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Delimitando áreas de ignorância: bases eletrônicas de dados e conservação de primatas na Bacia Amazônica

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Manaus, Amazonas

Fevereiro, 2019

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Sinopse: Este trabalho avaliou as informações digitalmente acessíveis sobre registro de ocorrência de espécies de primatas na bacia Amazônica. Foram identificadas as áreas de lacuna de registros, bem como a vulnerabilidade das mesmas em termos de porcentagem de área protegida e desmatada.

Palavras-chave: Bacia Amazônica, informações digitalmente acessíveis, primatas, áreas protegidas, desmatamento

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RESUMO

O desmatamento é uma das maiores ameaças para a Bacia Amazônica e sua biodiversidade. Áreas protegidas representam a principal estratégia atual para conservação *in situ* da vida selvagem. Com o intuito de estabelecer prioridades para conservação, é necessário primeiro reunir informações biológicas básicas, como por exemplo, registro de ocorrência de espécies. Para auxiliar os tomadores de decisões, tem havido um esforço internacional para disponibilizar digitalmente esse tipo de informação em formatos padronizados. Entretanto, essas informações não são igualmente distribuídas no espaço geográfico. Dessa forma, o presente estudo tem como objetivo avaliar as informações digitalmente acessíveis sobre registros de ocorrência de espécies de primatas amazônicos e identificar regiões de lacunas vulneráveis em termos de porcentagem de área protegida e desmatada. Nós filtramos os dados disponíveis online para reter os registros de ocorrência de primatas, que definimos como uma combinação única de um táxon e um par de coordenadas latitude/longitude. Utilizamos uma grade de 0,25º de resolução para avaliar a escassez geográfica de informação, onde cada célula foi considerada uma unidade amostral. Utilizamos o teste de Mann-Whitney U para comparar a porcentagem de área protegida e desmatada entre as células com e sem registros de primatas. Também calculamos a distância ambiental de cada célula de lacuna (sem registro) para a célula de ocorrência (com registro) mais próxima. Encontramos que apenas 11,31% dos dados disponíveis representam informações relevantes que podem ser utilizadas para planejamento de conservação e estudos ecológicos. Apenas 14 das 122 espécies esperadas possuíam o número mínimo viável de registros (30) para executar modelos de distribuição de espécies. Além disso, 95,56% das células não tiveram nenhum registro de ocorrência, e o Brasil representou a maior área de lacuna comparado com os seis outros países da região amazônica. 64,75% das células possuíram algum grau de proteção, enquanto 46,35% possuíram algum grau de desmatamento. As informações digitalmente acessíveis sobre registro de ocorrência de primatas amazônicos estão longe do ideal, porém existe um potencial para esse tipo de informação reduzir o déficit Wallaceano (i.e. a falta de conhecimento sobre a distribuição das espécies). Além disso, a áreas protegidas na Bacia Amazônica formam uma extensa malha de proteção, evidenciando seu papel para proteger populações de primatas ainda não registradas.

Palavras-chave: Amazônia, informações digitalmente acessíveis, primatas, áreas protegidas, desmatamento, déficit Wallaceano.

ABSTRACT

Deforestation is one of the major threats to the Amazon Basin and its biodiversity. Managing areas for conservation currently represents the main strategy for *in situ* wildlife protection. In order to establish conservation priorities, it is necessary to gather primary biological information, such as species occurrence records. To help decision-makers, there has been an international effort to make this information digitally available in standard formats. However, such information is not evenly distributed in space, being concentrated mainly in accessible regions. Thus, in the present study, we aim to evaluate digitally accessible information on occurrence records of Amazonian primate species and identify vulnerable lacuna areas in terms of percentage of protected and deforested area. We filtered the online-available data to retain primate records, as we defined as a unique combination of a taxon and a pair of longitude/latitude records. We used a 0.25º x 0.25º grid to evaluate geographical scarcity of information, and each cell was considered a sampling unit. A Mann-Whitney U test was used to compare the percentage of protected and deforested area between cells with and without records. We also calculated the environmental distance from each lacuna cell (without records) to the closest occurrence cell (with records). We found that only 11.31% of available data contained relevant information that could be used for conservation planning and ecological studies. Only 14 of the 122 expected species studied had the minimum viable number of records (30) to perform analysis with species distribution models. Additionally, 95.56% of the cells had no primate occurrence records, and Brazil had the largest lacuna area, compared with the other six countries analysed. Overall, 64.75% of cells had some degree of protection, while 46.35% of cells had some degree of deforestation. Digitally accessible information is far from ideal, but it has the potential to reduce the Wallacean shortfall (i.e. the lack of knowledge of species distributions). Moreover, protected areas form a large network that protectes a great deal of the Basin's area, highlighting its potential to protected primates' populations.

Key-words: Amazon, digital accessible information, primates, protected area, deforestation, Wallacean shortfall.

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INTRODUÇÃO GERAL

A Bacia Amazônica cobre uma área de mais de 6 milhões de km^2 (GOULDING et al., 2003), e é um dos lugares mais biodiversos do planeta (MEYER et al., 2015), lar para mais de 100 espécies de primatas (RYLANDS; MITTERMEIER; SILVA, 2012). Entretanto, o desmatamento representa uma severa ameaça atual e futura para a bacia Amazônica e sua biodiversidade (SOARES-FILHO et al., 2006; OMETTO et al., 2011). Entre 2000 e 2010, cerca de 2,6% da área total da bacia foi desmatada, principalmente no Brasil e na Bolívia (HUANG et al., 2015), especialmente em razão da expansão da fronteira agrícola (SONG et al., 2018). Até o final do século, é projetada uma diminuição de 7 a 34% da área de floresta primária, em comparação com 2009, dependendo do cenário analisado (GUIMBERTEAU et al., 2017). Além disso, mais de 90% do desmatamento na Amazônia Brasileira está concentrado próximo a vias de acesso terrestre, o que é conhecido como "zona acessível" (BARBER et al., 2014; JUSYS, 2018). O desmatamento é considerado a principal ameaça para as espécies de primatas neotropicais, das quais mais de 36% estão ameaçadas, e mais de 60% possuem populações em declínio (ESTRADA et al., 2017).

Uma das principais estratégias para conservação *in situ* da biodiversidade e serviços ecossistêmicos é a criação de áreas protegidas (CHAPE et al., 2005; SOARES-FILHO et al., 2010). Uma área protegida pode ser definida como um espaço geográfico claramente demarcado e dedicado para conservação da natureza em longo prazo (BORRINI-FEYERABEND et al., 2013). A Amazônia é o bioma brasileiro mais protegido, com quase 50% do seu território dentro de áreas legalmente protegidas (OLIVEIRA et al., 2017). Essas áreas podem ser uma de três categorias: a) proteção integral, corresponde às categorias I a IV definidas pela IUCN, onde atividades humanas são restritas, b) uso sustentável, corresponde às categorias V e VI definidas pela IUCN, onde são permitidas atividades extrativistas, e c) terras indígenas, não correspondem a nenhuma categoria definida pela IUCN, porém possui o objetivo de proteger populações indígenas e tem grande potencial de mitigação dos efeitos do desmatamento (DUDLEY, 2008; NOLTE et al., 2013). Estudos recentes mostram que as áreas protegidas possuem um grande papel em reduzir o desmatamento, quando comparado com áreas não protegidas (SOARES-FILHO et al., 2006; NOLTE et al., 2013; BARBER et al., 2014; PFAFF et al., 2014; OLIVEIRA et al., 2017; JUSYS, 2018). Além disso, áreas protegidas representam estratégias importantes para a conservação da biodiversidade amazônica, uma vez que evidências recentes sugerem que a maioria das espécies amazônicas podem ser encontradas dentro de áreas protegidas (OLIVEIRA et al., 2017). Áreas protegidas também podem servir como santuários para a vida selvagem (ESTRADA et al., 2017), como, por exemplo, populações de 2 espécies primatas do velho mundo que permaneceram estáveis dentro das áreas protegidas, enquanto declinaram fora delas (ROVERO et al., 2015).

Com o objetivo de auxiliar os tomadores de decisão a conservarem a biodiversidade de maneira efetiva, os membros da Convenção da Diversidade Biológica, que ocorreu em Aichi, Japão, estabeleceram 20 objetivos para serem alcançados até 2020 (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2014). O objetivo Aichi de número 19 estabelece que o conhecimento acerca da biodiversidade deve ser amplamente compartilhado (cdb.int/sp/targets/rationale/target-19). Essa iniciativa levou a esforços internacionais com o objetivo de reunir informações biológicas básicas em bancos de dados online e acessíveis, como, por exemplo, Global Biodiversity Information Facility (GBIF), SpeciesLink e VertNet (Jetz, McPherson, & Guralnick, 2012). Atualmente, GBIF sozinho conta com mais de um bilhão de registros de ocorrência, enquanto que VertNet possui mais de 21 milhões e SpeciesLink possui mais de nove milhões de registros (GBIF.ORG, 2019; SPECIESLINK CONSORTIUM, 2019; THE VERTNET STEERING COMMITTEE, 2019). Essas informações digitalmente acessíveis em formatos padronizados (SOUSA-BAENA; GARCIA; PETERSON, 2014; MEYER et al., 2015) tem sido amplamente utilizadas em estudos ecológicos (HORTAL et al., 2015), como, por exemplo, os dados disponíveis em GBIF, por exemplo, foram utilizados em mais de três mil artigos científicos (GBIF.ORG, 2019).

Entretanto, informações digitalmente acessíveis não são igualmente distribuídas geograficamente, gerando grandes áreas com escassez de informação. Conhecido como déficit Wallaceano (LOMOLINO, 2004), ele reflete a escassez de conhecimento sobre a distribuição de espécies (WHITTAKER et al., 2005; HORTAL et al., 2015). Registros de ocorrência de espécies se concentram principalmente em regiões acessíveis, em decorrência de razões financeiras e logísticas, especialmente nos trópicos (MEYER et al., 2015), e mapas de diversidade frequentemente ilustram de fato acessibilidade ao invés de informação biológica (NELSON et al., 1990; OLIVEIRA et al., 2016; ESTRADA et al., 2017). Estudos anteriores mostraram que informações digitalmente acessíveis sobre distribuição de espécies não são uniformemente distribuídas ao longo da Bacia Amazônica, se concentrando próximo de grandes centros urbanos, estradas e rios navegáveis (NELSON et al., 1990; HOPKINS, 2007; SCHULMAN; TOIVONEN; RUOKOLAINEN, 2007; PITMAN et al., 2011; OBERMULLER et al., 2014; SOUSA-BAENA; GARCIA; PETERSON, 2014; RIBEIRO et al., 2016). No

Brasil, a densidade de registros de ocorrência de animais está correlacionada com a densidade de vias terrestres, e consequentemente, a Amazônia, o bioma com a menor malha viária, é também o bioma com menor densidade de registros (OLIVEIRA et al., 2016). Além disso, a densidade de registros de ocorrência é maior dentro das áreas protegidas brasileiras do que fora delas, e, novamente, as áreas protegidas na Amazônia possuem a menor densidade de registros entre os biomas brasileiros (OLIVEIRA et al., 2017). Primatas neotropicais não são exceção para esse padrão, uma vez que estudos ecológicos se concentram em um pequeno número de locais de coleta, principalmente próximos de grandes centros urbanos (HAWES; CALOURO; PERES, 2013). Além disso, diferentes taxa possuem diferentes padrões de concentração de registros de ocorrência, de maneira que estudos táxon-específicos são necessários (VALE; JENKINS, 2012).

As mais de 100 espécies de primatas amazônicos estão distribuídas em 17 gêneros nas famílias Aotidae, Atelidae, Callitrichidae, Cebidae e Pithecidae (RYLANDS; MITTERMEIER; SILVA, 2012; BYRNE et al., 2016; RYLANDS et al., 2016). Esses animais exercem um papel crucial nos ecossistemas amazônicos, agindo como dispersores e predadores de sementes, contribuindo assim para manutenção das florestas (CHAPMAN, 1989; NORCONK; GRAFTON; CONKLIN-BRITTAIN, 1998; CLARK; POULSEN; PARKER, 2001; NUÑEZ-ITURRI; HOWE, 2007; BARNETT et al., 2012). Além disso, são animais carismáticos que podem funcionar como espécies guarda-chuva, como, por exemplo, no caso da Reserva de Desenvolvimento Sustentável Mamirauá, criada em 1986 no estado do Amazonas principalmente para a proteção do uacari-branco (*Cacajao calvus calvus*) (QUEIROZ, 2005).

Finalmente, sabendo que o conhecimento é enviesado no espaço, e o desmatamento também o é, que uma abordagem táxon-específica é mais apropriada numa avaliação do conhecimento e do potencial das áreas protegidas para preservação da vida selvagem, buscamos nesse trabalho avaliar as informações digitalmente acessíveis sobre ocorrência de primatas da bacia Amazônica e identificar as áreas vulneráveis.

OBJETIVOS

O objetivo geral deste trabalho foi avaliar as informações digitalmente acessíveis sobre ocorrência de primatas da bacia Amazônica e identificar as áreas vulneráveis. Os objetivos específicos do estudo são:

a) Avaliar a qualidade dos registros de ocorrência de primatas amazônicos nas principais plataformas digitais;
b) Identificar as lacunas geográficas no banco de dados;
c) Comparar a vulnerabilidade, em termos de porcentagem de área protegida e desmatada, entre as regiões com e sem registros de ocorrência de espécies de primatas amazônicos;
d) Identificar as áreas com lacunas de conhecimento com maior vulnerabilidade.

Capítulo 1

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Article

Defining areas of ignorance: electronic data bases and primate conservation in the Amazon Basin

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Abstract To protect biodiversity from deforestation pressure it is necessary to set conservation priorities. To do so, there has been an international effort to gather primary biological information in online databases. However, such information is not evenly distributed in space. Here we aimed to evaluate the digitally accessible information (DAI) for occurrence records of Amazonian primate species and identify vulnerable lacuna areas in terms of percentage of protected and deforested area. We filtered the online-available data to retain primate records, defined as a unique combination of a taxon and a longitude/latitude data pair. We used a 0.25º x 0.25º grid to evaluate geographical scarcity of information, and each cell was considered a sampling unit. A Mann-Whitney U test was used to compare the percentage of protected and deforested area between cells with and without records. We found that only 11.31% of available data contain relevant information that can be used for conservation planning and ecological studies. Additionally, 95.56% of the cells had no primate occurrence records. Overall, 64.75%

of cells had some degree of protection, while 46.35% of cells had some degree of deforestation. DAI is far from ideal, but it has the potential to reduce Wallacean shortfalls (i.e. the lack of knowledge of species distributions). Moreover, most of the lacuna area is protected and can reduce the deforestation pressure on primate populations.

Key-words Amazon, deforestation, digital accessible information, Aichi target 19, primates, protected area, Wallacean shortfall

Introduction

The Amazon basin covers an area of more than 6 Mi km^2 (Goulding et al., 2003), and is one of the most biodiverse places on Earth (Meyer et al., 2015), holding over 100 primate species (Rylands et al., 2012). However, deforestation is a severe current and future threat to the Amazon basin and its biodiversity (Ometto et al., 2011; Soares-Filho et al., 2006). Between 2000 and 2010, 2.6% of the total basin area was deforested, mostly in Brazil and Bolivia (Huang et al., 2015), mainly due to the expansion of the agricultural frontier (Song et al., 2018). Overall, by the end of the century, the naturally forested area of the Amazon basin is projected to decrease by anywhere from 7% to 34%, relative to 2009, depending on which scenario is deployed (Guimberteau et al., 2017). Additionally, over 90% of deforestation in the Brazilian Amazon is concentrated near terrestrial access routes, the so-called ‘accessible zone’ (Barber et al., 2014; Jusys, 2018). Deforestation is considered to be the main threat to Neotropical primate species, of which more 36% are now threatened, and over 60% have declining populations (Estrada et al., 2017).

One of the main strategies for *in situ* conservation of biodiversity and ecosystem services is the creation of protected areas (PAs) (Chape et al., 2005; Soares-Filho et al., 2010). A PA can be defined as a clearly demarcated geographical space dedicated to the long-term conservation of nature (Borrini-Feyerabend et al., 2013). The Amazon is the most protected Brazilian biome, with nearly 50% of its territory lying inside PAs (Oliveira et al., 2017). Recent studies have shown that protected areas have a major role in reducing deforestation in the Amazon Basin, compared to unprotected areas (Barber et al., 2014; Jusys, 2018; Nolte et al., 2013; Oliveira et al., 2017; Pfaff et al., 2014; Soares-Filho et al., 2006). Furthermore, PAs constitute key parts of any strategy to conserve Amazonian biodiversity, as recent evidence suggests that most Brazilian Amazon species can be found inside PAs (Oliveira et al., 2017). Additionally, PAs can serve as sanctuaries for wildlife (Estrada et al., 2017), notably so when primate populations remain stable within them, while simultaneously declining in neighbouring unprotected areas (Rovero et al., 2015).

To help decision-makers plan for effective biodiversity conservation, the parties to the Convention on Biological Diversity, held in Aichi, Japan, established 20 targets to be achieved by 2020 (Secretariat of the Convention on Biological Diversity, 2014). Aichi Target 19 states that knowledge related to biodiversity must be shared widely (cdb.int/sp/targets/rationale/target-19). Such initiatives have led to international efforts to gather primary biological information into online-accessible databases, e.g. Global Biodiversity Information Facility (GBIF), SpeciesLink, and VertNet (Jetz et al., 2012). Such digitally accessible information (DAI), digital data accessible in standard formats (Meyer et al., 2015; Sousa-Baena et al., 2014), have been used widely in ecological studies (Hortal et al., 2015).

However, DAI is not evenly distributed in space, generating large areas from which information is lacking. Otherwise known as Wallacean shortfalls (Lomolino, 2004), it reflects the paucity of knowledge concerning species distributions (Hortal et al., 2015; Whittaker et al., 2005). Species distribution records concentrate in accessible regions due to financial and logistic limitations, especially in the tropics (Meyer et al., 2015), and diversity maps can often illustrate accessibility rather than reflect biology (Estrada et al., 2017; Oliveira et al., 2016). Previous studies have confirmed that DAI is also not evenly distributed in the Amazon basin, being concentrated closest to major cities, roads and navigable rivers (Nelson et al., 1990; Hopkins, 2007; Schulman et al., 2007; Pitman et al., 2011; Obermuller et al., 2014; Sousa-Baena et al., 2014; Ribeiro et al., 2016). In Brazil, species record density is correlated with terrestrial access route density, and Amazonia, the biome with the smallest road network, has the lowest record density (Oliveira et al., 2016). Additionally, it is important to identify climatically distinct regions to set priority areas in order to reduce knowledge gap (Sousa-Baena et al., 2013). Moreover, species record density is higher inside PAs in Brazil than outside, and, again, PAs in Brazilian Amazon has lower record densities than PAs in other biomes (Oliveira et al., 2017). Neotropical primates are no exception to this pattern, with ecological studies concentrating at a small number of sites, the majority of which are close to major cities (Hawes et al., 2013). Also, different taxa show different geographical gaps, so taxon-specific studies are needed (Vale & Jenkins, 2012).

Tropical forests, especially in the Amazon Basin, represent large areas of gaps of information on species distributions. The sites where there are species records are in the accessible zone (i.e. near terrestrial routes and navigable rivers), the same area that concentrates greatest deforestation pressure. Consequently, in the current study, we aimed to evaluate the quality of DAI on Amazonian primate occurrence, identify the geographical gaps within the dataset, compare vulnerability in terms of percentage of protected and deforested area between sites with and without species records, identify the gap areas environmentally distinct from sites with records and highlight knowledge gap within areas of high vulnerability.

Methods

Dataset

Occurrence records were obtained from the following online databases: GBIF (www.gbif.org/ - 13/08/2017), SpeciesLink (splink.cria.org.br/ - 18/07/2017) and VertNet (www.vertnet.org/ - 18/07/2017), as these are the main databases for vertebrate occurrence records. We selected records for Order Primates, located on the Amazon Basin countries (Brazil, Bolivia, Colombia, Ecuador, Guyana, Peru and Venezuela), categorized in the databases as: 'preserved specimen', 'human observation' or 'machine observation'. Records were plotted against the Amazon Basin map on Quantum GIS, and those that lay outside the Basin were excluded.

Each record represents a unique combination of a taxon and a pair of latitude/longitude coordinates. Records without coordinates were excluded. The location of each record was checked by comparing described locality with available coordinates. In case of a mismatch between locality and available coordinates, records were georeferenced using National Geospatial-Intelligence Agency (geonames.nga.mil/namesgaz), GeoNames (www.geonames.org) and Google Maps (www.google.com.br/maps). When it was not possible to validate or georeference the locality, the record was excluded. Records of captive animals were also excluded.

We also checked taxonomy, and records were classified to species level as most data was at this taxonomic level, while subspecies distribution limits were often blurred. To confirm taxonomy, we used the International Union for Conservation of Nature distribution maps as the geographic standard. When those maps were unavailable or out of date, we used distribution maps from taxonomic literature (Table S1). We confirmed the taxonomy when the record of a given species was within this species' distribution. In cases of sympatry, we verified whether there was a visual record (e.g. photographs), and/or if significant morphological distinction existed between species, so avoiding misidentification. In case of possible misidentification, and with a valid locality, the record was classified at genus level. We included records outside of a species known distribution only when there were a valid locality and no possibility of misidentification (as stated above). Only species identified up to the end of 2018 were included (e.g. not Boubli et al., 2019).

Analysis

To identify gaps in the knowledge of the geographical distributions of species and of threats, we built a 0.25º x 0.25º latitude/longitude grid, where each cell was considered a unit of analysis. Previous studies (e.g. Pinto et al., 2014) have shown that coarser grain tends to inflate species representation, and finer grid resolution would have a more realistic result. We included a cell if at least 25% of its area overlaid with the Amazon Basin. We then calculated the number of records and number of species per grid cell.

We considered lacuna (i.e. knowledge gap) to be a grid cell without occurrence records. For each cell, we calculated: 1) the percentage area inside protected areas (from World Database on Protected Areas), and 2) the percentage of area deforested (from Song et al., 2018). To test if there was a difference in protected and deforested area between cells with and without primate records, we used a Mann-Whitney U test, as data did not have a normal distribution, run in R (R Foundation for Statistical Computing, Vienna, Austria, v. 1.1.463).

To calculate the environmental distance from each lacuna cell to the nearest occurrence cell, we first identified the nearest occurrence cell as the one with the minimum Euclidean distance. Then, we characterized the Amazon Basin's climate through a PCA using the 19 bioclimatic variables from Worldclim (http://www.worldclim.org/). We retained the first four components of the PCA and calculated the minimum Euclidean distance between each lacuna cell to the nearest occurrence cell in this 4-dimensional space. All procedures were performed in Quantum GIS (v.2.18.1).

Results

Raw data provided 21,616 records. After all forms of data cleaning had been conducted (see methods), a total of 2,446 records remained, of which 2,406 included identification to species level. Thus, filtered records represented approximately 11.31% of the original records. Filtered data retained 92 of 122 primate species expected to occur in the Amazon Basin, according to followed taxonomies (Table S1). The number of records per species ranged from 1 to 389, with *Leontocebus nigricolis* being the species with the most records. Nearly half of the species had five records or less, and only 14 (11.47%) species had 30 records or more, the minimum viable number for species distribution model analysis (Fig. 1) (Franklin, 2010). Records came from 29 different sources, including museums, university collections, online databases, private enterprises and government agencies (Table 1).

The total number of grid cells across the study region was 7,959, of which only 353 held information on primate occurrence. This means that 95.56% of the studied area is lacuna in terms of DAI for the occurrence of Amazonian primates (Fig. 2). Records per cell ranged from 1 to 308. Proportionally, Brazil had the largest relative lacuna area (98.05% - 4932), followed by Peru (96.39% - 1290), Bolivia (95.34% - 988), Venezuela (95.18% - 83), Guyana (92.85% - 28), Colombia (87.3% - 457) and, lastly, Ecuador (81.76% - 181). Additionally, occurrence cells concentrated, especially, near Iquitos, Peru; southern Peru; southern and southwestern Colombia; northern Ecuador; and southern Acre, Brazil (Fig. 2).

Overall, 64.75% of cells had some degree of protection. Most protected areas occurred in the north and centre of the Amazon Basin, mostly in Brazil (Fig. 3). Of the lacuna region, 2,675 (35.17%) of the cells had 0% area under protection, 1,245 (16.37%) had 0.01 to 25% of the area under protection, 586 (7.7%) had 25.01 to 50%, 558 (7.33%) had 50.01 to 75%, and 2,542 (33.42%) had 75.01 to 100% of their area under protection. Occurrence cells had a lower percentage of protected area than lacuna cells c (Figure 3).

On the other hand, 46.35% of cells had some degree of deforestation over the surveyed period. Cells with the highest percentage of deforestation were in the southeast of the basin, mainly in Brazil and Bolivia, the so-called ‘deforestation arc’ (Fig. 4). Of the lacuna region, 4,059 (53.36%) cells had 0% of their area deforested during the surveyed period, 3,053 (40.13%) had 0.01 to 20% of their area deforested, 379 (4.98%) had 20.01 to 40%, and 115 (1.51%) had 40.01 to 63% of their area deforested. Occurrence cells had a lower percentage of deforested area than lacuna cells ($\chi^2 = 5.5616$, df = 1, p-value = 0.018) (Fig. 5).

In terms of environmental distance from occurrence cells, most of the Amazon Basin is relatively homogenous. The most climatically distinctive regions are in southern and central Peru; southern Bolivia; western Ecuador, western Colombia, near the Andes; and the southeast part of the basin, in Brazil (Fig. 6).

Discussion

Lack of knowledge on species distribution can have a major impact on conservation effectiveness, and DAI databases have a great potential to overcome Wallacean shortfall (Hortal et al., 2015). However, our study highlights the geographical scarcity of DAI for Amazon primate occurrence records. Nearly 95% of the Amazon Basin area, at a 0.25º resolution, has no primate records available on the main digital databases. Of all available information, only 11.31% of the data represented unique information, less than the 17.46% previously found for tree species at a global scale (Serra-Diaz et al., 2017). In our database, most records did not have coordinates or enough information on their localities, and, since they could not be validated, they were excluded. Moreover, many records were duplicated in more than one database, and duplicates were excluded. Although DAI of Amazonian primates may have a large amount of data, only a small portion represents valid information that can be used effectively for ecological studies and conservation planning.

Of the 14 species with the minimum viable number for SDMs analysis, *Leontocebus nigricolis* had the highest number of records, however, this is probably artefactual, as most records of this species are in the area with the highest record density. This area is in the Peru-Colombia border, near the municipality Letícia and the Amacayacu National Park. It has had continuous monitoring for 10 years and records are highly geographically proximate, but as we defined a record as a unique combination of a taxon and a pair of latitude/longitude coordinates, they were retained after data filtration. This may also hold for the following species that also had high numbers of records: *Alouatta seniculus*, *Saimiri cassiquiarensis*, *Cheracebus lucifer*, *Pithecia hirsuta*. Bombi et al. (2011) indicated that species distribution models are a method more suited to identifying priority areas than other methods, such as presence records in grid of cells and superimposition of species occurrence convex polygons. However, we found that only 11.47% of the species had the minimum viable number of records for SDMs.

For the species without records, 25 of the 30 species belonged to three genera: *Mico*, *Pithecia* and *Plecturocebus*. *Mico* species are, generally, small-bodied and range-restricted, and Hawes et al. (2013) found that primate species with such characteristics received less sampling effort for diet studies in the neotropics, and this may explain why those species had no records. On the other hand, *Pithecia* and *Plecturocebus* (Marsh, 2014; Byrne et al., 2016) have each recently received a very thorough taxonomic revision, in which some subspecies become full species and new species were described. Due to these taxonomic changes and the fact that most raw data were not classified at subspecies level, species confirmation was not possible in all cases, and, as a result, many *Pithecia* and *Plecturocebus* species end up with no records. In addition, for *Aotus*, there were more records classified at genus than species level because species identity confirmation was not possible in most cases.

The Brazilian Amazon represents a largely lacuna area of digital accessible information of primate species records, especially in the southeast, while the Ecuadorian Amazon and areas near Iquitos, Peru, have more occurrence cells, a pattern previously found for other taxonomic groups (Hopkins, 2007; Schulman et al., 2007; Vale & Jenkins, 2012). Haws et al. (2013) showed that, although Brazilian Amazon had a high sampling effort for studies of primate diet, it has a very low study site density, compared to other Amazon countries. This strength the importance of expanding the geographical cover of species records in the country with the largest portion of the Amazon basin. It is interesting to note that southern Peru had a high number of occurrence cells, and it may be due to the protected areas in this region, e.g. Manu National Park and Tombopata National Reserve, as they promote ecotourism and, therefore, species are recorded by the public.

Low spatial coverage of records can be explained by the absence from DAI important databases for Amazonian primates, such as the mammal collections of Museu Paraense Emilio Goeldi. This is available on the GBIF, but the records lack the coordinates. In addition, the scientific literature still represents an important source of species records and distribution. Pinto et al. (2014) gathered 1,690 localities from these two data sources (museum collection and scientific literature) for primate species in the Brazilian Amazon, which represented 11.73% of cells with records at a 0.25º resolution, while we found only 1.8% for the same area, ten times less.

Most data were from traditional scientific repositories, such as museums and university collections (Table 1). However, it is important to highlight the relevance of citizen science programmes, such as iNaturalist, for international biodiversity monitoring and scientific contribution (Chandler et al., 2017). Although opportunistic observation may be biased in space and time and may need expert taxonomic verification, previous studies have shown the potential of verified citizen science to add more data on ecological studies of not so attractive groups, e.g. reptiles, bees and plants (Dorin et al., 2017; Tiago, Pereira & Capinha, 2017). Primates are very charismatic, they can be used as flagship species to attract public opinion towards conservation of nature. Thus, citizen science can be a useful tool to reduce the Wallacean shortfall of this taxonomic group.

As knowledge and deforestation are biased toward accessible regions, we expected that occurrence cells would have more deforested area than lacuna cells. However, we found that occurrence cells had less protected and deforested area than lacuna cells. Brazil represents 61.96% of the study area, and it also had the largest lacuna area overall. Brazil also had the largest protected and deforested area, compared to other countries. The largest lacuna also had the largest protection and deforestation at the same time, and it would explain the pattern we found. Additionally, occurrence records concentrate close to accessible zones, including human settlements, areas where deforestation could have happened before the survey period (1982 – 2016), and it would not be detected in the dataset.

In conclusion, the DAI on Amazonian primate occurrence records remains extremely scarce, as vast areas of the basin have no available information whatsoever. Yet, there is a great potential of the DAI to reduce the Wallacean shortfall. As the deadline for the achievement of the Aichi Target 19 approaches, it becomes evident that a lot of work remains to be done. Many important museum collections, not only from Latin America, are not digitally accessible in any digital database. Additionally, occurrence records from scientific literature could be made available in those databases, as it provides a very important source of occurrence records. Also, Brazil has a major role in this process, as it has the largest lacuna area and concentrates the largest deforestation pressure. Furthermore, protected areas form a large network that covers a great deal of the lacuna area, highlighting their relevance in protecting primate population s from deforestation and other forms of anthropic pressure.

Author contributions Study design, data collection, analysis and writing: TJ; study design, interpretation of results, and assistance with writing: AAB, BMB.

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Conflicts of interest None

Ethical standards This research complied with the *Oryx* Code of Conduct.

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TABLE 1 Sources of Amazonian primates records available on GBIF, SpeciesLink and VerNet.

Dataset	**Institution type**	**N records**	**N species**
Fundación Entropika - Colombia	Private enterprise	1242	14
Field Museum of Natural History, Mammal Collection - USA	Museum	251	70
Asociación Primatológica Colombiana, Registros Primates Neotropicales Convocatoria	Private enterprise	194	27
Secretaria Estadual de Meio Ambiente do Acre - Brazil	Government agency	177	23
iNaturalist	Online database	130	42
Fundación Puerto Rastrojo - Colombia	Private enterprise	124	31
Macaulay Library Audio and Video Collection	Online database	94	42
Conservation International, Rapid Assessment Program Biodiversity Survey Database	Private enterprise	64	21
University of California, Museum of Vertebrate Zoology - USA	University collection	46	22
Smithsonian Institution, National Museum of Natural History - USA	Museum	38	25
Naturgucker	Online database	18	13
Louisiana State University Museum of Natural Science, Mammal Collection - USA	University collection	13	11
American Museum of Natural History, Mammal Collection - USA	Museum	8	7
Royal Ontario Museum, Mammal Collection - Canada	Museum	7	4
Universidade Federal de Minas Gerais, DNA, tissues, cells and biological subsamples Collection from the Taxonomic Collections Center - Brazil	University collection	6	6
University of Michigan, Museum of Zoology - USA	University collection	4	4
Universidade de Campinas, Museum Zoology, Mammal Collection - Brazil	University collection	4	4
University of Kansas Biodiversity Institute, Mammalogy Collection - USA	University collection	4	3
Harvard University, Museum of Comparative Zoology - USA	University collection	4	4
Michigan State University, Mammalogy, Ornithology and Vertebrate Paleontology Collections - USA	University collection	3	2
Museo Argentino de Ciencias Naturales Bernardino Rivadavia, National Mammalogy Collection - Argentina	Museum	3	3
Muséum d'histoire naturelle de la Ville de Genève - Switzerland	Museum	3	3
Natural History Museum of Los Angeles County, Vertebrate Collection - USA	Museum	2	1
Royal Belgian Institute of Natural Sciences - Belgium	Museum	2	2
Yale Peabody Museum, Vertebrate Zoology Division, Mammalogy - USA	Museum	1	1
University of Arizona, Museum of Natural History Mammal Collection - USA	University collection	1	1
University of Washington Burke Museum, Mammalogy Collection - USA	University collection	1	1
Universidade do Estado do Mato Grosso, Mammal collection - Brazil	University collection	1	1
Texas Tech University, Mammal Collection - USA	University collection	1	1

FIG. 1 Histogram of number of primate species per record number category.

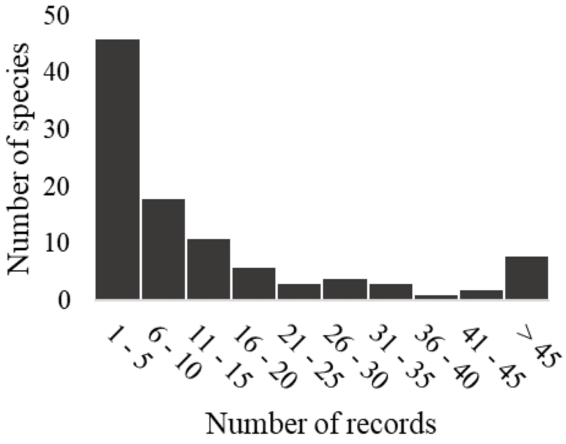

FIG. 2 Map of cells with primate records in a 0.25º grid cell, for the Amazon Basin.

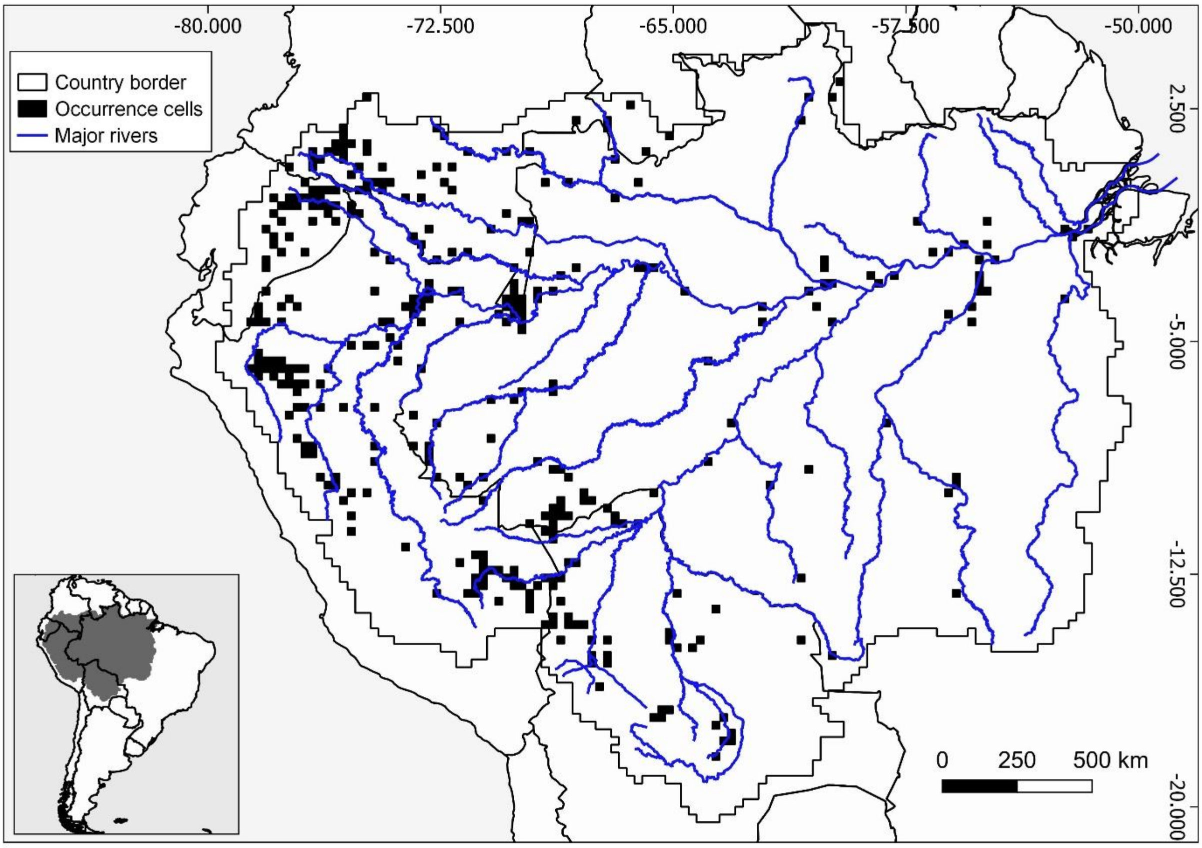

FIG. 3. Map of percentage of protected area in each 0.25º grid cell, for the Amazon Basin.

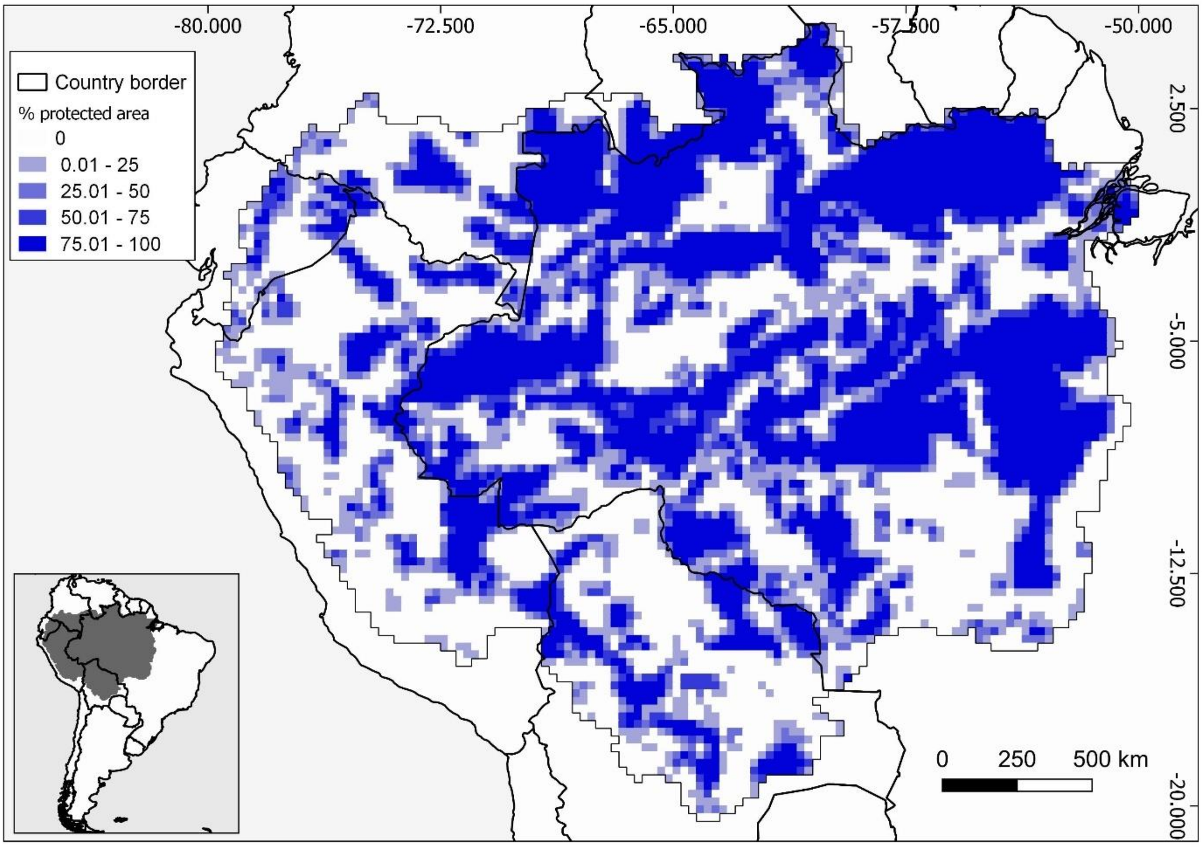

FIG. 4. Map of percentage of deforested area in each 0.25º grid cell, for the Amazon Basin.

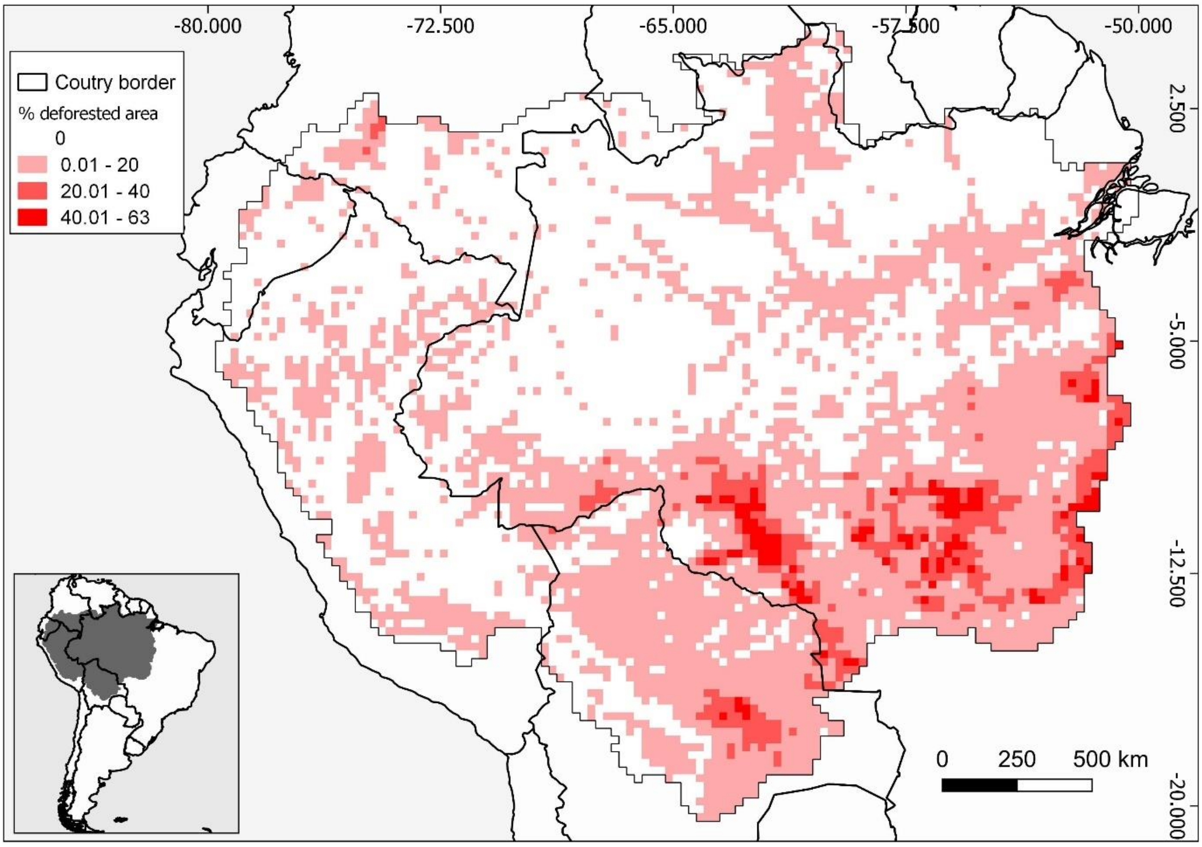

FIG. 5 Left, difference in protected area cover (%) for cells with (N = 353) and without (N = 7,606) primate records ($\chi^2 = 13.06$, df = 1, p-value < 0.001). Right, the difference in deforested area (%) between 1982 and 2016 for cells with and without primate records ($\chi^2 = 5.5616$, df = 1, p-value = 0.018). For both figures, bar width indicates sample size.

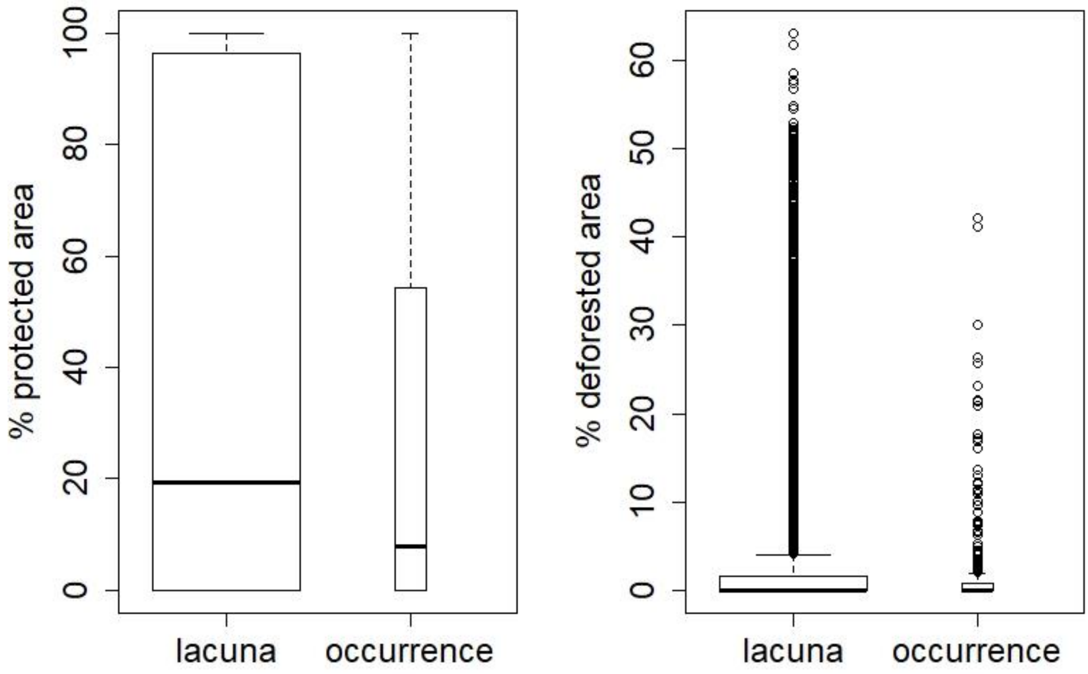

FIG. 6. Environmental distance from each lacuna cell in a 0.25º grid to the nearest occurrence cell. Blue shading indicates low distance, while red shading indicates high distance.

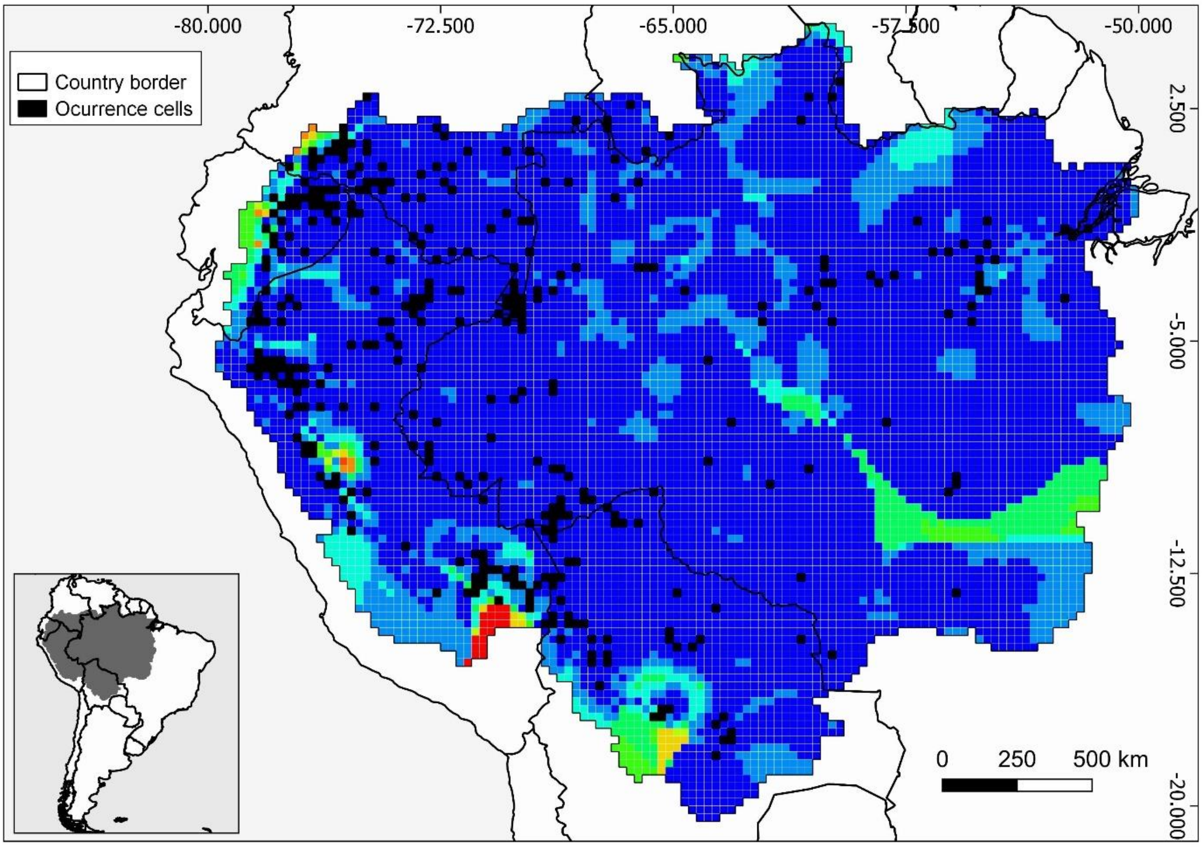

Table S1: Taxonomic literature followed for each taxonomic group.

Taxonomic group	**Taxonomic reference**
Alouatta	Cortés-Ortiz et al., 2003; Kowalewski, Garber, Cortés-Ortiz, Urbani, & Youlatos, 2015; Ruiz-garcía et al., 2016
Aotus	Menezes, Bonvicino, & Seuánez, 2010; Ruiz-García et al., 2011
Ateles	Morales-jimenez, Disotell, & Di, 2015
Cacajao	Silva-Junior et al., 2013; Ferrari et al., 2014
Callimico	Buckner, Lynch Alfaro, Rylands, & Alfaro, 2015; Garbino, 2015; Garbino & Martins-Junior, 2018; Perelman et al., 2011
Cebuella	Boubli et al., 2018; Buckner et al., 2015; Garbino, 2015
Cebus	Boubli, Rylands, Farias, Alfaro, & Alfaro, 2012; Lima et al., 2017; Lynch Alfaro et al., 2012; Mittermeier, Rylands, Bezerra, Paim, & Queiroz, 2013
Cheracebus	Byrne, Rylands, Carneiro, Alfaro, & Bertuol, 2016
Chiropotes	De Sousa e Silva Junior, Figueiredo-Ready, & Ferrari, 2013
Lagothrix	Botero, Stevenson, & Di Fiore, 2015; Di Fiore et al., 2015; Ruiz-García, Pinedo-Castro, & Shostell, 2014
Leontocebus	Buckner et al., 2015; Garbino & Martins-Junior, 2018; Anthony B. Rylands et al., 2016
Mico	Garbino, 2015; Garbino & Martins-Junior, 2018
Pithecia	Marsh, 2014
Plecturocebus	Byrne et al., 2016
Saguinus	Buckner et al., 2015; Garbino & Martins-Junior, 2018; Anthony B. Rylands et al., 2016
Saimiri	Lynch Alfaro et al., 2015; Ruiz-García, Luengas-Villamil, Leguizamon, de Thoisy, & Gálvez, 2015
Sapajus	Lima et al., 2017, 2018; Lynch Alfaro et al., 2012

CONCLUSÃO GERAL

Para preservar é preciso saber onde as espécies ocorrem, e bases de dados online possuem grande potencial para superar os problemas do déficit Wallaceano. Neste estudo, identificamos que cerca de 95% da Bacia Amazônica não possui registros de primatas em plataformas online. Dos dados disponíveis nas plataformas digitais apenas 11% representam de fato informações relevantes que podem ser utilizadas para planejamento de estratégias de conservação e estudos ecológicos. A região que concentra um número desproporcional de registros e possui um monitoramento de longo prazo com registros muito próximos uns dos outros. Já as espécies sem nenhum registro são, principalmente, aquelas que passaram por revisão taxonômica recente e que naturalmente recebem menos atenção nos estudos de dieta. O Brasil é o país que possui a maior porção da bacia amazônica, e também é o país que possui maior área proporcional de lacuna, desmatamento e sob proteção. A baixa cobertura geográfica na base de dados online está ligada também a não inclusão de coleções importantes para primatas da região, como a coleção do Museu Paraense Emilio Goeldi. Entretanto, a inclusão de dados de plataformas de registros feitos por amadores não ligadas a comunidade científica, tem grande potencial para complementar as informações de bases tradicionais. Como conhecimento e desmatamento se concentram principalmente próximo a assentamentos humanos, esperávamos encontrar maior proporção de área desmatada nas regiões com registros, mas não foi o encontrado.

Conforme o prazo final para atingir a Meta de Aichi 19 se aproxima, fica claro que ainda há muito trabalho a ser feito. Muitas coleções importantes de museus, não apenas da América Latina, ainda não estão disponíveis em uma única plataforma digitalmente acessível. Além disso, registros de ocorrência da literatura científica poderiam ser disponibilizados de maneira padronizada nessas bases de dados, já que ainda são uma importante fonte de dados. O Brasil possui um grande papel nesse processo, uma vez que é a maior região de lacuna e concentra a maior pressão de desmatamento. Ademais, áreas protegidas formam uma grande malha que cobre grande parte da região de lacuna, evidenciando sua importância para proteger populações de primatas da pressão do desmatamento.

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