povo e essencial à sadia qualidade de vida, impondo-se ao Poder Público e à coletividade o dever de defendê-lo e preservá- lo para as presentes e futuras gerações.
***§ 1º** Para assegurar a efetividade desse direito, incumbe ao Poder Público:*
***I** - preservar e restaurar os processos ecológicos essenciais e prover o manejo ecológico das espécies e ecossistemas;*
....
***VII** - proteger a fauna e a flora, vedadas, na forma da lei, as práticas que coloquem em risco sua função ecológica, provoquem a extinção de espécies ou submetam os animais a crueldade.*

Os aeroportos brasileiros são fonte de grande poluição sonora, que atinge grandes áreas em seu entorno, gerando picos de ruído, que vão muito além da média estabelecida nos Planos de Zoneamento de Ruído. Com isso, áreas destinadas à preservação da biodiversidade ficam desprovidas de proteção legislativa. Um estudo recente mostra que as Unidades de Conservação Norte Americanas sofrem com a poluição sonora, que atinge intensidades até 10 vezes maiores do que a intensidade de ruído que reconhecidamente causa impactos a humanos e à vida selvagem (Buxton et al. 2017).

2.4. Medidas mitigadoras do ruído

A atividade aeroportuária constitui um meio de transporte essencial nos dias de hoje, e a mitigação dos seus efeitos negativos deve ser realizada de maneira que não prejudique a atividade, mas que também garanta o bem-estar da população humana e da biodiversidade do seu entorno. Durante a 36ª sessão da Organização da Aviação Civil Internacional (OACI) de 2007, foi introduzida a "abordagem equilibrada", que visa "reduções de ruído na fonte, imposição de restrições de operação, desenvolvimento de procedimentos operacionais de redução de ruído, desenvolvimento de planos de controle do uso do solo vizinho aos aeroportos", além da retirada de circulação de aeronaves antigas e ruidosas (ANAC 2016b).

- Redução de ruídos na fonte: A produção de ruído pelas aeronaves foi reduzida ao longo dos anos, gerando uma redução de 20 dB entre os anos 1960 e 2004 (Antoine and Kroo 2004), o que torna cada vez mais difícil e custosa a redução adicional (Da Silva 2011), e fazendo necessária a adoção de medidas além da redução de ruído na fonte.

  Pesquisas recentes ainda investigam formas de reduzir o ruído produzido por aeronaves, dentre essas se destacam: o Projeto "Quiet Aircraft Technology" da NASA, o projeto "Silence" da comunidade Europeia, e o projeto "Aeronave silenciosa: uma investigação em aeroacústica" do Brasil em parcerias com outros países. Em países como Japão, Austrália e alguns países Europeus, existe uma taxa de ruído, paga pela companhia aérea, gerando fundos para ações que mitiguem o ruído (Nero and Black 2000).

- Restrição dos horários de voo: Os voos que ocorrem durante a noite (entre 22:00 e 07:00 h) são os que geram maiores distúrbios para a vizinhança. Assim, em alguns estados, aeroportos já operam com restrição completa ou parcial nesses horários (ANAC 2016b). Tal medida pode ser benéfica para áreas de preservação, mas não resolvem o problema.
- Mudanças operacionais de pouso e decolagem: Os procedimentos de pouso e decolagem são os períodos de maior produção de ruído, sendo a descida mais ruidosa do que a subida.

As mudanças operacionais utilizadas hoje em dia envolvem seleção de trajetórias de voos que evitam áreas urbanizadas e dão preferência a áreas desabitadas, além da determinação de alturas mínimas para realização de manobras (ANAC 2016a).

Como o sobrevoo de áreas desabitadas representa perturbação da fauna, sugerimos que em sobrevoos sobre Unidades de Conservação sejam utilizados os mesmos procedimentos utilizados em áreas povoadas. Tais procedimentos incluem pousos e decolagens com maior angulação e manobras apenas em alturas tão elevadas quanto as utilizadas em áreas povoadas. Apesar de exigir investimento no treinamento de pilotos, a realização de pousos com 4.5º graus de inclinação, ao invés de 3º graus, gera redução de cerca de 7.7 dB no ruído produzido (Antoine and Kroo 2004).

- Planos de controle do uso do solo vizinho aos aeroportos: definem os tipos de empreendimentos que são permitidos no entorno de aeródromos. Dentre as proibições se encontram lixões, onde pode haver concentração de urubus, gerando risco aviário. Os planos atuais não preveem a presença de Unidades de Conservação de Proteção Integral no entorno de aeródromos, nem as condições necessárias para manutenção do bem-estar nessa reserva.

Além das quatro medidas de mitigação do ruído, previstas na abordagem equilibrada, propomos ainda mais três medidas adicionais.

- Programas de isolamento acústico nas construções: Esta estratégia é citada na análise preliminar de impacto ambiental do Aeroporto Internacional de Brasília (ANAC 2016a), e representa uma forma de suavização do impacto do ruído sobre a população vizinha ao aeroporto. Essa estratégia pode representar uma redução na pressão exercida sobre as Unidades de Conservação, já que reduziria a necessidade de se evitar zonas ocupadas por humanos.
- Métricas mais específicas de medição de ruído: As métricas utilizadas hoje em dia nos PZR de aeródromos brasileiros levam em conta a média do ruído produzido durante o dia e

durante a noite (L_{DN}), e ainda restringe essas medições à faixa de frequência audível a humanos. Sugerimos que sejam feitas medições abrangendo diversas faixas de frequência (abaixo de 20 Hz e acima de 20 kHz), contemplando o ruído audível a outros animais (a audição de mamíferos não humanos varia entre as faixas de 10 Hz a 150 kHz (Bowles 1995)). E ainda, que as métricas incluam também valores máximos de pressão sonora.

- Proibição de sobrevoos sobre áreas de proteção e conservação: Nos Estados Unidos, os sobrevoos de baixa altitude utilizados em treinamentos militares, os sobrevoos turísticos (e.g. Grand Canyon) e os sobrevoos comerciais sobre Unidades de Conservação, são atualmente regulamentados, restritos ou mesmo banidos em algumas áreas onde representam risco à vida selvagem (Mace et al. 2003; Kelly and Allan 2006). A maior razão para a restrição deste tipo de atividade é o desconforto que a mesma causa aos visitantes dos parques (Mace et al. 2003; Rapoza et al. 2015), e em alguns casos ao impacto de curto e longo prazo inferido à vida selvagem (Harrington and Veitch 1991; Stockwell et al. 1991).

No Brasil, os sobrevoos militares de baixa altitude e os sobrevoos turísticos não representam uma realidade tão alarmante quanto os sobrevoos comerciais sobre áreas sensíveis. Sugerimos que a legislação Brasileira que protege a fauna seja revista, incluindo limites de poluição sonora aceitáveis em áreas de proteção integral, e em áreas onde animais sejam mantidos em cativeiro e possam ser afetados pelo intenso ruído de aeronaves (e.g. Jardins Zoológicos, Centros de Triagem de Animais Silvestres (CETAS), Centros de Reabilitação de Animais Silvestres (CRAS), criadouros científicos, etc.), já que esta interferência humana é incoerente com os objetivos destas áreas, e poderia ser controlada afim de se aumentar a qualidade destes ambientes (Buxton et al. 2017). Tal medida é apoiada pelo art. 28 da Lei 9.985, onde: "*São proibidas, nas Unidades de Conservação, quaisquer alterações, atividades ou modalidades de utilização em desacordo com os seus objetivos, o seu Plano de Manejo e seus regulamentos*".

CONCLUSÃO GERAL

Apesar de o Brasil ser uma grande referência em relação à biodiversidade que abriga, a preservação deste bem ainda é bastante negligenciada. As atuais leis aeroportuárias que regem o impacto do ruído produzidos nos aeroportos estão exclusivamente preocupadas com os efeitos sobre o bem estar humano, mas excluem os aspectos que indiretamente podem vir a prejudicar nossa qualidade de vida. As Unidades de Proteção Integral são criadas para proteger o que ainda nos resta de subsídio natural, e devem ser protegidas a todo custo de toda e qualquer ação humana que possa prejudicar e deteriorar esse bem.

Os três aeroportos estudados estão entre os seis aeroportos mais importantes do país (Couto et al. 2015), e o crescimento da atividade aeroportuária Brasileira não tem se preocupado com a proteção acústica de áreas ecologicamente importantes. De acordo com o "Relatório de Áreas Sensíveis de Espécies Ameaçadas de Extinção Relacionadas a Aeroportos" (ICMBio 2016), as áreas do entorno dos aeroportos de Brasília e Salvador possuem ambientes designados como sensíveis (2 a 5 espécies ameaçadas de distribuição restrita) e muito sensíveis (6 a 12 espécies), enquanto a região do aeroporto de Campinas possui uma área designada como sensível. Apesar deste relatório ser direcionado ao licenciamento ambiental de aeroportos de menor porte (Resolução Nº 470, CONAMA (2015)), ele também pode ser utilizado como ferramenta para cumprimento do Planejamento estratégico 2015-2019 da Agência Nacional de Aviação Civil (ANAC 2014a), que prevê o "*aprimoramento do processo de acompanhamento das condições ambientais das operações aéreas*", afim de atingir os requerimentos internacionais.

Por fim, deve-se dar maior atenção ao impacto dos ruídos produzidos pelo ser humano sobre as poucas áreas onde é prevista a proteção e conservação da biodiversidade Brasileira. Essa atenção não se restringe a aeródromos, às aves, ou à terra firme. Devem ser considerados os ruídos produzidos por embarcações, caminhões, carros e motocicletas, e os impactos sobre qualquer ser vivo, incluindo seres aquáticos.

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MATERIAL SUPLEMENTAR DA TESE

Anexo I – Comitê de ética no uso animal

Universidade de Brasília
Instituto de Ciências Biológicas
Comissão de Ética no Uso Animal

Brasília, 19 de setembro de 2017.

DECLARAÇÃO – 2ª Via

Declaramos que o projeto intitulado "**NÍVEL DE ESTRESSE EM AVES, ASSOCIADO AO RUÍDO DE AERONAVES**", Protocolo n.º 129022/2015, sob responsabilidade da Professora Regina Helena Ferraz Macedo foi avaliado e aprovado pela Comissão de Ética no Uso Animal (CEUA) da Universidade de Brasília. Este projeto foi aprovado para utilização de: aves *(1000)*. A presente aprovação é válida pelo período de: 01/11/2015 a 01/03/2017.

Profa. Dra. Paula Diniz Galera
Coordenadora da CEUA – UnB

*Este documento se restringe à avaliação ética do projeto supracitado e não substitui outras licenças e permissões que porventura se façam necessárias.

Anexo II – Medidas de frequência

Foram realizadas medições de frequência mínima, máxima e dominante (Peak Frequency) do canto de 34 espécies de interesse. As medidas foram extraídas manualmente no programa Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY) com FFT fixo de 1024. Para cada espécie, foram selecionadas 5 gravações pertencentes ao arquivo pessoal de RDA, e dessas gravações foram extraídas medidas de 20 repetições de canto (4 em cada). Para espécies que vocalizam poucas vezes durante a manhã, foram selecionadas gravações adicionais, até que fossem completadas as 20 repetições. As gravações selecionadas são representativas de ambientes não aeroportuário e com baixo ruído.

Espécie	**Tipo**	**Frequência Mínima (Hz)**	**dp**	**Frequência Máxima (Hz)**	**dp**	**Frequência Dominante (Hz)**	**dp**
Amazona aestiva		440.11	202.05	5643.81	1474.13	1837.50	571.39
Ammodramus humeralis		2826.99	175.13	8476.23	535.88	4153.12	521.18
Aramides cajaneus		943.08	99.91	1980.30	179.63	1335.94	234.86
Brotogeris chiriri		1759.34	284.45	8834.39	1026.82	4863.28	885.46
Camptostoma obsoletum	Call	3225.21	158.82	4156.97	181.73	3809.22	102.19
Camptostoma obsoletum	Song	1363.76	374.92	8268.72	1115.81	4218.69	304.45
Caracara plancus		979.17	277.61	5304.12	1590.86	2350.78	513.77
Cariama cristata		782.74	102.46	7483.07	1178.83	1875.24	362.94
Colaptes campestres		1170.78	290.18	5903.53	2091.79	2429.01	183.72
Coryphospingus cucculatus		1763.16	187.46	8078.28	1192.44	3691.40	338.32
Coryphospingus pileatus		1846.59	252.79	4521.89	571.09	3042.20	78.88
Cyanocorax cristatellus		811.76	112.53	8865.88	1731.88	2580.97	170.58
Cyclarhis gujanensis		1719.04	366.71	3415.32	731.92	2861.22	533.17
Elaenia chiriquensis	Call	1495.06	158.79	6177.89	1541.26	3113.70	395.96
Elaenia chiriquensis	Song	1185.89	345.57	5275.76	975.01	3213.27	318.11
Elaenia cristata		1486.59	317.63	5000.47	1248.84	3496.40	535.69
Elaenia flavogaster	Call	2090.87	113.56	4027.83	753.57	3159.08	248.65
Elaenia flavogaster	Dawn	2472.77	158.22	4533.02	226.77	3540.03	405.84
Elaenia flavogaster	Song	1759.15	445.27	5001.69	1316.77	3358.60	373.85
Furnarius rufus		1797.10	439.35	5680.90	2322.54	3353.91	416.06
Hydropsalis parvula		703.56	139.84	3134.41	401.42	2271.06	301.22

Lepidocolaptes angustirostris		1286.95	200.17	5012.52	498.06	2522.79	93.37
Leptotila rufaxila		381.15	19.29	572.51	27.33	462.95	19.10
Megascops choliba		527.75	71.59	1918.44	228.51	818.18	48.62
Melanopareia torquata		1882.08	186.78	2717.29	161.74	2350.79	130.18
Myiarchus swainsoni	Call	1287.95	100.34	1881.29	117.23	1690.76	95.19
Myiarchus swainsoni	Song	1235.68	229.01	4412.80	1110.81	2412.95	660.16
Neothraupis fasciata		1631.85	144.49	5291.75	757.34	3173.34	340.04
Nyctidromus albicollis		770.73	108.26	2557.34	310.02	1598.53	262.37
Patagioenas picazuro		337.99	47.77	821.53	110.16	536.96	69.57
Pitangus sulphuratus	Call	759.81	173.13	8533.66	2697.24	3303.19	489.44
Pitangus sulphuratus	Song	896.60	105.20	8954.56	1491.40	3409.15	281.56
Suiriri suiriri		996.71	299.11	6197.32	1616.84	3018.21	735.46
Synallaxis frontalis		1559.16	200.67	7483.70	601.57	4008.01	858.15
Thraupis sayaca		2387.20	538.13	8094.86	372.89	5887.18	737.40
Troglodytes musculus		1538.31	283.43	7732.43	1423.78	3898.64	781.06
Turdus leucomelas	Call	1556.23	503.52	8960.12	1504.50	4200.00	1291.03
Turdus leucomelas	Song	1510.06	159.06	3095.79	310.76	2375.59	305.31
Tyrannus melancholicus		4438.58	352.84	6642.35	390.26	6070.09	360.74
Vanellus chilensis		853.34	220.53	8771.76	1958.94	3231.66	833.36
Zonotrichia capensis		2748.46	339.50	6830.53	287.92	4043.92	352.89

Anexo III – Índice de urbanidade

Using Ebird citizen surveys to characterize bird species by their degree of urban avoidance

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METHODS

Data Collection

We obtained a total of 304 daily census lists from Ebird (ebird.org), an online bird checklist in which birdwatchers share their observations. We downloaded data between August and September of 2017. We selected a series of cities (N = 35) in Brazil, distributed in 13 of Brazil´s 26 states, covering all regions of Brazil except for the Amazon biome and southern Brazil. We excluded these regions because they have very distinct vegetation, climate and species diversity with respect to other Brazilian regions, where the rest of the study was conducted. We chose cities that had a good number of urban areas with many checklists available in Ebird. We selected for each city 1-2 urban areas (parks, squares, University campuses) and non-urban areas (national parks, natural reserves, protected areas, private farms). The distance between the urban city areas and the non-urban areas varied depending on availability of sites, but was always at least 100 km apart (much shorter range than the mean distance between urban sites). For each selected urban and non-urban area, we downloaded 3 observation lists. We downloaded checklists in two rounds. In a first round, we based our selection upon a visual search of hotspot lists in urban and non-urban areas, keeping a balanced number of areas within the same state. In a second search round we used species-specific criteria, to include some key species for which we had physiological and behavioural data, but which were missing from the first round checklists (e.g. *Myiachus swainsoni*, *Elaenia chiriquensis*, *Elaenia cristata*, *Suiriri suiriri*, *Synallaxis frontalis*, *Ammodramus humeralis*, *Coryphospingus cucculatus* and *Mimus gilvus*). In this second round we searched for cities in which these species had been detected (mostly not assigned to Ebird hotspots), and which consequently did not appear in the first search round. To obtained a balanced sampling, we chose a corresponding number of non-urban areas near these cities. Our criterion to select a checklist was that the visit had lasted between 0.5 and 4 hours, with a minimum of 1 and a maximum of 4 observers. We gave preference to lists recorded between August and March of any year (N=211), when most birds are breeding and are more active in the selected Brazilian regions, but we also included lists from other periods of the year (N=93).

Statistical models

All statistical analyses were done in R 3.2.1 (R Development Core Team, 2016). Using the list of species surveyed in Ebird as presence/absence data, our objective was to understand the effect of urbanized habitat on the site occupancy rates of each species. For this purpose, we used site-occupancy models that consider presence/absence data as the result of two separate stochastic processes: the probability that a site is occupied by the species and the probability that the species is detected by the observer (MacKenzie et al 2002; MacKnezie et al 2006). Site occupancy models estimate the probability of occupancy and detection with a likelihood based method (MacKenzie et al. 2006). Because the two processes are modeled separately, this method also allows us to introduce covariates in both processes independently. We were interested in the urban effect on the occupancy rate, hence we included habitat type (urban vs. rural) as a covariate of the probability of occupancy. Ebird citizen surveys of bird species are not standardized and, in particular, the duration and number of observers vary widely across surveys. We attempted to correct this by using the number of observers and the duration of the survey as two covariates of the detection probability process. This analysis was performed using the *occu* function in the *r* package UNMARKED (Fiske and Chandler 2011). Apart from this we assumed variation in detectability among sites was constant (or random).

Table 1. Values of urbanity for 105 species. We used the value of the Z statistic as a representation of the *degree of urbanity* for each species. This means that high positive Z values for the urban effect reflect species that exhibit some degree of preference for urban habitats while low negative values are associated with species that exhibit some degree of avoidance for urban environments. Species that have a Z statistic close to zero are those that occupy urban and rural habitats to a similar degree.

Species	**Urbanity (Z statistics)**
Columba livia	0.757
Estrilda astrild	0.739
Machetornis rixosa	0.696
Passer domesticus	0.642
Paroaria dominicana	0.617
Egretta thula	0.546

Phalacrocorax brasilianus	0.486
Ardea alba	0.469
Forpus xanthopterygius	0.467
Fluvicola nengeta	0.438
Butorides striata	0.435
Mimus gilvus	0.425
Eupetomena macroura	0.420
Molothrus bonariensis	0.416
Certhiaxis cinnamomeus	0.395
Colaptes melanochloros	0.379
Notiochelidon cyanoleuca	0.356
Synallaxis frontalis	0.334
Crotophaga ani	0.332
Todirostrum cinereum	0.325
Zenaida auriculata	0.281
Turdus amaurochalinus	0.277
Polioptila dumicola	0.276
Furnarius rufus	0.267
Thraupis sayaca	0.254
Megarynchus pitangua	0.254
Myiarchus tyrannulus	0.245
Thraupis palmarum	0.236
Myiodynastes maculatus	0.225
Brotogeris chiriri	0.224
Vanellus chilensis	0.202
Tangara cayana	0.196
Gallinula galeata	0.192
Coereba flaveola	0.191
Guira guira	0.187
Sicalis flaveola	0.175
Lepidocolaptes angustirostris	0.168
Chlorostilbon lucidus	0.160
Pitangus sulphuratus	0.156
Tyrannus melancholicus	0.155
Myiozetetes similis	0.149
Veniliornis passerinus	0.139
Columbina squammata	0.138
Volatinia jacarina	0.138
Cyclarhis gujanensis	0.131
Piaya cayana	0.127
Milvago chimachima	0.098
Patagioenas picazuro	0.094
Athene cunicularia	0.094
Mimus saturninus	0.089

Tyrannus savana	0.076
Psittacara leucophthalmus	0.074
Suiriri suiriri	0.071
Coragyps atratus	0.055
Chloroceryle amazona	0.047
Euphonia chlorotica	0.047
Turdus leucomelas	0.046
Troglodytes aedon	0.044
Columbina talpacoti	0.040
Caracara plancus	0.036
Turdus rufiventris	0.034
Elaenia flavogaster	0.013
Progne chalybea	0.006
Sporophila nigricollis	-0.016
Diopsittaca nobilis	-0.043
Megaceryle torquata	-0.053
Leptotila verreauxi	-0.055
Rupornis magnirostris	-0.062
Jacana jacana	-0.066
Picumnus albosquamatus	-0.072
Bubulcus ibis	-0.074
Camptostoma obsoletum	-0.108
Cantorchilus leucotis	-0.123
Galbula ruficauda	-0.138
Progne tapera	-0.148
Stelgidopteryx ruficollis	-0.149
Myiarchus ferox	-0.150
Coryphospingus cucullatus	-0.256
Tolmomyias sulphurescens	-0.281
Theristicus caudatus	-0.282
Patagioenas cayennensis	-0.301
Ramphastos toco	-0.316
Eupsittula aurea	-0.322
Colaptes campestris	-0.335
Zonotrichia capensis	-0.337
Dacnis cayana	-0.343
Ammodramus humeralis	-0.379
Gnorimopsar chopi	-0.406
Amazona aestiva	-0.416
Vireo olivaceus	-0.429
Phaethornis pretrei	-0.434
Myiarchus swainsoni	-0.472
Basileuterus culicivorus	-0.484
Cariama cristata	-0.499

Thamnophilus caerulescens	-0.522
Cathartes aura	-0.531
Elaenia cristata	-0.540
Saltator similis	-0.634
Cyanocorax cristatellus	-0.654
Myiothlypis flaveola	-0.665
Antilophia galeata	-0.697
Elaenia chiriquensis	-0.698
Tachyphonus rufus	-0.700
Neothraupis fasciata	-0.722
Sittasomus griseicapillus	-0.798

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