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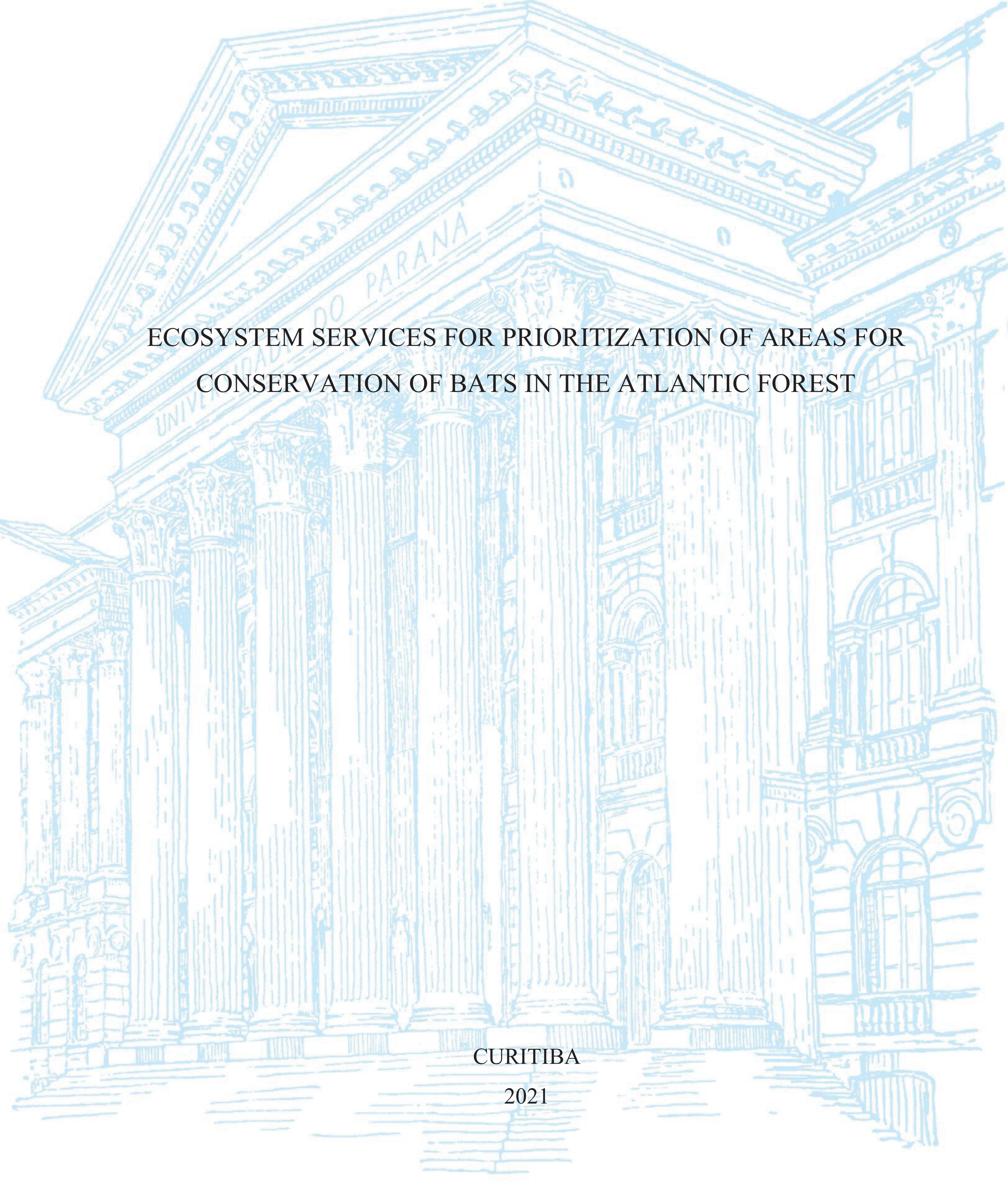

ECOSYSTEM SERVICES FOR PRIORITIZATION OF AREAS FOR CONSERVATION OF BATS IN THE ATLANTIC FOREST

CURITIBA

2021

GABRIEL PREUSS CUSTÓDIO

ECOSYSTEM SERVICES FOR PRIORITIZATION OF AREAS FOR CONSERVATION OF BATS IN THE ATLANTIC FOREST

Dissertação apresentada ao Curso de Pós-graduação em Ecologia e Conservação, Setor de Ciências Biológicas, da Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Ecologia e Conservação.

Orientador: Dr. André Andrian Padial

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TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em ECOLOGIA E CONSERVAÇÃO da Universidade Federal do Paraná foram convocados para realizar a arguição da Dissertação de Mestrado de **GABRIEL PREUSS CUSTÓDIO** intitulada: **Ecosystem services for prioritization of areas for conservation of bats in the Atlantic Forest**, sob orientação do Prof. Dr. ANDRE ANDRIAN PADIAL, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

A outorga do título de mestre está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

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RESUMO

Serviços ecossistêmicos são aspectos do ecossistema responsáveis por produzir direta ou indiretamente o bem-estar humano. Dada a imprescindível necessidade de dispor destes serviços em um futuro cada vez mais preocupante, as investigações têm-se concentrado cada vez mais na detecção e estimativa de valores de serviços prestados por diferentes modelos ecológicos. Apresentando a maior plasticidade alimentar entre todas as ordens de mamíferos, os morcegos são um táxon chave na provisão de serviços ecossistêmicos. Dessa forma, o presente estudo tem como objetivos: avaliar a importância dos serviços ecossistêmicos prestados por morcegos na Mata Atlântica brasileira, bem como calcular o valor desses serviços, a perda de habitat, abundância e riqueza de espécies de acordo com as mudanças climáticas, avaliar a cobertura atual de áreas protegidas na Mata Atlântica e identificar áreas prioritárias para a conservação de Phyllostomidae. Estimamos os valores de riqueza, abundância e serviços ecossistêmicos para 30 espécies de morcegos filostomídeos da Mata Atlântica. A partir desses dados, construímos modelos de distribuição e áreas prioritárias para a conservação de morcegos. Nossas projeções sugerem uma redução média nos serviços ecossistêmicos de US $ 900 milhões e uma redução na abundância de morcegos em aproximadamente 87 milhões de indivíduos até 2070 na Mata Atlântica. Nossos resultados também destacam o processo de homogeneização biótica que tende a se estabelecer na Mata Atlântica com as mudanças climáticas. Sugerimos que áreas protegidas com mais de 100 km de área têm papel indispensável na manutenção da riqueza de espécies de morcegos da Mata Atlântica, mostrando que escolher o local onde uma unidade de conservação será implantada pode ser tão importante quanto decidir o tamanho dessas unidades. De acordo com o supracitado, acreditamos que o presente trabalho pode apoiar a manutenção e a implementação de futuras unidades de conservação.

Palavras-chave: Homogeneização biótica, valoração de serviços ecossistêmicos, mudanças climáticas, perda de habitat, perda de espécies.

ABSTRACT

Ecosystem services are aspects of the ecosystem responsible for directly or indirectly produce human well-being. Because of the indispensable need to have these services in an increasingly worrying future, research have been increasingly focused in detecting and estimating values from services provided by several ecological entities. Showing the greatest food plasticity among all orders of mammals, bats are a key taxa in the provision of ecosystem services. This study aims to: (1) evaluate the importance of ecosystem services provided by bats in the Brazilian Atlantic Forest, as well as (2) calculate the value of these services, the habitat loss, abundance and species richness according to climate change, (3) evaluate the current coverage of protected areas in the Atlantic Forest and (4) identify priority areas for Phyllostomidae's conservation. We estimate the values of richness, abundance and ecosystem services for 30 species of phyllostomid bats from the Atlantic Forest. From these data, we build distribution models and priority areas for bat conservation. Our projections suggest an average reduction in ecosystem services of US $ 900 million and a reduction in bat abundance in approximately 87 million individuals by 2070 in the Atlantic Forest. Our findings also highlight the process of biotic homogenization that tends to establish itself in the Atlantic Forest with climate change. We suggest that protected areas over 100 km of area play an indispensable role in maintaining the richness of bat species in the Atlantic Forest, showing that choosing the location where a protected area will be implanted can be just as important when deciding on its size. We believe that the present work can support maintenance and implementation of future protected areas.

Keywords: ecosystem services valuation, biotic homogenization, climate change, habitat loss, species loss.

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ECOSYSTEM SERVICES AS CONSERVATION TOOL FOR PHYLLOSTOMID BATS IN THE ATLANTIC FOREST

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ABSTRACT

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Keywords: ecosystem services valuation, biotic homogenization, climate change, habitat loss, species loss.

INTRODUCTION

Ecosystem services (ES) can be defined as aspects of the ecosystem used to directly or indirectly produce human well-being (Fisher et al., 2009). Such services are fundamental in the provision of health, well-being, and survival (Cardinale et al., 2012). Understanding the relationship between humans and the rest of nature is probably what separates the human population from sustainable development (Constanza et al., 1993; 1996; 1997; Heal, 2000). There is no sustainable development without considering nature conservation and ecosystem services (Abson et al., 2014). The term ecosystem services were first described in 1970 at The Study of Critical Environmental Problems conference. Since 1981, environmental services were conceptualized as "ecosystem services" by Ehrlich and Ehrlich, 1981. During the 1970s and 1980s the main concern was to understand how the loss of biodiversity would affect environmental services, and from the 1990s onwards, with the Scientific Committee On Problems of the Environment - SCOPE, the eyes turned to the influence of climate change on ecosystem services (DEGENS et al., 1991). Seeking to make the importance of ecosystem services clearer, comparable, and close to the real magnitude of ecosystem services, Contanza et al., 1997 published the first work that calculated ecosystem services in monetary values. After this work, several authors sought alternative estimations (Bolund and Hunhammar, 1999; Chen, 2000; Barbier et al., 2011).

Establishing monetary values for ecosystem services is complex and requires a variety of information (Naidoo et al., 2008). However, making ecosystem services valuable can be one of the most efficient ways to show the importance of these services to the population and decision-makers (Bingham et al., 1999; Díaz et al., 2019). Especially in Brazil, where environmental policies suffer constant dismantlement (Fearnside, 2016; Escobar, 2019). Even with the recurrent change in policies and the little investment in research, recently several collaborating authors published data-papers providing important data for different biomes in Brazil (Muylaert et al., 2017; Gonçalves et al., 2018; Grilo et al., 2018; Santos et al., 2019). Data from these researches can be useful tools for different study methods, including the valuation of ecosystem services.

Different ways of valuing ecosystem services have already been addressed (Constanza et al., 2014). However, the vast majority of them consider ecosystem services to be focused on the production of inputs (e.g. Zhang et al., 2007; Dale and Polasky., 2007; Zhong et al., 2020). This means that important ecosystem services such as seed seed dispersal and degraded areas restoration are poorly explored (Hutchins et al., 1996, Whelan et al., 2008).

Although little is known about the monetary value of ecosystem services other than the production of inputs, there are alternatives to calculate them, as is the case with the cost replacement method (Sundberg, 2004). This methodology is based on the idea that it is possible to find a substitute for the provision of ecosystem services, such as work performed by human labor (Sundberg, 2004; Allsop, 2008; López-Morales and Mesa-Jurado, 2017). This method is only valid to calculate the economic value of ecosystem services provided, if: (a) human labor is able to offer equivalent services in quality and magnitude; (b) the labor has the lowest cost to replace the ecosystem service; and (c) society is willing to pay for such services when natural ecosystem services are no longer available (Shabman and Batie, 1978; Leschine et al., 1997; Bocksteal et al., 2000; Freeman, 2003). Although this approach makes it possible to value different ecosystem services in different taxa, the use of this method in any vertebrate taxa is nonexistent.

Presenting the greatest diet variation among all mammalian orders, Phyllostomidae family emerges as one of the main taxa provider of ecosystem services (Kunz et al., 2011). Directly responsible for seed dispersal pollination, population control of insects and restoration of degraded areas, especially at an early stage, bats are indispensable for the maintenance of a balanced ecosystem (Kunz et al., 2011; Williams-Guillen et al., 2016). Refining the taxonomic filter without losing the diversity of ecosystem functions, the Phyllostomidae family stands out (Williams-Guillén and Perfecto, 2010). Phylostomid bats, besides providing all ecosystem services of the order Chiroptera, are more commonly captured by mist nets - the most used method for capturing bats in Brazil (Esbérard 2006; Scultori et al., 2008). This fact contributes especially where there is little availability of research, as in the case of the Atlantic Forest biome (Carnaval, 2009).

The Brazilian Atlantic Forest is one of the most threatened and least studied biomes on the planet, being considered one of the 35 world hotspots of biodiversity (Mittermeier et al., 2011). Overexploited since colonization, currently the Atlantic Forest is conserved in approximately one quarter of its original cover (Morellato, 2000; Rezende et al., 2018). Even with a recognized study gap in the biome, it is known that the Atlantic Forest is habitat to a high diversity of species in general, characterized by a high level of endemism (Brown and Brown, 1992; Myers, 2000; Carnaval, 2009). These characteristics, combined with the recurrent threat to conservation in Brazil and predicted climate change in the future, make the Brazilian Atlantic Forest one of the most alarming conservation problems in the world (Morellato and Haddad, 2000; Fearnside, 2016; Escobar, 2019); which highlights the importance of setting priority conservation areas (Margules and Pressey, 2000).

The aims of the present study are: (1) to evaluate the importance of ecosystem services provided by Phyllostomidae bats in the Brazilian Atlantic Forest, as well as (2) to estimate the value of these services, the change of area, abundance and richness considering current and future scenarios according to climate change drivers (3) to assess the current coverage of protected areas in the Atlantic Forest and (4) to identify priority areas for the conservation of Phyllostomidae in the Atlantic Forest. In this way, we can bring subsidies for future conservation plans in a biome increasingly threatened by the lack of studies and inadequate public policies.

MATERIAL AND METHODS

Occurrence data

The occurrence records of the bat species of Phyllostomidae were obtained from the study of Gonçalves et al. (2018). In this work, authors compiled more than 23,000 occurrence records for all species in the Atlantic Forest biome. Such data were reviewed and corrected by authors, ensuring its reliability. We filtered the occurrence data only for Phyllostomidae, with wide food plasticity, and greater role considering ES. After filtering the data, 21,368 records of the occurrence of 56 species of phyllostomid bats remained (Supplementary File 1).

Climatic data

We used all 19 bioclimatic variables available in the Climatologies at High Resolution for the Earth's Land Surface Areas (CHELSA) database (Karger et al., 2017), with a resolution of 0.5 minutes of arc (~ 1 x 1 km^2). In addition to current climate data, we also used projections for the 2041-2060 and 2061-2080 climate scenarios. All under the same General Circulation Model (GCM -CCSM4). GCMs are representation of atmospheric processes with its interactions (Mekonnen et al., 2019). For each GCM we used two possibilities for Representative Concentration Pathway (RCP) 4.5 and 8.5. RCPs are possible scenarios of emission of greenhouse gases and land use (Moss et al., 2008). The possible RCPs in CHELSA are 2.6, 4.5, 6.0 and 8.5. The RCP of 2.6 was not considered because we believe that such scenario has become unrealistic according to the current CO2 emission rates. And the 6.0 was not used because we wanted to project possible scenarios in an optimistic and pessimist view.

Data preparation

In order not to consider twice a point with the same information on the same pixel, we eliminated the duplicate points within the same climate grid for each species. In addition, we excluded species that had three or less points of occurrence. Such cleaning resulted in 993 records of 35 species of the Phyllostomidae family. Species with a predominantly carnivorous and / or hematophagous habit following Reis et al. 2007, as well as those that do not contain abundance data available in the work of Muylaert et al. (2017), were also excluded from the analysis, resulting in 30 species. To avoid multiple collinearity in the climatic data, we used the Pearson correlation method to select the variables that are less correlated using as exclusion criteria a correlation equal to or greater than 0.6. The six environmental variables selected were mean diurnal range, isothermality, mean temperature of wettest quarter, mean temperature of driest quarter, precipitation of wettest month, and precipitation of coldest quarter.

Modelling

From the selected predictor variables, we built 30 distribution models in the current scenario, one for each species. Considering that we only used presence data, the algorithm used was the Maximum Entropy Model (Maxent). According to Elith and Graham (2009) this is a presence-background algorithm that generates even better results than presence-absence algorithms. For each model we used 75% of the occurrence data for calibration and 25% for test validation, both the calibration and the test were applied to the Atlantic Forest. We used 100,000 occurrence points randomly distributed throughout the study area as background, considered pseudo-absence data. For each species, 10 replication simulations were performed (cross-validation = 10). The average of these simulations made up the final map of climatic suitability for each species. This process was repeated for each proposed climate scenario (all codes used may be seen in Supplementary File 2).

Predicting abundance

Data on morphometric traits and abundance were obtained through the work of Muylaert et al. 2017. With regard to the area of life data, we used the information found in literature based on results of studies that used the telemetry method, since these data represent more reliable estimates of the area of life than the mark-recapture method (White and Shenk, 2001; Sandercock, 2003; Ivan et al., 2013). According to Norberg, 1994, the home ranges of bats is mostly determined predominantly by their body size. Thus, we use average home ranges according to the size of the forearm. We did this because some species do not have telemetry data recorded in the literature. As a home ranges, we use the longest distance ever recorded for each forearm size category in order to avoid overvaluation.

For each species, the average forearm size of all adult individuals was calculated according to the work of Muylaert et al. 2017. This average forearm value was used to separate bat species into two size classes: A $\leq$ 55 mm and B > 55 mm. bats have been separated into these categories according to how close their home range is to the four and nine km pixel values, which are possible to create with our weather data. Based on these categories, we stipulated an average home ranges according to the data found in the literature. Thus, the home ranges were four and nine km radius, respectively. We used the home ranges so that we can calculate abundance values for each pixel independently, avoiding counting the same abundance estimate twice. According to the home ranges of each species, we established these areas for each pixel, considering each pixel as having independent abundance. According to the meta-analysis made by Weber et al. 2017, environmental suitability and abundance are correlated. Building from this concept, we used the maximum values of abundance already sampled in the Atlantic Forest, relating them to the maximum values of suitability. The minimum suitability value was established by the maximum limit between sensitivity and specificity in the species distribution model, and the minimum limit for the presence of the species, was considered as the lowest possible abundance capable of generating new individuals and an increase in abundance (2 individuals). From the maximum and minimum population value, we adjusted a linear model to assign the abundance value through the intercept according to suitability (Figure 1). In this way, we established abundance values for the entire Atlantic Forest, according to the environmental suitability and the home ranges of each species (Codes used may be seen in Supplementary File 3).

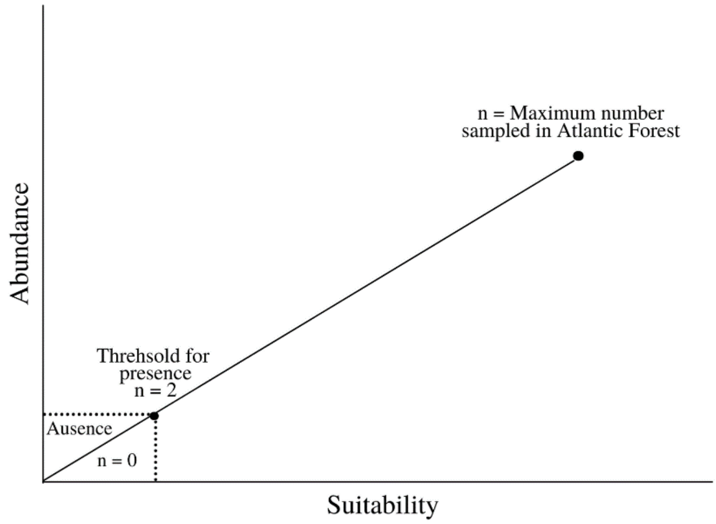


Figure 1: Theoretical graph representing the scheme used to establish the abundance value of each species in each pixel of the distribution area.

Ecosystem services accounting

To account for the service's value that each bat provides nightly, we calculated how much it would cost for the service to be performed by human labor. Considering the ecosystem services provided by bats and which can be measured by labor, we calculated three different types of labor: pollination, seed dispersal, and pest control. To discern functional groups among frugivores, insectivores, and nectarivores, we used the study of Reis et al., 2007. The pollination values were counted according to hand-pollination values. The seed dispersal values were counted with the average of the market value of the seeds, and the number of seeds dispersed per night. The value for pest control was based on the value of insecticides that would be applied to the same number of insects preyed upon by a bat in one night (table 1). When it was not possible to find specific information for each species, we used averages from other species to get close to the specific value of each service and each species (All codes may be seen in Supplementary File 4).

Table 1: Information used for the calculation of ecosystem services provided by phyllostomid bats in the Brazilian Atlantic Forest.

Information for calculating ecosystem services	**Reference**
Pollination	
Number of Flowers visited per night	USA Department of Agriculture
Value of labor	LEI Nº 5.889 de 1973; Allsop et al., 2008.

Number of Flowers hand-pollinated per hour	Junqueira et al., 2001
Seed dispersal	
Average number of seeds dispersed per night	Sarmento et al., 2014
Average cost per seed	Market Research
Seeds eaten by a major number of phyllostomid bats	Bredt et al., 2012
Pest control	
Quantity of insecticide required per insect weight	Bovi, 2013
Average weight per insect	Silva et al., 2020
Average value of the pesticide on the market	Market Research
Average amount of insects eaten in one night	Anthony e Kunz, 1997; Boyles et al., 2011; Kunz et al., 2011
Most commonly used insecticides	Vasconcelos, 2018

Pollination

To calculate the monetary value provided by each bat per night, we used the following formula:

$$\left(\frac{RW}{NF}\right) \times FN$$

Where: RW = Hourly value of hand-pollination, NF = Average number of flowers pollinated per hour by hand-pollination and FN = number of flowers pollinated per night by a bat.

We used as a parameter the number of pollinated flowers per hour in the passion fruit culture, since it was the only information available in relation to the number of hand-pollinated flowers (Junqueira et al., 2001). Although Allsop et al. 2008 reported that the value of labor for hand-pollination is four times higher than the value for harvest work, we believe that in Brazil, a reasonable estimation is to consider the same for both. As our proposal is to make a conservative estimate of ecosystem services fulfilling the premise of the cost replacement method, we chose not to multiply the value of labor by four. In this way, we have the value provided in labor for each nectarivorous bat in one night.

Pest control

To calculate the value provided by insectivorous bats on a foraging night, we calculated the amount that would be spent on insecticides. The calculation of the amount spent on insecticide followed the formula:

$$(DL100 \times IN \div IV)$$

Where: DL100 = average of the most used insecticides for each predated individual, IN = Average number of insects predated per night, IV = average monetary value of the most applied insecticides for each insect.

We disregarded the time of application of the insecticide, since this value can be very variable according to the form of application. Therefore, we chose to calculate this way to avoid overvaluing services.

Seed dispersal

To calculate the value provided by bats in relation to seed dispersal, we did not consider the value of the labor of a rural worker because the number of seeds dispersed in a day can vary widely. Therefore, the formula used to calculate the seed dispersal value was:

$$SV \times SD$$

Where: SV = average market value of a seed of the species most consumed by bats in the Atlantic Forest; SD = average number of seeds dispersed by a bat per night.

To check the plant species most consumed by bats, we used the study of Bredt et al. 2012, which carried out a survey of the interactions between bats and plants in the Neotropics. Plant species with a higher number of interactions with bats species. Among the total of 267 species, we selected those that interact with at least 8 bat species, representing a half of our frugivore species (30), excluded those that do not occur naturally in the Atlantic Forest biome and those that were not found in the Brazilian market (4).

Data analysis

We calculated the value provided by each species in each pixel using the maps of each species according to the estimated home ranges and abundance separated by pixel. Therefore, each pixel has the estimated home ranges of the species and the estimated value of abundance. Multiplying the abundance by the value of labor provided by bat per night, we have the value provided nightly for each species in the Atlantic Forest. Multiplying this value by the days of the year (365) we have the annual value provided by each species of bat. As each species has an estimate of the population area and a different pixel resolution, we calculated the species individually, and after the calculations performed, we increased the resolution of the pixels by dividing the values equally between the new pixels. Thus, at the end of the calculations, all species had maps at the same resolution (~ 1km²). With the maps in the same resolution, we overlapped the results and arrived at the annual values of ecosystem services provided by all the species of phyllostomid bats analyzed. All calculations were performed for each scenario and RCP (current, 2050 - RCP 4.5 and 8.5, and 2070 - RCP 4.5 and 8.5).

Assessing the current coverage of protected areas

In order to assess which are the protected areas in the Atlantic Forest that shelter the most species richness, abundance and value of ecosystem services, we extracted the following data from each protected area: area, abundance, species richness, and ecosystem services provided. Such data were evaluated both in relation to the total area and per km². Since there was no linear relation between area and species richness, we separated the conservation units into four size classes to verify if the size of the protected area is determinant for the values of species richness, thus dividing the classes into: A, B, C and D. These classes represent, respectively: up to 100km; between 100 and 1000 km, between 1000 and 2000 km, and above 2000 km. We use these class sizes to divide the protected areas into classes with similar sample sizes. We applied the ANOVA test with permutations to verify the difference in the maintenance of species richness between the protected areas. We used post-hoc Tuckey's test to check the difference between the size classes. In this way, we can discuss whether what matters most in establishing protected areas is the size or location chosen.

Analysis of priority areas for conservation

We analyzed the areas that showed the highest values in order to establish a coverage map for priority areas for bat conservation in the Atlantic Forest using maps of species richness, estimated abundance, and ecosystem services. For each map, we transformed the value of each pixel into a percentage by dividing it by the largest possible value in the sum of the values of all species using the following formula:

$$(PV \div MV) \times 100 \div 2$$

Where: PV = Pixel value, MV = Maximum value of a pixel within the map, 100 = transformation of the value into a percentage, 2 = transformation of the percentage by 50%.

The highest possible value on each map represents 50%. In this way, the species richness and value of the ecosystem services were equally relevant for the selection of priority areas. Overlapping the two maps, we have a map with pixels that can reach up to 100% priority. We chose to exclude the abundance map from the selection of priority areas as this is a proxy for ecosystem services, resulting in a correlation of 0.998 with the ecosystem services map. With the percentage map, we added a layer map representing all the existing protected areas in the Atlantic Forest biome. From this, we extracted the percentage data, where we analyzed the areas that present the greatest conservation urgency. In this way, we verify the efficiency of the current protected areas in the Atlantic Forest (Supplementary File 5).

RESULTS

Our predictions suggest that the abundance of phyllostomid bats will be concentrated at the latitudinal extremes (northern and southern) of the distribution of the Atlantic Forest. Both in the optimistic and in the pessimistic scenario, the abundance of bats decreases in the central part of the current distribution (Figure 2). Another pattern that can be seen in all future projections of abundance is the increase in abundance in the area that comprises the Serra do Mar ecoregion, where the current model does not predict abundance. In addition, there is an increase in the abundance in the western direction of the distribution of the Atlantic Forest in future scenarios. In the projection of the current scenario, abundance is concentrated in the eastern region of the biome's distribution.

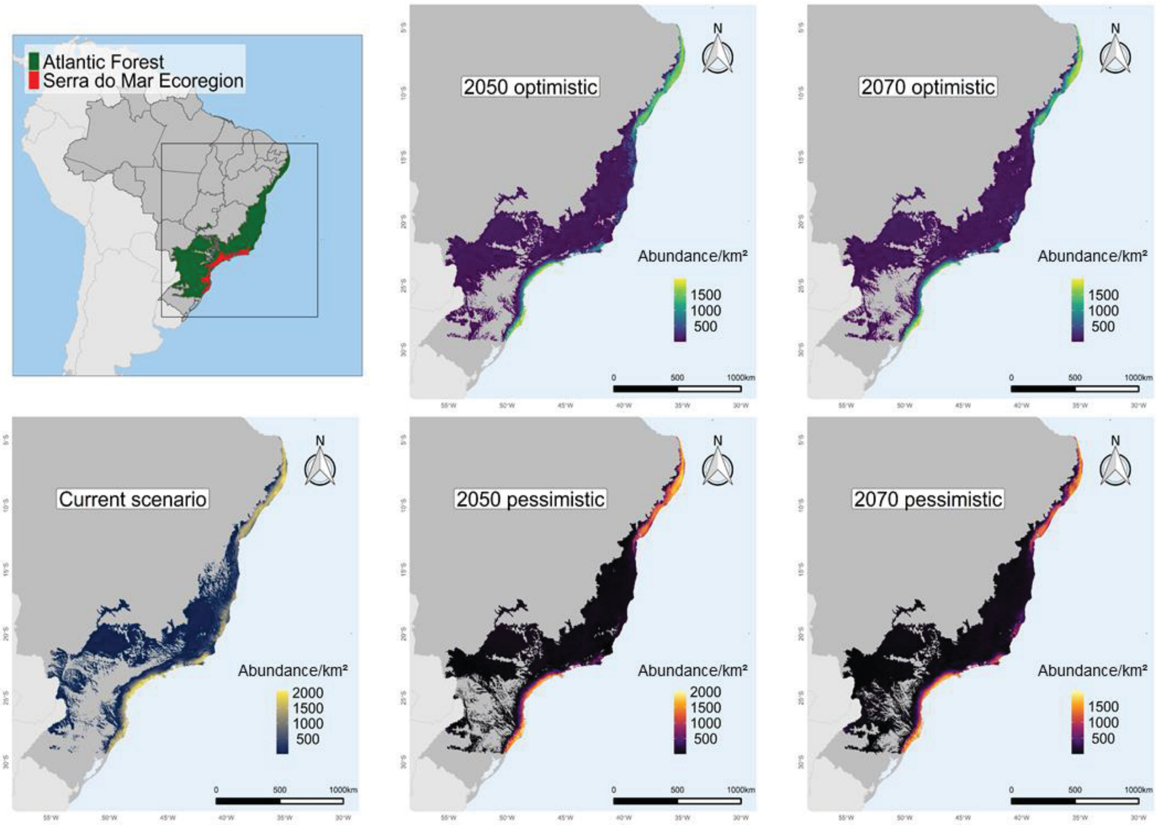


Figure 2: Projected abundance of the phyllostomid bats species selected for this study in current and future climatic scenarios. Yellow scale represents current scenario, green scales represent optimistic scenario, and red scales represent pessimist scenario.

Unlike what was observed for abundance, the highest values of species richness were distributed over the entire Atlantic Forest coastline (Figure 3). In comparison to what was observed in the abundance projections, in the species richness maps the values also tend to increase towards the western distribution region, a pattern that can be observed more clearly in the most pessimistic scenarios.

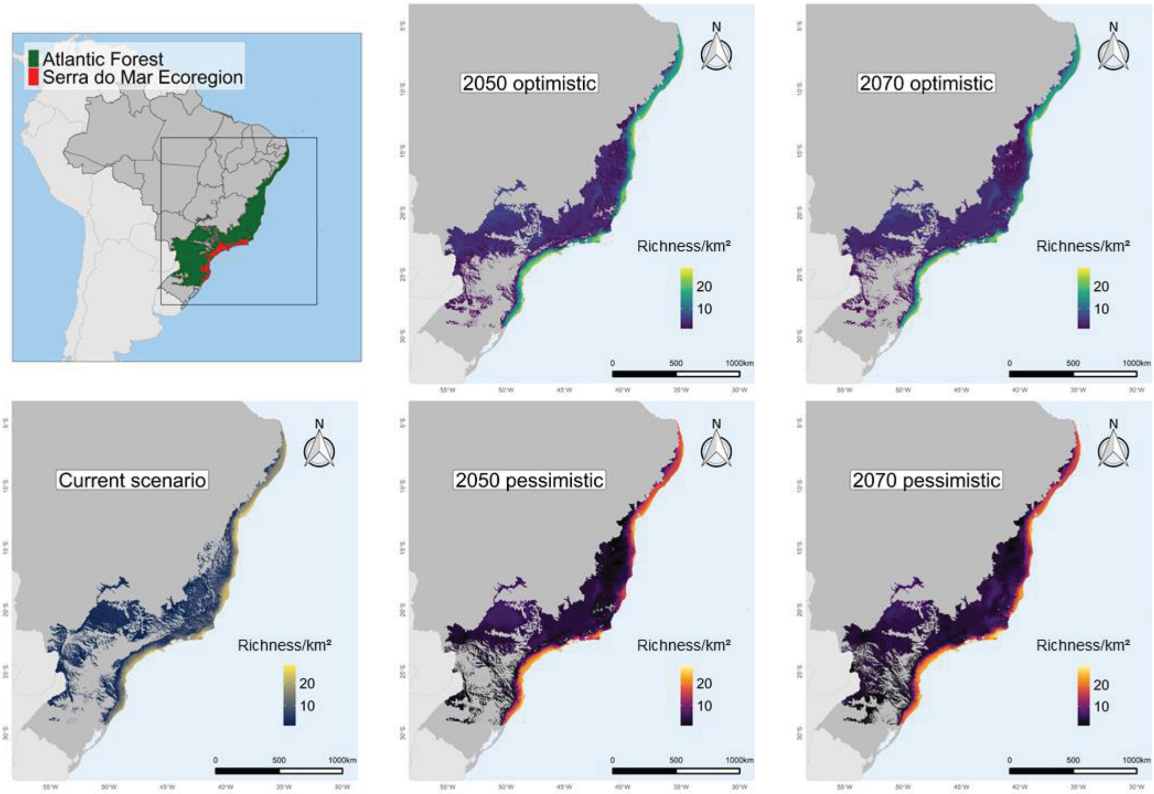


Figure 3: Projected richness of the phyllostomid bats species selected for this study in current and future climatic scenarios. Yellow scale represents current scenario, green scales represent optimistic scenario, and red scales represent pessimist scenario

Our maps of projected value of ecosystem services provided by bats in all five scenarios resemble the projection maps of abundance (Figure 4). Likewise, the highest values of ecosystem services provided are found mainly at the northern and southern edges of the Atlantic Forest, with lower values towards the central region. Maps for each ecosystem service value can be seen in supplementary file 6.

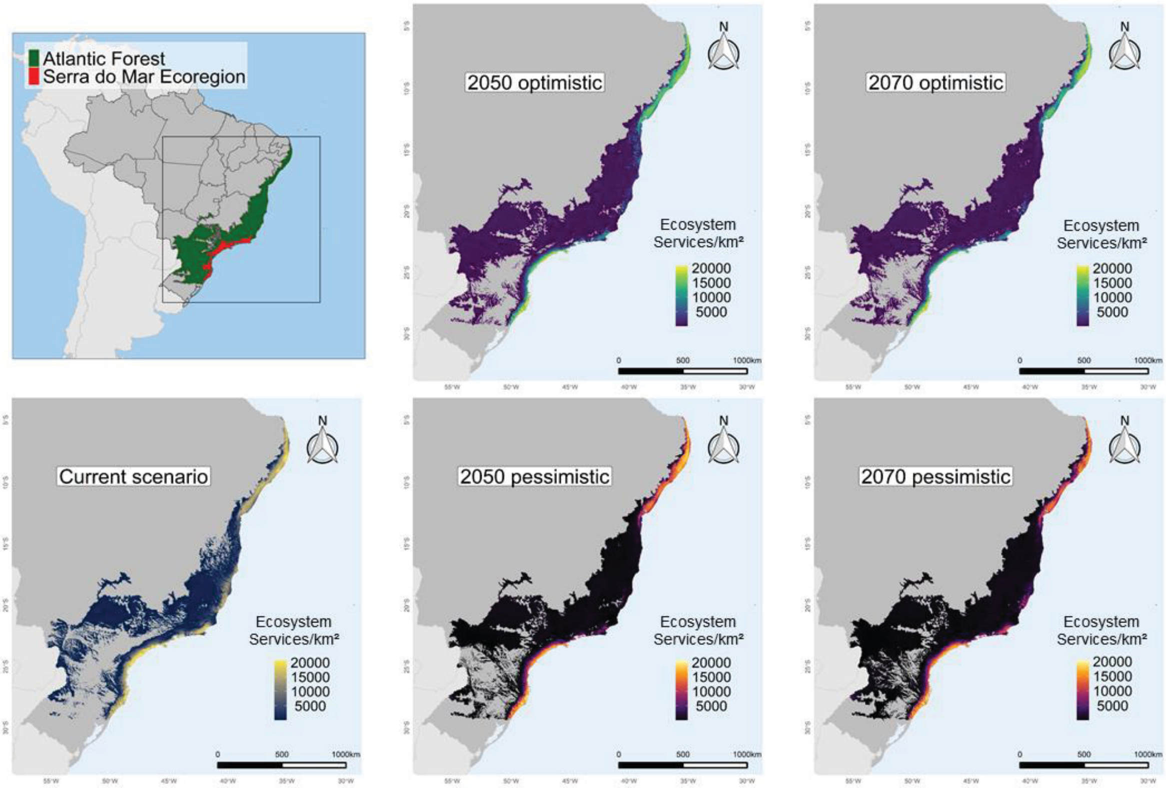


Figure 4: Projected ecosystem services of the phyllostomid bats species selected for this study in current and future climatic scenarios. Yellow scale represents current scenario, green scales represent optimistic scenario, and red scales represent pessimist scenario

In addition to the change in the distribution of species richness, abundance, and ecosystem services, we can observe a steep loss of ecosystem services and abundance of individuals, reaching a reduction of approximately 31% in abundance and 32% in ecosystem services provided by 2070 (Table 2). Although the bats' distribution area in the Atlantic Forest apparently tends to increase, these values are related only to a few species that display an increase in their distribution area.

Table 2: Aggregated values of abundance, distribution area and ecosystem services of all analyzed species of phyllostomid bats in Atlantic Forest biome.

	Nowadays	2050 Optimistic	2070 Optmistic	2050 Pessimist	2070 Pessimist
Abundance (millions Individuals)	276.49	211.48	186.38	195.11	197.97
Area (millions Km²)	5.82	6.73	6.08	6.47	7.69
Ecosystem services (billions U$)	2.83	2.15	1.89	1.97	1.99

Ten species showed an increase in geographic distribution: *Artibeus planirostris* (Spix, 1823), *Artibeus cinereus* (Gervais, 1856), *Chiroderma doriae* Thomas, 1891, *Chiroderma villosum* Peters, 1860, *Glossophaga soricina* (Pallas, 1766), *Lonchorhina aurita* Tomes, 1863, *Lophostoma brasiliense* Peters, 1867, *Mycronicteris microtis* Miller, 1898, *Phyllostomus hastatus* (Pallas, 1767) and *Platyrrhinus recifinus* (Thomas, 1901)(Table 3). Of the 30 species analyzed, 20 (66%) of them show a reduction in the area of life and in the provision of ecosystem services (Table 3). In addition, of the three species with a predominantly nectarivorous habit, two of them show a decrease in the distribution area and in the provision of ecosystem services (Table 3). Regarding species threatened with extinction according to IUCN, all of them show a decrease both in the area of distribution and in the provision of ecosystem services considering all the proposed climatic scenarios (Table 3).

Table 3: Average percentage of change of habitat area and ecosystem services (ES) in each proposed climate scenario with food habit and conservation status of each species (LC = Least Concern, DD = Data Deficient).

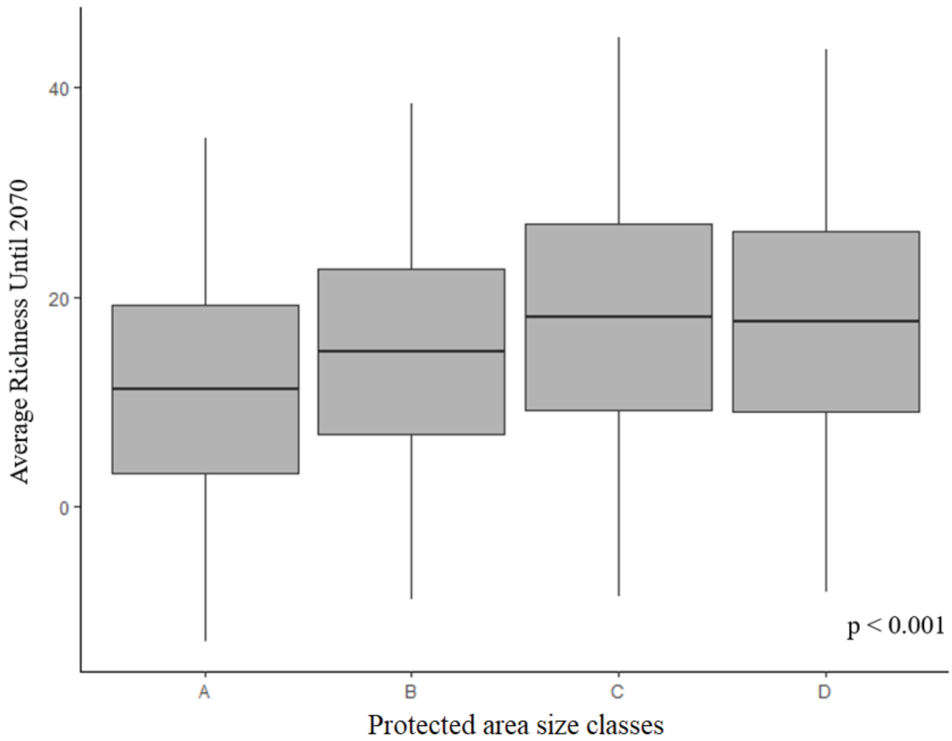
Species	Food habit	Conservation Status	2050		2070	
			Area	ES	Area	ES
Anoura caudifer (É. Geoffroy, 1818)	Nectarivory	LC	-32.27%	-20.57%	-11.81%	-14.42%
Anoura geoffroyi Gray, 1838	Nectarivory	LC	-45.58%	-43.44%	-50.04%	-44.85%
Glossophaga soricina (Pallas, 1766)	Nectarivory	LC	170.13%	68.29%	191.31%	66.83%
Artibeus cinereus (Gervais, 1856)	Frugivory	LC	15.52%	28.44%	17.66%	22.33%
Artibeus fimbriatus Gray, 1838	Frugivory	LC	-66.44%	-60.75%	-66.61%	-61.21%
Artibeus lituratus (Olfers, 1818)	Frugivory	LC	-32.55%	-32.69%	-35.21%	-39.52%
Artibeus obscurus (Schinz, 1821)	Frugivory	LC	-23.94%	-33.03%	-26.68%	-39.03%
Artibeus planirostris (Spix, 1823)	Frugivory	LC	174.01%	216.44%	192.40%	226.54%

Carollia brevicauda (Schinz, 1821)	Frugivory	LC	-17.70%	-26.90%	-15.59%	-24.90%
Carollia perspicillata (Linnaeus, 1758)	Frugivory	LC	-29.33%	-38.79%	-31.64%	-44.80%
Chiroderma doriae Thomas, 1891	Frugivory	LC	94.62%	145.90%	103.19%	150.82%
Chiroderma villosum Peters, 1860	Frugivory	LC	160.52%	156.71%	170.27%	157.92%
Platyrrhinus lineatu s(É. Geoffroy, 1810)	Frugivory	LC	-23.82%	-33.07%	-39.54%	-40.41%
Platyrrhinus recifinus (Thomas, 1901)	Frugivory	LC	17.01%	15.88%	21.21%	18.20%
Pygoderma bilabiatum (Wagner, 1843)	Frugivory	LC	-22.79%	-10.84%	-26.46%	-18.02%
Rhinophylla pumilio Peters, 1865	Frugivory	LC	-8.45%	-9.84%	-2.97%	-4.12%
Sturnira lilium (É. Geoffroy, 1810)	Frugivory	LC	-46.70%	-48.74%	-43.00%	-51.23%
Sturnira tildae de la Torre, 1959	Frugivory	LC	-45.42%	-38.45%	-41.11%	-38.82%
Vampyressa pusilla (Wagner, 1843)	Frugivory	LC	-61.38%	-51.75%	-60.67%	-52.47%
Lonchorhina aurita Tomes, 1863	Insectivory	LC	63.82%	41.50%	64.49%	37.26%
Lophostoma brasiliense Peters, 1867	Insectivory	LC	259.24%	146.46%	285.69%	165.19%
Lophostoma silvicola d'Orbigny, 1836	Insectivory	LC	-35.93%	-43.16%	-33.72%	-40.83%
Micronycteris hirsuta (Peters, 1869)	Insectivory	LC	0.98%	-10.64%	3.63%	-8.36%
Micronycteris megalotis (Gray, 1842)	Insectivory	LC	-25.99%	-40.62%	-28.59%	-43.28%
Micronycteris microtis	Insectivory	LC	88.13%	-13.65%	121.03%	9.47%

Miller, 1898						
Mimon bennettii (Gray, 1838)	Insectivory	LC	-22.11%	-29.73%	-37.77%	-46.53%
Phyllostomus discolor Wagner, 1843	Insectivory	LC	-32.66%	-49.87%	-31.87%	-55.48%
Phyllostomus hastatus (Pallas, 1767)	Insectivory	DD	57.47%	28.27%	91.91%	46.58%
Tonatia bidens (Spix, 1823)	Insectivory	LC	-32.95%	-22.79%	-31.62%	-25.01%
Tonatia saurophila Koopman & Williams, 1951	Insectivory	DD	-38.78%	-39.97%	-42.55%	-42.27%

Although the standard deviation between the size groups of the protected areas is high, our results suggest that there is a significant relation between the size of the protected areas and the estimated species richness (Figure 5).

Figure 5: Graphic represention of the relation between size of protected areas and species richness of phyllostomid bats inside those areas in Brazilian Atlantic Forest biome.



Applying the post-hoc Tukey's test, we can identify that all areas above 100 km have a higher estimated species richness than protected areas with up to 100 km. In contrast, classes of protected areas with an area greater than 100 km did not show any significant difference between them (Table 4).

Table 4: Comparison among pairs of size classes of protected areas in Brazilian Atlantic Forest, values represent scores of ANOVA with permutations.

Comparison between categories	Adjusted p value
B-A	<0.001
C-A	<0.001
D-A	<0.001
C-B	0.246
D-B	0.284
D-C	0.997

Considering the projections of richness and ecosystem services provided in all proposed climate scenarios, our map of overlapping areas between ecosystem services and richness provided by phyllostomid bats in Atlantic Forest highlights the importance of coastal areas and latitudinal extremes within the distribution of the Atlantic Forest biome (Figure 5).

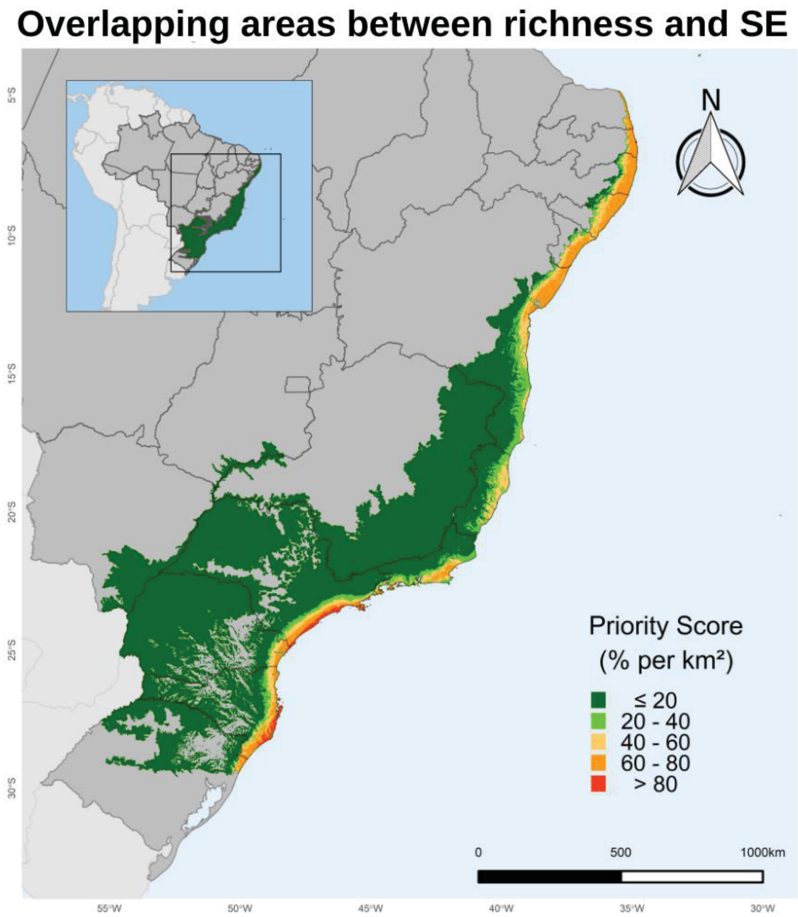


Figure 6: Overlapping areas between richness and ecosystem services provided by phyllostomid bats in Brazilian Atlantic Forest biome.

According to what was observed in the map of overlapping areas for conservation until 2070, the coast of the states of Santa Catarina, São Paulo, Rio de Janeiro, Bahia, Sergipe, Alagoas, Pernambuco and Paraíba stands out as the greatest holders of priority for conservation considering species richness and ecosystem services provided by bats. The states that make up the limits of the Serra do Mar ecoregion seems to be particularly important, a region that will likely maintain the greatest species richness and provision of ecosystem services in a future affected by climate changes.

DISCUSSION

Our projections suggested a concerning average reduction in ecosystem services of about US$ 900 million and a reduction in bat abundance in approximately 87 million individuals by 2070 in the Atlantic Forest. These numbers show the great ecological and economic importance of this group, as well as the drastic reduction in the number of bats in the Atlantic Forest according to climate change. Although some underestimates the importance of conservation – particularly nowadays in Brazil (Tomé and Haddad, 2019), our results reiterate the importance of conservation also for the country's economy, a fact corroborated by other studies (Mertz et al., 2007; Christie et al., 2012). Values can reach exponentially higher figures when considering other factors such as: soil fertility, food security, resistance to insecticides, cultural and tourism services, guano and diseases control (Wheelan et al., 2008; Ghanem and Voigt, 2012). All of ecosystem services bring direct and indirect benefits to human well-being, being indispensable factors in sustainable socioeconomic development (Abson et al., 2014; Schröter et al., 2017). We reiterate that our projections were conservatively made, and only for the Atlantic Forest biome. Considering other ecosystem services, biomes and taxonomic groups, ecosystem services provided in Brazil is very likely incalculable compared to gross world product.

Our findings suggest that even with climate change, there is a maintenance of species richness along the entire coastline of the Atlantic Forest biome, while the highest values of ecosystem services tend to be concentrated in the regions closest to the latitudinal extremes. Such findings are corroborated by studies with different taxa that suggest that this pattern of change in distribution is determined by the process of biotic homogenization (Menéndez et al. 2006, Davey et al. 2012, Savage and Vellend, 2015, Batista et al., 2021). Furthermore, as we analyze the entire biome, this pattern can also be influenced by the geographic scale of the analyses (Batista et al., 2021). The present study is congruent with what other studies have identified (McKinney and Lockwood, 1999, Clavel et al., 2011), since our data suggest a reduction in the geographic distribution of most of the studied species, while few species increase their distribution in up to 285%, showing the biotic homogenization process. In addition to reducing biodiversity, the process of biotic homogenization can likewise compromise stability, adaptability, and ecosystem functions (Olden, 2004).

Our maps also show the increased distribution of bats in areas with high altitude, as in the case of expansion in distribution covering the western region of Serra do Mar. This pattern is equally corroborated by other studies, which suggest that where today only specialist species of habitat occur, in a future of climate change, generalist species will also colonize, further accentuating the biotic homogenization in these locations (Parmesan, 2006; Moritz et al., 2008; Chen et al., 2011). Furthermore, the exclusion of species in certain locations can cause other functionally redundant species to take their role in ecological functions, stabilizing the species loss process (Walker, 1992).

Regarding the loss of species, 66% of them show a reduction in their area of distribution in some of the proposed climatic scenarios. Of the three predominantly nectarivorous species, two (*Anoura geoffroyi* Gray, 1838 and *Anoura caudiffer* (É. Geoffroy, 1818)) show reductions of more than 30% in their range, while *Glossophaga soricina* (Pallas, 1766) shows an increase of up to 190% in their range. Such evidence reaffirms the theory of Walker (1992), which suggests that redundant species functionally and with greater environmental plasticity tend to assume the role of the ecological functions of that functional group – also in line with biotic homogenization phenomenon (McKinney and Lockwood, 1999). In addition, all species threatened with extinction to some degree, lose habitat area, showing that species with greater habitat specialization tend to lose range for more generalist species (Warren et al., 2001; Devictor et al., 2008). For the species that present an increase in the distribution of species, *Artibeus planirostris* (Spix, 1823), *Chiroderma doriae* Thomas, 1891, *Chiroderma villosum* Peters, 1860, *G. soricina*, and *Lophostoma Brasiliense* Peters, 1867 stand out, presenting an increase in geographic distribution above 90%. Such evidence can be explained by two factors: I - habitat plasticity, or II - favorable climate changes for the species' biology. Thus, even if these species do not have a large seed dispersal capacity in the current scenario, climate change can expand the tolerance limit of these species, causing their range of distribution to be expanded. In a future scenario, this homogenization process may be even more worrying if we consider interspecific competitions that can further decrease species richness (Robertson et al., 2013).

Such evidence of biotic homogenization reinforces the need to maintain protected areas (Rooney et al., 2007) in order to promote local-distributed and endemic species. Furthermore, our results suggest that, like the Primack and Rodrigues (2001) theory, it is more advantageous in terms of biodiversity maintenance to establish a larger number of smaller conservation units than few larger conservation units. Our findings suggest that protected areas with over 100 km² of area, are already playing an important role in maintaining the richness of bat species in the Atlantic Forest. Therefore, choosing the location where a protected area will be implanted can be just as important as its size.

We argue that our map of overlapping areas of richness and ecosystem services provided by phyllostomid bats until 2070 can be an used as a tool in future conservation planning. According to the data extracted from this map, the protected areas that are found on the coast of the Atlantic Forest and in the continuum of vegetation close to the Serra do Mar corridor of biodiversity (Rocha et al., 2003), are areas of high species richness and values of provision of ecosystem services. These data are even more relevant if we consider that coastal ecosystems in Brazil are poorly studied and severely threatened by urbanization (Rocha et al., 2007). Although areas located more west may concentrate lower values of richness and ecosystem services, these places may display the presence of more specialized species of habitat, such as endemic species and with a more restricted distribution area. Thus, even the furthest areas off the coast of the Atlantic Forest can be instrumental in maintaining biodiversity. However, this information still needs to be confirmed by field studies. Even though there are information gaps about species biodiversity in the Atlantic Forest, our map of overlapping areas can serve as a subsidy for decision-makers to efficiently choose the location for the establishment of new protected areas, as well as encourage maintenance and increased protection of areas that play a key role in maintaining biodiversity.

Although our study shows important data for the conservation of phylostomid bats in the Atlantic Forest, there are variables that cannot be disregarded. The geographic scale in which the study was carried out, using the entire extension of the Atlantic Forest, can lead to the identification of patterns that would not have been detected at other geographic scales (Batista et al., 2021). In addition, like most macroecological studies, the generality of the data can mask factors that more specific data would evidence. New approaches that consider, individually for each species, ecosystem values, home ranges, population size, and distribution predictors can arrive at more accurate values in both species' distribution and ecosystem service values. we believe that the present study can be a good starting point for the creation of new databases that will allow the application of this approach in a more realistic and less conservative way, as was our proposal.

Especially in Brazil, studies that show how important it is to conserve and maintain minimally balanced environments for the provision of ecosystem services are indispensable (Pereira et al., 2020). When we bring the monetary perspective to ecosystem services, we bring the theme closer to everyday life, in addition to directly representing the importance of conservation (Fisher et al., 2009; Poppy et al., 2014). Although ecosystem services are indispensable for the production of inputs and for agriculture, understanding the importance of ecosystem services related to regulatory and cultural services, for example, are as important as provision services, possibly generating equal or greater monetary values (Alamgir et al., 2016). Thus, the application of the cost replacement method can be a comparison tool, being useful and reliable to directly contribute to decision making and the population's awareness of the most diverse ecosystem services (Brännlund and Kriström, 1998; López-Morales and Mesa-Jurado, 2017).

New studies that assess the value of ecosystem services are essential, as well as studies that carry out experiments to calculate increasingly accurate estimates in different taxa. It is worth mentioning that the present study was only possible by compiling the information present in data-papers with bat data in the Atlantic Forest, recently published (Muylaert et al., 2017; Gonçalves et al., 2018). We believe that data-papers represent a reliable source of information that is extremely useful especially for environments that have not been studied much, such as the Atlantic Forest, as these provide data compiled and verified by researchers. The only way to be able to save a biome as threatened as the Atlantic Forest, is through knowledge, the urgent change in the way of thinking and acting, and the collaboration between researchers, society, and decision-makers (Díaz et al., 2019). We believe that the present study can serve as a subsidy for the maintenance and implementation of future protected areas, as well as to demystify the role of bats, and contribute to the awareness of the importance of conserving and maintaining the balance of ecosystem services.

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SUPPLEMENTARY MATERIAL

https://drive.google.com/drive/folders/1zBlyp2EiDTu6cdSh52Wrild8v1u8KVNd?usp=sharing