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Geographical and socioeconomic determinants of species discovery trends in a biodiversity hotspot

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ABSTRACT

Understanding how we built our knowledge on species descriptions is especially important in biodiversity hotspots, since those regions potentially harbour many undescribed-endemic species that are already threatened by intensification of human activities. We compiled an extensive dataset on anuran, lizard, and snake assemblages in the Atlantic Forest (AF) hotspot, South America, to evaluate the role of geographic and socioeconomic factors on herpetofaunal species discoveries. We applied spatial autoregressive methods under a multimodel inference framework to quantify the extent to which human occupation, economic development, on-ground accessibility, biodiversity appeal (*i.e.* interest of first researching preserved areas), and expertise availability explain geographical discovery trends of distinct herpetofaunal groups. More populous regions show more recently described species, particularly in southeastern AF where regional expert availability and economic development are greater. The influence of human occupation on geographical discovery trends carries the impact of historical human colonization in the AF, which happened mainly over endemism-rich mountainous regions in its southeastern section. Similarly, the biodiversity appeal effect is linked to the current reserve network in the AF that was only established after the massive human disturbance of lowland forest regions. Overall, our findings indicate that low-populated areas with low on-ground accessibility should be prioritized in future studies in the AF, since these are where the taxonomic impediment is more likely to occur.

1. Introduction

Among the most recognized gaps in our knowledge of biodiversity is the Linnean shortfall, which refers to the discrepancy between the number of existing species and those formally described (Raven and Wilson, 1992; Whittaker et al., 2005). To reduce the Linnean shortfall is the same as to accumulate knowledge on species descriptions. Understanding how we have accumulated such knowledge is especially important in biodiversity hotspots as these regions concentrate significant levels of biodiversity and are highly threatened by human activities (Mittermeier et al., 2005; Zachos and Habel, 2011). Undescribed species occurring in biodiversity hotspots face higher threats to their persistence than undescribed species occurring elsewhere, which may lead them to become extinct before their formal descriptions (Lees and Pimm, 2015). Quantifying the species discoveries also has a direct role in the reduction of the taxonomic impediment for biodiversity conservation, which is the core aim of the Global Taxonomy Initiative, established under the Convention of Biological Diversity (Secretariat of the Convention on Biological Diversity, 2010). Identifying factors that boost species descriptions helps to develop strategies that minimize discovery trends and improve conservation planning (Hortal et al., 2015).

Most studies on the Linnean shortfall have linked species discovery trends to intrinsic factors, such as the smaller body size and narrower geographical distribution, that make the detection and description of new species more difficult (Blackburn and Gaston, 1995; Collen et al., 2004; Jiménez-Valverde and Ortuño, 2007). Those works improve our understanding of what kinds of species are described first. However, in investigating the discovery trends only across species, one may overshadow important links between species discoveries and extrinsic factors, particularly those related to geographical and socioeconomic attributes of a given region (Colli et al., 2016; Diniz-Filho et al., 2005). At

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the same time, knowledge on species distribution is also imperfect and subject to biases (the so-called Wallacean shortfall, Whittaker et al., 2005), because geographical and socioeconomic factors result in uneven data availability across species ranges (Meyer, 2016; Meyer et al., 2015). Addressing discovery trends across geographical assemblages may be more promising than focusing on attributes affecting species-specific detectability, since it is easier to incorporate site-specific data biases and uncertainty into conservation planning.

Herein, we explore geographical patterns of average description dates of amphibian, lizard, and snake assemblages in the Atlantic Forest hotspot, in South America. Amphibians and reptiles are often used as target groups in conservation planning (Loyola et al., 2009), and due to their intrinsic physiological requirements, these organisms have long been known by their vulnerability to global climate change (Gibbons et al., 2000; Stuart et al., 2004). While few new species of birds and mammals have been described over the last decade, dozens of amphibians and reptiles are described every year (Costello et al., 2012; Pimm et al., 2010; Uetz & Stylianou, 2018). Half of the currently recognized species of amphibians have been described after 1978, and half of the reptiles after 1925. Only in the 21st century, > 2300 species of amphibians and 1920 of reptiles were described, which is almost 25% of the currently valid herpetofaunal species (Fig. 1). An assessment of amphibian and reptile discovery trends across geographical assemblages can be linked to local and regional public policies that could minimize biodiversity knowledge gaps in the long-term.

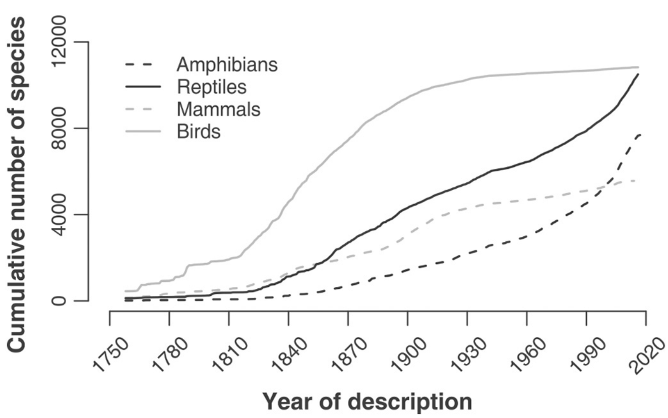

Fig. 1. Accumulated number of species descriptions for terrestrial vertebrates. Description years extracted separately for birds (Gill and Donsker, 2017), mammals (IUCN, 2016), reptiles (Uetz and Hošek, 2017), and amphibians (IUCN, 2016; AmphibiaWeb, 2017).

We test five major hypotheses to associate the average description date of species assemblages with geographical and socioeconomic site-specific factors:

1. Human occupation – Greater human settlements may enhance the detectability of species nearby humans and thus hasten their formal description. Localities with either older history of colonization or greater human population are expected to show, on average, earlier description dates of species (Colli et al., 2016).
2. Economic development – Localities with higher economic development may reflect greater exploration of the nearby environment and consequently more environmental impact assessment reports (and consequently more mandatory biological surveys), potentially reflecting on the accumulated knowledge of local biodiversity (Colli et al., 2016; Tundisi and Matsumura-Tundisi, 2008). We expect earlier description dates for species from localities with greater economic development.
3. Accessibility – Species occurring in localities with higher on-ground accessibility are easier to find than those occurring in remote areas. The proximity to roads and to major cities can reflect reduced logistic costs and thus greater sampling effort (Oliveira et al., 2016), which may increase the probability of detecting and describing species. We expect earlier description dates of species from localities with greater roadside accessibility.
4. Biodiversity appeal – Protected areas may be preferable for biological surveys since researchers often expect to find more species in preserved regions (Freitag et al., 1998; Meyer et al., 2015), which would reflect in more surveys being done in and around protected areas. We expect older descriptions for species assemblages located near protected areas, particularly those with larger areas.
5. Expertise availability – Our fifth expectation is intrinsically related to the craft of describing species, that is, the availability of taxonomists (Rodrigues et al., 2010). We expect earlier average description dates of species assemblages from localities with greater numbers of taxonomists.

Overall, our predictions vary from factors mostly related to societal development (*e.g.* human occupation, economic development), going through transportation infrastructure (*e.g.* roadside accessibility), to factors intrinsically linked to the public and/or governmental awareness of the biodiversity value (*e.g.* establishment of protected areas, investments in expertise availability). In understanding how species discoveries relate to these multiple geographic and socioeconomic factors, we hope to elucidate processes affecting the Linnean shortfall in amphibians and reptiles in one of the most threatened tropical forest regions of the planet.

2. Methods

2.1. Species assemblage data and average description dates

Although there is a substantial overlap of methodical approaches for herpetofauna sampling, some methods clearly indicate preference of researchers for sampling a given herpetofaunal group. For instance, in using auditory surveys one gets field data for anurans; glue-traps are mostly effective for lizards, and local collectors tend to capture snakes. In addition, it is common to find inventories focusing on separate groups (*e.g.* amphibians or reptiles, lizards or snakes). Thus, we compiled data sources separately for anuran, lizard, and snake assemblages in the Atlantic Forest (AF). We searched herpetofaunal inventories available in the public literature, either published (articles and books) or not (theses, dissertations, environmental impact assessments, management plans), including unpublished data from several researchers. To reduce potential biases due to methodical differences in sampling procedures, all inventories met the following criteria: (i) present at least five species of the respective group (*i.e.* amphibians, lizards, or snakes), (ii) samplings in two or more seasons (dry and rainy seasons), and (iii) at least two out of 10 sampling methods: active search/transect, funnel traps, pitfall traps, quadrat plots, museum records, auditory surveys (only for anurans), glue traps (only for lizards), collected by local collectors (only for snakes), artificial shelters, and road survey/casual encounters (only for reptiles). Exceptions were made for long-term inventories (> 4 years) whose sampling procedure did not necessarily cover more than one sampling method.

Briefly, the number of surveyed sites in our dataset comprised 376 sites for anurans, 150 for lizards, 235 for snakes (see Appendix A – Data Sources). Overall, we compiled 15,348 occurrence records for herpetofaunal species in the AF (9317 of anurans, 1753 of lizards, 4278 of snakes). We critically reviewed the species composition of each inventory before entering them into the database. Whenever necessary, we contacted the authors and/or collectors of the respective data source to confirm the reliability of doubtful records. Species not identified to the species level were not included in the database. After data checking, our dataset included 8604 occurrence records of 556 anurans species, 1534 occurrence records of 108 lizard species, and 3904 occurrence records of 210 snake species (see Appendix B for the total species lists).