

THE RESILIENCE OF BIRD SPECIES IN A BRAZILIAN ATLANTIC FOREST REMNANT IN THE FACE OF ACCELERATED EXTINCTIONS IN THE NEOTROPICS

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ABSTRACT

The Caetetus Ecological Station is located in south-eastern Brazil. It is a unique protected area given it was set aside for preservation in the early 1930s, when all surrounding forests were clear-cut. Because the birds of this area have been inventoried on a number of occasions since the late 1970s, Caetetus represents a singular case study to evaluate how the bird communities have changed over time in a relatively small (2,178-ha) but intact site. We searched the literature, ornithological platforms data and included our unpublished surveys to compile ornithological records. From the 184 species initially reported, all but two appear to be still present. Unlike other well-studied forest fragments in the Neotropics, where between 10–27 per cent of all forest bird species are suggested to have become locally extinct, Caetetus stands out as a notable exception. We suggest that, based on all available evidence for other similar forests, Caetetus' long-standing undisturbed status could be the main driver for this persistence of species. However, it is uncertain how bird species will be affected by fragmentation and species relaxation in the long term, and how they will respond to climate change. The ability to access citizen science records on public databases makes current and future tracking of species persistence much easier and more comprehensive.

Keywords: avian communities, Caetetus Ecological Station, historical records, literature review, ornithological platforms, seasonal semideciduous forests.

INTRODUCTION

After the Amazon, the Atlantic Forest is the second largest tropical forest in South America, covering parts of Argentina, Paraguay and Brazil. It once occupied approximately 13 per cent of the Brazilian territory (Vancine et al., 2024). It is among the most threatened worldwide hotspots for biodiversity (Myers et al., 2000) and is home to thousands of endemic plant and vertebrate species (Figueiredo et al., 2021; da Silva & Casteleti, 2003). Currently, only 22.9 per cent (37,327 Mha) of its original vegetation cover remains, 97 per cent of which consists of highly disturbed, isolated forest remnants smaller than 50 ha (Vancine et al., 2024). The remaining Atlantic Forest cover is mainly composed of small secondary forest fragments with low

connectivity inserted within agricultural landscapes, vulnerable to edge effects and specific anthropogenic disturbances, such as selective logging, livestock trampling and pesticides (Vancine et al., 2024). As a result, forest fragments have since undergone ecological changes resulting from their partial or full protection, as shown by medium and long-term studies in the region, monitored in the last 10–20 years (Souza et al., 2020).

Fragmentation reconfigures the landscape affecting species distribution and movement patterns of wildlife. Within the remaining fragments, overharvesting threatens mainly medium and large-sized species across all trophic levels, reducing their populations (Benítez-López et al., 2017). The conversion of large areas of habitat into a number of small patches affects the distribution and

abundance of species in the landscape, with negative effects on most species, while habitat loss leads to changes in landscape configuration, such as size, shape and degree of isolation of habitat patches (Ewers & Didham, 2005).

Despite the attention given to birds worldwide, 1,445 or 13 per cent of the 11,162 bird species are threatened with extinction, with threats from agriculture, climate change, selective logging, and hunting and trapping affecting the largest number of bird species (IUCN, 2023). These threats often interact synergistically. Agricultural expansion, for example, is accompanied by degradation of the remaining habitat, and the increased accessibility of habitat remnants permits consumptive usage of birds for bushmeat and the wildlife trade (Symes et al., 2018). In previous studies, in a myriad of landscapes of the Atlantic Forest, researchers studied bird communities in severely fragmented scenarios and have provided important results on the responses of bird communities to habitat fragmentation (e.g. Aleixo & Vielliard, 1995; Donatelli et al., 2004; Pizo & Tonetti, 2020; Willis, 1979; Willis & Oniki, 1981). Frequently, their results suggest the effect of patch size, shape and isolation, as well as broader landscape features (matrix composition, connectivity and vegetation cover) are the main drivers of the loss and reduced distribution of bird species (Pizo & Tonetti, 2020).

Because internally modified habitats might not demonstrate the natural responses of bird communities to large-scale landscape fragmentation, several researchers focused their studies on protected areas, assigning them as control areas, on the assumption that they represent preserved habitats. This assumption is true for the continuous forests protected by the Serra do Mar State Park (300,000 ha) in São Paulo state, for example. However, protected areas further west of these vegetation blocks were delineated 40 years ago when they constituted some of the few remaining forests, following extensive deforestation in inland São Paulo during the 19th century for coffee plantations. Consequently, despite their protected status, these areas have lost some forest species and cannot function as control areas (Cavarzere et al., 2023).

Like taxonomic studies, inventories have been largely, but incorrectly, disregarded by scientists due to the fact that they are not hypothesis-driven studies. Monitoring of bird communities from Brazilian protected areas has been limited, resulting in few assessments of the patterns of bird communities over time (e.g. Cavarzere et al., 2023). However, inventories are needed more than ever, as they are the base upon which studies provide large datasets (e.g. Hasui et al., 2018) indicating large-scale ecological responses.

In this study, we wished to compile, organise and evaluate ornithological data produced over a period of about 50 years in a relatively small patch of Seasonal Semi-deciduous Forest that was never clear-cut and remains mostly without anthropic modifications. Its birds were first censused in the late 1970s, and surveys and inventories have been carried out at least once in every decade since then. We hypothesised that this site may demonstrate a lower loss of forest bird species when compared to larger areas of continuous seasonal semi-deciduous old growth forests that have been subjected to clear-cutting or anthropogenic modification. In addition to testing this hypothesis, we wished to compile all information sources to create a solid avian database to be used as a reference upon which future studies can compare their results.

MATERIAL AND METHODS

Study area

Caetetus Ecological Station (hereafter Caetetus) is a 2,178-ha remnant of Seasonal Semi-deciduous Forest, which once covered almost the entire interior of São Paulo state in south-eastern Brazil (Figure 1). Because 7 per cent of Interior Atlantic Seasonal Forests remain, and only 6.8 per cent of these remnants are protected (0.8 per cent of the original cover), they represent the most threatened Atlantic Forest vegetation type in southern Brazil (Carlucci et al., 2021). This forest type occupies the interior plateaus of São Paulo and is characterised by the loss of leaves of 20–50 per cent of all individual trees during the driest months of the year. It is among the most diverse habitats of the Atlantic Forest (da Silva & Casteleti, 2003).

Caetetus was deliberately left standing from 1931 onwards, while the remaining forested areas around it were clear-cut and destined for coffee plantations. This forest had never been subjected to selective logging and was intentionally preserved by its owner. While there have been instances of fires and cattle encroachment along its borders, these events occurred more recently. The man who ordered the pristine forest to be left in this area that contains many springs was Olavo Amaral Ferraz, then owner of the Paraíso Farm. Initially this preservation was to maintain his hunting activities, but he later began protecting the animals, even feeding them during the driest months. Worried about the fate of his forest reserve after his death, he asked the Government of the state of São Paulo to create a protected area, which materialised after 12 years, in 1976 (Tabanez et al., 2005). Thus, although border effects, erosion and pollution of the Peixe River and illegal hunting pose threats to Caetetus, it is one of the few remnants that most closely represent the pristine forests that covered western São Paulo (Figure 1).

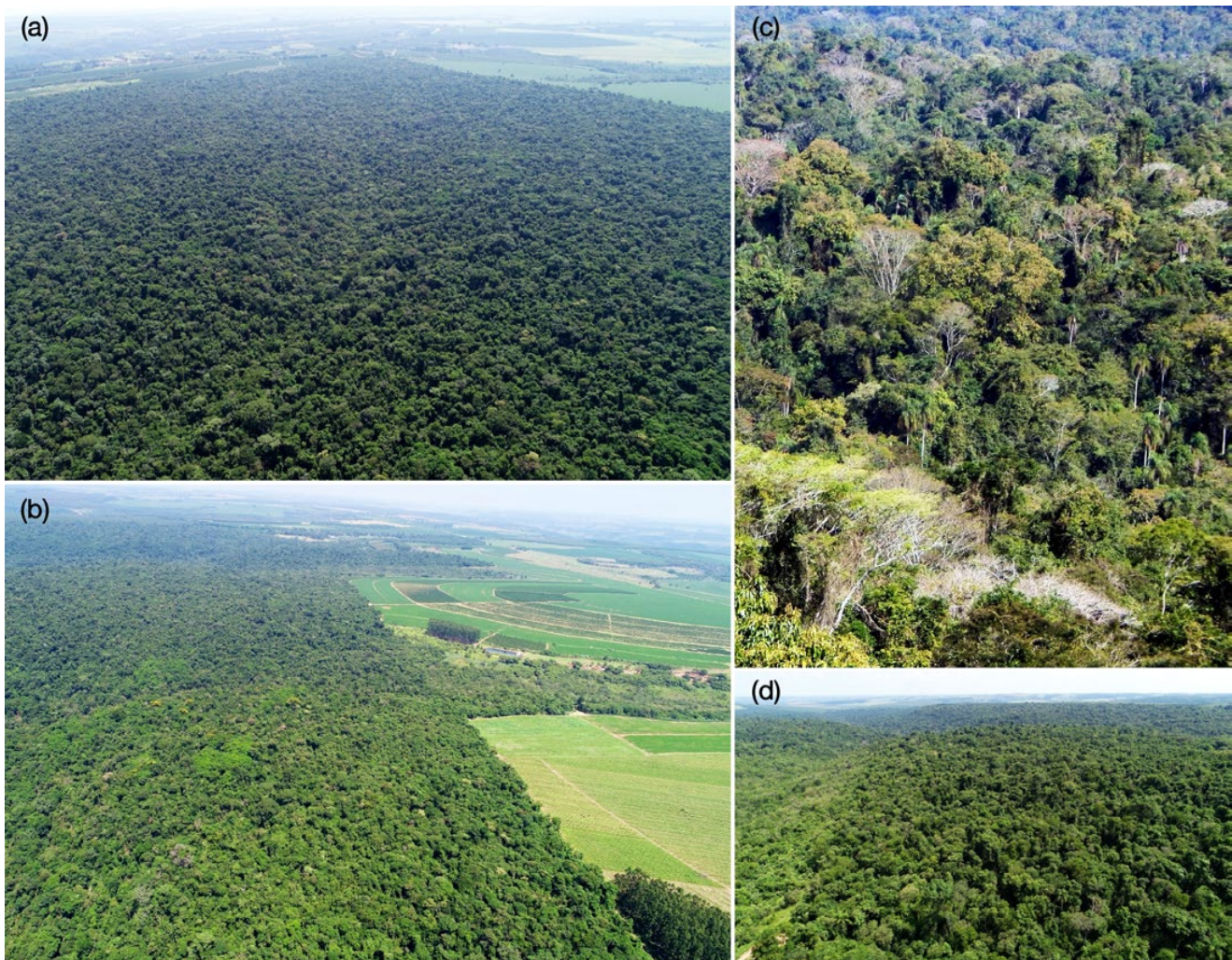


Figure 1. Representations of the vegetation at Caetetus Ecological Station in south-eastern Brazil: (a) aerial view of the fragment, (b) a corridor with a neighbouring private forest, (c) view of the preserved forest and (d) tree height comparison between the preserved forest to the right as opposed to the border and neighbouring private forest to the left. Images from the collection of the Fundação Florestal.

Most of the Caetetus borders onto cleared land, primarily coffee plantations and pastures for cattle (Tabanez et al., 2005). Therefore, the protected area is largely isolated from natural habitat, though a few contiguous remnants add another 1,000 ha to the total forest area (Figure 2). The mean annual temperature is 21.5 °C, with June as the coldest and January and February as the hottest months (16.5–24.7 °C), and the mean annual precipitation is 1,431 mm (21–251 mm), with July as the driest and January as the rainiest months (Tabanez et al., 2005).

Unpublished field data

Two methods were used. Birds were mist-netted (10 m x 3 m x 20 mm) in irregular intervals from 2006 to 2023, when 10 net lines were kept open for approximately 12 h each day for one or two days at a given month. Individuals were identified and then released. Nets were checked every hour, or earlier, if weather conditions were inclement. Species were also censused using lists of 10 species, in which 10 species are recorded in sequence,

without repetition of species per list, while observers walked along transects (MacKinnon & Phillipps, 1993). Species already detected can only be recorded again in subsequent lists. Sampling effort is given as the number of accumulated lists. We started observations about 15 min before sunrise, and birds were visually identified with binoculars and aurally. Inventories were carried out from 2006 to 2023 (Supplementary Online Material 2).

Secondary data

Literature review

Avian publications based on Caetetus were searched on Doaj (<https://doaj.org/>), Google Scholar (<https://scholar.google.com/>), Jstor (<https://www.jstor.org/>), Scopus (<https://www.scopus.com/home.uri>), Scielo (<https://scielo.org/pt/>) and Web of Science (<https://www.webofscience.com/wos/>) using the following Boolean operators and combinations of keywords: bird* OR avian* OR ornithol*, as well as their Portuguese counterparts ave* OR avian* OR ornitol*, AND Caetetus.

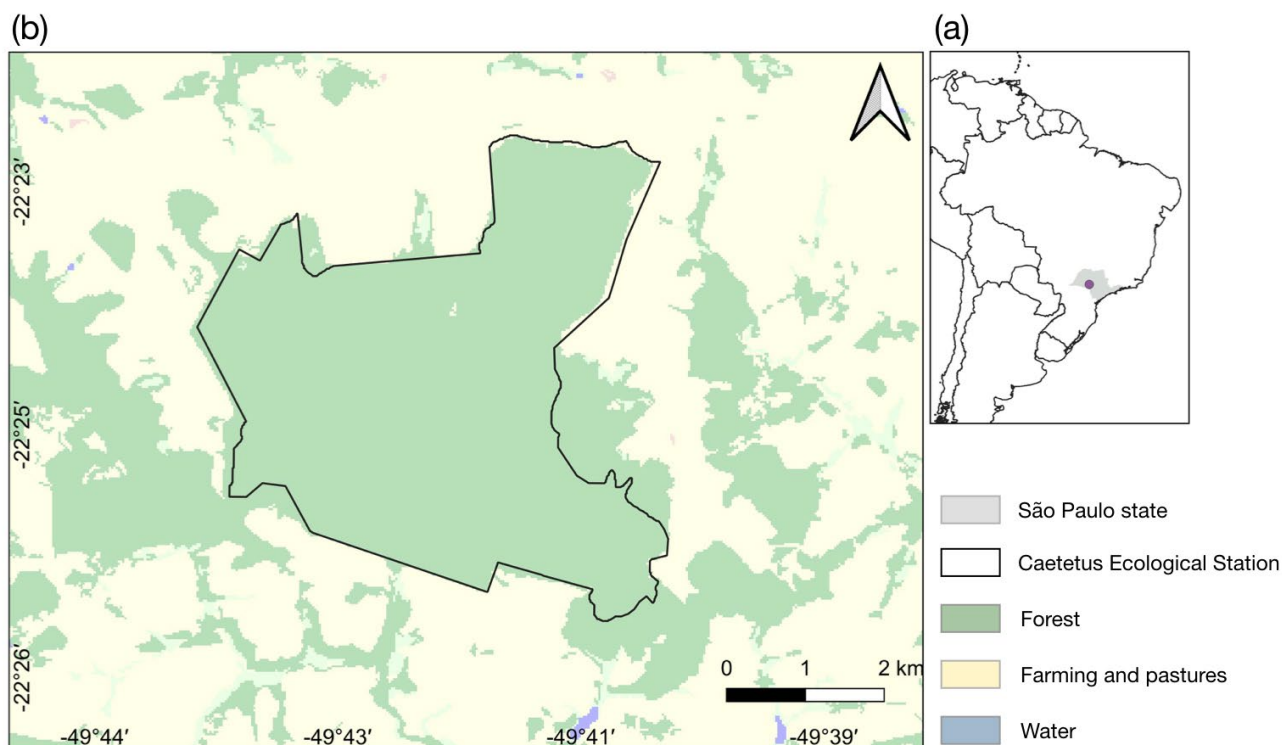


Figure 1. São Paulo state, south-eastern Brazil, within South America (a) and Caetetus Ecological Station and landscape use in its surroundings (b).

In Google Scholar the first 10 pages of results were considered. This review, conducted until 31 December 2023, resulted in 23 papers, one book and one book chapter (Supplementary Online Material 1). The Global Biodiversity Information Facility (GBIF; <https://www.gbif.org/>) and the Sistema de Informação sobre a Biodiversidade Brasileira (SiBBR; <https://www.sibbr.gov.br/>) were consulted but contained no Caetetus bird records.

Ornithological platforms

Records of bird species deposited in the online ornithological platforms eBird (<https://ebird.org/>) – both lists and media files under Caetetus (259 species in 443 observations), iNaturalist (<https://www.inaturalist.org/>) – under Caetetus (four species in four observations), WikiAves (WA), under observation area ‘Estação Ecológica dos Caetetus’, (<https://www.wikiaves.com.br/especies.php?&t=ao&ao=781>) (173 species in the same number of documented records) and xeno-canto (<https://xeno-canto.org/>) – under Gália (seven species and seven observations) – were considered until 31 December 2023. The list produced by the members of the Centro de Estudos Ornitológicos (CEO), an NGO that inventories birds within São Paulo, was also consulted (<https://ceo.org.br/avifaunaestado/avifest.htm>). Only species recorded within and in the immediate surroundings of Caetetus were considered. The WikiAves record of the Palm Tanager *Thraupis palmarum* (WA3464587 and WA3464652) was discarded as a misidentification.

Analyses

Species records were critically evaluated and categorised according to the presence of documented evidence (specimen, photograph, audio or video recording), which produced a primary list. Species from the literature that lack documentation but are likely to occur in Caetetus based on distribution were included in a secondary list. Published records of species whose documental evidence is invalid or whose distribution falls outside the Caetetus region and requires further documentation were included in the tertiary list. To assess how species accumulated over time we constructed a collector curve based on the number of species as a function of the years.

The sequence of species and taxonomic arrangements followed the Brazilian Ornithological Records Committee (Pacheco et al., 2021). The 1976 census was the baseline against which all subsequent records were compared (Willis & Oniki, 1981).

We also checked whether records were made within the Ecological Station, or from the surroundings. Species that were unequivocally detected within a 100 m buffer from the borders of the station were considered as probable residents of Caetetus. Species that inhabit environments which are not represented within the station, such as Cerrado vegetation, were excluded from all analyses. This was the case of the Pearly-vented Tody-tyrant *Hemitriccus margaritaceiventer*. Relevant taxonomic arrangements are mentioned in Supplementary Online Material 2.

RESULTS

Overall, from 1976–2023 (47 years), 346 bird species were recorded from Caetetus (Supplementary Online Material 2). Most records came from traditional researchers. By 1996, 12 species already recorded were mentioned in eBird. It was only in 2016 when both eBird and WikiAves accounted for 42 species which were filed as observed before (Figure 3). The primary list accounted for 183 (53 per cent) species, while another 133 (38 per cent) undocumented species were included in the secondary list; the remaining 30 (9 per cent) species were entered on the tertiary list (Supplementary Online Material 3).

Four species were detected only once in the 1970s, and never recorded again. These are the Rusty-breasted Nunlet *Nonnula rubecula*, the Saffron Toucanet *Pteroglossus bailloni*, the Chilean Elaenia *Elaenia chilensis* and the Tawny-headed Swallow *Alopochelidon fucata* (Supplementary Online Material 3).

DISCUSSION

We considered three possible explanations for the high persistence rates for bird species in Caetetus: habitat quality and disturbance; landscape connectivity and fragmentation; and history of clear-cutting.

Habitat quality and disturbance

One factor is that Caetetus represents a singular well-preserved environment for forest bird species when compared to protected areas that were delimited after the clear-cutting of the inland forests. Such areas are somewhat depauperate in habitat-specialist bird species, especially due to, among other reasons, habitat modification (Aleixo & Vielliard, 1995; Cavarzere et al., 2023; Ribon et al., 2003; Willis, 1979). This is particularly problematic in fragmented landscapes, where only a subset of tree species may survive, compromising the sustainability of regenerated forests in the long term (de Souza & Batista, 2004), consequently altering the dynamics of bird communities.

For example, a 1,400-ha semi-deciduous forest remnant some 115 km to the south-east has a similar history to Caetetus and has been monitored since the 1950s (Magalhães, 1999). However, being privately owned, it seems more susceptible to external hazards, such as arson fires, logging and hunting. There, the forest cover is quite degraded, with an irregular canopy and a large abundance of lianas, mainly along the edges and clearings. Selective logging up to 200 m into the fragment occurred in the 1990s along the northern edge (Antunes, 2005). As a result, it has lost almost 10 per cent of all forest species over the last 40 years

(Antunes, 2005). Public protected areas within the Atlantic Forest domain may also suffer from edge effects and disturbances, and the loss of forest bird species has been strongly suggested in protected areas in interior São Paulo (Aleixo & Vielliard, 1995; Antunes, 2005; Cavarzere et al., 2023).

Landscape connectivity

We also considered the issues of matrix quality, which is fundamentally relevant to forest birds and their functional connectivity. The best chance for survival of habitat specialists would be expected in a large fragment connected to other forests (Pizo & Tonetti, 2020). For Caetetus this criterion for survival is met.

However, the loss of forest species has been documented in seasonal semi-deciduous forest fragments with similar matrix compositions in the state (Bispo et al., 2012; Cavarzere et al., 2017). It has been suggested that the restoration to approximately 30% of native habitat is needed to preserve the integrity of vertebrate communities within a given landscape (Banks-Leite et al., 2014). The current distribution of seasonal forest fragments does not correspond to this landscape configuration and the loss of forest species seems to be a prevailing pattern in inland forests in São Paulo state (Table 1).

Protected areas in interior São Paulo did not harbour habitat-specialist species even in the 1970s (Willis & Oniki, 1981), and we found few published studies which compared bird communities in the same Semi-deciduous Forests between intervals of several decades. They strongly suggest local extinctions of habitat-specialists (Aleixo & Vielliard, 1995; Antunes, 2005; Cavarzere et

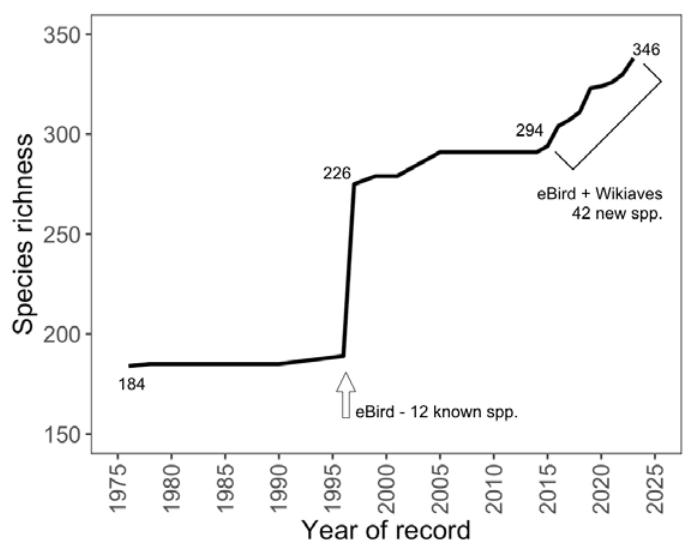


Figure 3. Collector curve indicating how fast the species richness accumulated over the years in Caetetus Ecological Station, south-eastern Brazil.

al., 2017). The only remaining large Semi-deciduous Forest in São Paulo is the Morro do Diabo State Park (> 37,000 ha), which represents what is left of the western forests in the state. However, this forest block does not remain as undisturbed as Caetetus given serious conflicts over landownership and the widespread destruction of its forests for timber and cattle pasture during the last 50 years (Valladares-Padua et al., 2002). In fact, 75 per cent of the entire area burnt in 1968. Some researchers demonstrated that new bird species can be recorded in large, protected areas, such as Morro do Diabo (e.g. Willis & Oniki, 1981), but there is no study comparing that locality regarding the composition of past and current bird communities.

Stage of regeneration

Another fragment (>2,000 ha) with advanced successional stage vegetation found in the municipality of Matão, north-western São Paulo, is known to harbour several Atlantic Forest endemic bird species. Old bird records (from 1905 and 1982) indicate the existence of Atlantic Forest endemics and forest-specialist species in that locality (Willis & Oniki, 2003). In this site, removal of hardwood was reported from the 1960s until 1990, as well as uncontrolled fires have been reported. However, no clear-cutting of vegetation was ever reported (Rozza, 1997).

The age of temperate forests has been suggested to determine species abundance and composition according

to each species' habitat preference (Conner & Dickson, 1997), but this theory has been disputed as a determinant of bird community recovery in Atlantic Forest fragments within a gradient of regeneration stages (Dias et al., 2016). However, ornithologists do not particularly address the issue that, in São Paulo, most forest fragments represent regeneration after previously clear-cuttings (Victor et al., 2005). In the north-eastern Atlantic Forest, forests' recovery after clear-cutting showed a distinct structure that profoundly interfered with bird movements (Faria et al., 2009). A southern Semi-deciduous Atlantic Forest which was previously clear-cut and actively reforested was not able to maintain the bird community comparable to surrounding native forests, though it was connected to source areas for 40 years (Quagliato & Cavarzere, 2021).

Based on the available evidence discussed above, the only exclusive feature of Caetetus is the fact that it was never clear-cut. Thus, we propose the maintenance of Caetetus as a never clear-cut, almost intact forest over 90 years, to be the primary driver of the resilience of forest bird species.

As revealed by other studies which evaluated the contribution of citizen science and ornithological platforms, researchers tend to rapidly accumulate species records in initial years, but citizen scientists greatly contribute to both the number of observations and new species, with increasing

Table 1: Number of recorded species and presumed locally extinct (lost) species in fragmented Seasonal Semi-deciduous Forests. When available, a brief observation regarding the vegetation history is provided. 'Years' refers to the interval between the first and last bird inventories.

Source	Forest name	Forested area (ha)	Recorded species	Lost species	Observation	Years
Antunes (2014)	Santa Carlota	1,400	195	0	Not available	25
This study	Caetetus	2,250	346	2 (0.5 per cent)	Fragmented in 1931; never clear-cut	47
Ribon et al. (2003)	Viçosa region	12,000	221	28 (17 per cent)	Extensively clear-cut in the 1870s	68
Antunes (2005)	Barreiro Rico	1,451	202	20 (10 per cent)	Extensively fragmented in 1956; selective logging until the 1980s; isolated	45
Donatelli et al. (2004)	Mata do Rincão	600	300	20 (6 per cent)	Selective logging until the 1970s; interspersed with Eucalyptus	18
Aleixo & Vielliard (1995)	Santa Genebra	251	248	30 (12 per cent)	Fragmented in 1969, delimited in 1984; isolated	16
Cavarzere et al. (2017)	Ipanema	5,000	410	89 (22 per cent)	Deforestation since the 19th century; isolated	200

observation hours in more recent years (Januário et al., 2023). Caetetus is once again an exception, as traditional researchers have accumulated more information over the years. However, several important recent records have been contributed by citizen scientists who make their verifiable data freely available online and who are more likely to perform continued inventories. Thus, publicly available databases with both researcher and citizen scientist records should enable analyses over time and space to better inform conservation science.

CONCLUSIONS

Caetetus is a unique protected area given its history as a fragment that has never been clear-cut. It also stands out for having a good historic reference of the bird community, which was surveyed in the late 1970s. These exceptional features allowed a comparison with bird inventories conducted over five decades. Comparisons with other forest remnants strongly suggest that being preserved and never clear-cut was a primary factor in the persistence of all but two forest species, a hypothesis that should be considered for future studies. Thus, prioritising protection of long-standing undisturbed areas must be treated as an urgent need. The continued monitoring of the forest birds is necessary, as the outcomes of their relaxation and response to climate change and other threats remain unclear. Due to the high costs of long-term studies and the tendency of traditional researchers to engage in distinct research works, accessing citizen science records in public databases significantly facilitates current and future tracking of species persistence, making it easier and more comprehensive, thus contributing to conservation science.

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SUPPLEMENTARY ONLINE MATERIAL

Supplementary Online Material 1. Studies conducted at the Caetetus Ecological Station, south-eastern Brazil, recovered by the literature review.

Supplementary Online Material 2. Tables for Results and Discussion section.

Supplementary Online Material 3. List of bird species reported from the Caetetus Ecological Station, south-eastern Brazil.

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RESUMEN

La Estación Ecológica de Caetetus está situada en el sudeste de Brasil. Se trata de un área protegida única, ya que se reservó para su conservación a principios de la década de 1930, cuando se talaron todos los bosques circundantes. Dado que las aves de esta zona han sido inventariadas en varias ocasiones desde finales de la década de 1970, Caetetus representa un caso de estudio singular para evaluar cómo las comunidades de aves han cambiado con el tiempo en un sitio relativamente pequeño (2.178 ha) pero intacto. Buscamos en la bibliografía, en los datos de las plataformas ornitológicas e incluimos nuestros estudios inéditos para recopilar los registros ornitológicos. De las 184 especies citadas inicialmente, todas menos dos parecen seguir presentes. A diferencia de otros fragmentos de bosque bien estudiados en el Neotrópico, donde se sugiere que entre el 10 y el 27% de todas las especies de aves forestales se han extinguido localmente, Caetetus destaca como una notable excepción. Sugerimos que, basándonos en todas las pruebas disponibles para otros bosques similares, el hecho de que Caetetus no haya sido perturbado durante mucho tiempo podría ser el principal factor de esta persistencia de especies. Sin embargo, es incierto cómo se verán afectadas las especies de aves por la fragmentación y la relajación de las especies a largo plazo, y cómo responderán al cambio climático. La posibilidad de acceder a los registros de la ciencia ciudadana en bases de datos públicas hace que el seguimiento actual y futuro de la persistencia de las especies sea mucho más fácil y exhaustivo.

RÉSUMÉ

La station écologique de Caetetus est située dans le sud-est du Brésil. Il s'agit d'une zone protégée unique, car elle a été mise en réserve au début des années 1930, lorsque toutes les forêts environnantes ont été coupées à blanc. Comme les oiseaux de cette zone ont été inventoriés à plusieurs reprises depuis la fin des années 1970, Caetetus représente une étude de cas singulière pour évaluer comment les communautés d'oiseaux ont changé au fil du temps dans un site relativement petit (2 178 ha) mais intact. Nous avons consulté la littérature, les données des plates-formes ornithologiques et nous avons inclus nos études non publiées pour compiler les données ornithologiques. Des 184 espèces initialement signalées, toutes sauf deux semblent encore présentes. Contrairement à d'autres fragments de forêt bien étudiés dans la région néotropicale, où entre 10 et 27 % de toutes les espèces d'oiseaux forestiers auraient disparu localement, Caetetus constitue une exception notable. Nous suggérons que, sur la base de toutes les preuves disponibles pour d'autres forêts similaires, le fait que Caetetus soit resté intact depuis longtemps pourrait être le principal moteur de cette persistance des espèces. Cependant, on ne sait pas comment les espèces d'oiseaux seront affectées par la fragmentation et la relaxation des espèces à long terme, ni comment elles réagiront au changement climatique. La possibilité d'accéder aux enregistrements de la science citoyenne dans des bases de données publiques facilite grandement le suivi actuel et futur de la persistance des espèces et le rend plus complet.