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RESEARCH ARTICLE

Studies of Brazilian birds along altitudinal gradients: a critical review

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ABSTRACT. Brazil is home to many mountain ranges which harbor diverse avifauna. However, studies on the altitudinal distribution of Brazilian birds are still few and many have never been published, hampering both the dissemination of basic information and conservation actions. Here we present a critical review of ornithological studies undertaken in Brazilian mountain ranges, and propose a classification of geographic scope, altitudinal gradient, and methodology. Since 1922, 184 ornithological studies included altitude in some way in Brazil, encompassing a variety of research topics and species. About a quarter of these studies were never published in peer-reviewed journals, and 39% do not provide basic data on elevation nor link the bird species with sampling plots, thus limiting their applicability. The majority of studies are concentrated (83%) in southern and southeastern Brazil, especially in the Serra do Mar range, and so most data are associated with the Atlantic Forest. Gaps remain in other regions, such as Amazonia (Pantepui region). Most studies either did not sample the entire elevation gradient, were not standardized, lacked explicit hypothesis, or did not account for a seasonal sampling embracing the four seasons of the year, so interpretation of the observed patterns remains difficult. With this compilation, we organize the available information and point to future altitudinal research on birds, in addition to highlighting the importance of preserving habitats along altitudinal gradients in the mountainous regions in Brazil.

KEY WORDS. Brazil, birds, data base, literature.

INTRODUCTION

Interest in understanding and scientifically explaining the distribution of animals and plants around the world began to take shape in the 18th and 19th centuries, with naturalists Alexander von Humboldt, Charles Darwin, and Alfred Russel Wallace, among many others (von Humboldt 1849, Wallace 1876, 1878, Darwin 1839, 1859). Birds quickly received (and continue to receive) attention because of their conspicuousness and presence on all continents (e.g., Grinnel and Storer 1924, Kikkawa and Williams 1971, Jetz and Rahbek 2001, Kessler 2001). Birds in mountain ranges, such as the Andes, were also interesting because of their relationships with altitude, and were studied by important researchers such as Frank M. Chapman (who described life zones – Chapman 1917, 1921, 1926), Walter Todd and Melbourne Carriker (altitudinal distributions – Todd and Carriker-Jr 1922), John Terborgh (altitudinal species richness patterns – e.g., Terborgh 1971, 1977), and John Blake and Bette Loiselle (community-resource relationships and altitudinal migration – e.g., Blake and Loiselle 1991, 2000, Loiselle and Blake 1991, 1994). Other mountainous regions in South America were also studied, including the Pantepui on the border of Venezuela and Guiana (Mayr and Phelps-Jr 1967), along with other mountain ranges, including those in Brazil (e.g., Paynter-Jr 1982, Stephens and Traylor-Jr 1985, Paynter-Jr and Traylor-Jr 1991a, 1991b).

Studies of birds in montane regions of Brazil began in the early 1800s (Pelzeln 1871, Paynter-Jr and Traylor-Jr 1991a, 1991b, Sick 1997) but the first studies that examined how altitude influenced distributions occurred in 1921–1922, in Itatiaia (in the state of Rio de Janeiro). Ernest G. Holt was sent by Dr. Chapman to classify the avian community by their respective life zones (Holt 1928). Similar studies (birds grouped by altitude) continued in Itatiaia during 1949–1954 by researchers from the Paulista Museum (now the Museum of Zoology of the University of São Paulo, MZUSP), overseen by Olivério Pinto (Pinto 1951, 1954). Again, continuing from 1984–1999, this line of the study included the use of banding (capture and recapture) coordinated by Élio Gouvêa (Gouvêa et al. 1996), and from 1989–2011 by Mallet-Rodrigues et al. (2015).

During the 1980s bird studies in montane regions of Brazil began to be more popular, with inventories to characterize the local fauna and its relation to altitude, as well as focusing on endemic and threatened species (e.g., Willis and Oniki 1981, Scott and Brooke 1985). In the 1990s momentum built and moved from basic lists (e.g., Straube 1990, Marterer 1996) to more varied and more specific studies, with families and genera (e.g., Guix 1997, Mañosa and Pedrocchi 1997), including altitudinal changes in species richness (e.g., Goerck 1999), and species substitutions as altitude changes (e.g., Bencke and Kindel 1999). At this time, data compilations were published that provided details of species occurrence in the mountains of Brazil (Stotz et al. 1996, Sick 1997). In the 2000s more studies were carried out, including natural history (e.g., Buzato et al. 2000, Santos-Neto and Camandaroba 2008) and assemblages (e.g., Fávaro et al. 2006, Rajão and Cerqueira 2006). Continuing through the 2010s, standardized studies of seasonal altitudinal movement patterns became available (e.g., Castro et al. 2012, Hasui et al. 2012), but which was based on very little methodology or theory and were only mentioned superficially (e.g., Andrade and Freitas 1989, Galetti et al. 1997, Machado and Fonseca 2000). At this time, a hypothetical explanation for altitudinal richness patterns was the Mid-Domain Effect (Colwell and Lees 2000), which predicted increased diversity in the middle of altitudinal gradients and was initially examined in Brazil by Cavarzere and Silveira (2012).

Despite the quantity and variety of studies carried out in mountainous regions of Brazil, altitudinal ornithological knowledge has never been compiled, organized, and classified. The lack of a critical review can mislead some to consider that studies about altitudinal movements are scarce or little explored in Brazil. Here we reveal how many and which are ornithological studies already produced in the mountainous regions of Brazil, showing their geographic scope, altitudinal gradients studied, and methodological approaches.

MATERIAL AND METHODS

We begin this compilation by establishing definitions and how studies will be selected and treated (based on McCain 2009). We used two main criteria to include studies: 1) they must have been carried out in regions with large differences in elevations in Brazil, including mountains and mountain ranges, deep canyons, and valleys, and 2) they must have included at least two study sites at very different elevations (in regions with large differences in elevations). The references obtained were separated into two groups of data: 1) primary, composed of sources that inform the altitudes of the studied localities and make the association of the data of the bird species recorded in the field with the respective localities-altitudes, allowing the full and direct use of this information in different altitudinal approaches, and 2) secondary, which do not mention the localities-altitudes or do not assign the data from the localities to the respective species, making it difficult to fully and directly use this information by third parties.

Data compilation

We consulted journals, chapters and books, undergraduate monographs, master and doctoral theses, and presentations from scientific meetings (see references). Search engines included the Web of Science, Scopus, and Google (through May 2022), with the following keywords (in both Portuguese and English): avifauna, birds, diversity, species richness, altitude, elevation, following McCain (2009). We did not include studies that compiled information from others without clearly citing the original source of the data (e.g., Ridgely and Tudor 1989, 1994, Collar et al. 1992, Scherer-Neto and Straube 1995, Stotz et al. 1996, Sick 1997, Bencke et al. 2006, Sigrist 2007, De Luca et al. 2009, Straube et al. 2014, Somenzari et al. 2018). Belton (1984, 1985) and Willis and Oniki (2003) were not included because they were not specific to montane regions. References that only cite the range of altitudinal occurrence of a respective species, as well as random altitudes, were not considered.

The maps were created using the QGis 2.14 program. Studies with several localities had a determined central coordinate, except for references located in conservation units or well-known regions in the national ornithological

scenario. Compilations of data from large regions, such as Vasconcelos and Rodrigues (2010), did not have the areas plotted on the maps. The primary and secondary references were numbered sequentially and plotted separately on the maps, but when a location has both categories, the primary data symbol was prioritized and the secondary reference numbers were highlighted with an asterisk in the respective tables. The altitude cartographic base was extracted from the WorldClim – Global Climate Data digital platform, with 30 seconds of resolution (https://www.worldclim.org – WorldClim 2015). The basis of the Brazilian territory follows the Instituto Brasileiro de Geografia e Estatística (https://www.ibge.gov.br).

Variables

Primary studies provided nine variables:

Altitudinal arrangement of the study areas. For this variable, we used three categories: 1) Continuous local, in which a continuous transect connected the data collecting locations (such as along a trail or road, usually perpendicular to the slope); 2) Regional, with data collecting points not along transect but within the same local area and 3) Wide, at a larger scale than local, but within the same geological formation. Studies that were carried out on an even larger scale were classified in this group if they had at least two data collecting points within the same formation. Due to their wide geographic coverage, type 3 studies did not have the amplitude of the altitudinal gradient and the number of altitudinal ranges classified.

Amplitude of the altitudinal gradient: This variable indicates the proportion of the altitudinal gradient that was studied, and is considered complete or incomplete. Because gradients are typically not studied in their entirety, the complete category included those studies that attempted more than 70% of the slope and include most habitats on the slope. Incomplete includes studies that covered less than 70% of the slope and included the minority of existing habitats. Studies that were over larger ranges in longitude or latitude typically had only one study area in each region, even if each location was at a different elevation. For this variable, these are simply classified as not applicable (NA). This classification was based on the altitudes cited by the studies and compared with the altitudinal range of the respective regions, obtained through the literature and the Google Earth Pro program (https://google-earth-pro.gosur.com/).

Number of altitudinal ranges: This classification was made only for studies performed on local and regional gradients. This variable was used when the study clearly designated different elevations at which data were collected and the number of distinct altitudinal locations was the number of ranges. If the study did not report individual study sites, we considered the value of the variable to be absent (NI, Not Indicated).

Type of study: This variable is based on the dominant theme of the study; 1) Basic species list, such as rapid assessments; 2) Community, in which the data were collected more systematically and which permitted statistical comparisons between communities; 3) Occurrences (e.g., families, groups, genera, species); 4) Biological data; 5) Compilation data; 6) Seasonal altitudinal movements and 7) Natural history.

Hypothesis testing: Studies that presented clear questions and/or proposed to test a respective hypothesis through systematic observations, including standardized quantitative sampling, with data analysis.

Taxonomic level: 1) Communities (all species encountered); 2) groups (species of some families or genera), and 3) Species.

Data collection: The main sampling methods used by each analyzed study were classified: 1) Direct observation; 2) Point counts; 3) MacKinnon lists; 4) transect; 5) mist-net; 6) Trap; 7) collecting and 8) literature.

Standardization: Standardization implies controlling for sampling effort and sampling area. Studies were classified as standardized or not standardized.

Seasonal-temporal coverage: 1) study duration of at least one year and including the four seasons; 2) a year of study, dividing the year into two seasons, dry and wet; 3) one year, but without information on periodicity; 4) more than one year and including all four seasons; 5) less than a year, and systematic (studies with temporally planned field seasons); 6) several years with occasional data collection, without a planned seasonal collecting pattern.

RESULTS

Altitudinal studies of birds

We found 184 studies carried out in Brazil between 1923 and 2022 that fit our requirements. Of these, 140 (76%) were peer-reviewed and 44 (24%) were from gray literature (including books and book chapters). Of the total, 112 (61%) were primary, with 86 (77%) peer-reviewed (scientific articles). The remaining 26 studies (23%) were theses and undergraduate monographs (13, 50%), meeting abstracts (7. 27%), and book and book chapters (6. 23%). Of the 72 secondary

sources, 54 (75%) were peer-reviewed, and 18 (25%) were gray literature (Fig. 1; Supplementary Material – Tables S1–S4). During these 99 years, the number of studies that include altitudinal patterns and birds has increased, especially since the 1980s and 1990s and even more so since the 2000s (Fig. 2).

Geographic coverage

The primary references include records from 13 Brazilian states (Rio Grande do Sul – RS, Santa Catarina – SC, Paraná – PR, São Paulo – SP, Rio de Janeiro – RJ, Minas Gerais – MG, Espírito Santo – ES, Bahia – BA, Piauí – PI, Sergipe – SE, Paraíba – PB, Mato Grosso do Sul – MS, Mato Grosso – MT), and regions include southeastern (77 studies), southern (20), northeastern (10) and western-central (6). Biogeographic Biomes included are the Atlantic Forest (97), Cerrado (20), Caatinga (10) and Pampa (1). The most studied geological formations were the Serra do Mar (52), Serra da Mantiqueira (16), Serra do Espinhaço (15), Serra Geral (6), Serra Capixaba (5) and Campos Gerais – second plateau of Paraná (3). Secondary sources are from 19 states

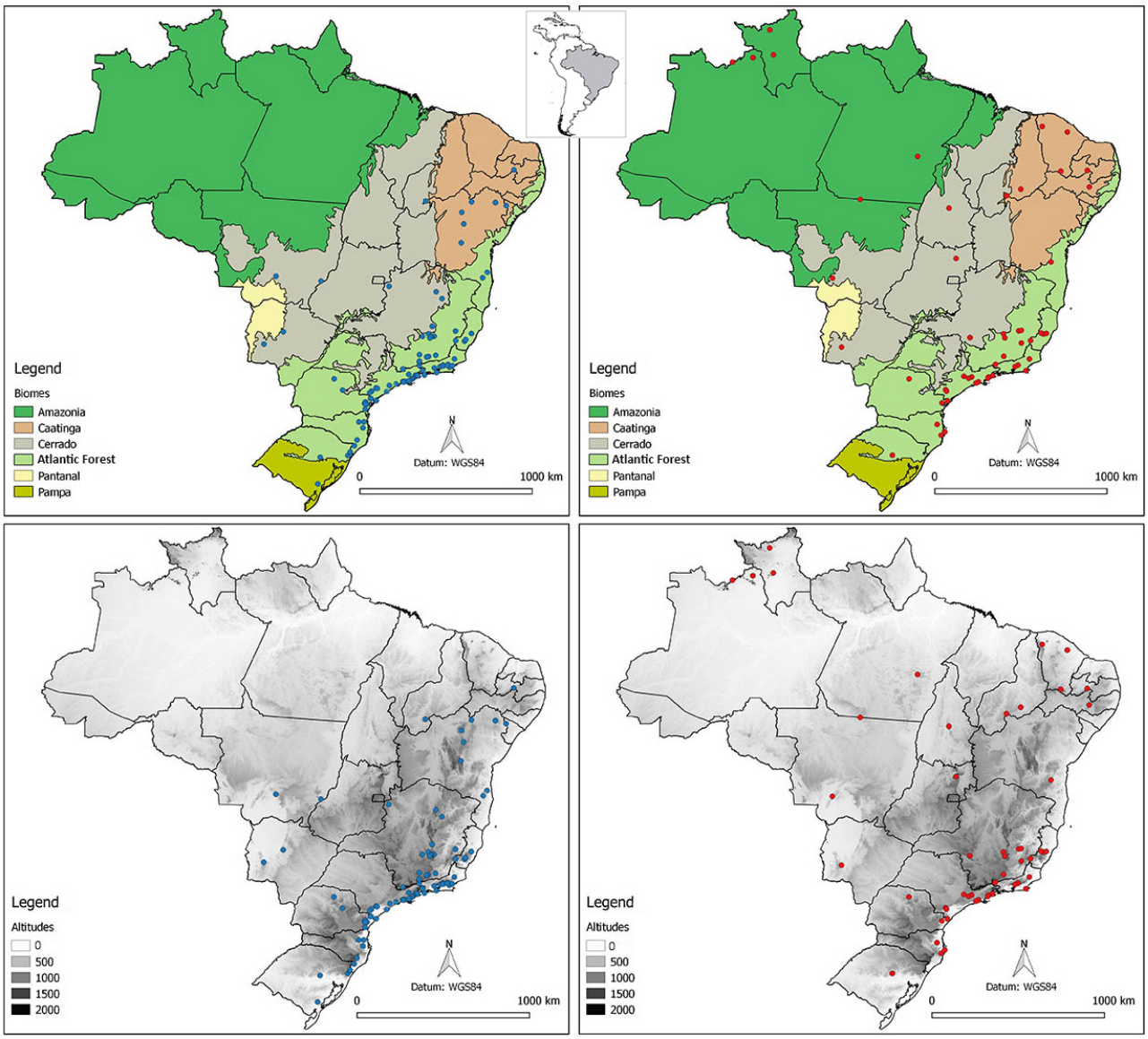

Figure 1. Map illustrating the locations where altitudinal bird studies were carried out. Primary sources indicated by blue circles, secondary by red circles.

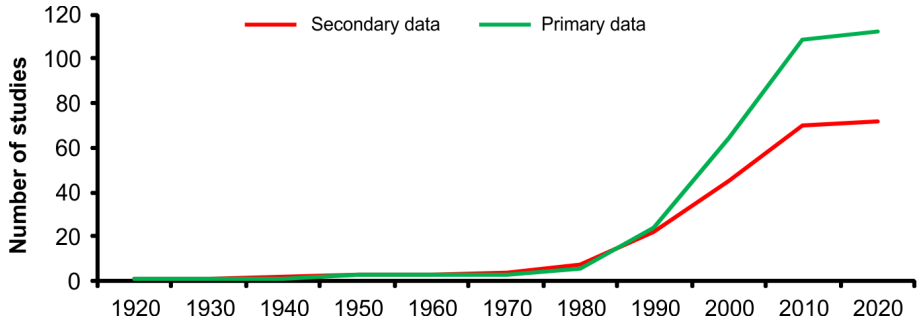

Figure 2. Cumulative curve of the number of avian altitudinal studies in Brazil.

(Amazonas – AM, Pará – PA, Roraima – RR, Tocantins – TO, Goiás – GO, Ceará – CE, Pernambuco – PE), and including the southeast (38), northeast (11), north (10), south (8) and west-central (5) regions, increasing the representation of the Caatinga and Cerrado Biomes, in addition to the inclusion of the Amazonia, absent in the primary data (Fig. 1; Supplementary Material – Tables S1–S4, Fig. S1).

Altitudinal gradients

Among the 92 studies evaluated regarding the amplitude of the gradient studied, 49 were complete and 43 were incomplete. There were 20 studies with complete gradients and 21 with incomplete gradients in the Serra do Mar, and the complete ones comprise elevations from sea level to the high part of the plateau, concentrated mainly in Serra de Paranapiacaba, SP (7), Serra dos Órgãos, RJ (5) and Marumbi, PR (5). Those 83 with numbers of altitudinal ranges had between two and 35 distinct altitudes. Studies carried out in gradients and continuous transects had two to 11 distinct altitudes. Of the 108 studies with spatial relationships describe, 16 were continuous local, 76 were regional and 16 were wide (Supplementary Material – Tables S1, S2, and Fig. S1B, C, D).

Technical characteristics

Twelve of the 112 primary studies were simple inventories, 66 were community studies, 14 are specific occurrences (four with species and 10 with certain groups, such as families and genera), two were biological, one data compilation and six were seasonal altitudinal movements, and 10 were about natural history. Hypothesis testing was carried out in 29 studies, 20 of which were in the Serra do Mar. Of the 100 studies that permitted evaluation of standardization, only 34 collected data in a standardized way. Direct observation was reported in 30 as the only form of data collection, 18 included point counts, five used MacKinnon lists, 18 used transects, 34 with mist-nets, two with traps (butterfly net, feeder trap), 21 collected specimens, and 24 were literature searches, some of which included museum records. Of the 103 that were evaluated for seasonality or time, 26 included a year of fieldwork (and four seasons), three were a year of fieldwork (wet and dry seasons), and a one-year study in which periodicity was not mentioned, two study over more than one year (and all four seasons), 21 were less than a year-long, and 50 were several years long (Supplementary Material – Tables S1, S2).

DISCUSSION

The 184 altitudinal ornithological studies produced since 1928 show the rich and broad investigations of Brazilian montane avifaunas. This is contrary to the perspective that such studies and knowledge are limited that has been mentioned by some authors in recent years (e.g., Rahbek 1995, 1997, Melo-Júnior et al. 2001, Colwell et al. 2004, McCain 2009, Purificação et al. 2013, Barçante et al. 2017, Boyle 2017, Quintero and Jetz 2018). This number of organized references (184) is much higher than the few sources mentioned in recent literature (e.g., Holt 1928, Scott and Brooke 1985, Höfling and Lencioni 1992, Bencke and Kindel 1999, Goerck 1999, Buzzetti 2000, Melo-Júnior et al. 2001, Cavarzere and Silveira 2012), and part of these most cited works was published in leading scientific journals and are available in a digital and online format. Most of the rarely cited references were published in regional scientific journals, without periodicity, in printed format, not digitized, and not available online, making access to information difficult. This historical-scientific review is important to show that we have a much broader literature than one might think about birds from the mountainous regions of Brazil.

About one-quarter of the sources remain unpublished in peer-reviewed journals and are held in university libraries

as monographs, dissertations, and theses, or as abstracts in scientific meetings. Also, of the 20 academic studies that were considered primary, five were carried out between 1996 and 2009, and therefore are unlikely to ever be published. About half of the remaining 15 are dated between 2015 and 2017, which improves their chances of still being published (Supplementary Material – Tables S1, S2). An example of an unpublished study that is not fully available 26 years later was carried out in Itatiatia in the state of Rio de Janeiro for an interval of 15 years (Gouvêa et al. 2005), and which was only mentioned in abstracts from scientific meetings (Gouvêa et al. 1996, Gouvêa 2006, Piratelli et al. 2010).

The number of publications has increased over time, especially since the 1990s. At that time, ornithology in Brazil became increasingly important, with the creation of the Brazilian Society of Ornithology and an associated increase in academic ornithologists, especially in southeastern Brazil. At that time, a few important studies were published in international journals (e.g., Bencke and Kindel 1999, Goerck 1999, Melo-Júnior et al. 2001) that also may have provided the impulse for increased interest in this area.

The 72 secondary references demonstrate that many authors were unconcerned about the association between their data, the altitudes at which they were collected, and the birds they studied. Without this information, these publications are much less useful to others. This absence of basic data is also present in many references considered primary, but partially (e.g., Pizo et al. 2002, Silveira et al. 2005). Despite the lack of information, many of these studies still provide very important details for understanding altitudinal movement patterns along with conservation and other important topics.

Geographic region

Most studies (115, 77 primary, 38 secondary) were carried out in southeastern Brazil, in the Serra do Mar, Mantiqueira, and Espinhaço mountain ranges, in which seven of the 10 highest points in Brazil are found, along with the largest urban centers with the largest universities (Fig. 1; Supplementary Material – Fig. S1D). An example of this proximity-number of studies relationship can be found in eight primary studies in the Serra dos Órgãos, which is the highest region of the Serra do Mar near the Rio de Janeiro metropolitan area (Supplementary Material – Tables S1, S2). Another advantage favoring research in this region can be seen in the many highways and roads that make accessing research areas very easy, with access to a variety of elevations and several conservation units, as well as the largest Atlantic Forest fragments (Ribeiro et al. 2009). The mountains of southeastern Brazil are extensive, and still, in many regions, details of avian ecology remain unknown. For example, the Serra do Caparaó is very poorly studied (Vasconcelos 2003) as is much of the Serra do Mar (Pacheco and Bauer 1999, Bencke et al. 2006).

Southern Brazil follows with the second-most number of studies (28, 20 of which are primary), which is likely for reasons similar to that in the southeast (Fig. 1; Supplementary Material – Fig. S1E). This region also has higher elevations (Paraná Peak) down to sea level, but with more canyons, and with both smooth slopes and steeper escarpments, such as in the state of Santa Catarina at the southern limit of the Serra do Mar. Avian studies are also limited here (e.g., Marterer 1996). From the mountains westward in the high plains (Campos Gerais), in what is locally called the second plateau in Paraná, where the valley of the Tibagi River has great potential and in which some studies have been carried out (e.g., Anjos 2002, Fávaro et al. 2006). Topographic relief here is very different, but includes more valleys than mountains, which provide potential for altitudinal studies in Brazil, similar to Bahia (Salitre River valley – Silveira and Machado 2012) and Rio de Janeiro (Taquara Valley – Pacheco et al. 2014), because there are still large gaps, such as in the Ribeira de Iguape River Valley, in São Paulo, in addition to several others, being a promising potential that needs to be explored by future studies.

The Northeast and Central-western regions have 10 and six primary studies and 11 and five secondary studies, respectively, possibly due to the few mountainous regions with elevations above 1000/1500 m a.s.l. and the smaller number of research institutions and ornithologists in relation to the south and southeast of the country (Fig. 1; Supplementary Material – Fig. S1B). In the central-western region, the Serra de Maracaju (Mato Grosso do Sul), Chapada dos Guimarães (Mato Grosso) and the Chapada dos Veadeiros (Goiás), while potentially interesting, has had relatively few, simple altitudinal studies (e.g., Pivatto et al. 2006, Lopes et al. 2009) or published studies did not include information about altitude (e.g., Silva and Oniki 1988, Reinert et al. 1998, Bagno and Abreu 2001). In Northeastern Brazil, the Caatinga (Brazilian dry forest) includes several, relatively high-elevation locations in which birds and altitudes might be studied, including the Chapada Diamantina (Bahia), the Chapada do Araripe (Ceará, Piaui, and Pernambuco), the Baturité, Ubajara (Ceará) and Capivara (Piauí) ranges. These regions, however, remain poorly studied (e.g., Parrini et al. 1999) and without associating birds with elevation

(e.g., Nascimento et al. 2000, Girão et al. 2006, Olmos and Albano 2012). The Caatinga is strongly seasonal (wet and dry) and strongly influences the presence of birds through seasonal and regional nomadism or migration (Sick 1997, Pereira and Azevedo-Júnior 2013, Marcondes et al. 2014). Thus, some ideas about the influence of climate on altitude could be addressed here.

Northern Brazil is devoid of primary altitudinal bird studies (only 10 secondary studies), even though sampling has been carried out in many places (e.g., Paynter-Jr and Traylor-Jr 1991a, 1991b, Fig. 1; Supplementary Material – Fig. S1A). The Serra do Imeri, where the highest peaks in Brazil are found (Neblina and 31 de Março), is isolated and difficult to reach, which impedes field studies. The Pantepui region on the border of Venezuela is also difficult to reach but has great potential. Additional highlands are also found in the north, some fairly isolated, such as the Serra do Divisor (Acre), the Serra do Aracá (Amazonas) and the Serra do Cachimbo (Pará, Mato Grosso), and more easily accessible, such as the Chapada das Mesas (Maranhão), the Serra do Lajeado (Tocantins) and the Serra dos Carajás (Pará). While basic bird studies have been carried out in many of these places, none was associated with altitudinal movement patterns (e.g., Pinto and Camargo 1957, Bagno and Abreu 2001, Borges 2007, Aleixo et al. 2012, Santos et al. 2012, Borges et al. 2014), all of which impedes deeper analysis of species distribution patterns associated with altitude.

In the Pampas we found a single study (Maurício and Dias 2001), carried out in the Serra dos Tapes, within a region known as the Southeastern Range, in the southern half of the state of Rio Grande do Sul, with fragments of Atlantic Forest. While having fewer high mountains and covering a smaller area, the region still has potential due to these characteristics that deserve further study.

Most altitudinal studies of birds have been carried out in the Atlantic Forest, and this region has many ecotones between the forest and other formations. For example, in the Cadeia do Espinhaço (Minas Gerais, Bahia) (e.g., Vasconcelos et al. 1999, Melo-Júnior et al. 2001) the Atlantic Forest abuts both Cerrado (open savanna) and Caatinga. Thus, while all ecoregions of Brazil have interesting possibilities for altitudinal studies of birds, the Cerrado, Caatinga, and Amazonia are large ecoregions with few studies and so should be prioritized in the future.

Altitudinal gradients

Despite the amplitude of the altitudinal gradient available in the studied regions, almost half (43.47%) of all the studies had incompletely sampled gradients. This may be due to lack of available habitat along the entire gradient. For example, Holt (1928) commented that because of deforestation at lower elevations beginning in the 16th century makes part of this gradient unavailable for study. This continues to be a problem throughout the region. Nonetheless, a few places remain where a complete gradient may be examined in the Serra do Mar, even though they have only been partially examined (e.g., Höfling and Lencioni 1992, Castro et al. 2012).

Technical characteristics

Altitudinal studies of birds have tended to address community patterns, and today community studies remain the most common (59% of 112 primary studies). Also, fewer, but still many altitudinal studies have been carried out during graduate work or technical environmental analyses, and which remain unpublished in peer-reviewed journals (e.g., Bencke and Kindel 1999, Develey 2004). Unpublished studies, naturally, have been somewhat ignored in the publications of other avian altitudinal studies (e.g., Melo-Júnior et al. 2001, Cavarzere and Silveira 2012, Purificação et al. 2013).

Studies with clear hypotheses being tested (26%), or with some kind of standardization (34%) are unusual because they account for about half the studies. The remainder tends to be descriptive, usually with simple lists that include either threatened or endemic species. While understanding species composition is important, hypothesis tests and standardization are essential for delineating and testing patterns associated with species distributions over altitudinal gradients. For example, while the species lists presented for three regions in southeastern Brazil by Mallet-Rodrigues et al. (2015) are valuable comparisons of altitudinal species richness and composition between the regions are limited due to a lack of standardization. Standardization and hypothesis testing are becoming more common and half of the literature in which these were included was published since 2010. Yet, in the Serra do Mar only two studies were found that were standardized and tested hypotheses about altitudinal species-richness patterns (Goerck 1999, Cavarzere and Silveira 2012).

Communities and especially inventories dominate these studies. Studies of subsets of the avian community were less common but tended to be among those examining altitudinal patterns (Venturini and Paz 2005, Rajão and Cerqueira 2006), biology (e.g., Giancoli 2014), and natural history (e.g., Parrini and Pacheco 2011). It is not clear why so few studies examine specific groups, considering that they are more common elsewhere (see Barçante et al. 2017).

Field methods used in these studies tended to be more or less in similar proportions, perhaps because more than one method may be used in the same study, and methods are more or fewer standards. Inventories, for example, often use direct observation, collecting, transects and mist-nets, as well as compiling the associated literature. Mackinnon lists were only used in four studies, perhaps because it has a shorter history of use in Brazil (Sutherland et al. 2004, Ribon 2010). A few studies of hummingbirds used butterfly nets or feeder traps, both of which are of limited use with other species (Ruschi and Simon 2012, Giancoli 2014).

Around 48.5% of studies were carried out over several years with not properly planned field seasons. These are typical of bird inventories in Brazil. Fewer studies examine at least a one-year cycle, with either four or two seasons (28%). This is problematic because it is a minimum requirement when the goal is to explain the annual cycle or periodic altitudinal movement patterns. Several studies were less than a year long, and some more than a year-long, which they were well-planned with defined sampling periods, such as during the breeding season. However, they did not necessarily include the time period when migration may have occurred. Only two studies were found that sampled all four seasons, included more than a year of study, and were directed at seasonality (Hasui et al. 2009, Schunck et al. 2019). Scarcity of this kind of study may be due to the difficult logistics and financial requirements inherent in this kind of study, in contrast to studies elsewhere (e.g., Inouye et al. 2000).

Recommendations for adequate sampling

Researchers interested in investigating the avifauna of mountainous regions of Brazil, mainly with the objective of detecting patterns, need to be concerned with some basic technical criteria in a simultaneous and complementary way: 1) Data collection must be standardized or planned so that sampling effort can be controlled for in the analyses so that all moments in time are comparable; 2) At least 12 months should be included in the study; 3) Entire elevation gradients should be included; 4) Study areas should be completely described, including geographic coordinates and altitude; 5) Analyze the relationship between the species and altitude and; 6) Data must be published with peer review and made available on online platforms, including citizen science platforms. While leaving any one of these out may not completely compromise the study, the association between the ecology of the species of interest and altitude will remain unclear if they are not all followed. The ornithological potential of the Brazilian mountains includes studies related to sistematic and taxonomy; biogeographic hypotheses (e.g., species richness along altitudinal gradientes, factors that limit species' ranges); altitudinal movements (including possible altitudinal migrations); monitoring populations of vulnerable or threatened species and monitoring bird species' responses to climate change and land use change, besides others.

Altitudinal ornithological research in Brazil is more advanced than at first glance because unfortunately much of the information has not been published in peer-reviewed journals. Nonetheless, for this area to gain popularity, more attention must be paid to the technical and practical details of the theme, and they must be publishable in quality peer-reviewed journals.

South and southeastern Brazil, and the Atlantic Forest, are the most studied regions due to the combination of mountains and urban centers with their institutions of higher learning. Northern Brazil, on the other hand, with the highest peaks, is also very isolated, so fewer studies have been carried out there. While altitudinal studies in Brazil can be carried out wherever there are mountains, more attention should be given to the Cerrado, Caatinga and the Amazonia.

Habitat loss in mountainous regions of Brazil is having a permanent and irreversible effect on biodiversity and may compromise the study of birds and altitude if both habitats and species are lost faster than they can be studied. The creation of protected areas that include complete altitudinal gradients should receive maximum priority, especially with climate change, which may cause changes in the geographic distribution and migratory behaviors of many bird species.

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