UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E RECURSOS NATURAIS

LAHERT WILLIAM LOBO DE ARAÚJO

Sobrevivência de ninhos e novos aspectos da biologia reprodutiva de aves para o Centro de Endemismo Pernambuco

São Carlos – SP
2024

LAHERT WILLIAM LOBO DE ARAÚJO

Sobrevivência de ninhos e novos aspectos da biologia reprodutiva de aves para o Centro de Endemismo Pernambuco

Tese apresentada ao Programa de Pós-Graduação em Ecologia e Recursos Naturais (PPGERN) da Universidade Federal de São Carlos, para obtenção do título de Doutor em Ciências.

Área de concentração: Ecologia e Recursos Naturais

Orientador: Prof. Dr. Mercival Roberto Francisco

São Carlos – SP

2024

UNIVERSIDADE FEDERAL DE SÃO CARLOS

Centro de Ciências Biológicas e da Saúde
Programa de Pós-Graduação em Ecologia e Recursos Naturais

Folha de Aprovação

Defesa de Tese de Doutorado do candidato Lahert William Lobo de Araújo, realizada em 01/03/2024.

Comissão Julgadora:

Prof. Dr. Mercival Roberto Francisco (UFSCar)

Prof. Dr. Manoel Martins Dias Filho (UFSCar)

Prof. Dr. Guilherme Santos Toledo de Lima (UFAPE)

Prof. Dr. Wallace Rodrigues Telino Júnior (UFAPE)

Profa. Dra. Flor Maria Guedes Las-Casas (UEMA)

O Relatório de Defesa assinado pelos membros da Comissão Julgadora encontra-se arquivado junto ao Programa de Pós-Graduação em Ecologia e Recursos Naturais.

Aos meus pais, Laerço e Heliane, ao meu filho, Nícolas, e minha esposa, Cecília, aos meus irmãos, demais familiares e amigos, que me deram muito apoio e carinho, ao meu orientador, Prof. Dr. Mercival Roberto Francisco, pelos ensinamentos e suporte acadêmico, além do exemplo como pessoa e profissional ao qual terei sempre como referência,

***dedico**.*

AGRADECIMENTOS

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) pela bolsa de doutorado concedida (Processo #142308/2019-6).

À Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) pelo apoio financeiro ao Projeto Temático ARCA do CEP (Processo # 2017/23548–2).

À Universidade Federal de São Carlos (UFSCar) e ao Programa de Pós-Graduação em Ecologia e Recursos Naturais (PPGERN).

Ao Laboratório de Ornitologia, do Departamento de Ciências Ambientais no Centro de Ciências e Tecnologias para Sustentabilidade da UFSCar – Sorocaba.

Ao SISBio/MMA e a Comissão de Ética no Uso de Animais da UFSCar (CEUA), pela autorização do trabalho de campo e pela aprovação dos métodos de pesquisa (Processo # 66157-6 e 1405291118).

Ao Fernando Pinto, pelo suporte e apoio logístico, através do Instituto de Preservação da Mata Atlântica (IPMA) e Zooparque Pedro Nardelli.

À Sônia Roda e Marcela Daher, pelo suporte e apoio logístico, através da Usina Utinga, Grupo EQM.

Ao Luzenilton Brito, pelo suporte e apoio logístico, através da Usina Coruripe.

Ao Carlos Monteiro, Luiz Eugênio e Genilson, pelo suporte e apoio logístico, através da Usina Porto Rico, Grupo Olival Tenório.

À Luís Fábio Silveira, Luiza Prado, Mariellen Cristine, pela ajuda e companheirismo, além de toda equipe do Projeto ARCA do CEP.

Aos amigos, Dubeux, Arthur Andrade, Ubiratan, Mário Tanio e Edelmo Gonçalves, pelo incentivo, ajuda de campo e apoio.

Ao Prof. Dr. Mercival Roberto Francisco, pela amizade, confiança, paciência e pelas valiosas orientações com sugestões e contribuições indispensáveis para o desenvolvimento e conclusão da tese, me ajudando a trilhar no caminho certo na vida acadêmica.

Aos meus pais, Laerço e Heliane, e irmãos, pelo incentivo aos estudos, apoio sempre que foi necessário e compreensão nos momentos em que estive ausente.

Ao meu filho, que tanto amo, Nícolas, e minha querida esposa e companheira, Cecília, pelo incentivo e por compreenderem os momentos em que, durante as campanhas de campo, tive que me ausentar por vários dias, além dos meus sogros, Osvaldo e Nena, pelo suporte para que eu prosseguisse com os meus objetivos e não desistisse.

“Dedicação é a capacidade de se entregar à realização de um objetivo. Não conheço ninguém que tenha progredido na carreira sem trabalhar pelo menos doze horas por dia nos primeiros anos. Não conheço ninguém que conseguiu realizar seu sonho sem sacrificar sábados e domingos pelo menos uma centena de vezes. A realização de um sonho depende da dedicação.”

(Roberto Shinyashiki)

RESUMO

As florestas tropicais são megadiversas, mas em algumas regiões o nível de degradação é tão intenso que a conservação da biodiversidade tem dependido totalmente da gestão das manchas florestais restantes. Teoricamente, as populações de aves poderiam experimentar uma redução na sobrevivência dos ninhos em habitats fragmentados devido à extinção de predadores de topo, causando aumento da densidade populacional de predadores de ninhos de pequeno e médio porte, ou devido à invasão de espécies predadoras exóticas. Grandes extensões florestais não existem mais no Centro de Endemismo de Pernambuco (CEP) e todos os predadores de topo foram extintos há muito tempo. Aqui, investigamos a sobrevivência de ninhos de aves do sub-bosque florestal de três fragmentos de CEP (690, 979 e 1.049 ha) e usamos armadilhas fotográficas com sensor infravermelho para registro e identificação de predadores. A taxa aparente de sobrevivência dos ninhos de 15 espécies de aves foi 15,5% e as probabilidades de sobrevivência modeladas para quatro espécies com maiores tamanhos amostrais (incluindo dois táxons endêmicos e ameaçados) variaram entre 2,6 e 18,9%. Os principais predadores foram primatas (25%), marsupiais (25%), teiú (19,4%), quati (16,7%), serpentes (8,3%) e aves de rapina (5,5%). Além disso, são apresentadas descrições dos ninhos e dados reprodutivos inéditos para o flautim-marrom, *Schiffornis turdina intermedia* e para a maria-de-barriga-branca *Hemitriccus griseipectus naumburgae*, além da primeira descrição do cortejo pré-copulatório do beija-flor rabo-branco-rubro *Phaethornis ruber*. Estas informações contribuíram com o entendimento dos fatores que ameaçam a sobrevivência de algumas das espécies de aves do CEP e para o apontamento de estratégias de manejo para conservação.

Palavras-chave: predação de ninhos; florestas tropicais; Mata Atlântica; câmeras-trap; comportamento de nidificação.

ABSTRACT

Tropical forests are megadiverse, but at the same time they have been highly degraded in such a way that biodiversity conservation has often relied on the management of the remaining forest patches. The survival of bird's nests can be low in fragmented habitats due to top-predators extinction causing increased population densities of small and medium-sized nest predators, or because of the invasion of alien nest predators. Large forest tracts no longer exist in the Pernambuco Endemism Center (PEC) and all of the top-predators were long extinct. Here, we addressed nest survival of forest understory birds from three PEC fragments (690, 979, and 1049 ha), and we used infra-red camera-traps for predators' identification. Apparent nest survival was 15.5%, and nest-day based survival probability for the four more representative species (including two endemic and threatened taxa) were 2.6, 4.4, 6.9, and 18.9%. Predators were marmosets (25%), opossums (25%), tegu (19.4%), coati (16.7%), snakes (8.3%) and hawks (5.5%). Furthermore, we present nest descriptions and new reproductive information for the brown-winged mourner *Schiffornis turdina intermedia* and for the tody-tyrant *Hemitriccus griseipectus naumburgae*, as well as the first description of the pre-copulatory display of the reddish hermite *Phaetornis ruber*. Our data improved our understanding about the main threats to the birds of the PEC and provided a background for the development of conservation management strategies.

Keywords: nest predation; tropical forests; Atlantic Forest; camera-traps; nesting behaviour.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

INTRODUÇÃO GERAL

A região biogeográfica da Mata Atlântica conhecida como Centro de Endemismo Pernambuco (CEP), localizada ao norte do Rio São Francisco, se destaca como um *hotspot* localizado dentro de outro *hotspot*, por abrigar um elevado número de espécies endêmicas e ameaçadas (Tabarelli, Siqueira-Filho e Santos, 2006). Estendendo-se originalmente por cerca de 4,4 milhões de hectares nos estados de Alagoas, Pernambuco, Paraíba e Rio Grande do Norte (Ribeiro *et al*., 2009), o CEP está inserido em um contexto de isolamento geográfico que proporcionou o cenário ideal para a ação de processos de especiação que geraram uma biodiversidade única (Bocalini *et al*., 2021; Lins-e-Silva, Ferreira e Roda, 2021). A região abriga cerca de 486 táxons de aves, sendo 171 dependentes de ambientes florestais e 50 ameaçados (Araujo *et al*., 2023), e foi cenário para as extinções modernas de aves no Brasil, com os desaparecimentos do limpa-folha-do-nordeste *Philydor novaesi*, do gritador-do-nordeste *Cichlocolaptes mazarbarnetti*, e do caburé-de-pernambuco *Glaucidium mooreorum* (Develey e Phalan, 2021). O mutum-de-alagoas (*Pauxi mitu*), maior ave frugívora do CEP, foi declarado extinto na natureza no final dos anos 1970, sendo salvo graças à ação de criadouros conservacionistas e da parceria entre órgão públicos e privados, que auxiliaram a espécie a superar um gargalo genético extremo e proporcionaram a reintrodução de seis indivíduos no estado de Alagoas em 2019 (Francisco *et al*., 2021). São notáveis os indícios de defaunação nos ecossistemas do CEP (e.g., Garbino *et al*., 2018; Pontes *et al*., 2016; Pontes, Beltrão e Santos, 2019), gerados, principalmente, pelo intenso desmatamento e degradação da vegetação nativa da região no passado, que foram responsáveis por reduzir a cobertura florestal original em cerca de 87% (Lins-e-Silva, Ferreira e Roda, 2021; Ribeiro *et al*., 2009).

Atualmente restaram apenas 12,3% dos 4,4 Mha originais de áreas florestadas (539.877 ha), e desse total, 29,5% são representados por fragmentos de 100 a 1.000 ha; 24,5% são representados por fragmentos maiores que 1.000 ha, e o restante das florestas (46%) está distribuído em fragmentos menores que 100 ha (Dias et al. 2023). Portanto, o cenário das paisagens do CEP é caracterizado por mosaicos de cultivos agrícolas, pastagens e pequenos fragmentos isolados de vegetação nativa, localizados, principalmente, nas áreas íngremes e nos topos dos morros (Lins-e-Silva, Ferreira e Roda, 2021; Ribeiro *et al*., 2009). Assim como em outras paisagens modificadas pela ação antrópica, os padrões de riqueza e abundância de espécies do CEP devem estar intimamente relacionados ao tamanho dos remanescentes florestais na região (Martensen, Pimentel e Metzger, 2008). Nesses contextos, o tamanho reduzido das florestas pode (i) aumentar a susceptibilidade de populações à eventos estocásticos genéticos e demográficos (Uezu e Metzger, 2011), (ii) reduzir a heterogeneidade dos habitats, (iii) a disponibilidade de recursos, e (iv) o sucesso reprodutivo de indivíduos (Fahrig, 2001; Tews *et al.*, 2004; Zanette, Doyle e Trémont, 2000). Vertebrados especialistas de nicho e/ou estritamente florestais também podem ser prejudicados por conta da dominância de habitats influenciados pelos efeitos de borda, já que os mesmos só atingem picos de abundância a cerca de 200 – 400 m das bordas florestais (Hansbauer *et al.*, 2008; Pfeifer *et al.*, 2017), ambientes, estes, que muitas vezes não estão sequer disponíveis em paisagens alteradas (Banks-Leite, Ewers e Metzger, 2010).

A situação dos ecossistemas do CEP é extremamente preocupante devido à alta degradação de sua cobertura florestal e às graves ameaças enfrentadas por uma parcela significativa da fauna local. Infelizmente, grande parte das espécies endêmicas e ameaçadas do CEP não estão incluídas em programas de conservação *ex situ*, o que poderia ter prevenido ao menos parte das extinções que ocorreram na região (Francisco *et al.*, 2021). Essa situação intensifica ainda mais a necessidade de avaliar e proteger os remanescentes dos habitats florestais da região para a manutenção da biodiversidade local. Apenas 1% da cobertura florestal do CEP é protegida por unidades de conservação públicas (Ribeiro *et al.*, 2009), e, mesmo com as iniciativas de criação de Reservas Privadas do Patrimônio Natural (RPPNs) durante as últimas três décadas (Carvalho *et al.*, 2021), grande parte das florestas permanecem desprotegidas.

Os fatores que podem moldar a biodiversidade em áreas fragmentadas são diversos. Além das clássicas respostas das comunidades a características das áreas como tamanho, forma e proximidade de outras áreas (Santos *et al.* 2002, Cintra *et al.* 2013), outros fatores bióticos e abióticos podem contribuir para os níveis de diversidade de espécies de um determinado remanescente, como o tipo de entorno, níveis de conectividade e fluxo gênico, proximidade de populações humanas, tipo e estrutura de vegetação, estágio sucessional, presença de pessoas dentro da área, presença de corpos d’agua, complexidade do habitat, presença de espécies invasoras e ferais, níveis de vigilância e até mesmo se estas áreas são públicas ou privadas (Beca *et al.* 2017).

Em regiões como o CEP, onde a defaunação é drástica e os predadores de topo de cadeia já foram extintos (Pontes *et al.* 2016), os mesopredadores (gambás, quatis, saguis, pequenos roedores etc.) tendem a aumentar em densidade devido à falta de seus predadores (principalmente felinos e grandes aves de rapina; hipótese da liberação dos mesopredadores) (Terborgh 1974, Robinson e Sherry 2012).

Uma vez que estes mesopredadores são importantes predadores dos ovos e filhotes de aves, a predação sobre os ninhos pode ser a explicação do porquê mesmo espécies de aves pequenas e que não têm interesse de caça serem ameaçadas de extinção no CEP, como acontece em outras regiões do planeta (Jansen 2005, Newmark e Stanley 2011). Outro fato importante é que alguns mesopredadores, principalmente roedores, são grandes predadores de sementes, o que pode fazer que algumas espécies arbóreas sejam extintas e com isto leve a cascatas de extinções devido à redução na oferta de alimentos (frutos) nestes ambientes.

Além disso, os efeitos sinergísticos da redução, fragmentação e alterações dos habitats e a caça podem levar à extinção dos grandes dispersores de sementes. Silva e Tabarelli (2000) estimaram que 34% das espécies de árvores (correspondendo àquelas com frutos acima de 15 mm de diâmetro) poderão desaparecer da região do CEP e a consequência final é a redução das assembleias de dispersores, especialmente os de grande porte (Melo *et al*. 2006, 2007, Oliveira *et al*. 2004, Santos *et al*. 2008), um processo que muito possivelmente já possa estar em andamento no CEP.

O cenário de intensa destruição do habitat e a perda dos principais predadores no CEP sugerem que a intensidade da predação dos ninhos deve ser investigada como um efeito potencial de cascata da fragmentação do habitat que contribui para a vulnerabilidade das comunidades de aves. Para apoiar potenciais planos de gestão de conservação, os predadores de ninhos também devem ser identificados e os seus impactos relativos ao sucesso da nidificação devem ser revelados, especialmente porque, em todo o mundo, a sobrevivência de um número crescente de espécies de aves que habitam ecossistemas perturbados depende do controle populacional de espécies nativas ou predadores de ninhos exóticos (Stantial et al. 2021). Aqui, investigamos a sobrevivência de ninhos de pássaros no subbosque florestal em três fragmentos representativos do CEP do estado de Alagoas e usamos armadilhas fotográficas infravermelhas para identificação de predadores. Uma estimativa de diversidade alfa foi usada para contrastar os números observados e previstos pelo modelo de espécies de predadores de ninhos, e para os táxons de aves com tamanhos de amostra de ninhos maiores estimamos a probabilidade de sobrevivência dos ninhos de Mayfield (Mayfield

1975), o que permitiu comparações entre populações dos mesmos táxons, ou entre congêneres de outras regiões da Mata Atlântica. Com esta investigação, descobrimos pela primeira vez os principais predadores de ninhos de aves no CEP e para quatro espécies de aves, duas das quais ameaçadas e endêmicas, revelamos taxas de sobrevivência de ninhos 2,5 a 8,5 vezes menores do que em outras regiões da Mata Atlântica, demonstrando que as taxas massivas de predação de ninhos podem estar entre as causas do declínio dos táxons de aves do CEP.

No contexto da importância do Centro de Endemismo Pernambuco para as aves, estudos que possam detalhas novos aspectos da biologia reprodutiva para os gêneros *Schiffornis*, *Hemitriccus* e *Phaethornis* possuem alta relevância, dentro do cenário de extinções locais e elevadas taxas de predações dos ninhos, além da importância de se conhecer aspectos básicos da história natural das espécies neotropicais.

Apesar do CEP concentrar o maior número de espécies de aves ameaçadas do Brasil e ser uma das áreas mais críticas para a conservação de aves no mundo, muito pouco se sabe sobre estas espécies e sobre os fatores que possam explicar a raridade de muitas delas. Embora diversas espécies sejam alvo de caça cinegética e/ou da captura voltada para o abastecimento do tráfico de animais silvestres, mesmo aves de pequeno porte, que não constituem populações cinegéticas, têm desaparecido ou se tornado muito raras nesta região (Pereira et al. 2014). Um dos fatores que pode explicar a raridade de muitas das espécies que não estão suscetíveis às atividades cinegéticas é o fato de que em paisagens fragmentadas, as taxas de predação de ovos e filhotes tendem a ser maiores (Newmark & Stanley 2011), tornando-se uma das principais causas de extinção de diversas espécies de aves no mundo todo (Savidge 1987, Dinsmore et al. 2017).

Portanto, os desequilíbrios nas interações entre os ninhos e seus predadores poderiam ser a razão do declínio de muitas populações e espécies de aves também no CEP. Considerando esse contexto, informações sobre as taxas de predação e a diversidade de predadores, além de novos aspectos sobre a biologia reprodutiva de determinadas espécies de aves serão fundamentais para ampliação do conhecimento e gerar subsídios para criação de estratégias de manejo e conservação da avifauna.

CAPÍTULO I - MASSIVE BIRD NEST LOSSES AND NEST PREDATORS' ALPHA DIVERSITY IN ATLANTIC FOREST FRAGMENTS FROM THE PERNAMBUCO ENDEMISM CENTER

Abstract: Tropical forests are megadiverse, but in some regions the level of degradation is so intense that biodiversity conservation has relied totally on the management of the remaining forest patches. Then, understanding the mechanisms by which tropical forest reduction and fragmentation can affect the persistence of species and populations is of scientific and practical interest. Theoretically, bird populations could experience reduced nest survival in fragmented habitats due to top-predators extinction causing increased population densities of small and medium-sized nest predators, or because of the invasion of alien nest predators in disturbed habitats. However, nest survival has been one the least addressed of the potentially harmful effects associated with habitat fragmentation, and studies involving nest predator's identification are still insipient, especially in tropical forests. The Pernambuco Endemism Center (PEC) is the part of the Atlantic Forest located northern from the São Francisco River, in northeastern Brazil. Large forest tracts no longer exist in the PEC and all of the top predators were long extinct. Here, we investigated the nest survival of forest understory birds from three PEC fragments (690, 979, and 1049 ha), and we used infra-red camera-traps for predators' identification. We monitored 84 nests of 13 bird species, totaling 937 camera/days. Of the 84 nests, 63 (75%) were depredated, eight were lost due to other causes (9.5%), and only 13 survived to fledging stage (15.5%). Nest survival probability estimated for the four more representative species (including two endemic and threatened taxa) were 6.9% for the Plain Antvireo *Dysithamnus mentalis*, 18.9% for the White-shouldered Antshrike *Thamnophilus aethiops distans*, 2.6% for the Black-cheeked Gnateater *Conopophaga melanops nigrifrons*, and 4.4% for the Blue-backed Manakin *Chiroxiphia pareola*. When compared with other populations or closely related taxa from the Atlantic Forest of southeastern Brazil, nest survival estimates were 2.7 to 8.5 times smaller in the PEC areas. Predators included 11 animal species, and overall, 25% of the recorded predations were caused by marmosets, 25% by opossums, 19.4% by the Tegu, 16.7% by the Coati, 8.3% by snakes, and 5.5% by hawks. The Jackknife2 model-predicted nest predator's richness was 20.7 (SD = 1.6). We showed for the first time that rates of nest loss can be alarming in PEC fragments and we provide further support for nest predation as one of the mechanisms by which habitat fragmentation can affect negatively the bird populations from tropical forests. Furthermore, we provide the first insights into the animal species that must be monitored, and if necessary controlled, in future conservation plans aiming to minimize the unprecedented number of ongoing bird extinctions in this important hotspot.

Keywords: nest predators identification, camera traps, nest survival, high nest predation, tropical forests, threatened species

1. Introduction

Animal species and local populations have been extirpated worldwide because of the effects of habitat loss and fragmentation, and the impacts can be more dramatic in megadiverse regions in which the whole habitat is degraded (Crooks et al. 2017, Liu et al. 2018, Costa-Araújo et al. 2021). This is the case of the Pernambuco Center of Endemism (PEC) of the Atlantic Forest. The PEC is the part of the Atlantic Forest located northern from the São Francisco River, in northeastern Brazil, covering the coastal regions of the states of Alagoas, Pernambuco, Paraíba and Rio Grande do Norte. This is the most disturbed of the three Atlantic Forest endemism centers and due to the concentration of endemic organisms it has been considered as hotspot within a hotspot (Pontes et al. 2016). Only 12.3% of the original 4.4 Mha of forested areas has remained (539,877 ha), and of this total, 29.5% is represented by fragments of 100–1000 ha; 24.5% is represented by fragments larger than 1000 ha, and the rest of the forests (46%) is distributed across fragments smaller than 100 ha (Dias et al. 2023). For this reason, large mammals, including the top predators (jaguars and cougars), were long extinct in the PEC, as well as about half of the medium-sized mammals (Pontes et al. 2016). Three bird species endemic to the PEC were recently extinct (the Pernambuco Pygmy-Owl *Glaucidium mooreorum*, the Cryptic Treehunter *Cichlocolaptes mazarbarnetti*, and the Alagoas Foliage-gleaner *Philydor novaesi*; Pereira et al. 2014, ICMBio 2018), many are nearly extinct (e.g. the Black-tailed Leaftosser *Sclerurus caudacutus caligineus*, the Alagoas Antwren *Myrmotherula snowi*, and the Alagoas Black-throated Trogon *Trogon muriciensis*) (ICMBio 2018, Dickens et al. 2021, Lima et al. 2022), and a great wave of extinctions will likely occur in a near future if intensive management plans are not implemented (Develey & Phalan 2021, Lima et al. 2022). Paradoxally, none of the recently lost species were game-birds or were target to trapping. Instead, like many other threatened birds form the PEC, they are small forest birds that may have been victims to the harmful effects of habitat loss and fragmentation.

Habitat fragmentation can affect the organisms in many ways, including the habitat reduction for habitat-dependent organisms; reduction of movements and gene flow; exposure to border effects; invasion of alien species; impediment of certain organisms to change their geographic distributions in response to global climate changes, and increase in conflicts between humans and wildlife (Crooks et al. 2017). Many bird species or local populations also have been vanished because of high nest predation rates resulted from habitat disturbances. A commonly advocated theory to account for increased nest predation rates in fragmented habitats is the mesopredator release hypothesis (Oniki 1979, Soulé et al. 1988, Rogers & Caro 1998, Robinson & Cherry 2012), which predicts that trophic cascading effects caused by the loss of top predators permit small and medium-sized animals (the main nest predators) to increase in density, culminating in elevated nest predation rates (Stantial et al. 2021). Furthermore, habitat deterioration can favor the invasion of exotic nest predators against which local bird communities have no evolutionary nest antipredatory defenses, leading to increased bird reproductive failures (Savidge 1987, Bonnington et al. 2013, Ballarini et al. 2021). Most of the reported cases of bird decline caused by nest predation are from shorebirds (e.g. Dinsmore at al. 2017, Stantial et al. 2021), or from experiments conducted in temperate regions (Rogers & Caro 1998,), while for tropical forests most of the data is derived from experiments using artificial nests, which provide only approximations of real nests' survival (e.g. Carlson & Hartman 2001, Maina & Jackson 2003). Important data was generated for eight forest understory bird species studied in tropical forests of Usambara Mountains, Tanzania, for which nest survival rates were higher is large than in small fragments (Newmark & Stanley 2011). On the other hand, nest survival of the chestnut-backed antbird (*Myrmeciza exsul*) was higher in fragments than in continuous tropical forests from Costa Rica (Visco & Sherry 2015), suggesting that the relationships between nesting birds and nest predators still need further investigations in tropical forests. In addition to the limited number of studies of natural nest predation in tropical forest fragments, studies involving nest predator's identification are even more scarce, which precludes proper interpretations of the causes of habitat changes on nest predation rates (but see Visco & Sherry 2015 and Ballarini et al. 2021).

The scenario of intense habitat degradation and the loss of the top predators in the PEC suggest that nest predation intensity should be investigated as a potential cascading effect of habitat fragmentation contributing to the vulnerability of the bird communities. To give support to potential conservation management plans, nest predators also must be identified and their relative impacts to nesting success must be revealed, especially because worldwide the survival of a growing the number of bird species inhabiting disturbed ecosystems have relied on population control of native or exotic nest predators (see also Stantial et al. 2021). Here, we investigated the survival of forest understory bird nests in three representative PEC fragments from Alagoas state, and we used infra-red camera-traps for predators' identification. An alpha diversity estimator was used to contrast observed and model-predicted numbers of nest predator species, and to the bird taxa with higher nest sample sizes we estimated Mayfield's nest survival probability (Mayfield 1975), which permitted comparisons between populations of the same taxa, or between congeners from other Atlantic Forest regions. With this investigation, we uncovered the main predators of bird's nests in the PEC for the first time and to four bird species, two of which threatened and endemic, we revealed nest survival rates that were 2.5 to 8.5 times lower than in other Atlantic Forest regions, suggesting that massive nest predation rates can be among the causes of declines of bird taxa from the PEC.

2. Materials and Methods

2.1. Study Areas

Field work was conducted at three Atlantic Forest fragments from the state of Alagoas, northeastern Brazil: RPPN (Private Natural Heritage Reserves) Mata do Cedro (9°31'S, 35°55'W: 979 ha); a fragment belonging to Usina Coruripe that totals 1049 ha (10°00'S, 36°16'W), and RPPN Dubinha-Guimarães, previously called Mata do Matão (9°46'00"S, 36°14'00"W: 690 ha). These areas are all isolated by sugar cane plantations and the vegetation is classified as open ombrophilous forest (Roda & Santos 2005). Selective logging was a common practice over the PEC fragments during the decades of 1970 and 1980, and today these areas are mosaics of forests in middle to late generation stages, with shadowed understory and emergent trees (Roda & Santos 2005, Pereira et al. 2014, 2016). The climate is AS´ according to Köppen classification: tropical with a well-defined dry season (October through January), and the rainy season concentrated in the autumn and winter. Average annual precipitation is 1600–1700 mm, and average minimum and maximum temperatures are 21–22°C, and 30–31°C, respectively (Roda & Santos 2005, Barros et al. 2012).

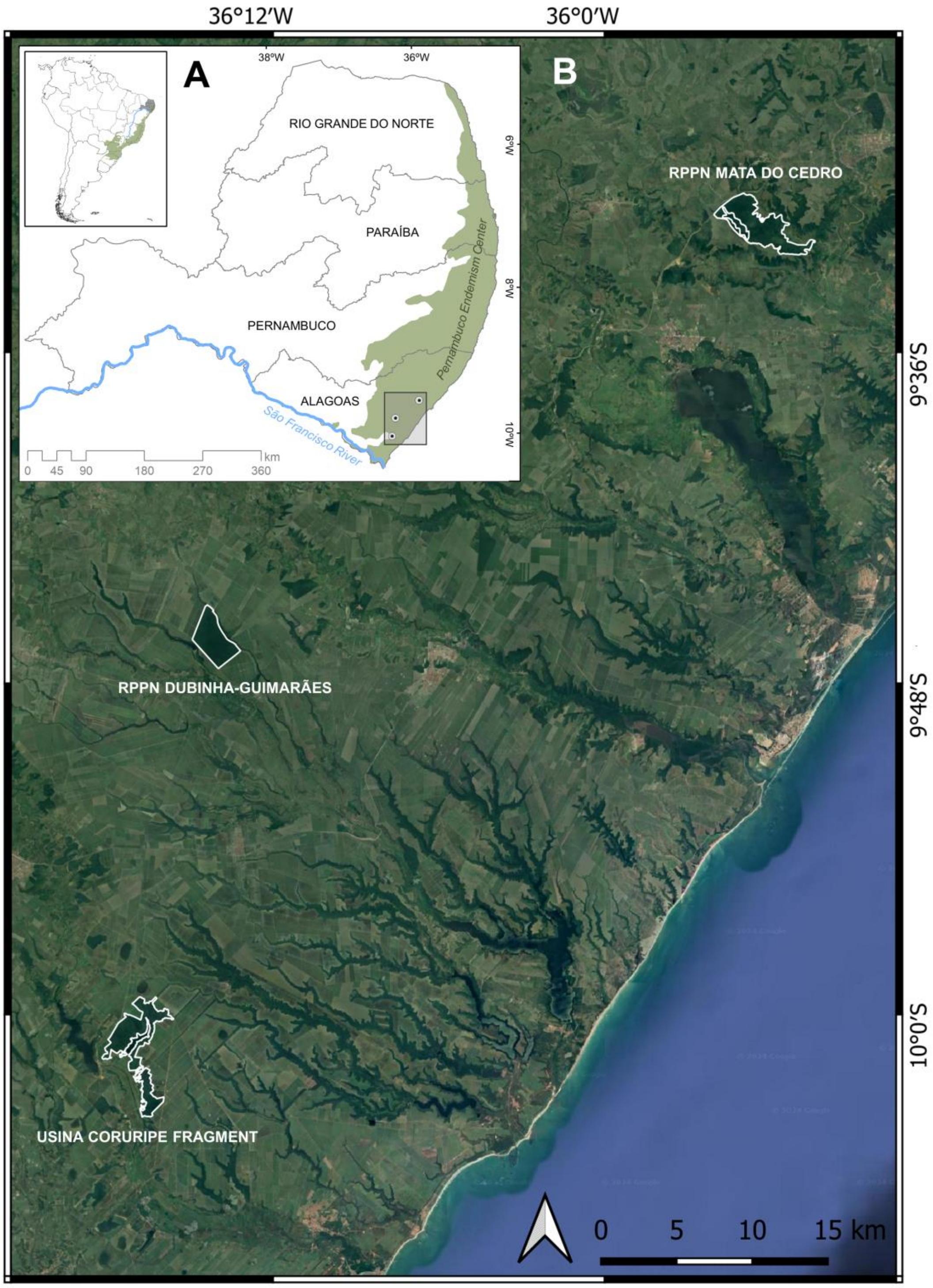

Figure 1. Distribution of the Atlantic Forest areas studied, in the Pernambuco Endemism Center (CEP), northeastern Brazil.

2.2. Nest searches and monitoring

Field work was conducted from September to May during 2021/2022 and 2022/2023, because these are the warmer months in which the days are longer, and a few evidence from species-specific studies suggest that these months correspond to the seasons of higher bird reproductive activities in the region (Studer et al. 2018, 2019). Nests were searched *ad libitum* by walking across the whole areas, and were located based on evidences of parental individuals defending territories; carrying nest material, or delivering food to the nestlings, and also by thoroughly inspecting the vegetation (Martin & Geupel 1993). Programmed walks for nest searches occurred, on average, three days per month in each of the areas, but further nests were also found during the more frequent returns to these areas for nest and camera checking. Once found, nests were georeferenced for posterior re-sighting and were monitored for predator identification using digital camera traps Bushnell TrophyCam, model 119437C (Bushnell Outdoor Products, Kansas, USA). The cameras were positioned 1–3 m from the nest, depending on the availability of tree branches to tie the camera. They were programmed to obtain 30 sec videos, with Low LED intensity (eight LEDs); "High" sensor level; intervals of 3 sec between triggers, and recorded date and time, following the optimization procedures suggested by Ribeiro-Silva et al. (2018). Detections were stored on 14 GB memory cards. Nests and cameras were checked twice a week, but monitoring was intensified in nests containing nestlings near fledgling age to confirm nest fate in case of camera failures. Predation was assumed when nest contents disappeared before fledging age or when predation events were caught on cameras (Ribeiro-Silva et al. 2018).

2.3. Nest survival estimates

For determining the magnitude of nest survival, estimating the simple percentage of nest losses is not enough because nests that were depredated in early stages have lower chances of being found, leading to overestimated nest survival rates. Furthermore, most nests are found after laying stage, meaning that the information obtained for each nest is often fragmented. For these reasons, we followed the broadly used nest-day based method of Mayfield (1961) to estimate nest survival, which accounts for the above sources of uncertainty by calculating Daily Survival Rate (DSR). Nest-days are the summation of the numbers of days that a number of nests of a target species are monitored. Then, the number of nest-days subdivided by the number of nest losses results in the daily nest loss rate, and 1 minus the daily nest loss results in the daily nest survival rate. Here, we used the daily survival rate raised to the power of the nesting cycle length (incubation plus nestling period) to estimate the average probability of nest survival for a bird species (Mayfield 1961). We applied the method of Mayfield only for species for which nest samples were at least 10 (see also Newmark & Stanley 2011), and for those species with lower nest sample sizes, only apparent nest survival was provided (the simple percentage of nests that survived to fledging stage). We obtained nesting cycle lengths for the most representative bird species from the literature. More specifically, the nesting cycle duration for the Plain Antvireo *Dysithamnus mentalis* was obtained from Zimmer & Isler (2020) (25 days); for the Black-cheeked Gnateater *Conopophaga melanops* from Studer et al. (2019) (32 days), and for the Blue-backed Manakin *Chiroxiphia pareola* from Snow (2020) (33 days). For the White-shouldered Antshrike *Thamnophilus aethiops*, due to the lack of specific information, we used the estimates available for the Barred Antshrike *T. doliatus* (26 days) (Koloff & Mennill 2020).

2.4. Nest predator’s identification and alpha diversity

Among the animals recorded in this study by camera traps (see results below), small nocturnal marsupials are the most difficult to identify based solely on video recordings. However, the present work was part of major project that aimed to perform faunal surveys in the same study areas, including small mammals and reptiles. Then, using the still unpublished species lists as references, we could identify even the small marsupials with satisfactory precision based on diagnostic morphological characters of each species, i.e. the proportional sizes of tail, ears and eyes. For taxonomic nomenclature, we followed the annotated Brazilian checklists of reptiles (Costa et al. 2021), birds (Pacheco et al. 2021), and mammals (Quintela et al. 2020).

Because species richness (alpha diversity) is a proxy of sampling effort, uncovering all of the species in a target community can be a challenging task, especially in megadiverse habitats such as the Atlantic Forest (Gotelli & Cowell 2011). Among the innumerous methods developed to estimate expected species richness based on collected data, the non-parametric estimators, e.g. Chao2, ICE, Jackknife1, Jackknife2 have been widely used in studies involving camera trap data (Tobler et al. 2008, Arévalo-Sandi et al. 2021, Morales-Martínez et al. 2021). Here, we chose a Jackknife estimator because this class of estimator performed better than others in two comparative studies that used camera traps for faunal surveys in tropical forests (Tobler et al. 2008, Morales-Martínez et al. 2021). Specifically, we used Jackknife 2, which is a model that takes into account the numbers of singletons (species represented by only one individual) and doubletons (species represented by only two individuals) to generate expected species richness (Burnham & Overton 1979, Palmer 1991), as both were present in our dataset. The 95% confidence interval and standard deviation (SD) were generated by the resampling method implemented in the R-package ‘’vegan’’ (Oksanen et al. 2020), with 1,000 permutations, and all of the analyses were performed in R Studio (version 2022.02.2). Because our study involved a number of endangered bird taxa in highly vulnerable habitats, nest sample sizes were moderate and for this reason we pooled the data from the three study areas together for the statistical analyses.

Although in some regular camera-trap surveys the cameras can be arranged in the field across pre-defined grids or transects (Tobler et al. 2008, Rosa et al. 2021, Ponce-Martins et al. 2022), in many other works the cameras are distributed randomly across sites with animal traces, respecting only a minimum distance interval (Arévalo-Sandi et al. 2021, Morales-Martínez et al. 2021, Lim et al. 2023), and our study involving widespread nests may not differ from the later. Although each camera-day can be treated as a sampling unit for species richness estimation, here, for graphical purposes, we partitioned our dataset into 50 camera-days subsets, that were used as sampling unities for Jackknife2 calculation (see also Ponce-Martins et al. 2022).

Nest density is low, in such a way that the probability of capturing the same predator individuals across the different nests may be reduced. Because nest predation were unique events (partial nests predations were never observed) and often lasted only a few seconds, pseudoreplications were unlikely and all of the records were considered as independent detections, but when nests were depredated by groups of individuals, all of them were counted for modeling expected species richness (see below). Records of animals that only approached the nests, without depredating the eggs or nestlings, were not considered.

3. Results

We monitored 84 nests of 13 bird species (Table 1), totaling 937 camera/days, with an average of 11.1 camera/days per nest. Of the 84 nests, 63 (75%) were depredated, eight were lost due to other causes (abandonment, nest fall, or hatching failure) (9.5%), and 13 survived to fledging stage (15.5%). The bird species with the highest nest sample sizes were the Plain Antvireo *Dysithamnus mentalis* (Thamnophilidae) (n = 23), the White-shouldered Antshrike *Thamnophilus aethiops distans* (Thamnophilidae) (n = 10), Black-cheeked Gnateater *Conopophaga melanops nigrifrons* (Conopophagidae) (n = 12), and the Blue-backed Manakin *Chiroxiphia pareola* (Pipridae) (n = 10) (Table 1). Nest survival probability estimated using the nest-day based method of Mayfield for these four more representative species were 6.9% for the Plain Antvireo (22 nest losses in 217 nest-days), 18.9% for the White-shouldered Antshrike (eight nest losses in 129 nest-days), 2.6% for the Black-cheeked Gnateater (11 nest losses in 103 nest-days), and 4.4% for the Blue-backed Manakin (nine nest losses in 100 nest-days).

Table 1. Bird taxa that had their nests monitored with infra-red camera traps in three Atlantic Forest fragments from the Pernambuco Endemism Center. For each species, we provide the total number of nests monitored (Total), the number of depredated nests (Depredated), the number of nests that failed due to other causes, such as abandonment, nest fall, or due to the presence of infertile eggs (Failed), the number of successful nests (Successful), and apparent survival, i.e. the simple percentage of nests that survived to fledging stage (Apparent Survival).

Bird Taxa	Total	Depredated	Failed	Successful	Apparent survival
Columbidae					
Leptotila sp.	1	1			0%
Geotrygon montana	1	1			0%
Caprimulgidae					
Antrostomus rufus	2	1		1	50%
Nyctidromus albicollis	5	3		2	40%
Trochilidae					
Chlorestes notata	5	3	1	1	20%
Thamnophilidae					
Myrmotherula axillaris	4	2		2	50%
Dysithamnus mentalis	23	20	2	1	4.3%
Thamnophilus aethiops distans	10	6	2	2	20%
Conopophagidae					
Conopophaga melanops nigrifrons	12	11	0	1	8.3%
Pipridae					
Chiroxiphia pareola	10	8	1	1	10%
Ceratopipra ribrocapilla	1	1			0%
Tityridae					
Schiffornis turdina intermedia	2	2			0%
Platyrinchidae					
Platyrinchus mystaceus niveigularis	2	2			0%
Rhynchocyclidae					
Leptopogon amaurocephalus	1	1	0	0	0%
Hemitriccus griseipectus naumburgae	5	1	2	2	40%

Predators were recorded by the camera traps in 36 (57 %) of the 63 predation events. Of the 27 predation events not captured by the cameras, two were caused by camera malfunction, four were caused by memory cards malfunction, and 21 predation events were not caught even with the cameras being in good conditions. Then, when we excluded the nests in which predators were not detected due to camera and memory cards malfunctions, the cameras were capable of recording predators in 63% of the predation events. The predators included 11 animal species: four reptiles, two birds, and five mammal species. Among the reptiles we recorded the Tegu *Salvator merianae* (Teiidae) and the snakes *Chironius* sp. (Colubridae), the Indigo Snake *Drymarchon corais* (Colubridae), and *Philodryas* sp. (Dipsadidae). Birds were represented by the Gray-lined Hawk *Buteo nitidus* (Accipitridae), and the Collared Forest-Falcon *Micrastur semitorquatus* (Falconidae). Among the mammals, we detected the Big-eared Opossum (*Didelphis aurita*), the Emilia's Gracile Opossum *Gracilinanus emiliae* (Didelphidae), the Woolly Mouse Opossum *Marmosa demerarae* (Didelphidae), the Common Marmoset *Callithrix jacchus* (Callitrichidae), and the South American Coati *Nasua nasua* (Procyonidae) (Table 2). Overall, 25% of the recorded predations were caused by marmosets, 25% by opossums, 19.4% by the Tegu, 16.7% by the Coati, 8.3% by snakes, and 5.5% by hawks (Figure 2).

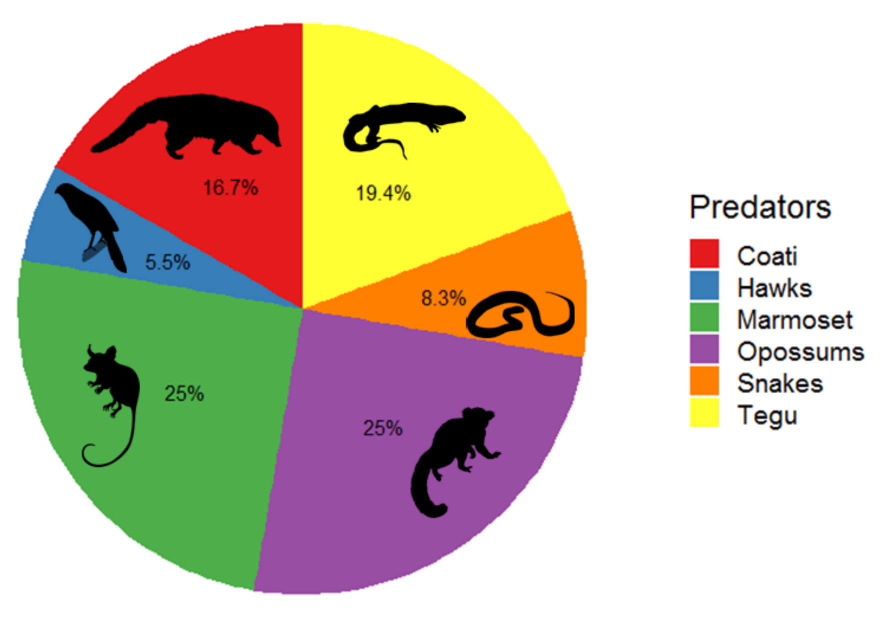

Figure 2. Percentages of nests depredated by the main animal groups, including the Tegu, snakes, the Common Marmoset, opossums, hawks, and the Coati, in three Atlantic Forest fragments from the Pernambuco Endemism Center.

Table 2. Nesting birds and numbers of nests depredated by each nest predator species across three Atlantic Forest fragments from the Pernambuco Endemism Center.

Taxa Name	Tegu	*Chironius* sp.	Indigo Snake	*Philodryas* sp.	Gray-lined Hawk	Collared Forest-Falcon	Big-eared Opossum	Emilia’s Gracile Opossum	Woolly Mouse Opossum	Common Marmoset	Coati
Leptotila sp.	-	-	-	1	-	-	-	-	-	-	-
Antrostomus rufus	-	-	-	-	-	-	1	-	-	-	-
Nyctidromus albicollis	2	-	-	-	-	-	-	-	-	-	-
Chlorestes notata	-	-	-	-	-	-	-	1	-	-	-
Myrmotherula axillaris	1	-	-	-	-	-	-	-	-	-	-
Dysithamnus mentalis	2	-	1	-	1	-	-	1	1	6	1
Thamnophilus aethiops distans	-	-	-	-	-	-	-	1	-	1	1
Conopophaga melanops nigrifrons	2	-	-	-	-	-	-	2	1	-	2
Chiroxiphia pareola	-	-	-	-	-	1	-	1	-	2	-
Schiffornis turdina intermedia	-	1	-	-	-	-	-	-	-	-	1
Leptopogon amaurocephalus	-	-	-	-	-	-	-	-	-	-	1
Total	**7**	**1**	**1**		**1**	**1**	**1**	**6**	**2**	**9**	**6**

Three of the nests depredated by the Common Marmoset were depredated by groups of individuals, being one group of two and two groups of three individuals, while for the other nest predator species only single individuals were observed depredating the nests. Then, when numbers of individuals were considered, the Common Marmoset was the most representative nest predator, with 14 records (34% of the predator individuals). The Jackknife2 model-predicted nest predator's richness estimate was 20.7 (95% CI = 18.4 – 23.9, SD = 1.6), without tendency to asymptote. It suggested that at least 10 further rare nest predator species would be expected whether field effort was increased (Figure 3).

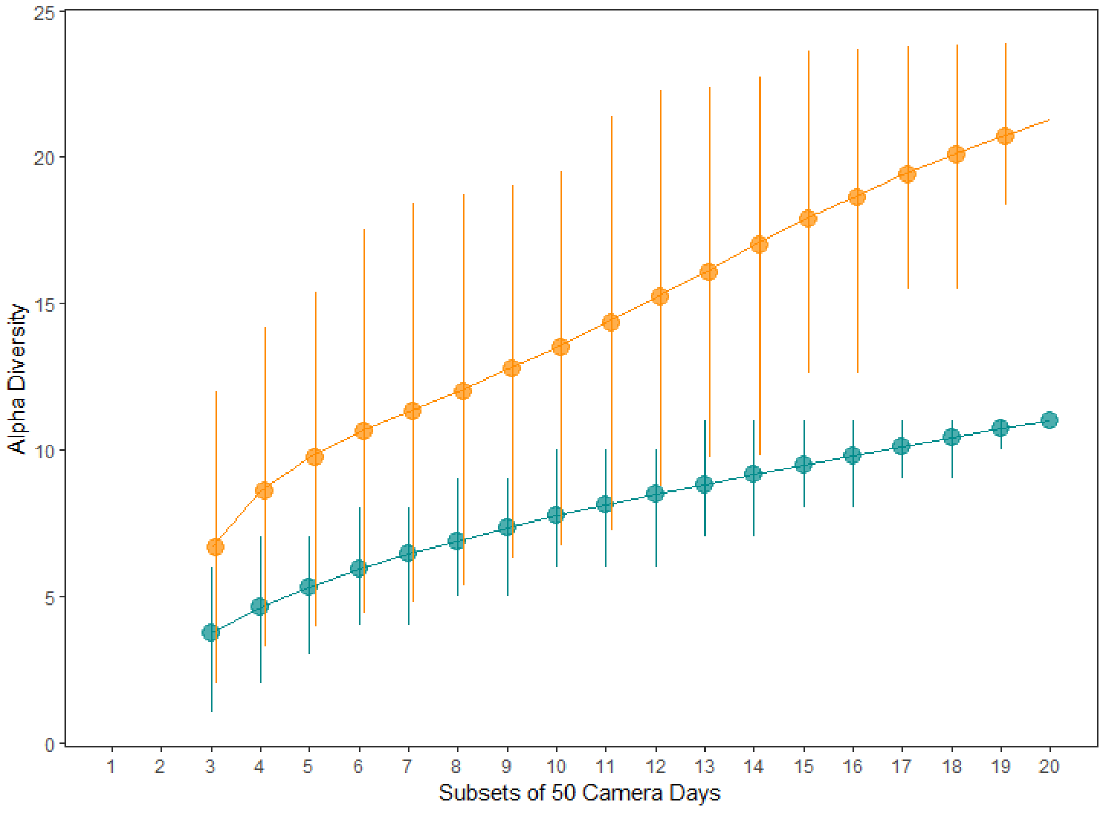

Figure 3. Observed and estimated species richness derived from Jackknife2 estimator, and 95% confidence intervals generated by resampling method.

4. Discussion

Testing whether forest fragmentation can affect predators' community composition and nest survival rates should rely on comparisons between continuous and fragmented habitats (Newmark & Stanley 2011, Visco & Sherry 2015), however, continuous forests no longer exist in the PEC (Dias et al. 2023). The only non-fragmented forest tracts of the whole Atlantic Forest are located in southeastern Brazil, especially at the coastal mountains of Serra do Mar, from the states of São Paulo, Paraná and Rio de Janeiro, where a complex of protected areas gather more than 1 million ha of continuous forests (Ribeiro et al. 2009). Despite the differences in species composition and physical parameters, Serra do Mar is the region that best preserves the original conditions of the Atlantic Forest and the only that could serve as control. Within the scenario of extreme fragmentation of the PEC, some of the biggest and most important fragments are Pedra Talhada Biological Reserve (4,500 ha), Engenho Coimbra, Usina Serra Grande (4,300 ha), and Murici Ecological Station (6,116 ha), which are also in the state of Alagoas and are considered as IBAS (Important Bird Areas) by BirdLife International (Devely & Goerck 2009). For Pedra Talhada, valuable bird breeding biology information is available, including nest survival information for a few species (Studer et al. 2018, 2019), while Serra Grande and Murici Ecological Station should be in the scope of future works. Then, the best option to interpret the effects of forest fragmentation in the PEC is through comparisons with data from the continuous Atlantic Forest tracts from southeastern Brazil; with the few larger fragments from the PEC, as well as with other tropical forest biomes, especially when information from the same bird species or congeners are available.

In one of the best preserved areas of the Serra do Mar continuum, the Carlos Botelho State Park, apparent survival of 122 nests of 24 bird species was 49% (Ribeiro-Silva et al. 2018), and in two Atlantic Forest fragments of 50 and 200 ha from the state of Minas Gerais apparent survival of 257 nests of 22 bird species was 44.5% (Marini 2017), while in our study areas this figure was only 15.5%. Although these are rough comparisons because they involve only apparent survival and bird communities with different compositions and breeding strategies, nest survival estimates based on daily nest survival for the taxa with higher sample sizes may provide better opportunities for comparisons. For the Plain Antvireo, Mayfield's nest survival probability in the fragments from Minas Gerais was 48% (Marini 2017) and in our study it was only 6.9%. For the Atlantic Forest congener, the Blue Manakin *C. caudata*, nest survival probability in the Serra do Mar continuum was 34% (Zima et al. 2017), and at the fragments from Minas Gerais it was 60.4%, while the nest survival probability of the Blue-backed Manakin at the PEC fragments was only 4.4%. For the Black-cheeked Gnateater, nest survival rate of the subspecies *C. m. melanops* from the Serra do Mar continuum of the state of Paraná, nest survival rate was 22%, and for our study subspecies it was 12% at Pedra Talhada Biological Reserve of the PEC and only 2.6% in the fragments we studied. For another representative of the genus *Thamnophilus* that also breeds in Atlantic Forest tracts, the Variable Antshrike *Thamnophilus caerulescens*, nest survival rate at the Atlantic Forest fragments from Minas Gerais was 50.6%, while for the White-shouldered Antshrike nest survival probability in the PEC fragments was 19%. At Pedra Talhada, nest survival probabilities were also estimated for the Scalloped Antbird *Myrmoderus ruficauda* and for the Short-tailed Antthrush *Chamaeza camapanisona*, and they were 22 and 32%, respectively (Studer et al. 2017, 2018). Although nest survival rate seem to be a little higher at Pedra Talhada in comparison with our 660 to 978 ha fragments, they are overall much smaller than the values found for continuous and fragmented areas from the Atlantic Forest of southeastern Brazil. In other tropical forest systems, nest survival probability of the Chestnut-backed Antbird (*Myrmeciza exsul*) was 28 and 36% in two forest fragments of 41 and 92 ha from Costa Rica (Visco & Sherry 2015). The values we found in the PEC fragments were closer to those found for eight forest understory bird species studied in tropical forests of Usambara Mountains, Tanzania, where nest survival rates varied from less than 1% to 13.4%, but this study addressed much smaller fragments, with some presenting only around 0.2 ha (Newmark & Stanley 2011). It is worth noting, however, that in the two later studies (i.e. Visco & Sherry 2015 and Newmark & Stanley 2011), nest survival rates were estimated using the likelihood-based model of Dinsmore et al (2002), which is also based on nest-days but may provide slightly different estimates when compared with the method of Mayfield. Despite the lack of adequate control areas for comparisons, these are evidence that the rates of nests losses are alarming in some of the important PEC fragments.

The model-estimated alpha diversity diverged in about 10 predator species in relation to the observed number of 11 species, which was likely caused by the presence of rare predator species. However, about 78% of the detected nest predations were caused by only four animal species, the Tegu, the Emilia’s Gracile opossum, the Common Marmoset, and the Coati, suggesting that our sampling effort was enough to capture the main nest predators from our study areas. Marmosets and opossums are agile animals and excellent tree climbers. Some of our videos evidenced that not only the marmosets, but also the opossums, were capable of long jumps even between very thin bush branches and lianas. Although the coatis are larger ground mammals, they could climb the larger branches to access the nests, and when bushes or saplings were too thin to support their weights, they often grabbed and folded the whole saplings down to reach the nests and their contents. The Tegus are large terrestrial lizards, and the observation of these animals climbing slender bushes and saplings to access nest contents was totally surprising. This capacity seemed to be attributed to juvenile individuals, but at least one larger adult was recorded standing its body in upright position to reach the content of a nest that was about 60 cm above ground. To our knowledge, all of these tactics used by these nest predators have been revealed here for the first time and may contribute to the understanding of the types of interactions between nesting birds and their predators.

Marmosets are plague species in southeastern Brazil, where they are invasive animals mainly due to illegal faunal releases and because of the lack of predators and competitors (Ballarini et al 2021). Although the Common Marmoset is native to the forests of the PEC, some populations also may be experiencing the absence of predators (e.g. large hawks, awls, and felids) and like in southeastern Brazil their population densities can be inflated in certain areas even within its original distribution, which deserves future studies. At least one of the nests was depredated by a female Common Marmoset carrying a young on its back, suggesting that young marmosets can learn with their parents how to recognize nests as sources of food in their early life stages (see for instance Coelho et al. 2015 for foraging social learning in Neotropical primates). Notably, the critically endangered Whit-collared Kite *Leptodon forbesi* was filmed checking a nest that was already depredated by marmosets. Checking empty nests reveal a certain level of specialization, since the predator was capable of recognizing the nest *per se* as a source of food, even without eye contact with eggs or nestlings (see also Zima et al. 2021). At Carlos Botelho State Park, in southeastern Brazil, the White-necked Hawk *Amadonastur lacernulatus* was an important nest predator, evidencing that the rare Whit-collared kite could have been a potential nest predator in the PEC that had its abundance drastically affected by habitat loss and fragmentation, as today it is one of the most threatened birds of prey on earth (ICMBio 2018).

The identity of nest predators has only recently being revealed for tropical forests and the number of studies is still insipient (Cockle et al. 2016, Ribeiro-Silva et al 2018, Londoño et al. 2022). In continuous Atlantic Forest tracts from São Paulo state, 28% of the nest predations were conducted by large birds of prey (White-necked Hawk, Barred-forest Falcon *Micrastur ruficollis*, Collared-forest Falcon); 24% by large toucans (Red-breasted Toucan *Ramphastos dicolorus*); 24% by marsupials; 10% by primates, and 11% by other animals, including felids, mustelids, coati, and tegú, with snakes never detected (Ribeiro-Silva et al. 2018). Comparing predators diversity between the areas of the PEC and the Atlantic Forest of southeastern Brazil is not straightforward because they involve different endemism centers, and it is difficult to infer about how the original nest predator communities were in the PEC in the past. However, we cannot discard the possibility that alterations in nest predator communities can have contributed to the massive nest losses we observed for some bird species. While large birds of prey and large frugivorous birds were the main nest predators at the Serra do Mar continuum, with marsupials and primates contributing only a little and reptiles being virtually absent in the samplings, at the PEC fragments marsupials, marmosets, coatis, and reptiles were the main nest predators. These differences were somewhat expected because forest birds of prey and toucans, especially the large ones, may have been common in the past at the PEC but today they can be regularly found only at the largest fragments (e.g. Murici, Pedra Talhada and Serra Grande). It is not only nest predator species composition, but also their densities and behaviors that affect bird nest survival, and the relatively low nest survival rates we observed in the studied fragments can be evidence for increased incidence of certain animal groups acting as nest predators, because their densities are inflated or because of the lack of other feeding resources, which must be in the scope of future investigations. Within this pessimistic scenario, however, a positive finding was the fact that exotic and/or feral animals, that can become the main nest predators in some disturbed ecosystems (Duron et al. 2017, Ballarini et al. 2021), were not detected depredating nests in our study areas, although potentially harmful species such as rats, cats, and domestic dogs are abundant in the farms and sugar-cane plantations that surround the fragments (personal observation).

Although the Plain Antvireo and the Blue-backed Manakin are not endemic to the PEC and are not threatened, the subspecies of the Black-cheeked Gnateater *C. m. nigrifrons* and of the White-shouldered Antshrike *T. a. distans* are endemic to the PEC and are listed as Vulnerable and Endangered, respectively, in the Brazilian red list, with *T. a. distans* occurring in only 25 fragments (ICMBio 2018). The fragments we analyzed are among the biggest for the pattern of spatial distribution of the PEC forests (Dias et al. 2023) and together with other fragments similar in size they certainly hold significant portions of the total populations of many threatened and endemic taxa, and finding such small nest survival rates in fragments of these size classes was concerning. Because most of the vanishing bird species of the PEC are small insectivorous birds that are not target to poaching and trapping, we suggest that nest survival rates should be better investigated in the few remaining fragments larger than 1,000–2,000 ha to see if they could provide better chances of nest survival, especially because top-predators were long extinct at these areas too (Pontes et al 2016). Although testing the mesopredator release hypothesis was far away from the scope of this work, we present evidence that nest loss rates were likely inflated in our study sites and predation was the main cause of nest failures. Our main conclusion is that low nest survival and the action of nest predators can be among the causes of bird population declines in the PEC and these subjects must be in the scope of future conservation management plans aiming to minimize the unprecedented number of ongoing bird extinctions in this important hotspot. The survival of a growing number of endangered bird species worldwide has relied on nest predators management (Vanderwerf & Smith 2002, Jansen 2005), and the identification of the nest predators' community composition in the PEC fragments provided the first insights into the animal species that must be monitored, and if necessary controlled, as a way to improve the demographic aspects of the most threatened bird taxa endemic to the PEC.

5. References

ARÉVALO-SANDI, A. R. *et al*. Mammal diversity among vertical strata and the evaluation of a survey technique in a central Amazonian forest. Pap. Avulsos Zool, v. 61, p. e20216133, 2021.

BALLARINI, Y. *et al.* High rates of predation of the nests of two endemic antbirds of the Brazilian Atlantic Forest by invasive marmosets (*Callithrix* spp.). Annales Zoologici Fennici, v. 58, n. 1-3, p. 31-40, 2021.

BARROS, A. H. C. *et al.* Climatologia do estado de Alagoas; Boletín de pesquisa e desenvolvimento: Embrapa, PE, Brasil, 2012.

BONNINGTON, C.; GASTON, K. J.; EVANS K. L. Fearing the feline: domestic cats reduce avian fecundity through trait-mediated indirect effects that increase nest predation by other species. Journal of Applied Ecology, v. p. 15-24, 2013.

BURNHAM, K. P.; OVERTON, W. S. Robust estimation of population size when capture probabilities vary among animals. Ecology, v. 60, p. 927-936, 1979.

COELHO, C. G. *et al*. Social learning strategies for nut-cracking by tufted capuchin monkeys (*Sapajus* spp.). Anim. Cogn., v. 18, p. 911-919, 2015.

COCKLE, K. L. *et al*. Predators of bird nests in the Atlantic Forest of Argentina and Paraguay. The Wilson Journal of Ornithology, v. 128, p. 120-131, 2016.

COSTA, H. C.; GUEDES, T. B.; BÉRNILS, R. S. Lista de répteis do Brasil: padrões e tendências. Herpetologia Brasileira, v. 10, n. 3, p. 1-279, 2021.

COSTA-ARAÚJO, R. *et al*. Occurrence and conservation of the vulnerable titi monkey *Callicebus melanochir* in fragmented landscapes of the Atlantic Forest hotspot. Oryx, v. 55, n. 6, p. 916-923, 2021.

CROOKS, K. R. *et al*. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. Proceedings of the national Academy of Sciences, v. 114, p. 7635-7640, 2017.

DEVELEY, P. F.; GOERCK, J. M. Important Bird Areas Americas - Priority sites for biodiversity conservation. BirdLife Conservation Series, n. 16, Quito, Ecuador, 2009.

DEVELEY, P. F.; PHALAN, B. Bird Extinctions in Brazil's Atlantic Forest and How They Can Be Prevented. Front. Ecol. Evol., v. 9, p. 1-8, 2021.

DIAS, T. C.; SILVEIRA, L. F.; FRANCISCO, M. R. Spatiotemporal dynamics reveals forest rejuvenation, fragmentation, and edge effects in an Atlantic Forest hotspot, the Pernambuco Endemism Center, northeastern Brazil. PLoS ONE, v. 18, n. 9, p. e0291234, 2023.

DICKENS, J. K. *et al*. Species limits, patterns of secondary contact and a new species in the *Trogon rufus* complex (Aves: Trogonidae). Zoological Journal of the Linnean Society, v. 193, p. 499-540, 2021.

DINSMORE, S. J.; WHITE, G. C.; KNOPF, F. L. Advanced techniques for modeling avian nest survival. Ecology, v. 83, p. 3476-3488, 2002.

DINSMORE, S. J. *et al*. Factors affecting Snowy Plover chick survival in a managed population. The Condor, v. 119, p. 34-43, 2017.

DURON, Q. *et al*. Invasive rats strengthen predation pressure on bird eggs in a South Pacific island rainforest. Current Zoology, v. 63, n. 6, p. 583-590, 2017.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (ICMBIO). Livro vermelho da fauna brasileira ameaçada de extinção: Volume III – Aves; ICMBio/MMA, Brasília, DF, Brazil, 2018.

JANSEN, W.P. Rat Rattus control at nests of the endangered kakapo *Strigops habroptilus* on Codfish Island, New Zealand. Conservation Evidence, v. 2, p. 1-2, 2005.

KOLOFF, J.; MENNILL, D. Barred Antshrike (*Thamnophilus doliatus*). In Birds of the World; Schulenberg, T.S., Ed.; Cornell Lab of Ornithology: Ithaca, NY, USA 2020.

LIM, S. J. *et al*. Relative abundance of mammals and estimation of minimum trapping effort using camera traps in Jangsudae, Seoraksan National Park. Mammal Study, v. 48, n. 3, p. 171-179, 2023.

LIMA, R. D. *et al*. An annotated avian inventory of the Brazilian state of Alagoas, one of the world's most threatened avifauna. Pap. Avulsos Zool., v. 62, p. e202262034, 2022.

LIU, J. *et al*. How does habitat fragmentation affect the biodiversity and ecosystem functioning relationship? Landscape Ecology, v. 33, p. 341-352, 2018.

LONDOÑO, G. A. *et al*. Changing patterns of nest predation and predator communities along a tropical elevation gradient. Ecology Letters, v. 26, n. 4, p. 609-620, 2023.

MAINA, G. G.; JACKSON, W. M. Effects of fragmentation on artificial nest predation in a tropical forest in Kenya. Biol. Conserv., v. 111, n. 2, p. 161-169, 2003.

MARTIN, T. E.; GEUPEL, G. R. Nest-monitoring plots: methods for locating nests and monitoring success. J. Field Ornithol., v. 64, n. 4, p. 507-519, 1993.

MAYFIELD, H. Nesting success calculated from exposure. Wilson Bull., v. 73, p. 255-261, 1961.

MORALES-MARTINEZ, D. M. *et al*. Completeness of rapid assessments of medium and large mammal diversity in the northwestern Amazon in Colombia. Acta Amazonica, v. 51, p. 224-233, 2021.

NEWMARK, W. D.; STANLEY, T. R. Habitat fragmentation reduces nest survival in an Afrotropical bird community in a biodiversity hotspot. PNAS, v. 108, p. 1488-1493, 2011.

OKSANEN, J. *et al*. vegan: Community Ecology Package. R package version 2.5-7. 2020, https://CRAN.R-project.org/package=vegan

PACHECO, J. F. *et al*. Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee - second edition. Ornithol. Res., v. 29, p. 94-105, 2021, 29, 94–105..

PALMER, M. W. Estimating species richness: The second-order Jackknife reconsidered. Ecology, v. 72, p. 1512-1513, 1991.

PERERIRA, G. A.; ARAÚJO, H. F. P.; AZEVEDO-JÚNIOR, S. M. Distribution and conservation of three important bird groups of the Atlantic Forest in north-east Brazil. Braz. J. Biol., v. 76, p. 1004-1020, 2016.

PEREIRA, G. A. *et al*. Status of the globally threatened forest birds of northeast Brazil. Pap. Av. Zool., v. 54, p. 177-194, 2014.

PONCE-MARTINS, M. *et al*. Assessing the contribution of local experts in monitoring Neotropical vertebrates with camera traps, linear transects and track and sign surveys in the Amazon. Perspectives in Ecology and Conservation, v. 20, n. 4, p. 303-313, 2022.

PONTES, A. R. M. *et al*. Mass extinction and the disappearance of unknown mammal species: scenario and perspectives of a biodiversity hotspot’s hotspot. PLoS One, v. 11, n. 5, p. e0150887, 2016.

QUINTELA, F. M., ROSA, C. A., FEIJÓ, A. Updated and annotated checklist of recent mammals from Brazil. An. Acad. Bras. Cienc., v. 92, p. e20191004, 2020.

RIBEIRO, M. C. *et al*. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biol Conserv., v. 142, n. 6, p. 1141-1153, 2009.

RIBEIRO-SILVA, L. *et al*. Testing camera traps as a potential tool for detecting nest predation of birds in a tropical rainforest environment. *Zoologia* **2018**, 35, e14678.

ROBINSON, W. D.; SHERRY, T. W. Mechanisms of avian population decline and species loss in tropical forest fragments. Journal of Ornithology, v. 153, p. 141-152, 2012.

RODA, S.A.; Santos, A.M.M. Avaliação de fragmentos florestais para uma possível reintrodução do mutum-de-alagoas em seu ambiente natural; Centro de Pesquisas Ambientais do Nordeste: CEPAN, Brazil, 2005.

ROGERS, C.; CARO, M. Song sparrows, top carnivores and nest predation: a test of the mesopredator release hypothesis. Oecologia, v. 116, p. 227-233, 1998.

ROSA, D. C. P. *et al*. Species-rich but defaunated: the case of medium and large-bodied mammals in a sustainable use protected area in the Amazon. Acta Amazonica, v. 51, p. 323-333, 2021.

SAVIDGE, J.A. Extinction of an island forest avifauna by an introduced snake. Ecology, v. 68, p. 660-668, 1987.

SNOW, D. Blue-backed Manakin (*Chiroxiphia pareola*). In Birds of the World; del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A.; de Juana, Eds.; Cornell Lab of Ornithology: Ithaca, NY, USA, 2020.

STANTIAL, M. L. *et al*. The effect of top predator removal on the distribution of a mesocarnivore and nest survival of an endangered shorebird. Avian Conservation and Ecology, v. 16, n.1, p. 8, 2021.

STUDER, A.; SOUSA, M. C.; BARCENA-GOYENA, B. The breeding biology and nest success of the Short-tailed Antthrush *Chamaeza campanisona* (Aves: Formicariidae) in the Atlantic rainforest of northeastern Brazil. Zoologia, v. 35, p. e12906, 2017.

STUDER, A.; SOUSA, M. C.; BARCENA-GOYENA, B. The breeding biology and nest success of the Short-tailed Antthrush *Chamaeza campanisona* (Aves: Formicariidae) in the Atlantic rainforest of northeastern Brazil. Zoologia, v. 35, p. e12906, 2018.

STUDER, A.; SOUSA, M. C.; BARCENA-GOYENA, B. Breeding biology and nesting success of the endemic Black-cheeked Gnateater (*Conopophaga melanops*). Studies on Neotropical Fauna and Environment, v. 54, n. 3, p. 157-162, 2019.

TOBLER, M. W. et al. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation, v. 11, n. 3, p. 169-178, 2008.

VISCO, D. M.; SHERRY, T. W. Increased abundance, but reduced nest predation in the chestnut-backed antbird in Costa Rican rainforest fragments: surprising impacts of a pervasive snake species. Biological Conservation, v. 188, p. 22-31, 2015.

VANDERWERF, E.A.; SMITH, D.G. Effects of alien rodent control on demography of the O'ahu 'Elepaio, an endangered Hawaiian forest bird. Pacific Conservation Biology, v. 8, n. 2, p. 73-81, 2002.

ZIMA, P. V. Q. *et al*. Breeding behavior of the Atlantic Forest endemic Blue Manakin (*Chiroxiphia caudata*). Wilson J. Ornithol., v. 129, n. 1, p. 53-61, 2017.

ZIMA, P. V. Q.; PERRELLA, D. F.; FRANCISCO, M. R. The influence of egg presence and eggshell colour in the attraction of visually oriented predators to nests of a tropical forest bird. Ibis, v. 163, n. 3, p. 1080-1086, 2021.

ZIMMER, K.; ISLER, M. L. Plain Antvireo (*Dysithamnus mentalis*). In Birds of the World; del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A., de Juana, E. Eds.; Cornell Lab of Ornithology: Ithaca, NY, USA, 2020.

CAPÍTULO II - NESTING ASPECTS OF THE THREATENED BROWN-WINGED MOURNER, *SCHIFFORNIS TURDINA INTERMEDIA* (AVES, TITYRIDAE), WITH ADDITIONAL OBSERVATIONS ON NESTLING MIMICRY

1. Introduction

The suboscine passerines of the genus *Schiffornis* are represented by seven species that occur throughout the humid forests and old growth woodlands from Central and South America (Winkler et al. 2020), and together with *Laniisoma* and *Laniocera*, they form a distinct clade within the family Tityridae (Ohlson et al. 2013). They are characterized by dull plumages, with the predominance of olive green and brownish colors, the lack of sexual dimorphism, secretive behavior, and relatively low population densities (Ridgely & Tudor 1994, Kirwan & Green 2011, Prado et al. 2022). They inhabit forest understory and midstory, where they are rarely seen, being more often detected only by their loud whistled songs (Ridgely & Tudor 1994, Snow & Kirwan 2020).

The Brown-winged Shiffornis, *S. turdina*, is widely distributed in South America, with four subspecies occurring across the Amazon and Atlantic Forests: *S. t. wallacii* in eastern Brazilian Amazon southern from the Amazon river; *S. t. steinbachi* in southeastern Peru and northern Bolivia; *S. t. intermedia* in the Atlantic Forest of northeastern Brazil in the states of Alagoas, Pernambuco, and Paraíba, and *S. t. turdina* in the Atlantic Forest of southeastern Brazil, in the states of Espírito Santo and Bahia (Snow & Kirwan 2020). The Atlantic Forest subspecies, *S. t. intermedia* and *S. t. turdina*, are geographically isolated, with distributions matching two endemism centers, the Pernambuco Endemism Center (PEC), and the Bahia Endemism Center, respectively (Snow & Kirwan 2020). The PEC is the most degraded of the Atlantic Forest regions, with only about 12% of original forest cover remaining in small and isolated fragments (Ribeiro et al. 2009, Dias et al. 2022). For this reason, *S. t. intermedia* is listed as Vulnerable in the Brazilian Red List based on the C2a(i) IUCN criteria, i.e. no individual populations may reach the minimum number of 1000 individuals (ICMBio 2018), which was reinforced by recent censuses data (Prado et al. 2022).

Most species of Schiffornis had their nests and eggs described, but reproductive information is still scarce and scattered for this bird group. For the Northern Schiffornis, *S. veraepacis*, four nests, eggs, nestlings, and one incubation period were described in Costa Rica (Skutch 1969), and the author noticed that these were the only nests found during 27 years of field work. For the Russet-winged Schiffornis, *S. stenorhyncha*, nest, eggs, nestlings, incubation, and nestling period were described for a single nest found in Colombia (Sandoval et al. 2017). For the Greenish Schiffornis, *S. virescens*, three nests and eggs were described in Argentina (Bodrati & Cockle 2017); one single nest with eggs and one hatchling was described in southern Brazil (Willrich & Silva 2019), and Marini & Heming (2017) described two clutches deposited in a museum egg collection. For the Olivaceous Schiffornis, *S. olivacea*, one nest with eggs was described in Guyana (del Hoyo et al. 2020). Although nestlings of Schiffornis have been observed only a few times, they have called attention by their intense and elongated downy feathers, sometimes with dendritic barbs, which could be an example of nestling camouflage (Londoño et al. 2022). Ancestral character reconstructions using the phylogeny of the Tityridae suggested that this could have been the ancestral condition that permitted the evolution of the Batesian mimicry present in nestlings and fledglings of the Cinereous Mourner, *Laniocera hypopyrra*, for which modified downy feathers makes it closely resemble toxic caterpillars found in its habitats (Londoño et al. 2015, 2022). It was suggested that the dense downy feathers of Schiffornis could be a type of Masquerade, i.e. organisms imitate structures that are inedible to predators (Londoño et al. 2021), which is still to be confirmed.

The breeding information available for the Brown-winged Schiffornis is limited to the description of only one nest and two eggs of the subspecies *S. t. steinbachi*, from the Peruvian Andes (Guerrero et al. 2020), and the brief information provided by Sick (1997) that the nest is constructed in a rotten truck and is lined with dry leaves. Here we describe for the first time the nests and eggs of the endangered Brown-winged Schiffornis (*S. t. intermedia*) from the Atlantic Forest of northeastern Brazil, with details on nestling characteristics and behavior that may contribute to elucidate mimicry interpretation within the clade.

2. Material and Methods

2.1. Study area

We found the nests at an approximately 900 ha Atlantic Forest fragment from the state of Alagoas, Rio Largo municipality, northeastern Brazil (9°31'23.82"S; 35°55'6.53"O; altitude 120 m). The area is a Privet Natural Heritage Reserve (RPPN Mata do Cedro), and it is surrounded by sugar cane plantations. The vegetation is open ombrophilous Atlantic Forest, and the climate is classified as AS’ according to Köppen: tropical with a well-defined dry and warm season from October through January, and a long rainy season during the autumn and winter. Average annual rainfall is 1600–1700 mm, and average minimum and maximum temperatures range from 21–22°C, and 30–31°C (Roda & Santos 2005, Barros et al. 2012). Although logging has occurred in the past in this area, today it present tracts in middle and in late regeneration stage, with abundant emergent trees (see also Prado et al. 2022).

2.2. Field procedures

We performed *ad libitum* searches for bird nests in general from September to December 2022, 2–3 times per week, from sunrise to sunset. The nests and eggs were measured with a metal caliper accurate to 0.1 mm, and they were weighted using spring scale (Pesola Inc., 10 g) accurate to 0.1 g. The nests were located when incubation adults were flushed from the nests, and once found, they were checked every two to three days. Details on the nest materials were obtained after the nests were no longer being used, and we classified the nests and eggs following Winkler (2004).

3. Results

In total, we found two active nests: one in 08 November 2022, and another in 11 November 2022, both containing two eggs each, in incubation stage. Both nests were cups constructed within crevices created by broken rotten trees, with one side of the nests totally hidden by the trunk (Figure 4.1, Figure 4.2). They were located in areas of mature forest, where the forest understory was poorly dense (Figure 4.2). The nests were lined with well-arranged dry leaves, many of them skeletonized, and black fungal hyphae. The bases of the nests, they filled the cravices below the nests with large amounts of decaying leaves and a few sticks, some of which were pointing out the lateral parts of the nests (Figure 4.1). They were 1.5 and 1.3 m above ground, and measurements of nest 2 were: 6.5 cm in internal diameter; 13.3 cm in external diameter; 13.3 cm in height, and 3.8 cm in depth. The eggs were glossy, with slightly beige background color, marked with intense brown blotches and dull blotches with grayish color, concentrated at the larger end (Figure 4.1). They were short-oval, and two eggs of nest 1 measured 26.7 X 19.6, and 26.4 X 19.9 mm, and they weighted 5.4 and 5.7 g, respectively.

Figure 4. (1) Nest and eggs of the Brown-winged Schiffornis, *S. t. intermedia*. (2) nesting habitat and a rotten truck used for nest support.

In 16 November nest 1 still contained two eggs, and in 28 November it contained two nestlings in early developmental stage. In 04 December the nestlings were still present, but in 06 December the nest was depredated. Nest 2 was depredated still during the incubation stage, a few days after being found. The nestlings were covered by brownish gray downy feathers, that were remarkably dense and elongated (Figure 5.1, Figure 5.2), that barely permitted the identification of the nestlings within the nest (Figure 5.3). They had dark gray legs, feet, and beaks, light yellow commissures, and dark red skin (Figure 5.1).

Figure 5. (1) Nestling of the Brown-winged Schiffornis, *S. t. intermedia*, in early developmental stage. (2) Nestling of the Brown-winged Schiffornis photographed from above, evidencing it similarity with a toxic caterpillar. (3) Nestlings hiding their heads, and legs within the nest, in a position likely associated with a camouflage strategy.

4. Discussion

The descriptions of the nests and eggs of *S. t. intermedia* matched the general patterns previously provided for the Brown-winged Schiffornis and also for the other congeners (Skutch 1969, Bodrati & Cockle 2017, Sandoval et al. 2017, Willrich & Silva 2019, Guerrero et al. 2020), indicating that they can be important diagnostic characteristics of this suboscine genus. The nest described for *S. t. steinbachi* in Colombia was sit on a crevice created by the root of a tree (Guerrero et al. 2020), while other nests described for the Schiffornis were placed at the basis of palm trees (Skutch 1969, Sandoval et al. 2017), within bromeliads, clumps of vines, and tangles of bulky vegetation (Skutch 1969, Bodrati & Cockle 2017, Willrich & Silva 2019). Differently these descriptions, the two nests we found were in crevices created by rotten trunks that were very similar one another. Although the number of described nests is still insipient to assert that this can be the general nest placement pattern for the subspecies we studied, this is something of conservation concern, once rotten trucks can be a scarce resource, e.g. in disturbed or in regenerating forests (Cockle et al. 2010), which should be carefully investigated in future works.

Not rarely, morphological traits evolve in association with behavioral characteristics to increase camouflage efficiency. For instance, birds can select nesting microhabitats where background surfaces maximize the camouflage of eggs or nestlings (background matching) (Gómez et al. 2018), or in the case of the Batesian mimicry observed for *Laniocera hypopyrra*, the way the nestlings move their heads when a potential predator arises, resemble the movements of the toxic caterpillar (Londoño et al. 2022). It was previously noticed that nestlings of the Northern Schiffornis remained motionless with the approach of the observers, differing from many other bird species that raise their heads begging for food in similar occasions (Skutch 1969). It was proposed that the dense downy feathers of Schiffornis nestlings could be a type of masquerading, a strategy by which the pray is confounded with inedible structures present in its habitats, namely tufts of species of fungus (Londoño et al. 2022). The lack of movements could part of this strategy, but this information is controversial because the motionless behavior was not observed in the Russet-winged Schiffornis (Sandoval et al. 2017, Londoño et al. 2022). In the nest we observed, we confirmed the finding that the nestlings of Schiffornis remain totally motionless with the approach of a potential predator (e.g., the observers). In addition, we observed that the nestlings remained in a position in which their heads, legs and feet were not visible in the middle of the downy feathers, neither from above nor laterally, and the limits between the bodies of the two nestlings could not be seen. If they were in the regular position adopted by the majority of the passerine nestlings, their extremities would certainly be exposed. Then, we advocate that hiding these body parts in the middle of the downy feathers is a behavior that works in association with these feathers, and together they are part of the same camouflage strategy.

Although we have not detected fungi species that could resemble the Schiffornis nestlings in our study area, the fungus mimetism is a plausible explanation for the evolution of the plumage pattern of Schiffornis nestlings (Londoño et al. 2022). However, based on our observations, we suggest that the hypothesis of disruptive camouflage also should not be discarded. In this strategy, organisms develop characteristics that give them an unreal shape, becoming less likely to be identified if detected by a potential visually-oriented predator (Mulder et al. 2021). It is difficult to confirm if the plumage characteristics and the motionless behavior of Schiffornis have served only to hide the real shape of the nestlings, or if it also evolved for simulating other types of caterpillars that are less aposematic than the Megalopygidae caterpillar imitated by *Laniocera hypopyrra* (see Londoño et al. 2022). It is undeniable that when photographed from above and individually, the nestlings of the Brown-winged Schiffornis closely resembled a toxic caterpillar. Despite the limited number of nests found for the species of these closely related bird genera, the nestling camouflages revealed for the Tytiridae are of great interest to evolutionary biology, and future experimental works could contribute to elucidate their functions within the Schiffornis.

5. References

BARROS, A. H. C. *et al*. Climatologia do estado de Alagoas. Boletín de pesquisa e desenvolvimento 211. Embrapa, PE, Brasil, 2012.

DIAS, T. C. *et al*. Greening and browning trends in a tropical forest hotspot: Accounting for fragment size and vegetation indices. Remote Sensing Applications: Society and Environment, v. 26, p. 100751, 2022.

BODRATI, A.; COCKLE, K. L. Nest, eggs and reproductive behavior of Greenish Schiffornis (*Schiffornis virescens*). Revista Brasileira de Ornitologia, v. 25, p. 273-276, 2017.

COCKLE, K. L.; MARTIN, K.; DREVER, M. C. Supply of tree-holes limits nest density of cavity-nesting birds in primary and logged subtropical Atlantic Forest. Biol. Conserv., v. 143, n. 11, p. 2851-2857, 2010.

DEL HOYO, J.; COLLAR, N.; KIRWAN, G. M. Olivaceous Schiffornis (*Schiffornis olivacea*), version 1.0. In Birds of the World (J. del Hoyo, A. Elliott, J. Sargatal, D. A.

Christie, and E. de Juana, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA, 2020. https://doi.org/10.2173/bow.thlsch7.01.

GERRERO, M. M. C.; MUÑOZ, J.; LONDOÑO, G. A. Nesting information for the Brown-winged Schiffornis (*Schiffornis turdina*). Ornitología Neotropical, v. 31, p. 42–46.

GOMEZ, J. *et al*. Individual egg camouflage is influenced by microhabitat selection and use of nest materials in ground nesting birds. Behav. Ecol. Sociobiol., v. 72, n. 142, 2018.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (ICMBIO). Livro vermelho da fauna brasileira ameaçada de extinção: Volume III – Aves, 1.ed. ICMBio/MMA, Brasília, DF, 2018.

KIRWAN, G. M.; GREEN, G. Cotingas and manakins. Christopher Helm, London, United Kingdom, 2011.

LONDOÑO, G.A.; GARCÍA, D. A.; SÁNCHEZ-MARTÍNEZ, M.A. Morphological and behavioural evidence of Batesian mimicry in nestlings of a lowland Amazonian bird. The American Naturalist, v. 185, n. 1, p. 135–141, 2015.

LONDOÑO, G. A. *et al*. On the evolution of mimicry in avian nestlings. Ecology and Evolution., v. 12, n. 4, p. e8842, 2022.

MARINI, M. A.; HEMING, N. M. Breeding of the Greenish Schiffornis (*Schiffornis virescens*, Tityridae). Revista Brasileira de Ornitologia, v. 25, p. 269–272, 2017.

MULDER, T.; CAMPBELL, C. J.; RUXTON, G. D. Evaluation of disruptive camouflage of avian cup-nests. Ibis, v. 163, n. 1, p. 150–158, 2021.

OHLSON, J. I. *et al*. Phylogeny and classification of the New World suboscines (Aves, Passeriformes). Zootaxa, v. 3613, n. 1, p. 001–035, 2013.

PRADO, L. C. *et al*. Population density estimates for three endangered bird taxa from the Pernambuco Endemism Center, northeastern Brazil. Biota Neotropica, v. 22, n. 3,p. e20221361, 2022.

RIBEIRO, M. C. *et al*. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv., v. 142, n. 6, p. 1141–1153, 2009.

RIDGELY, R. S.; TUDOR, G. The birds of South America: Vol II The suboscine passerines. University of Texas Press, Austin, 1994.

RODA, S. A.; SANTOS, A. M. M. Avaliação de fragmentos florestais para uma possível reintrodução do mutum-de-alagoas em seu ambiente natural. Centro de Pesquisas Ambientais do Nordeste – CEPAN, 2005.

SANDOVAL, H. J.; CHINOME, G. A.; LONDOÑO, G. A. Nesting Biology of *Schiffornis stenorhyncha* (Tityridae). The Wilson Journal of Ornithology, v. 129, n. 4, p. 827–833, 2017.

SICK, H. Ornitologia Brasileira. Editora Nova Fronteira, RJ, Brazil, 1997.

SKUTCH, A.F. Life histories of Central American birds III. Families Cotingidae, Pipridae, Formicariidae, Furnariidae, Dendrocolaptidae, and Picidae. Cooper Ornithological Society, Berkeley, California, USA, 1969.

SNOW, D.; KIRWAN, G. M. Brown-winged Schiffornis (*Schiffornis turdina*), version 1.0. In Birds of the World (J. del Hoyo, A. Elliott, J. Sargatal, D. A. Christie, and E. de Juana, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.thlsch3.01, 2020.

WILLRICH, G.; SILVA, L. Z. New description of the nest, eggs and nestling of Greenish Schiffornis (*Schiffornis virescens*). Cotinga, v. 41, p. 124–126, 2019.

WINKLER, D. W. Nest, eggs, and young: The breeding biology of birds. In: Podulka S, Rohrbaugh RW Jr, Bonney R, editors. Handbook of bird biology. 2nd Edition. Princeton (NJ): Princeton University Press; p. 8.1–8.152, 2004.

WINKLER, D. W.; BILLERMAN, S. M.; LOVETTE, I. J. Tityras and Allies (Tityridae), version 1.0. In Birds of the World (S. M. Billerman, B. K. Keeney, P. G. Rodewald, and T. S. Schulenberg, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.tityri1.01, 2020.

CAPÍTULO III - ON THE REPRODUCTIVE ASPECTS OF THE THREATENED WHITE-BELLIED TODY-TYRANT *HEMITRICCUS GRISEIPECTUS NAUMBURGAE* (AVES, TYRANNIDAE)

1. Introduction

The Tody-Tyrants of the genus *Hemitriccus* are tiny and inconspicuous representatives of the family Tyrannidae (9–11 cm), distributed mainly in tropical and subtropical South America (Sick 1997, Ridgely & Tudor 1994). Most species inhabit low and middle humid forest understory, mainly from the Andes, Amazon and Atlantic forest, with only a few taxa occurring in savannas and other arid environments (Ridgely & Tudor 1994). Despite their diversity and broad distribution, reproductive aspects are poorly known for most of the 22 species (Winkler et al. 2020). Detailed descriptions were provided for: one nest of *H. nidipendulus* from an non-described locality (Ihering 1900); one nest of *H. obsoletus* found in the Atlantic Forest of southern Brazil (Bencke et al. 2001); one nest of the Stripe-necked Tody-Tyrant, *H. striaticollis* found in a gallery forest from Brazilian Pantanal (Kirwan & Whittaker 2009); one nest of the Drab-breasted Pygmy-tyrant, *H. diops* found in the Atlantic Forest of the state of Espírito Santo, southeastern Brazil (Kirwan & Whittaker 2009), three nests of *H. granadensis* from Peru and Colombia (McCullough & Londoño 2017), and the nest of *H. rufigularis* was described based on an unknown sample size (Fitzpatrick 2004). A single nest of the threatened Kaempfer's Tody-tyrant, *H. kaempferi*, was partially described in the Atlantic Forest of southern Brazil, state of Santa Catarina, but details about the nest shape were dubious (Barnett et al. 2000). Information based on greater amount of nests were gathered only for *H. margaritaceiventer* (Narosky & Salvador 1998).

Clutch sizes and eggs were described for *H. nidipendulus* (Von Hering 1900), *H. margaritaceiventer* (Narosky & Salvador 1998), *H. obsoletus, H. diops* (Kirwan & Whittaker 2009), but they were weighted only for *H. granadensis* (McCullough & Londoño 2017), and for some species they were not measured (*H. obsoletus* and *H. diops*). For *H. rufigularis*, only clutch size was described (Fitzpatrick 2004). Nestlings were described only for *H. granadensis*, and incubation and nestling periods are still unknown for the genus, except for a nestling period of 13-14 days reported for *H. margaritaceiventer* (Narosky & Salvador 1998). Overall, basic information such as nest and egg descriptions are available for only seven and five species, respectively, evidencing the scarcity of information on the breeding aspects of the 22 representatives of the genus *Hemitriccus*.

The White-bellied Tody-tyrant, *H. griseipectus*, is represented by two recognized subspecies with highly disjunct geographic distributions. The nominal subspecies is widely distributed in Amazon Forest, southern from the Amazon river, across southeastern Peru and Brazil, east to Tocantins river. The subspecies *H. g. naumburgae* is endemic to the Atlantic Forest of northeastern Brazil (Pernambuco Endemism Center - PEC), in the states of Alagoas, Pernambuco, and Paraíba (Schulenberg 2020). Due to the high levels of degradation and fragmentation of the Atlantic Forest of the PEC (Ribeiro et al. 2009, Dias et al. 2022), the later subspecies is listed as Vulnerable in the Brazilian Red List of Endangered Bird Species, with an estimated occupancy area of 2000 km^2 that is still decreasing (ICMBio 2018), and a population size of approximately 146,000 individuals (Prado et al. 2022). Despite the conservation concern with one of the subspecies, the reproductive aspects of *H. griseipectus* are still totally unknown. Here we provide the first nest, egg, and nestling descriptions of *H. griseipectus*, based on nests found in the Atlantic Forest of the state of Alagoas, northeastern Brazil, with notes on its nesting habitats.

2. Material and Methods

2.1. Study area

We searched for nests at RRPN Mata do Cedro, a Privet Natural Heritage Reserve of approximately 900 ha from the state of Alagoas, Rio Largo municipality, northeastern Brazil (9°31'23.82"S; 35°55'6.53"O; altitude 120 m). This forest fragment is surrounded by sugar cane plantations and the vegetation is open ombrophilous Atlantic Forest, and the climate is classified as AS' according to Köppen: tropical with a well-defined dry and warm season from October through January, and a long rainy season during the autumn and winter. Average annual rainfall varies from 1600–1700 mm, and average minimum and maximum temperatures from 21–22°C, and 30–31°C (Roda & Santos 2005, Barros et al. 2012).

2.2. Field procedures

We located the nests during *ad libitum* searches for bird nests in general from September to December 2022, 2–3 times per week, from sunrise to sunset. To measure the nests and eggs, and to weight the eggs, we used a metal caliper accurate to 0.1 mm and a spring scale (Pesola Inc., 10 g) accurate to 0.1 g. To find the nests we thoroughly checked the vegetation, and looked for potential parental individuals carrying nesting or feeding materials in their territories (Martin & Geupel 1993). Nests and eggs were classified according to Winkler (2004).

3. Results

From October to December 2022, we found six active nests of the White-bellied Tody-tyrant. Although our field work was intensified from September on, the earliest active nest (containing two eggs) was found in 11 October, when the breeding season seemed to have started. The nests were closed and top-suspended, with a roofed, ellipsoid lateral entrance, and a noticeable tale of hung material underneath (Figure 6.1 and Figure 6.2). They were attached to slender descendent branches from bushes or saplings in forest understory, and were 50 cm to 1.4 m above ground (1.1 ± 0.36 m, n = 5), and the roof totally covered the nest entrance from a frontal view. Nest material consisted of elongated leafs, including leaves of palms and bamboo; stripes of bark; a variety of fibers, and plumed seeds that were loosely attached with the use of spider web. In general, only dry materials were used, giving the nests a yellowish color. The incubatory chamber was lined with cotton-like fibers (Figure 6.3), a material that in some nests was remarkably abundant and was also used in nest entrance and in nest walls. Exceptionally, an unique nest had a great amount of green moss in outer nest walls, diverging from the others. The nests were laterally compressed and they measured 10.5–11.6 cm in the largest width (11.07 ± 0.47, n = 4); 6.7–7.6 cm in the smallest width (7.22 ± 0.45, n = 4); 14.6–16.6 cm in height, from the basis to the attachment point (15.46 ± 0.82, n = 4), and the nest tails varied from 16.5–45.0 cm in length (30.62 ± 11.81, n = 4).

Of the six nests, five contained two eggs each when found, and one nest contained only one egg. The eggs were oval and measured 1.62–1.74 cm in length (1.68 ± 0.04, n = 10), 1.25–1.32 cm in width (1.29 ± 0.02, n = 10), and weighted 1.3–1.5 g (1.4 ± 0.1, n = 9). Egg background color was white in one clutch and they were slightly beige in the other clutches. They were marked with only a few brown dots and blotches (Figure 6.3). The hatchlings had pinkish skin, yellow mouth lining and commissure, and had very few downy feathers (Figure 6.4). Two of the nests were abandoned in incubation stage, two were depredated in incubation stage, one fledged one nestling successfully, and the fate of one nest was unknown.

Figure 6. (1) Lateral view of the top-suspended nest of the threatened White-bellied Tody-tyrant, *Hemitriccus griseipectus naumburgae*. (2) Frontal view of the nest entrance. (3) Eggs depicting markings patterns. (4) hatchling, evidencing skin color and the lack of downy feathers.

4. Discussion

Although our descriptions of nests, eggs, and nestlings were provided for the subspecies *H. g. naumburgae*, from northeastern Brazil, these are the first reproductive information for the whole species. Nest attachment mode and shape, i.e. top-suspended closed nests with a roofed lateral entrance, matched the descriptions of the nests of *H. nidipendulus*, *H. striaticollis*, *H. diops*, *H. granadensis*, *H. rufigularis*, and *H.*

margaritaceiventer (Ihering 1900, Narosky & Salvador 1998, Fitzpatrick 2004, Kirwan & Whittaker 2009, McCullough & Londoño 2017). Exception was a nest of *H. obsoletus*, that although closed with a lateral entrance, it was laterally supported by bamboo stems (Bencke et al. 2001), but we are uncertain about whether this variation could represent phylogenetic divergences. Although the Tody-tyrants (*Oncostoma*, *Lophotriccus*, *Hemitriccus*, *Atalotriccus*, *Myiornis*, *Todirostrum*, and *Poecilotriccus*) constitute a monophyletic group within the Tyrannidae, the genus *Hemitriccus* has long been evidenced to be polyphyletic. Three species addressed in phylogenies constructed with molecular data (*H. minor*, *H. zosterops*, and *H. margaritaceiventer*) were assigned to three independent clades (Tello & Bates 2007). Although some authors have argued that the representatives of the genus *Hemitriccus* are characterized by the construction of top-suspended enclosed nests, the lack of phylogenetic studies containing the other taxa currently classified as *Hemitriccus*, associated with the lack of nest descriptions for most species precludes the conclusion that top-suspended closed nests are characteristic of the true *Hemitriccus*, which is still to be investigated. It is also worth noting that the lateral nest attachment attributed to *H. obsoletus* was based on only one nest, suggesting that further nests should be analyzed before drawing the conclusion that this is the typical nest attachment pattern of this species (Bencke et al. 2001).

The use of dry leaves in nest walls seemed to be a common aspect of the nests of *Hemitriccus*, and the use of pieces of soft bark was also observed in *H. striaticollis* and *H. diops* (Kirwan & Whittaker 2009). For *H. granadensis*, *H. diops*, and *H. striaticollis* moss was the predominant material in nest walls, giving the nests a predominantly green color (Kirwan & Whittaker 2009, McCullough & Londoño 2017). Five of the nests we found had no green material and were yellowish brown in general color, but one nest had plenty green moss in its outer layers, suggesting that the use of certain nest materials can vary according to their availability, or as a function of the surrounding habitat for camouflage purposes (see Zima et al. 2023). The roof covering the lateral entrance and the tail of loose material underneath the nest were also observed for all of the species with detailed nest descriptions, except for *H. obsoletus* (Bencke et al. 2001).

The eggs and clutch sizes we recorded matched the descriptions reported for the other congeners, except for *H. margaritaceiventer*, for which some clutches of three eggs were reported (Narosky & Salvador 1998). The nestlings we observed were also similar to those described for *H. granadensis*, but the later had noticeable gray down

(McCullough & Londoño 2017). To date, these are the only nestling descriptions available for the genus, and it is possible that we have not observed the downy feathers because the nestling we described was too young.

At least three species of *Hemitriccus* are bamboo specialists (*H. flammulatus*, *H. obsoletus*, and *H. diops*). The species we studied is not a bamboo specialist, and bamboos were rare in our study areas during the time of our field work. However, one of the nests we found was close to a bamboo agglomerate of non-identified species, and bamboo leaves were largely used in the construction of this nest. Although nest placement near the bamboos could have occurred just by chance, it also could have resulted from phylogenetic behavioral effects, i.e. behavioral aspects inherited from bamboo specialist ancestors. It is to be confirmed if this, and other *Hemitriccus*, could select nesting sites with bamboo when it is available, even for those not considered as bamboo specialists. Reproductive information is still lacking for many Neotropical bird species, and *Hemitriccus* is one of the least known genera. Nest characteristics have been argued to be important for elucidating taxonomic aspects of this group, and some of the species and subspecies are threatened. Then, ornithologists should continue investigating the breeding parameters of *Hemitriccus* and their relevance for taxonomic and conservation purposes.

5. References

BARROS, A. H. C. *et al*. Climatologia do estado de Alagoas. Boletín de pesquisa e desenvolvimento 211. Embrapa, PE, Brasil, 2012.

BARNETT, J. M. *et al*. Rediscovery and subsequent observations of Kaempfer’s Tody-tyrant *Hemitriccus kaempferi* in Santa Catarina, Brazil, with notes on conservation, life history and plumage. Bird Conservation International, v. 10, n. 4, p. 371–379, 2000.

BENCKE, G. A. *et al*. First description of the nest of the Brown-breasted Pygmy-tyrant (*Hemitriccus obsoletus*) and additional information on the nesting of the Striolated Tit-spinetail (Leptasthenura striolata). Ornitología Neotropical, v. 12, n. 1, p. 1–9, 2001.

DIAS, T. C. *et al*. Greening and browning trends in a tropical forest hotspot: Accounting for fragment size and vegetation indices. Remote Sensing Applications: Society and Environment, v. 26, p. 100751, 2022.

FITZPATRICK, J.W. Family Tyrannidae (tyrant-flycatchers). Pages 170-462 in J. del Hoyo, A. Elliott, and D.A. Christie (editors), Handbook of the birds of the world. Volume 8. Lynx Edicions, Barcelona, 2004.

IHERING, H. V. Catálogo crítico-comparativo dos ninhos e ovos das aves do Brasil. Revista do Museu Paulista, v. 4, p. 191–300, 1900.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE (ICMBIO). Livro vermelho da fauna brasileira ameaçada de extinção: Volume III –

Aves, 1.ed. ICMBio/MMA, Brasília, DF, 2018.KIRWAN, G. M.; WHITTAKER, A. The nest of the Stripe-necked Tody-tyrant (*Hemitriccus striaticollis*), with the first detailed nesting data for the Drab-breasted Pygmy-tyrant (H. diops). Ornitología Neotropical, v. 20, p. 299–303, 2009.

MARTIN, T. E.; GEUPEL, G. R. Nest-monitoring plots: Methods for locating nests and monitoring success. Journal of Field Ornithology, v. 64, n. 4, p. 507–519, 1993.

MCCULLOUGH, J. M.; LONDOÑO, G. A. Nesting biology of the Black-throated Tody-tyrant (*Hemitriccus granadensis*) with notes on mating displays. The Wilson Journal of Ornithology, v. 129, n. 4, p. 820–826, 2017.

NAROSKY, T.; SALVADOR, S. Nidificacíon de las aves Argentinas (Tyrannidae). Asociación Ornitológica del Plata, Buenos Aires, 1998.

PRADO, L. C. *et al*. Population density estimates for three endangered bird taxa from the Pernambuco Endemism Center, northeastern Brazil. Biota Neotropica, v. 22, n. 3,p. e20221361, 2022.

RIBEIRO, M. C. *et al*. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv., v. 142, n. 6, p. 1141–1153, 2009.

RIDGELY, R. S.; TUDOR, G. The birds of South America: Vol II The suboscine passerines. University of Texas Press, Austin, 1994.

RODA, S. A.; SANTOS, A. M. M. Avaliação de fragmentos florestais para uma possível reintrodução do mutum-de-alagoas em seu ambiente natural. Centro de Pesquisas Ambientais do Nordeste – CEPAN, 2005.

SCHULENBERG, T. S. White-bellied Tody-Tyrant (*Hemitriccus griseipectus*), version 1.0. In Birds of the World (T. S. Schulenberg, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.whbtot1.01, 2020.

SICK, H. Ornitologia Brasileira. Editora Nova Fronteira, RJ, Brazil, 1997.

WINKLER, D. W.; BILLERMAN, S. M.;LOVETTE, I. J. Tyrant Flycatchers (Tyrannidae), version 1.0. In Birds of the World (S. M. Billerman, B. K. Keeney, P. G. Rodewald, and T. S. Schulenberg, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.tyrann2.01, 2020.

FITZPATRICK, J. W. Family Tyrannidae (tyrant-flycatchers). Pages 170-462 in J. del Hoyo, A. Elliott, and D.A. Christie (editors), Handbook of the birds of the world. Volume 8. Lynx Edicions, Barcelona, 2004.

WINKLER, D. W. Nest, eggs, and young: The breeding biology of birds. In: Podulka S, Rohrbaugh RW Jr, Bonney R, editors. Handbook of bird biology. 2nd Edition. Princeton (NJ): Princeton University Press; p. 8.1–8.152, 2004.

CAPÍTULO IV - THE COMPLEX COURTSHIP DISPLAY OF THE REDDISH HERMIT (PHAETHORNIS RUBER, AVES, TROCHILIDAE) IN THE ATLANTIC FOREST OF NORTHEASTERN BRAZIL

Abstract: The courtship displays of the hummingbirds (Aves, Trochilidae) are remarkable by their acrobatic flights and fluttering sounds, being important examples of sexual selection. The courtship display of the Reddish Hermit, *Phaethornis ruber*, was pointed out as one of the most complex among the Trochilidae, but only parts of the display have been described in the literature. Here we present the first record of the complete courtship display and of the copulation behavior of the Reddish Hermit. We also provide the first video-recording of this behavior and using slow-motion approach we reveal unprecedented details for the courtship display of a hermit hummingbird. Each male's performance session was composed by four main displays: *horizontal arc*, *pendulum*, *sliding horizontal*, and *pre-copulatory approach* displays. Remarkable variations occurred in some of these display categories, and they were accompanied by characteristic sounds. While lekking behaviors have been thoroughly described for many hermit hummingbird species, courtship displays are secretive and punctual behaviors that are difficult to be captured, and much has still to be learned about this subject. Because of the complexity of the observed behaviors, our findings provided further evidence for the importance of the energetic performance in the sexual selection of hummingbirds.

Keywords: Aves; courtship behavior; hummingbird; mating behavior; pre-copulatory display; sexual selection; Trochilidae.

1. Introduction

Hummingbirds (Aves, Trochilidae) have long called the attention of ornithologists due to the evolution of various outstanding characteristics, including their iridescent structural, and pigmentary colors (Gruson et al. 2021); miniaturization; high speed and maneuverability (Clark 2009, Nuñez-Rosas et al. 2018); nocturnal torpor (Shankar et al. 2020); highly specialized diet (Leimberger et al. 2022), and also their complex courtship displays, rich in vocal and fluttering sounds and acrobatic flights (Clark et al. 2013). Furthermore, they play important functional roles within communities, as more than 7000 plant species depend on hummingbirds for pollination, a type of mutualistic interaction that can potentially involve coevolutionary responses (Leimberger et al. 2022).

The hermit hummingbirds comprise a well-supported and likely monophyletic clade within the Trochilidae (*Eutoxeres, Ramphodon*, *Glaucis*, *Threnetes,* and *Phaethornis*) (McGuire et al. 2007, 2014). They can be diagnosed by the predominance of pigmentary colors, mainly brown, grayish and reddish, and in most species males display at leks to attract mates (Hinkelmann & Schuchmann 1997). During the breeding season, assemblages of males can display at the lekking sites almost during all day, exhibiting characteristic sounds and body movements (Schuchmann 1987), reason why the lekking behaviors have been described in details for many of the representatives of this hummingbird clade (Skutch 1964, Wiley 1971, Snow 1973, Schuchmann 1987, Felton et al. 2008). However, preliminary observations on at least two species of hermit hummingbirds (*P. ruber* and *P. griseogularis*) (Mobbs 1971, Schuchmann 1987) revealed that in addition to the conspicuous lekking displays, these birds also perform highly complex pre-copulatory courtship behaviors when in the presence of a female. Because courtship displays are punctual and likely less frequent than lekking behavior, they have remained poorly known for most hermit hummingbird species, despite the fact that they can be remarkable examples of sexual selection.

The Reddish Hermit, *P. ruber,* is one of the smallest hummingbirds (8 – 9cm; 1.8 – 3g), widely distributed in South America, from Ecuador, Bolivia, Colombia, Guyana and eastern Peru, southern to most of Brazil. It inhabits the understorey of a variety of forested habitats, such as cloud and lowland forests, as well as forest borders and some types of savanna (Hinkelmann et al. 2020). The courtship behavior of the Reddish Hermit was described for a pair maintained in captivity (Mobbs 1971) and for a pair observed in nature in the state of Mato Grosso, Brazil (Sick 1997), but only parts of the display sequences were captured. Here we provide the first record of the complete courtship display and copulation behavior of the Reddish Hermit. We also provide the first video-recording of this behavior and using slow-motion approach we reveal unprecedented details for the courtship display of a hermit hummingbird.

2. Material and Methods

2.1. Study area

This study was performed in an approximately 800 ha Atlantic Forest fragment from the state of Alagoas, northeastern Brazil. This area is a Privet Natural Heritage Reserve (RPPN Mutum de Alagoas) belonging to an ethanol and sugar industry (Usina Coruripe), and is surrounded by sugar cane plantations. The vegetation is classified as open ombrophilous Atlantic Forest, and the climate is classified as AS' according to Köppen: tropical with a well-defined dry and warm season from October through January, and a long rainy season during the autumn and winter. Average annual rainfall is 1600–1700 mm, and average minimum and maximum temperatures range from 21–22°C, and 30–31°C (Roda & Santos 2005, Barros et al. 2012). The observations occurred about 5m from a trail, in the interior of the forest, far from any border, in an area where the forest was in late regeneration stage, with the predominance of emergent trees and no evidence of forest degradation.

2.2. Field procedures

The courtship display was captured while we were performing *ad libitum* searches for bird nests, and we recorded the movements using a semi-professional camera Sony Cyber-shot DSC-HX1, Sony Corp., Japan. Due to the high speed of some movements, some display details were impossible to observe based only on human eyes. For this reason, in addition to providing the whole original video, we also generated slow motion videos of each display separately. Although most of the displays we observed did not perfectly match those described for other hummingbird species, whenever possible we classified the displays based on the nomenclatures of similar behaviors already published in the literature, e.g. ''pendulum'' (Myers et al. 2022), ''arc'' (Schuchmann 1987, Felton et al. 2008), and ''pre-copulatory approach'' displays (Schuchmann 1987).

3. Results

On 15 October 2022, at 3:30 pm, the buuzzz sound (drone sound) of a male's Reddish Hermit wings called our attention. At this moment we could observed a female perched in a slender horizontal twig, about 30 cm above ground, and a male performing an *arc* display (see below), hovering about 30 cm above the female. We immediately started the video recording, and we could observe two sequential, and likely complete, male's courtship display sessions, that together lasted almost 8 min. In the first display session the female was more active, and it resulted in copulation, while in the second session the male left the displaying area at the moment in which the copulation would occur, apparently because the female has not signalized interest. Each session was composed by four main aerial displays that we classified as *horizontal arc*, *pendulum*, *sliding horizontal line,* and *pre-copulatory approach*. The sequences of the displays were the same in the two sessions and below we describe these displays and their variations in the order they were performed:

Horizontal arc display – The male hovered approximately 30 cm above the female, forming an approximately 140° *horizontal arc*, like it was jumping laterally in the air. Its head and tail were positioned upwards, its chest was projected forwards, and its back was arched. During this performance, the yellow basis of the mandible; the whitish chin, and the white thigh feathers were exposed to the female. Notably, the feathers of the black chest patch were erected, likely due to the wind produced by the rapid wing movements. Three variations could be noticed. During most of the time, the male's head position was constantly adjusted to point to the female. At certain moments, however, the drone sound, the erection of the chest feathers and the body curvature were highly intensified, although the time to perform each arc did not change. When these highly accelerated arcs were performed, when reaching the extremity of each arc, the male turned his body to the outside (right and left). The other important variation that occurred during the *horizontal arc* display was when reaching the end of an arc, the male flew a little up, shaking its body laterally, wide opened the bill to show the yellow interior of the mandible to the female, and performed one or two pendulum dives before assuming the regular arc movement again, which was accompanied by a té-tek, té-tek sound.

Pendulum display – In this movement, the male performed sequential U-shaped flights, within a very limited space that was only slightly bigger than the size of its own body. With shallow dives, the male stretched the whole body, with the head and beak pointed forward. It alternated between a dive that involved a forward and a backward flight, and a dive that involved a body contortion to sharply shift the body direction. During these flights the male constantly exhibited the yellow basis of the mandible; the whitish chin; the white thigh feathers, and it constantly protruded its tong. This movement was accompanied by a distinctive sound (treeek; treeek; treeek), likely produced by the wing feathers.

Sliding horizontal line – The male moved back and forth across a horizontal line that was about 60 cm long, perpendicular to the female. This movement was so fast that the male could barely be seem by human eyes. The slow-motion video evidenced that during these flights the male changed its body direction before the end of the line, causing the impression that, near the end of the line, its body was sliding backwards. The premature direction change clearly permitted the yellow beak to be exposed to the female almost during the entire movement. This movement was accompanied by another distinctive, metalic sound (toii, toii, toii, toii…).

Pre-copulatory approach – the male approached the female frontally, shaking its body laterally, with the closed tail, head and beak positions contributing to give the whole body a concave shape. Although the lateral movements were constant, it approached the female slowly. After that, it kept performing this movement while stopped right in front of her, during 5-6 sec, after which the copulation occurred.

During the whole display sessions, the female constantly moved its head to follow the male’s movements, had its wings lowered and moved its tail up and down. The female’s tail movements became wider and more frequent near the end the first male’s display session, likely signalizing its interest in copulating. For the copulation, the male mounted the female by her left side and remained perched on her back during about 18 sec, while it kept protruding its tong.

4. Discussion

Our observations of the *horizontal arc* and of the *sliding horizontal* displays matched the descriptions provided by Sick (1997), although less details were provided especially for the *sliding horizontal* movement, likely because it was observed only based on human eyes. Mobbs (1971) also provided detailed descriptions of the *arc* and of the *pre-copulatory approach* displays for a pair of Reddish Hermits brought from

Brazil and held in captivity in England. However, the other phases of the courtship display and the copulation were not mentioned by the above authors, suggesting that they have observed only incomplete performances (Sick 1997). A painting provided in Ruschi (1986) depicts an individual with the protruding tong hovering very close to a perching individual, showing a body silhouette that seemed to be associated with the *pre-copulatory approach* display, but detailed information was not provided.

The most complete record of the courtship behavior of a hermit hummingbird was that provided for the Grey-chinned Hermit, *P. griseogularis*, from Colombia (Schuchmann 1987). For this species, three phases of areal displays were reported: i) the *horizontal arc*, in which male's tail and head positions were similar to that we observed for the Reddish hermit, but the variations in speed, in body directions, and the alternations of the *arc* movement with brief *pendulous dives* we observed were not mentioned for the Grey-chinned Hermit; ii) a rapid back and forth movement, that seemed to be analogous to our *sliding horizontal*, but for which little details were described. Based on the provided draw, this display seemed to follow a curve, and not a straight line like in the Reddish Hermit, but it is to be confirmed, and iii) the *pre-copulatory approach*, for which a draw evidenced the similar concave body silhouette we observed for the Reddish Hermit, but further details were not provided. The *pendulous* display was not reported and we are uncertain, however, whether the lower number of details provided for the courtship display of the Gey-chinned Hermit were because its display is less complex than that of the Reddish Hermit, or because the published description was simplified.

The *arc* display we observed seemed to be homologous to the *rotation* and *arc* movements recorded for a male Reddish Hermit hovering in front of another male in a lowland forest from Bolivia (Felton et al. 2008), but there were fundamental differences. The ''rotation display'' differed in that the tail of the displaying male was constantly raised and lowered with extreme speed, and this bird rhythmically opened and closed its bill to show the yellow gape. At times, this movement was alternated with an approximately 100° ''arc'' display. Because both the perching and the displaying individual were males, the authors attributed these displays to antagonistic behaviors between territorial individuals (Felton et al. 2008). Although simpler aerial displays were observed for males hovering in front of other males, apparently in territorial defense (Snow 1973, Felton et al. 2008), singing assemblages (leks) of the Reddish

Hermit, that were thoroughly described (Davis 1934, Felton et al. 2008), did not involve aerial movements, meaning that the courtship display is way more complex than the lekking behavior in this species.

Because we have observed two display sessions from the beginning, with one culminating in copulation, we are confident that we have captured all of the steps of the courtship display. For many hummingbird species and genera, courtship displays involve long diving and shuttle flights across the sky, covering areas of dozens of meters (Clark 2009). The displays of the Reddish Hermit, however, occurred very close to the female, within a very limited space, which may be an adaptation to the forest understory environment, where visibility reaches only a few meters. Although analyzing the diversity and evolution of hummingbird courtship displays is beyond the scope of this manuscript, to our knowledge this is the first record of the complete courtship display of a Hermit hummingbird and it is one of the most outstanding performances ever recorded for a bird. Mobbs (1971), after observing the courtship behaviors of various species of hummingbirds in captivity mentioned: ‘‘*the display of the male Reddish Hermit really has to be seen to be believed*’’. While lekking behaviors have been thoroughly described for many hummingbird species, courtship displays are secretive and punctual behaviors that are difficult to be captured, and much has still to be learned about this subject. Because this behavior is certainly highly energetically costly, our findings provided further evidence for the importance of energetic performance in the sexual selection of hummingbirds.

5. References

BARROS, A. H. C. *et al*. Climatologia do estado de Alagoas. Boletín de pesquisa e desenvolvimento 211. Embrapa, PE, Brasil, 2012.

CLARK, C. J.. Courtship dives of Anna’s hummingbird offer insights into flight performance limits. Proc. R. Soc. B, v. 276, p. 3047–3052, 2009.

CLARK, C. J.; ELIAS, D. O.; PRUM, R. O. Hummingbird feather sounds are produced by aeroelastic flutter, not vortex-induced vibration. The Journal of Experimental Biology, v. 216, n. 18, p. 3395-3403, 2013.

DAVIS, T. A. W. Notes on the display in the humming-birds *Phaethornis superciliosus* (Linn.) and Pygmonris ruber (Linn.). Ibis, v. 13, p. 732–738, 1934.

FELTON, A.; FELTON, A. M.; LINDENMAYER, D. B. The Display of a Reddish Hermit (*Phaethornis ruber*) in a Lowland Rainforest, Bolivia. Wilson J. Ornithology, v. 120, n. 1, p. 201-204, 2008.

GRUSON, H. *et al*. Distribution of iridescent colours in hummingbird communities results from the interplay between selection for camouflage and communication. Peer Community Journal, v. 1, p. e64, 2021.

HINKELMANN, C.; SCHUCHMANN, K. L. Phylogeny of the hermit hummingbirds (Trochilidae: Phaetornitinae). Stud. Neotrop. Fauna & Environm, v. 32, n. 3, p. 142-163, 1997.

HINKELMANN, C.; KIRWAN, G. M.; BOESMAN, P. F. D. Reddish Hermit (*Phaethornis ruber*), version 1.0. In Birds of the World (J. del Hoyo, A. Elliott, J. Sargatal, D. A. Christie, and E. de Juana, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.redher1.01, 2020.

LEIMBERGER, K. G. *et al*. The evolution, ecology, and conservation of hummingbirds and their interactions with flowering plants. Biol. Rev., v. 97, n. 3, p. 923-959,2022.

MCGUIRE, J. A. *et al*. Phylogenetic Systematics and Biogeography of Hummingbirds: Bayesian and Maximum Likelihood Analyses of Partitioned Data and Selection of an Appropriate Partitioning Strategy. Syst. Biol., v. 56, n. 5, p. 837-856, 2007.

MCGUIRE, J. A. *et al*, Molecular Phylogenetics and the Diversification of Hummingbirds. Current Biology, v. 24, n. 8, p. 910–916, 2014.

MOBBS, A. J. Notes on the Reddish Hermit hummingbird. Aviculturalist Magazine, v. 77, p. 160–163, 1971.

NUÑEZ-ROSAS, L. *et al*. Mating system, male territoriality and agility as predictors of the evolution of sexual size dimorphism in hummingbirds (Aves: Trochilidae). Behaviour, p. 1-45, 2018.

RODA, S. A.; SANTOS, A. M. M. Avaliação de fragmentos florestais para uma possível reintrodução do mutum-de-alagoas em seu ambiente natural. Centro de Pesquisas Ambientais do Nordeste – CEPAN, 2005.

RUSCHI, A. Aves do Brasil: Beija Flores. Expressão e Cultura, RJ, Brazil, 1986.

SCHUCHMANN, K.L. First record of the Grey-chinned Hermit (*Phaethornis griseogularis*) west of the Colombian Andes, with notes on the displays of the species. Wilson Bulletin, v. 99, n. 1, p. 122-124, 1987.

SHANKAR, A. *et al*. Hummingbird torpor in context: duration, more than temperature, is the key to nighttime energy savings. Journal of Avian Biology, v. 51, n. 5, p. e02305, 2020.

SICK, H. Ornitologia Brasileira. Editora Nova Fronteira, RJ, Brazil, 1997.

SKUTCH, A. F. Life histories of hermit hummingbirds. Auk, v. 81, p. 5-25, 1964.

SNOW, B. K. The behavior and ecology of hermit hummingbirds in the Kanaku Mountains, Guyana. Wilson Bulletin, v. 85, n. 2, p. 163–177, 1973.

WILEY, R. H. Song groups in a singing assembly of little hermits. Condor, v. 73, n. 1, p. 28-35, 1971.

CONSIDERAÇÕES FINAIS

Embora a choquinha-lisa e o tangará-príncipe não sejam endêmicos do CEP e não estejam ameaçados, as subespécies do cuspidor-de-máscara-preta *C. m. nigrifrons* e da choca-lisa *T. a. distans* são endêmicas do CEP e estão listados como Vulneráveis e Ameaçados, respectivamente, na lista vermelha brasileira, com *T. a. distans* ocorrendo em apenas 25 fragmentos (ICMBio 2018). Os fragmentos que analisamos estão entre os maiores para o padrão de distribuição espacial das florestas do CEP (Dias et al. 2023) e juntamente com outros fragmentos de tamanho semelhante certamente detêm porções significativas das populações totais de muitos táxons ameaçados e endêmicos, e encontrar taxas de sobrevivência de ninhos tão pequenas em fragmentos dessas classes de tamanho foi preocupante. Como a maioria das espécies de aves desaparecidas do CEP são pequenas aves insetívoras que não são alvo de caça furtiva e captura, sugerimos que as taxas de sobrevivência dos ninhos sejam melhor investigadas nos poucos fragmentos restantes maiores que 1.000-2.000 ha para ver se poderiam fornecer melhores chances de sobrevivência dos ninhos, especialmente porque os predadores de topo também estão extintos nessas áreas (Pontes et al 2016). Embora testar a hipótese da liberação de mesopredadores não estivesse no escopo deste trabalho, apresentamos evidências de que as taxas de perda de ninhos foram elevadas em nossos locais de estudo e a predação por mesopredadores foi a principal causa de falhas nos ninhos. Nossa principal conclusão é que a baixa sobrevivência dos ninhos decorrente da ação dos mesopredadores podem estar entre as causas do declínio das populações de aves no CEP e esses assuntos devem estar no escopo de futuros planos de manejo conservacionista visando minimizar o número sem precedentes de extinções de aves em curso neste importante local. A sobrevivência de um número crescente de espécies de aves ameaçadas de extinção em todo o mundo tem dependido do manejo de predadores de ninhos (Vanderwerf & Smith 2002, Jansen 2005), e a identificação da composição da comunidade de predadores de ninhos nos fragmentos CEP forneceu os primeiros insights sobre as espécies animais que devem ser monitoradas e, se necessário, controladas, como forma de melhorar os aspectos demográficos das espécies de aves endêmicas mais ameaçadas do CEP.

Embora não tenhamos detectado espécies de fungos que possam se assemelhar aos filhotes de flautim em nossa área de estudo, o mimetismo do fungo é uma explicação plausível para a evolução do padrão de plumagem dos filhotes de flautim

(Londoño et al. 2022). Contudo, com base nas nossas observações, sugerimos que a hipótese de camuflagem disruptiva também não deve ser descartada. Nesta estratégia, os organismos desenvolvem características que lhes conferem uma forma irreal, tornando-se menos propensos a serem identificados se detectados por um potencial predador visualmente orientado (Mulder et al. 2021). É difícil confirmar se as características da plumagem e o comportamento imóvel do flautim serviram apenas para esconder a real forma dos filhotes, ou se também evoluiu para simular outros tipos de lagartas menos aposemáticas que a lagarta Megalopygidae imitada por *Laniocera hypopyrra* (ver Londoño et al. 2022). É inegável que, quando fotografados de cima e individualmente, os filhotes do flautim-de-asa-marrom se assemelhavam muito a uma lagarta tóxica. Apesar do número limitado de ninhos encontrados para as espécies desses gêneros de aves intimamente relacionados, as camuflagens dos filhotes reveladas para os Tytiridae são de grande interesse para a biologia evolutiva, e futuros trabalhos experimentais poderão contribuir para elucidar suas funções dentro do gênero *Schiffornis*.

Pelo menos três espécies de *Hemitriccus* são especialistas em bambu (*H. flammulatus*, *H. obsoletus* e *H. diops*). A espécie que estudamos não é especialista em bambu, e os bambus eram raros em nossas áreas de estudo durante o período do nosso trabalho de campo. Porém, um dos ninhos que encontramos estava próximo a um aglomerado de bambu de espécies não identificadas, e folhas de bambu foram amplamente utilizadas na construção deste ninho. Embora a colocação dos ninhos perto dos bambus possa ter ocorrido apenas por acaso, também pode ter resultado de efeitos comportamentais filogenéticos, ou seja, aspectos comportamentais herdados de ancestrais especialistas em bambu. Resta confirmar se este e outros *Hemitriccus* poderiam selecionar locais de nidificação com bambu quando disponível, mesmo para aqueles que não são considerados especialistas em bambu. Ainda faltam informações reprodutivas para muitas espécies de aves neotropicais, e *Hemitriccus* é um dos gêneros menos conhecidos. As características dos ninhos têm sido consideradas importantes para elucidar os aspectos taxonômicos deste grupo, e algumas das espécies e subespécies estão ameaçadas. Então, os ornitólogos deverão continuar investigando os parâmetros reprodutivos de *Hemitriccus* e sua relevância para fins taxonômicos e de conservação.

Como observamos duas sessões de exibição desde o início, sendo a primeira delas culminando na cópula, estamos confiantes de que capturamos todas as etapas da exibição do cortejo do rabo-branco-rubro. Para muitas espécies e gêneros de beija-flores, as exibições de cortejo envolvem longos mergulhos e voos de ida e volta pelo céu, cobrindo áreas de dezenas de metros (Clark 2009). As exibições do rabo-branco-rubro, entretanto, ocorreram muito próximo da fêmea, em um espaço bastante limitado, o que pode ser uma adaptação ao ambiente de sub-bosque florestal, onde a visibilidade atinge apenas alguns metros. Embora a análise da diversidade e evolução das exibições de cortejo do beija-flor vá além do escopo deste manuscrito, até onde sabemos, este é o primeiro registro da exibição completa do cortejo de um colibri eremita e é uma das performances mais marcantes já registradas para um pássaro. Mobbs (1971), após observar os comportamentos de corte de várias espécies de beija-flores em cativeiro, mencionou: “a exibição do macho Rabo-branco-rubro realmente tem que ser vista para se acreditar”. Embora os comportamentos de lek tenham sido minuciosamente descritos para muitas espécies de beija-flores, as exibições de cortejo são comportamentos secretos e pontuais que são difíceis de serem capturados, e muito ainda precisa ser aprendido sobre esse assunto. Como esse comportamento é certamente altamente dispendioso energeticamente, nossas descobertas forneceram mais evidências da importância do desempenho energético na seleção sexual dos beija-flores.

REFERÊNCIAS BIBLIOGRÁFICAS

ALMEIDA, A. M.; SOUZA, A. F. Northern Atlantic Forest: Conservation Status and Perspectives. In: FILHO, G. A. P.; FRANÇA, F. G. P.; ALVES, R. R. N.; VASCONCELLOS, A. Animal Biodiversity and Conservation in Brazil’s Northern Atlantic Forest. Springer, p. 7–22, 2023.

ARAUJO, H. F. P. *et al*. Bird Diversity and Conservation of the Northern Atlantic Forest. In: FILHO, G. A. P.; FRANÇA, F. G. P.; ALVES, R. R. N.; VASCONCELLOS, A. Animal Biodiversity and Conservation in Brazil’s Northern Atlantic Forest. Springer, p. 185–200, 2023.

BANKS-LEITE, C.; EWERS, R. M.; METZGER, J. Edge effects as the principal cause of area effects on birds in fragmented secondary forest. Oikos, v. 119, n. 6, p. 918–926, 2010.

BARLOW, J. *et al*. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proceedings of the National Academy of Sciences, v. 104, n. 47, p. 18555–18560, 2007.

BECA, G. *et al*. High mammal species turnover in forest patches immersed in biofuel plantations. Biological Conservation, v. 210, p. 352–359, 2017.

BOCALINI, F. *et al*. Comparative phylogeographic and demographic analyses reveal a congruent pattern of sister relationships between bird populations of the northern and south-central Atlantic Forest. Molecular Phylogenetics and Evolution, v. 154, p. 106973, 2021.

BRITO, M. R. M. *et al*. Butterflies on the dry edge of the Atlantic Forest: water availability determines community structure at the Northern limit of Atlantic Forest. Insect Conservation and Diversity, v. 14, n. 4, p. 476–491, 2021.

BUCHANAN, G. M.; DONALD, P. F.; BUTCHART, S. H. M. Identifying priority areas for conservation: a global assessment for forest-dependent birds. PloS One, v. 6, n. 12, p. e29080, 2011.

CARVALHO, C. S. *et al*. Environmental heterogeneity and sampling relevance areas in an Atlantic forest endemism region. Perspectives in Ecology and Conservation, v. 19, n. 3, p. 311–318, 2021.

COELHO, M. T. P. *et al*. The effects of landscape structure on functional groups of Atlantic forest birds. The Wilson Journal of Ornithology, v. 128, n. 3, p. 520–534, 2016.

CROOKS, K. R. *et al*. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. Proceedings of the National Academy of Sciences, v. 114, n. 29, p. 7635–7640, 2017.

D’ANUNCIAÇÃO, P. E. R. *et al*. Forest fragments surrounded by sugar cane are more inhospitable to terrestrial amphibian abundance than fragments surrounded by pasture. International Journal of Ecology, v. 2013, 2013.

DEBINSKI, D. M.; HOLT, R. D. A survey and overview of habitat fragmentation experiments. Conservation Biology, v. 14, n. 2, p. 342–355, 2000.

DEGTEVA, S. V *et al*. Striking the balance: Challenges and perspectives for the protected areas network in northeastern European Russia. Ambio, v. 44, p. 473–490, 2015.

DEVELEY, P. F.; PHALAN, B. T. Bird extinctions in Brazil’s Atlantic Forest and how they can be prevented. Frontiers in Ecology and Evolution, v. 9, p. 624587, 2021.

DONALD, P. F. *et al*. Important Bird and Biodiversity Areas (IBAs): the development and characteristics of a global inventory of key sites for biodiversity. Bird Conservation International, v. 29, n. 2, p. 177–198, 2019.

DOVER, C. L. Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: a review. Marine Environmental Research, v. 102, p. 59–72, 2014.

DOYLE, M. W. *et al*. Dam removal: physical, biological, and societal considerations. In: HOTCHKISS, R. H.; GLADE, M. Building Partnerships. Proceedings of the 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, p. 1–10, 2000.

FAHRIG, L. How much habitat is enough? Biological Conservation, v. 100, n. 1, p. 65–74, 2001.

FEIJÓ, A. *et al*. Mammals of the Pernambuco Endemism Center: Diversity, Biogeography, Research Gaps, and Conservation Concerns. In: FILHO, G. A. P.; FRANÇA, F. G. P.; ALVES, R. R. N.; VASCONCELLOS, A. Animal Biodiversity and Conservation in Brazil’s Northern Atlantic Forest. Springer, p. 201–228, 2023.

FIGUEIREDO, M. S. L. *et al*. Tetrapod diversity in the Atlantic Forest: maps and gaps. In: MARQUES, M. C. M.; GRELLE, C. E. V. The Atlantic Forest: History, Biodiversity, Threats and Opportunities of the Mega-diverse Forest, p. 185–204, 2021.

FRANCISCO, M. R. *et al*. Recovered after an extreme bottleneck and saved by ex situ management: Lessons from the Alagoas curassow (*Pauxi mitu* [Linnaeus, 1766]; Aves, Galliformes, Cracidae). Zoo Biology, v. 40, n. 1, p. 76–78, 2021.

GALETTI, M. *et al*. Causes and consequences of large-scale defaunation in the Atlantic Forest. In: MARQUES, M. C. M.; GRELLE, C. E. V. The Atlantic Forest: History, Biodiversity, Threats and Opportunities of the Mega-diverse Forest, p. 297–324, 2021.

GARBINO, G. S. T. *et al*. Reconsidering mammal extinctions in the Pernambuco endemism center of the Brazilian Atlantic Forest. Animal Biodiversity and Conservation, v. 41, n. 1, p. 175–184, 2018.

GIBSON, L. *et al*. Primary forests are irreplaceable for sustaining tropical biodiversity. Nature, v. 478, n. 7369, p. 378–381, 2011.

HANSBAUER, M. M. *et al*. Movements of neotropical understory passerines affected by anthropogenic forest edges in the Brazilian Atlantic rainforest. Biological Conservation, v. 141, n. 3, p. 782–791, 2008.

HILTY, J. A. *et al*. Corridor ecology: linking landscapes for biodiversity conservation and climate adaptation. Island Press, p. 351, 2019.

ICMBIO. Livro Vermelho da Fauna Brasileira Ameaçada De Extinção: Volume I. Brasília: Ministério do Meio Ambiente, 2018a.

ICMBIO. Livro Vermelho da Fauna Brasileira Ameaçada De Extinção: volume III – Aves. Brasília: Ministério do Meio Ambiente, 2018b.

IUCN. The IUCN Red List of Threatened Species. Version 2022-2. 2022.

JOLY, C. A.; METZGER, J. P.; TABARELLI, M. Experiences from the Brazilian Atlantic Forest: ecological findings and conservation initiatives. New phytologist, v. 204, n. 3, p. 459–473, 2014.

KEELEY, A. T. H. *et al*. New concepts, models, and assessments of climate-wise connectivity. Environmental Research Letters, v. 13, n. 7, p. 073002, 2018.

KETTLE, A. J.; HAINES, K. How does the European eel (*Anguilla anguilla*) retain its population structure during its larval migration across the North Atlantic Ocean? Canadian Journal of Fisheries and Aquatic Sciences, v. 63, n. 1, p. 90–106, 2006.

KEYGHOBADI, N. The genetic implications of habitat fragmentation for animals. Canadian Journal of Zoology, v. 85, n. 10, p. 1049–1064, 2007.

LADONINA, N. N. *et al*. Managing Agricultural Resources fo Biodiversity Conservation-Case Study of Russia and CIS countries. Final Draft, p. 19, 2001.

MUYLAERT, R. L. *et al*. Uma nota sobre os limites territoriais da Mata Atlântica. Oecologia Australis, v. 22, n. 3, 2018.

LAURANCE, W. F. Conserving the hottest of the hotspots. Biological Conservation, v. 142, n. 6, p. 1137, 2009.

LIMA, R. A. F. *et al*. The erosion of biodiversity and biomass in the Atlantic Forest biodiversity hotspot. Nature Communications, v. 11, n. 1, p. 6347, 2020.

LINS-E-SILVA, A. C. B.; FERREIRA, P. S. M.; RODAL, M. J. N. The north-eastern Atlantic Forest: biogeographical, historical, and current aspects in the sugarcane zone. In: MARQUES, M. C. M.; GRELLE, C. E. V. The Atlantic Forest: History, Biodiversity, Threats and Opportunities of the Mega-diverse Forest of the Mega-diverse Forest, p. 45–61, 2021.

MARTENSEN, A. C.; PIMENTEL, R. G.; METZGER, J. P. Relative effects of fragment size and connectivity on bird community in the Atlantic Rain Forest: implications for conservation. Biological Conservation, v. 141, n. 9, p. 2184–2192, 2008.

MARTINELLI, G.; MORAES, M. A. Livro vermelho da flora do Brasil. Rio de Janeiro: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, p. 1100, 2013.

PONTES, A. R. M. *et al*. Mass extinction and the disappearance of unknown mammal species: scenario and perspectives of a biodiversity hotspot's hotspot. PLoS One, v. 11, n. 5, p. e0150887, 2016.

MENON, S. *et al*. Identifying conservation-priority areas in the tropics: a land-use change modeling approach. Conservation Biology, v. 15, n. 2, p. 501–512, 2001.

METZGER, J. P. *et al*. Time-lag in biological responses to landscape changes in a highly dynamic Atlantic Forest region. Biological Conservation, v. 142, n. 6, p. 1166–1177, 2009.

MMA. Portaria MMA no 148, de 7 de junho de 2022. Altera os Anexos da Portaria no 443, de 17 de dezembro de 2014, da Portaria no 444, de 17 de dezembro de 2014, e da Portaria no 445, de 17 de dezembro de 2014, referentes à atualização da Lista Nacional de Espécies Ameaçadas de Extinção. Brasília: Ministério do Meio Ambiente, 2022.

MYERS, N. *et al*. Biodiversity hotspots for conservation priorities. Nature, v. 403, n. 6772, p. 853–858, 2000.

PEREIRA, G. A. *et al*. Status of the globally threatened forest birds of northeast Brazil. Papéis Avulsos de Zoologia, v. 54, p. 177–194, 2014.

PEREIRA, G. A.; ARAÚJO, H. F. P.; AZEVEDO-JÚNIOR, S. M. Distribution and conservation of three important bird groups of the Atlantic Forest in north-east Brazil. Brazilian Journal of Biology, v. 76, p. 1004–1020, 2016.

PFEIFER, M. *et al*. Creation of forest edges has a global impact on forest vertebrates. Nature, v. 551, n. 7679, p. 187–191, 2017.

PIAO, S. *et al*. Characteristics, drivers and feedbacks of global greening. Nature Reviews Earth & Environment, v. 1, n. 1, p. 14–27, 2020.

PONTES, A. R. M.; BELTRÃO, A. C. M.; SANTOS, A. M. M. Reconsidering mammal extinctions in the Pernambuco Endemism Center of the Brazilian Atlantic Forest: a critique. Animal Biodiversity Conservation, v. 42, n. 1, p. 69–77, 2019.

REED, D. H. Extinction risk in fragmented habitats. Animal Conservation Forum, v. 7, n. 2, p. 181-191, 2004.

REZENDE, C. L. *et al*. From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. Perspectives in Ecology and Conservation, v. 16, n. 4, p. 208–214, 2018.

RIBEIRO, M. C. *et al*. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation, v. 142, n. 6, p. 1141–1153, 2009.

RIBEIRO, M. C. *et al*. The Brazilian Atlantic Forest: a shrinking biodiversity hotspot. In: ZACHOS, F. E.; HABEL, J. C. Biodiversity hotspots: distribution and protection of conservation priority areas. Springer, p. 405–434, 2011.

ROSA, M. R. *et al*. Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs. Science Advances, v. 7, n. 4, p. eabc4547, 2021.

SANTOS-COSTA, A. *et al*. Ecological outcomes of Atlantic Forest restoration initiatives by sugar cane producers. Land Use Policy, v. 52, p. 345–352, 2016.

SCARANO, F. R.; CEOTTO, P. Brazilian Atlantic Forest: impact, vulnerability, and adaptation to climate change. Biodiversity and Conservation, v. 24, n. 9, p. 2319–2331, 2015.

SEIDENSTICKER, J. *et al*. Tiger range collapse and recovery at the base of the Himalayas. Biology and Conservation of Wild Felids, v. 12, p. 305–324, 2010.

SERNEELS, S.; LAMBIN, E. F. Impact of land-use changes on the wildebeest migration in the northern part of the Serengeti–Mara ecosystem. Journal of Biogeography, v. 28, n. 3, p. 391–407, 2001.

SILVEIRA, L. F.; OLMOS, F.; LONG, A. J. Birds in Atlantic Forest fragments in north-east Brazil. Cotinga, v. 20, p. 32-46, 2003.

SOLÓRZANO, A.; BRASIL, L. S. C. A.; OLIVEIRA, R. R. The Atlantic Forest Ecological History: From Pre-colonial Times to the Anthropocene. In: MARQUES, M. C. M.; GRELLE, C. E. V. The Atlantic Forest: History, Biodiversity, Threats and Opportunities of the Mega-diverse Forest, p. 25–44, 2021.

STATTERSFIELD, A. J. Endemic bird areas of the world-Priorities for biodiversity conservation. Bird Life International, 1998.

TABARELLI, M.; SIQUEIRA-FILHO, J. A.; SANTOS, A. M. M. Conservação da Floresta Atlântica ao norte do rio São Francisco. In: PÔRTO, K. C.; ALMEIDA-CORTEZ, J. S.; TABARELLI, M. Biodiversidade Biológica e Conservação da Floresta Atlântica ao Norte do Rio São Francisco. Brasília: Ministério do Meio Ambiente, p. 41–48, 2006.

TEWS, J. *et al*. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography, v. 31, n. 1, p. 79–92, 2004.

UEZU, A.; METZGER, J. P. Vanishing bird species in the Atlantic Forest: relative importance of landscape configuration, forest structure and species characteristics. Biodiversity and Conservation, v. 20, p. 3627–3643, 2011.

VALE, M. M. *et al*. Endemic birds of the Atlantic Forest: traits, conservation status, and patterns of biodiversity. Journal of Field Ornithology, v. 89, n. 3, p. 193–206, 2018.

WATLING, J. I. *et al*. Meta-analysis reveals the importance of matrix composition for animals in fragmented habitat. Global Ecology and Biogeography, v. 20, n. 2, p. 209-217, 2011.

WEGE, D. C.; LONG, A. J. Key areas for threatened bird in the neotropics. BirdLife International, 1995.

ZACHOS, F. E.; HABEL, J. C. Biodiversity hotspots: distribution and protection of conservation priority areas. Springer Science & Business Media, 2011.

ZANETTE, L.; DOYLE, P.; TRÉMONT, S. M. Food shortage in small fragments: evidence from an area-sensitive passerine. Ecology, v. 81, n. 6, p. 1654–1666, 2000.

ZHANG, H. *et al*. Status and conservation strategy of Giant Panda habitat in Qinling tunnel area of 108 national road. Journal of Shaanxi Normal University, v. 35, p. 116–119, 2007.

ZHU, Z. *et al*. Greening of the Earth and its drivers. Nature Climate Change, v. 6, n. 8, p. 791–795, 2016.