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A first assessment of the productivity of Araucaria tit-spinetail (Leptasthenura setaria): the effects of the Araucaria and a plea for further studies

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Abstract

The Araucaria tit-spinetail (*Leptasthenura setaria*) is a furnariidae endemic to the Araucaria Mixed Forest (AMF) that inhabits the crowns of the emergent Araucaria (*Araucaria angustifolia*). This forest is highly threatened and fragmented, especially due to urbanization, presumably challenging the local maintenance of *L. setaria* population. Despite being highly vocal, this small bird is rarely seen from the ground, which has likely limited the gathering of information on its natural history, particularly on its breeding biology, a key parameter for assessing population trend. Our study indirectly estimated the productivity of the Araucaria tit-spinetail as a proxy of breeding success on 79 AMF fragments in South Brazil. We also examined whether this parameter is influenced by the Araucaria density using zero-inflated negative binomial generalized linear models (ZINB-GLM) on samplings taken in the breeding and post-breeding periods. We found a significant increase in individual counts during the post-breeding season, estimating an average production of 2.32 young per couple. Moreover, higher Araucaria density significantly reduced bird detectability, likely due to a habitat dilution effect, but the conifer density had no effect on the species abundance or productivity. While urban fragmentation poses conservation challenges, *L. setaria* exhibits positive productivity and a likely local resilience. These findings estimate the first primary productivity for *L. setaria*, highlighting the complexity of the relationship between this bird and the Araucaria and emphasizing the need for continued ecological monitoring and habitat connectivity to ensure the long-term conservation of this poorly known bird, even though its regular presence in human-modified landscapes.

Introduction

The Atlantic Rainforest is a biodiversity hotspot, with an abundance of endemic species (Grelle et al. 2021). This biome extends over the Brazilian coast and well inland, covering most of Minas Gerais, São Paulo, Santa Catarina and Rio Grande do Sul, among other states. Nevertheless, it has been critically degraded over the last few decades (Ranta et al. 1998; Grelle et al. 2021). The Araucaria Moist Forest (AMF) is one of the habitats that compose the Atlantic Rainforest, a formation that ranges mainly across the southern states of Brazil and is characterized by the abundant presence of Araucaria (*Araucaria angustifolia* (Bretol.) Kuntze), a large conifer that plays a key role in this biome (Souza 2021).

Some of the endemic animal groups that inhabit the AMF include several bird species (Vale et al. 2018). The Araucaria tit-spinetail *Leptasthenura setaria* (Aves: Furnariidae) is an endemic species that diversified less than five million years ago (Derryberry et al. 2011). Some studies have shown that this bird is strongly related to the Araucaria and that its geographical distribution is directly correlated with the extent of occurrence of the conifer (Anjos et al. 2015; Remsen 2020). The canopies of isolated or grouped Araucaria trees are year-round territories actively defended by the strictly insectivorous Araucaria tit-spinetail for foraging, nesting, and mating (Vaurie and Vuilleumier 1980; Bóçon 1993; Joenck 2005; Zurita et al. 2006; Cabanne et al. 2007). This bird is currently listed as of Least Concern for conservation, as it has a distribution area of approximately 600,000 km² (BirdLife International 2024; IUCN 2024). However, its current population size is unknown, and its tendency is to decrease following

the suppression of the AMF to about 4% of its original cover (Zorek et al. 2024; BirdLife International 2024).

Urban expansion and the economic and financial activities linked to it are characteristic features of the Capitalocene (Moore, 2017). Consequently, the intensive impact of the current capitalist production system has profoundly affected the ecosystems, especially in biomes such as the AMF, where fragmentation is of growing concern (Olson and Dinerstein 2002; Ribeiro et al. 2009; Santos-Silva 2016; Mohebalian et al. 2022) since the biome covers the region of the country with the largest urban centers and highest population density. Fragmentation in this environmental system represents a major threat to its biodiversity, potentially limiting fauna dispersal and limiting their potential distribution due to habitat availability restrictions (Galletti et al. 2021). Zorek et al. (2024) emphasizes that the AMF is facing significant rates of deforestation, given that 2.151 ha were degradedin 2019–2020 in a single Brazilian region (Paraná). The impact of fragmentation on the Araucaria has been very significant, leading to its Critically Endangered status (Zorek et al. 2024; IUCN 2013).

Given that the ecological interaction with Araucarias is apparently obligatory for the Araucaria tit-spinetail, the process of reducing distribution and increasing fragmented populations of Araucaria also have a plausible impact on the bird's populations. Understanding the Araucaria tit-spinetail population dynamics, as well as its distribution and reproduction, is essential for conservation. This bird species occurs from preserved AMF remnants to urban centers with isolated Araucaria, therefore exhibiting plasticity and adaptation to different habitat conditions. The strong connection between the species and the Araucaria includes the nesting demands, but it is not yet clear whether the fragmentation of Araucaria populations has a direct impact on the bird's productivity, a proxy for breeding success. A better understanding of the Araucaria tit-spinetail's productivity is thus valuable for understanding the species' populations trend over time and to develop and guide conservation strategies.

There is, nevertheless, a need to better support the above statements with studies on the bird's natural history, ecology, and demography, which is currently based on superficial information due to the lack of dedicated studies on the bird species. Regarding its reproductive behavior, most information is based on isolated or incidental evidence. Details on the species' nest, for instance, are limited to two nests found (Bóçon 1994), and suggests that the species' reproductive period generally occurs in the southern hemisphere spring-summer (Remsen 2020). It has been reported that the species lays two eggs (de la Peña 1988 apud Bóçon 1993), although there is no information on the productivity of couples (e.g. number of offspring that leave the nest). We therefore lack key information for estimating population growth potential (Frederiksen et al. 2024).

A measure of a species' productivity is defined by the number of juveniles born during the reproductive season that reach independence (Powell et al. 1999; Streby and Andersen 2011; Jarrett, Lehikoinen and Willis 2024). Gottschalk and Huettmann (2011) discuss how variations in habitat can influence census methods and abundance estimates in bird species. In coniferous forests, the probability of detecting birds is described as apparently lower, leading to less precise density estimates (Gottschalk and

Huettmann 2011). Species detectability can vary according to their mobility and conspicuousness. More mobile species, for instance, may be over-detected, and their abundance overestimated, as a result of constant movements in and out of the sampling area (Fuller and Langslow 1984). When counting fledged broods, methods such as estimating daily detection probabilities provide accurate estimates of bird productivity and are essential for understanding variations in productivity that may be associated with factors such as habitat management (Sange et al. 2011).

The aim of this work was to estimate the breeding productivity of the Araucaria tit-spinetail within AMF fragments in the largest metropolitan region in South Brazil. The study site has a high apparent incidence of the bird and is representative of the increasing fragmentation of the Araucaria tit-spinetail's habitat (i.e., the AMF) due to urbanization. Specifically, the study quantified the breeding productivity of the bird species in the context of forest fragmentation and urbanization, highlighting the effect of Araucaria density on this life-history parameter of the Araucaria tit-spinetail.

Materials and methods

Data

The data was collected by MROR, from September 2023 to March 2024, as a side data to an occupancy study. The sampling sites were in Curitiba (Paraná, Brazil) and in 10 of its metropolitan region cities: Almirante Tamandaré, Araucária, Campina Grande do Sul, Campo Largo, Campo Magro, Colombo, Fazenda Rio Grande, Pinhais, Piraquara e São José dos Pinhais. We randomly set 79 sampling points in AMF fragment, with a distance of at least 500 m between them to ensure independence (Fig. 1).

We registered the number of bird individuals in each sampling point through fixed 30 m radius point counts (Gregory et al. 2004). We sampled each point once for seven minutes in the mornings of non-rainy days during both the breeding (October to December) and post-breeding seasons (March to May 2024), recording every heard or seen individual. We also recorded the number of Araucarias with a diameter at breast height (DBH) > 30 cm in each sampled point, thus the mature conifers that reach the canopy stratum.

Data analyses

Due to 58% of absence of Araucaria tit-spinetail in the samplings (but only in five out of the 79 sampled points), we ran a zero-inflated negative binomial (quadratic parameterization) generalized linear model (ZINB-GLM) with a log link to assess the effects of density of Araucaria in the Araucaria tit-spinetail productivity. For this model, we tested the number of individuals recorded at each point considering the main effects of the sampling period (i.e. breeding and post-breeding) and the number of Araucaria individuals, in both the counting and zero-inflated components of the model. We ensured that the ZINB-GLM met its assumptions through graphical diagnostics, using the "simulateResiduals()" function of the DHARMa package (Hartig, 2021). We ran the analyses in the R environment (R Core Team, 2024), using

the “glmmTMB()” function of the glmmTMB (Brooks et al. 2017), ggplot2 (Wickham 2016) and ggeffects (Ludecke 2018) packages.

Results

Detectability and productivity

The ZINB-GLM results show that the chance of recording Araucaria tit-spinetail individuals significantly decreased with the number of Araucaria at the sampled point (ß ± SD: -0.35 ± 0.14; z = -2.60; p = 0.01) but remained unchanged between periods (i.e., breeding *vs.* post-breeding: ß ± SD = 0.70 ± 0.71; z = 0.98; p = 0.33).

The conditional model results indicate a significant increase of bird individuals in the breeding compared to the non-breeding period (ß ± SD = 0.84 ± 0.25; z = 3.31; p < 0.01; Fig. 2A), i.e., an average ± SD production of $e^{0.84 \pm 0.25}$ = 2.32 ± 1.29 young per couple (range: 1.03 to 3.61). On the other hand, the number of Araucaria had no significant influence on this response variable (ß ± SD = 0.004 ± 0.005; z = 0.72; p = 0.47; Fig. 2B).

Discussion

At the study site, the Araucaria tit-spinetail population approximately doubled from the breeding to the post-breeding period, suggesting breeding success even in this fragmented habitat. Araucaria density reduced the species’ detectability, likely through a dilution effect in which greater habitat availability causes birds to spread over a larger area or territories. Nevertheless, abundance estimates remained unaffected by the number of Araucaria trees, and although season did not affect detectability, abundance increased markedly during the post-breeding period. In this severe fragmentated and urbanized AMF context, this pattern likely emerges because young remained in the parental territory after the breeding season, a delayed natal dispersal behavior already documented in Furnariidae (e.g. Amorim et al. 2024).

Reproductive success in a species should not be assessed solely by the survival of juveniles while still in the nest, since the selective pressures may vary throughout the different stages of an individual's life (Strebry et al. 2014). For individuals seeking to establish new territories, juvenile dispersal can be influenced by several factors, among which territory size of the neighborhood, local and regional population density, and resource availability appear to be the most relevant (Martín et al. 2008; Nicolaus et al. 2012). Additionally, vegetation density and habitat fragmentation may restrict territory size and, consequently, limit juvenile dispersal (Haggerty 1998; Cunningham and Johnson 2012; Cornelius et al. 2017). In some cases, when dispersal is delayed and juveniles remain in the natal territory for extended periods, their likelihood of integrating into the local breeding population may increase (Gill and Stutchbury 2010). For example, *Furnarius rufus* juveniles often establish territories close to their parental area, possibly as a strategy to maintain kin-based neighborhoods (Amorim et al. 2024). In the case of *L.*

setaria, the detected increase in the number of individuals during the post-breeding period (Fig. 2A) suggests the prolonged presence of juveniles in the parental territory for this species, as well as their more frequent vocalizations. This delayed dispersal could enhance reproductive success through extended parental care. Tarwater and Brawn (2010), in a study on *Thamnophilus atrinucha*, described delayed dispersal and prolonged family association as an adaptive strategy. In this context, the benefits of remaining in parental territory, such as increased access to resources and protection from competitors and predators, can significantly enhance juvenile survival (Tarwater and Brawn 2010). For the Araucaria tit-spinetail, behaviors related to territory defense and its close ecological association with the Araucaria may also play a role in improving chick survival (Remsen 2020).

Delayed dispersal, however, warrants further investigation in this species, as it seems to be a widespread and advantageous strategy among birds, especially in competitive environments or fragmented habitats (Lens and Dhondt 1994). The relationship between productivity and delayed dispersal has been discussed in the literature primarily in terms of reproductive and habitat quality (e.g. Luna et al. 2021; Chu and Claramunt 2023). Species with slow life histories (e.g. many tropical birds) can exhibit low annual reproductive output, which is compensated for by high survival rates, particularly among juveniles (e.g. Tarwater et al. 2011). Such patterns are connected to delayed dispersal as strategies that increase the likelihood of surviving the reproductive age (Covas and Griesser 2007; Tarwater et al. 2011). For example, some urban birds show higher survival and lower reproductive output compared to rural counterparts, reflecting a shift toward a slower pace of life (Sepp et al. 2017). In the burrowing owl *Athene cunicularia*, delayed dispersal and family group formation are common in urban habitats and areas with high population density, which suggest that habitat quality and productivity are key factors (Luna et al. 2021). The individuals tend to remain in high-quality and more productive nests although their presence does not increase the number of fledglings (Preston et al. 2016; Luna et al. 2021). Overall, delayed dispersal is more common and advantageous in contexts where the costs of dispersal are high, and breeding opportunities are limited or unpredictable, such as in stable or saturated environments (Tarwater and Brawn 2010; Kingma et al. 2016). In addition, the extent and patterns of delayed dispersal often vary between males and females depending on the ecological and social context (Nelson-Flower et al. 2018). In such cases, remaining in the natal territory can bring indirect and direct fitness benefits, highlighting that individual productivity is central to the evolution of this strategy (Tarwater and Brawn 2010).

The productivity observed in the Araucaria tit-spinetail, even under the severe fragmentation and urbanization of the AMF sampled here, offers encouraging evidence for the conservation of both the species and this unique bird–plant specialization. The observed decline in detectability of the bird individuals in areas with higher densities of Araucaria aligns with the expectations for Neotropical forest systems, where high species diversity, large territory size, and low individual density per territory are common characteristics (Stouffer, 2007). Nevertheless, the effects of fragmentation and urbanization on key life-history traits of the Araucaria tit-spinetail remain largely unknown. Further research should uncover potential behavioral adaptations of this bird to the environmental pressures, including the minimum needed amount of Araucaria crops as habitat for territory and nest establishment, and

including vocal adjustments to urban noise pollution aimed at reducing signal overlap and mitigating intraspecific competition in the increasingly fragmented landscape in which these birds currently live (Staniewicz et al. 2023).

Conclusions

This study revealed key aspects of the interspecific relationship between the Araucaria tit-spinetail (*L. setaria*) and the Araucaria (*A. angustifolia*), highlighting the presence of the bird in approximately 74% of the sampled points and an average production of one to three young per couple in the sampled breeding season, leading to a momentaneous population increase of around 50% in the post-breeding period in the studied region. The density of Araucaria in the sampled fragments had no influence in the species' productivity. This suggests that the ecological relationship between these two species is more complex than previously assumed, likely involving additional behavioral factors that warrant further investigation, such as territory size variation, interspecific competition, nest predation rate, and insect (i.e., food) availability. Moreover, the ongoing fragmentation of the AMF (Zorek et al. 2024) remains a critical conservation concern for this bird. This is especially true given the endangered status of Araucaria (IUCN 2013), on which the bird depends. A decline in Araucaria populations may exert a potentially significant but poorly understood influence on the population dynamics of the Araucaria tit-spinetail, another aspect that deserve attention in future research.

Although this study clarifies aspects of the relationship between the Araucaria tit-spinetail and the Araucaria in the currently fragmented and urbanized context of AMF, we emphasize that further research is essential to fully understand the complexity of their ecological association. Key aspects of this bird’s ecology (i.e. territory size, survival rates, longevity, and juvenile dispersal) warrant quantitative studies. Additionally, exploring how the density of Araucaria within fragments affects the bird’s territorial, nesting, and vocal activity could yield valuable insights for conservation planning. The integration of bioacoustics monitoring and occupancy modeling presents a promising approach to obtain more accurate estimates of the species’ distribution and population density (e.g. Campos-Cerqueira and Aide 2016; Pillay et al. 2019; Abrahams and Geary 2020; Oliveira et al *in prep.*), including individual movements in the fragmented landscape. Such findings would be essential to inform the development of ecological corridors and long-term monitoring programs aimed at tracking population trends under the continued pressures of fragmentation and urbanization of this biome.

Declarations

Author Contribution

C.M. participated in the analysis, interpretation, writing, and translation of the text; A.C.G. performed a major part of the analysis and reviewed the text; MROR participated in the data collection and text revision.

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Figures

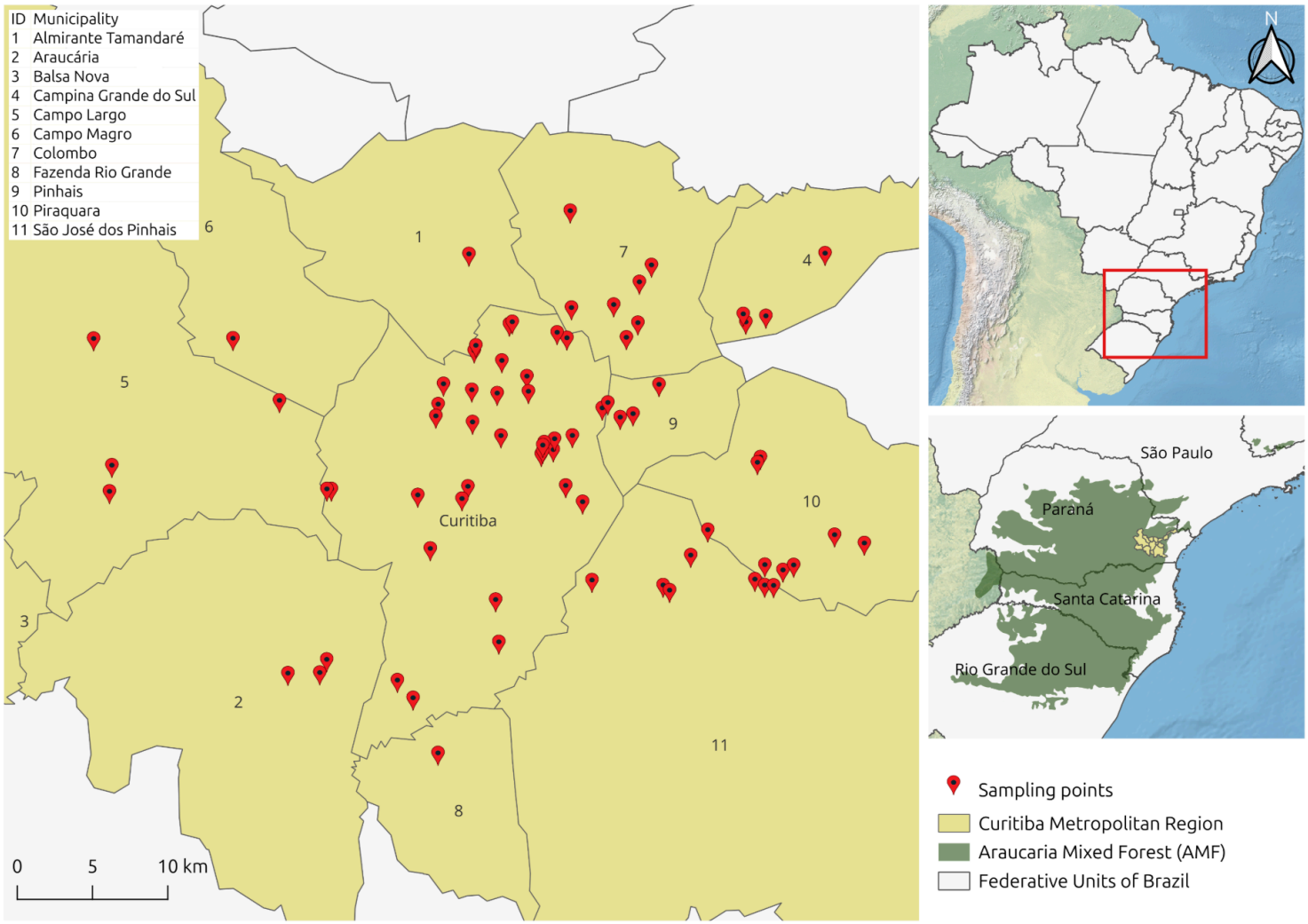


Figure 1

Map of the 79 count points sampled for the number of Araucaria tit-spinetail (*Leptasthenura setaria*) in the Curitiba Metropolitan Region.

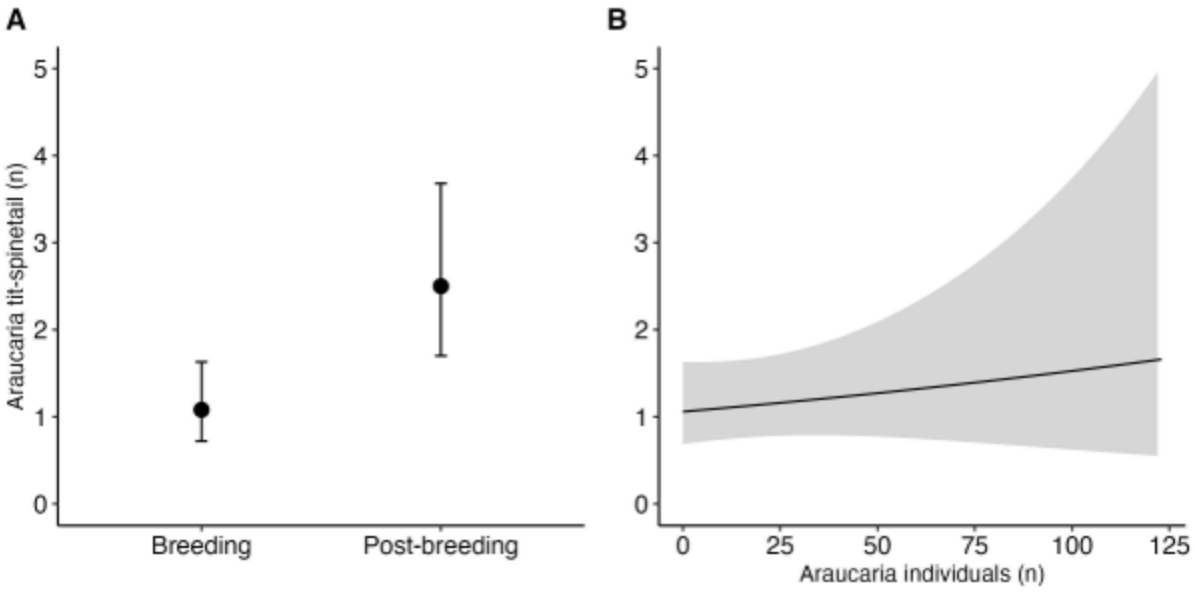


Figure 2

A) Model estimates for the number of individuals of Araucaria tit-spinetail (*Leptasthenura setaria*) in the breeding and post-breeding periods, indicating the significant population increase due to young production (refer to the text for statistics). B) Non-significant shift on the number of bird individuals due to the number of Araucaria (*Araucaria angustifolia*).