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PUBLICATION TRENDS IN SPECIES DISTRIBUTION MODELING AND THE PIONEER CONTRIBUTION OF DR. RUI CERQUEIRA TO ECOLOGICAL BIOGEOGRAPHY AND DISTRIBUTION MODELING IN BRAZIL

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ABSTRACT

The quantification of species-environment relationship represents the core of predictive geographical modeling in ecology and the root of contemporary species distribution modeling. The correlative approaches that link known occurrences of species with environmental variation across landscapes to estimate ecological niches and geographic distributions are generally termed ecological niche modeling (ENM) or species distribution modeling (SDM). The theoretical basis of these models is that each organism is adapted to specific tolerance zones or "niches" which, in a Grinellian sense, can be considered as the set of abiotic requirements in which a species can maintain itself. Here we provided an overview of the publication trends on ENM/SDM, both globally and in Brazil, through a scientometric approach. We also review the most important contributions of Dr. Rui Cerqueira's pioneer scientific research program on biogeography and distribution modeling in Brazil. The global production in the ENM/SDM field showed a growing trend in publication from 1990s on, with peaks on global production output occurring five times from 2005 to 2012. After 2009, more than a hundred articles were published yearly. In Brazil, although the production has also increased in the last decade, especially from 2006 on, the increase did not follow the magnitude of the global trend. Only after 2009 the number of articles published yearly surpassed ten. Cerqueira figures among the top ten authors in Brazil, being the only author to publish on the topic before 2002. Cerqueira has also made few, but quite important contributions to the understanding of biogeographical patterns in the Neotropics. These results highlight the pioneer contribution of Dr. Rui Cerqueira to the fields of ecological niche modeling / species distribution modeling and biogeography in Brazil, which we present and discuss here.

Keywords: ecological niche modelling; Neotropical biogeography; scientometrics; *Restinga*; South American mammalogy.

INTRODUCTION

Why species are distributed as they are? Why are there so geographically restricted species while others are widely distributed? What determines the limit of species distribution? These questions have always been inspirational for biogeographers and ecologists. Throughout the centuries humans have observed and recorded consistent relationships between species distributions and the physical environment (Elith and Leathwick 2009) and the importance of climate and terrain characteristics to explain distributions was recognized early on the scientific writings (Humboldt and Bonpland 1807, de Candolle 1855, Grinnell 1904). The quantification of species-environment relationship represents the core of predictive geographical modeling in ecology and the root of contemporary species distribution modeling (Guisan and Zimmermann 2000, Elith and Leathwick 2009). The correlative approaches that link known occurrences of species with environmental variation across landscapes to estimate ecological niches and geographic distributions are generally termed ecological niche modeling (ENM) or species distribution modeling (SDM) (see Peterson and Soberón 2012a,b for further terminology discussion). The theoretical basis of these models is that each organism is adapted to specific tolerance zones or "niches" which, in a Grinellian sense, can be considered as the set of abiotic requirements in which a species can maintain a net positive rate of population increase without immigration (Soberón 2007, 2010, Colwell and Rangel 2009, Soberón and Nakamura 2009).

The history of ENM/SDM can be divided in three phases (Guisan and Thuiller 2005): (i) non-spatial statistical quantification of species-environment relationship based on empirical data, that peaked in the 1970s, (ii) expert-based (non-statistical, non-empirical) spatial modeling of species distribution, more common in the 1980s, and (iii) spatially explicit statistical and empirical modeling of species distribution, that began in the late 1970s, experienced a massive growing since, and is currently the most common approach to quantitative modeling and mapping of species distributions. One of the earliest ENM/SDM attempt is the niche-based spatial predictions of crop species by Henry Nix and collaborators in Australia (Nix *et al.* 1977, Guisan and Thuiller 2005). This and some of the earliest numerical SDMs used environmental envelope and similarity models to describe the species' distribution in relation to a set of predictors (Box 1981, Nix 1986, Elith and Leathwick 2009), sometimes combined with discriminant function analyses.

Logistic regression and generalized linear models expanded on envelope and similarity approaches, allowing to select predictors according to their observed importance to species occurrence, and generalized additive models provided flexibility to deal with nonlinear species' responses to environment (Elith and Leathwick 2009). Next, ENM/SDM also started to use methods developed towards prediction, including machine learning and data mining algorithms (Elith and Leathwick 2009), such as: ANNs (Olden *et al.* 2008), multivariate adaptive regression splines (Moisen and Frescino 2002), classification and regression trees (Prasad *et al.* 2006, Elith *et al.* 2008), genetic algorithms (Stockwell and Peters 1999), support vector machines (Drake *et al.* 2006), and maximum entropy models (Phillips *et al.* 2006).

Comparisons among the results from the wide range of ENM/SDM methods available revealed that many methodological decisions taken during the modeling process may lead to great variability in the predictions (Araújo and Guisan 2006, Dormann *et al.* 2008). Also, as many ENM/SDM applications demand extrapolation, i.e., need to project models in temporal and/or spatial domains different from which the model is fitted (for example, climate change or biological invasion), researchers developed methods that could generate more robust predictions and minimize variation around model projections. A growing concern has recently emerged for ensemble forecasting approaches to improve reliability and characterize uncertainty (Araújo and New 2007, Marmion *et al.* 2009, Diniz-Filho *et al.* 2009, 2010, Buisson *et al.* 2010, Loyola *et al.* 2014).

ENM/SDM are widely used to infer the ecological requirements of species and to predict their geographic distributions. Such models have been applied to a broad set of conservation, ecological and evolutionary questions (Zimmermann *et al.* 2010), including discovery of new populations of known species, discovery of previously unknown species, spatial conservation prioritization, assessment of potential geographic ranges of invasive species, mapping risk of disease transmission, forecasting the effects of climate change on species distributions and on phylogenetic diversity, and identifying historical refugia for biodiversity (Franklin 2010, 2013, Peterson *et al.* 2011). ENM/SDM can be also particularly useful to support conservation biogeography (Franklin 2013) and to address the Wallacean shortfall.

The purpose of this paper is two-fold. First, we provided an overview of the publication trends on Ecological Niche and Species Distribution Modeling, both globally and in Brazil, through a scientometric analysis. Second, we reviewed the most important contributions of Dr. Rui Cerqueira, Professor at the Ecology Department of the Federal University of Rio de Janeiro (UFRJ), in his pioneer scientific research program on biogeography and distribution modeling in Brazil.

Dr. Rui Cerqueira is one of the most influential mammalogists in South America. In 1982 he created the Vertebrate Laboratory (LabVert) at the UFRJ, which develops scientific research in ecology and evolution, using terrestrial vertebrates as a model, with emphasis on mammals and birds. Since then, Dr. Cerqueira and his students developed a research program on vertebrates, involving various fields of ecology and evolution. He has published more than 150 papers, book chapters and books on mammal and vertebrate ecology, ecology of animal adaptations, population ecology, community ecology, landscape ecology, ecological biogeography, and conservation biology. Dr. Cerqueira has mentored dozen of B.Sc., 37 M.Sc., 18 Ph.D. students, and 06 postdoctoral scholars. His mentorship has produced a body of independent Brazilian scientists, especially in the arena of mammalogy. In 2012, Dr. Cerqueira was elected as Honorary Member of the American

Society of Mammalogists, the Society's highest honor, awarded to few nominees in recognition to their distinguished service to mammalogy, including research, teaching, student training, and outreach. Dr. Cerqueira's work on diet and water balance biology and on population ecology are discussed somewhere else (Gentile and Kajin this volume, Vieira *et al*. this volume). Here we discuss the work of Dr. Cerqueira and his collaborators on biogeography, including important contributions to Brazilian and South American biogeography and the understanding of biogeographical patterns in the Neotropics, and to the development of ecological niche and distribution modeling.

RESULTS AND DISCUSSION

Publication trends in Species Distribution Modeling

After combining and filtering the articles retrieved from WoS, Scopus and SciELO, we found 994 articles on Ecologic Niche Modeling/Species Distribution Modeling (hereafter referred to as ENM/SDM) and 85 on Ecologic Niche Modeling/Species Distribution Modeling in Brazil (hereafter referred to as ENM/SDM in Brazil) published between 1945 and 2012.

The global production in the ENM/SDM field showed a growing trend in publication from 1990s on, although before 2005 the mean year increase rate on percentage of publication did not surpass 1.47-fold, and less than ten articles were published yearly (Figure 1). This first increase in academic production on ENM/SDM followed the 1990's progress in computer, statistical and geoinformation sciences, as well as the theoretical advances in predictive ecology (Guisan and Thuiller 2005, Alexandre *et al.* 2013). Indeed, the two review papers that summarized ENM/SDM's methodology and framework – Guisan and Zimmermann (2000) and Guisan and Thuiller (2005) – are ranked first and fourth most cited papers in the field, with 2,474 and 1,575 citations, respectively (Web of Science, consulted 3 August 2014).

From 2005 on, a mean year increase rate on percentage of publication reached 1.56-fold (Figure 1). A peak on global production output can be identified when the mean year increase on percentage of publication surpass 1.5-fold, which occurred five times from 2005 to 2012. After 2009, more than a hundred articles were published yearly (Figure 1).

This second increasing in global production on ENM/SDM seems to reflect the continued advances in computer, statistical, geoinformatics and ecoinformatics technology, which eased the handling of large amounts of data and made the data accessible. Occurrence data from museum collections, surveys and monitoring programs, for example, were digitalized and became freely available via Internet portals (*e.g.* Global Biodiversity Information Facility - GBIF, www.gbif.org; VertNet, www.vertnet.org; Ocean Biogeographic Information System - OBIS, www.iobis.org; speciesLink, splink.cria.org.br). Environmental data such as climate (*e.g.* WorldClim, www.worldclim.

org; CliMond, www.climond.org), and land cover/use (*e.g.* GlobCover, due.esrin.esa.int/globcover; CORINE Land Cover, www.eea.europa.eu; CCI - Land Cover, maps.elie.ucl.ac.be/CCI/viewer/index.php) also become freely available online. The most illustrative example of the importance of compiling and breaking barriers to access of detailed global geographic databases is WorldClim's data, which is repeatedly and massively used in ENM/SDM studies. WorldClim is a global climatic database freely available on the web, described by Hijmans *et al.* (2005) in a paper cited 3,276 times (Web of Science, consulted 3 August 2014). In parallel, software packages and platforms for ENM/SDM also become available (*e.g.* MAXENT, www.cs.princeton.edu/~schapire/maxent; openModeller, openmodeller.sourceforge.net; ModEco, gis.ucmerced.edu; BIOMOD, cran.r-project.org/web/packages/biomod2; Dismo, cran.r-project.org/web/packages/dismo). In fact, the second most cited paper in ENM/SDM, Phillips *et al.* (2006), is the article that introduced the use of the maximum entropy method for modeling species geographic distributions, implemented via MAXENT, a free software with a friendly graphical user interface. The MAXENT package is one of the most popular tools for ENM/SDM, with over 1,000 published applications since 2006 (Merow *et al.* 2013). Among the top five papers in ENM/SDM, Guisan and Zimmermann (2000) has been cited 2,474 times, Phillips *et al.* (2006) 2,314 times, Elith *et al.* (2006) 2,129 times, and Guisan and Thuiller (2005) 1,575 times (Web of Science, consulted 3 August 2014).

Such results are in agreement with Lobo *et al.* (2010), indicating that ENM/SDM is a field of research that become a hot topic in the ecological, biogeographical or conservation literature in the last two decades. Besides the massive increase in publications on ENM/SDM, two book-length syntheses are now available (Franklin 2010, Peterson *et al.* 2011). In addittion, the extensive citation of the top five papers indicates considerable popularity of the ENM/SDM techniques, as already highlighted by Peterson and Soberón (2012a). The explosion of interest on the topic in recent decades has resulted from a convergence of the growing need for information on the spatial distribution of biodiversity and new and improved techniques and data suitable for addressing this need – remote sensing, global positioning system technology, geographic information systems, and statistical learning methods (Franklin 2010). Indeed, the combination of Geoinformatics and Ecoinformatics is a promising field that has great potential to optimize decision support for biodiversity conservation and management (Lorini *et al.* 2011). Such synergy has contributed to ENM/SDM becoming one of the emergent methods in spatial ecology (Skidmore *et al.* 2011, Lorini *et al.* 2011), and part of the basic "toolkit" of macroecologists and biogeographers (Peterson and Soberón 2012a).

In regard to ENM/SDM in Brazil, although the production has also increased in the last decade, until 2005 the mean year increase rate on percentage of publication did not surpass 1.1-fold. From 2006, however, publications showed a growing trend. The mean year increase rate on percentage of publication in this period reaching about 1.66-fold, and three peaks on production output can be identified. However, only after 2009 the number of articles published yearly surpassed ten (Figure 1).

In terms of authorship, thousands of worldwide authors have contributed papers to ENM/SDM. Each one of the top ten authors in the field contributed with more than 15 papers: A. T. Peterson (106), A. Guisan (40), W. Thuiller (33), D. Rodder (31), N. E. Zimmerman (24), E. Martinez-Meyer (24), J. M. Lobo (22), M. Araújo (21), C. H. Graham (20), and J. Elith (18). On the other hand, there were a total of 241 authors contributing 85 articles related to ENM/SDM in Brazil. Most authors (79.2%, n=191) contributed with one paper and 17% (n=41) with two to four papers. The authors that contributed with five to ten papers (3.3%, n=8) are among the top nine authors (A. T. Peterson, M. F. Siqueira, J. C. Nabout, P. De Marco Jr, J. A. Diniz-Filho, R. Scachetti-Pereira, R. Gurgel-Gonçalves, C. L. Terrible, and R. Cerqueira). Only one author contributed with more than ten articles (A. T. Peterson), and only one published on ENM/SDM in Brazil before 2002 (R. Cerqueira) (Figure 1). Therefore, Cerqueira figures among the top ten authors in Brazil, being the only one to publish on the topic before 2002. These results highlight the pioneer contribution of Rui Cerqueira to the

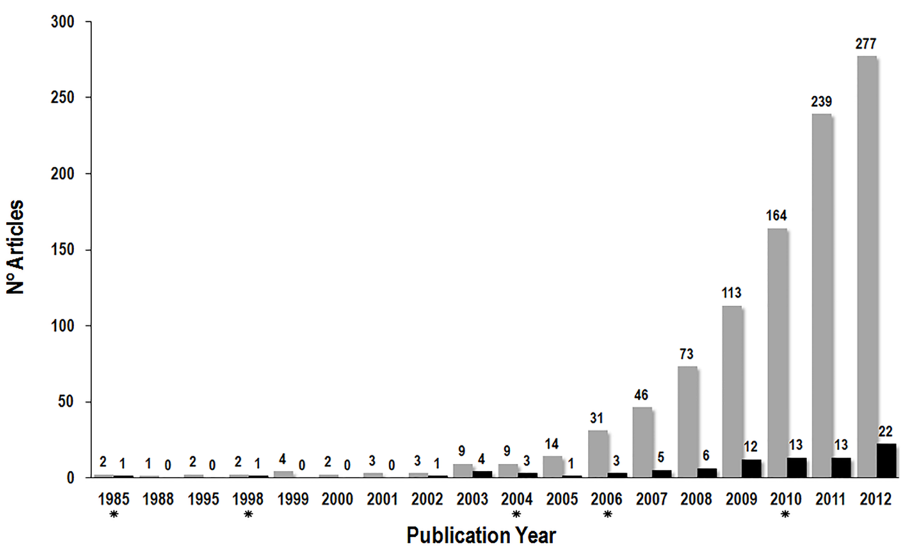

Figure 1. Publications on Ecologic Niche Modeling/Species Distribution Modeling from 1985 to 2012. The graph shows publications worldwide (gray), and from Brazil (black), and the years in which Dr. Rui Cerqueira has contributed publications (*).

fields of species distribution modeling and biogeography in Brazil, that will be presented and discussed in the following sections.

Rui Cerqueira's contributions to biogeographical studies

Cerqueira has made few, but quite important contributions to the understanding of biogeographical patterns in the Neotropics. He has also been the fearful professor of the biogeography course of Federal University of Rio de Janeiro bachelor program in Ecology for decades.

Cerqueira (1982) discusses the biogeography of South American mammals during the Quaternary, providing a review of vegetational and climatic changes (glaciations cycles) during that period, and a detailed analysis of present-day mammal distribution patterns. He presents and discusses three main distribution patterns of South American mammals, using rodents, marsupials, primates and edentates examples: (i) those that fit the disjunct distribution of open habitats, forests or mountains, (ii) those that may be related to forest refugia, and (iii) those that seem not to correlate directly to historical causes. Cerqueira (1982) emphasizes how Pleistocene Refugia (Prance 1982), although a major advance in Neotropical biogeography at the time, should not be used to explain every observed pattern of speciation. The study also defends that the two distinct mammal faunas of the Quaternary cannot be easily correlated with major climatic events, because there were several such events during the Quaternary.

In what is arguably one of his team best scientific contributions, Gabriel Marroig and Cerqueira uses the Amazon Lagoon Hypothesis, restricted until then to geology, to explain diversification in the Neotropics (Marroig and Cerqueira 1997). The hypothesis combines the Refuge and Riverine Barrier Hypotheses with evidences indicating the existence of an extensive lagoon in the Amazon basin, millions of years ago. This lagoon was likely formed several times, in marine regressions and transgressions cycles, when sea level increased up to 180 m above current level. The hypothesis helps to explain several biogeographical patterns in South America, particularly in mammals, birds and fishes. The Amazon Lagoon Hypothesis is illustrated using the example of Spider Monkeys (*Ateles* spp.), which display a cline of differentiated populations bordering the Amazon River, forming a ring species. According to the authors, several bird and some primate groups show biogeographical patterns similar to *Ateles*.

Another important contribution of Dr. Cerqueira to the biogeography of Neotropical fauna concerns to the origins and biogeographical affinities of *restinga* mammals. As discussed in this volume by Vieira and collaborators, water deprivation experiments with rodents typical of *restinga*, revealed a relation between habitat occupancy and diet choice on a local scale. Cerqueira, however, has thought of *restinga* at much broader temporal and spatial scales. *Restinga* is an ecosystem found along beaches of the Brazilian Atlantic Forest, with herbaceous and arbustivearboreal vegetation occurring on sandy coastal plains formed by marine deposits in the late Quaternary (Ab'Saber 1977, Scarano 2002, Rocha *et al*. 2007). Cerqueira's work on mammals of the Maricá *restinga* of Rio de Janeiro, developed during the 90's (*e.g.* Cerqueira 1984, Cerqueira *et al.* 1990, Gentile and Cerqueira 1995, Gentile *et al.* 1995, Gentile *et al.* 1997, Freitas *et al.* 1997, Santori *et al.* 1997) provided Cerqueira with important insights into *restinga*'s biogeography. In a review of the subject, he discusses *restinga*'s low endemicity and the prevalence of a particular subset of species from nearby biomes, in light of Pleistocene glacial cycles, particularly sea level changes, starting thousands of years ago (Cerqueira 2000). To Cerqueira, what makes *restinga* unique are the combination of origins and the particular ensemble of species capable of surviving in that xeric environment. With marine transgression, sea level increased up to 8 m above current level (Late Pleistocene transgression, *ca.* 123,000 years BP, Suguio 2001), flooding many portions of *restingas*, which would be reduced and fragmented into islets. During subsequent marine regression these areas would reconnect, although within a generalized semi-arid climatic condition. These climatic events created interesting extinction/colonization dynamics, which Cerqueira discusses in terms of the speciation of a few endemic reptiles and the only bird endemic of *restinga*, *Formicivora litoralis*. These publications of Cerqueira were fundamental to the recent discussions and reviews about *restinga*'s endemism (Lorini *et al*. 2010, Pessôa *et al.* 2010, Tavares *et al*. 2010, 2011).

According to Cerqueira (1995), determining the area occupied by a given species at a given time, i.e. the species' geographic distribution, forms the basis of Biogeography. In the following section we present the advances on species' distribution modeling in Brazil brought about by Dr. Rui Cerqueira's work.

Rui Cerqueira's contributions to Species Distribution Modelling studies

Cerqueira has worked on species distribution modeling since the beginning of his career and for a long time was the only biologist working on the subject in Brazil, as demonstrated in the section about Publication Trends in ENM/SDM (Figure 1). Cerqueira's first contribution was 30 years ago, on a study of the distribution of the opossums of the genus *Didephis* (Cerqueira 1985), developed during his doctorate at the University of London, in England. In this pioneer work, Cerqueira investigates the ecological factors that determine the occurrence of species of the genus in South America. He associates climatic, altitudinal and vegetation information to species' occurrence records. A qualitative analysis reveals that the different forms show no preference for terrain, vegetation or morphoclimatic domain (*sensu* Ab'Saber 1977). The plotting of sites in a latitude x altitude space also shows that "highland and lowland" also does not explain the distribution of the different species, contrary to was what known at the time (Hershkovitz 1969). Cerqueira shows, however, that different forms occur in distinct climatic conditions by carrying a discriminant function analysis on site's climatic data. He also discusses the implications of last glacial maxima on the distribution and isolation of different forms of the genus *Didelphis*. More interestingly, the study goes beyond a description of environmental versus distribution relationship, mapping species' potential distribution by superposing vegetation and climatic data, in what Cerqueira calls "a testable hypothetical map".

This work served as the basis for a publication that was, for a long time, the main reference for species distribution modeling in Brazil (Cerqueira 1995). Back then the methods used to determine species' distribution (mostly drawing a line surrounding species' outermost occurrence records), did not take into account ecological requirements (Udvardy 1969). The study argues that mapping species' distribution based on environmental factors is more biologically meaningful and proposes a method for doing it. Cerqueira presents the "potential distribution" of a species as the area where it finds its "niche" and "habitat" (*sensu* Whittaker *et al.* 1973). In order to circumscribe such distribution, we must first establish which environmental variables are related to the species and map their geographic distribution. The overlap of the mapped variables should equate to species' potential distribution. Cerqueira then provides a detailed protocol for gathering, treating and analyzing occurrence and environmental data. He proposes a combination of descriptive statistics, multiple discriminant analysis and analysis of variance to establish which climatic variables are related to species occurrence, using antwren birds of the genus *Formicivora* as an example. Cerqueira extracts the maximum and minimum climatic values from the sample of occurrence records, establishing the range of values where the species is found. He also maps the vegetation types where the species is known to occur from those same occurrence records. Cerqueira then maps species' potential distribution as the area where the range of climatic values and vegetation boundaries coincide.

At that time, Cerqueira developed a digital climatic database and analytical package (called LabVertCli), which would interpolate data from Brazilian meteorological stations, providing climatic data for any location within Brazil, in a precursor of today's extensively used WorldClim dataset (see section about Publication Trends in SDM). The method to map species' potential distribution and the LabVertCli dataset was applied in a number of subsequent studies, mostly with primates. A study on marmosets and tamarins in Rio de Janeiro State (Cerqueira *et al.* 1998) shows that climate, vegetation and topography can determine the distribution of the Buffy-tufted-ear Marmoset (*Callithrix aurita*) and the Golden-Lion-Tamarin (*Leontopithecus rosalia*), but not that of the White-tufted-ear Marmoset (*C. jacchus*), which has great invasive potential because of its ability to survive in disturbed habitats. Contradicting common knowledge at the time, the authors conclude that the Golden-Lion-Tamarin is not an inhabitant of Atlantic forest (*sensu lato*), and that this species' macrohabitat is characterised by a mosaic of lowland swamp and broad-leaved forest. They also conclude that the White-tufted-ear Marmoset displaces the Buffy-tufted-ear Marmoset as a consequence of habitat degradation rather than by direct competition. This study was an early warning about the potential risk that aloctone invasive marmosets (*C. jacchus* and *C. penicilatta*) can represent to authoctone threatened species like Buffy-tufted-ear Marmoset (*C. aurita*). In a study focusing on capuchin monkeys (*Cebus nigritus* and *C. robustus*), Cerqueira and his crew call the attention to the issue of distribution limits in taxa exhibiting parapatric distribution patterns (Vilanova *et al.* 2005). Cerqueira and his colleagues show that vegetation is the main determinant of these species' distribution, while rivers and interspecific interactions are key in defining their distribution boundaries. The next study about primates, focusing on Buffy-headed marmoset (*Callithrix flaviceps*), innovates by using a non-linear method (logistic regression) to model climatic distribution, in combination with ecoregions (Olson *et al.* 2001) as environmental predictor variable (Grelle and Cerqueira 2006). This article also discusses the role of interspecific interactions in parapatric taxa. Finally, a study with six antbirds of the genus *Drymophila* assesses the role of climate and vegetation on species' distribution, showing that discriminant analysis was not satisfactory for sympatric species, when compared with similar analysis carried out on parapatric species (Rajão *et al.* 2010).

Cerqueira's most recent studies show that he is keeping with the development of the field, using new datasets and analytical approaches. Teixeira *et al.* (2014) proposes a method to gather needed information to determine the conservation status of rare, small-ranged, forest species classified as "Data Deficient" by the International Union for Nature Conservation (IUCN). Cerqueira and his colleagues combine maximum entropy distribution modeling (Phillips and Dudík 2008) with connectivity analysis to indicate new sites for the search of a newly described nectar bat (*Lonchophylla peracchii*), and discusses its likely IUCN conservation status. Finally, Cerqueira's most recent publication (Vale *et al.* this volume) maps the distribution of Neotropical wild cats under climate change scenarios using the ensemble of various distribution modeling algorithms (Araújo and New 2007) and the most up-to-date climatic change forecasts (IPCC 2013). They predict important contraction of climatically suitable areas for virtually all Neotropical cats, with particularly worrisome predictions for the Guiña (*Leopardus guigna*) and the Andean Cat (*L. jacobitus*). Both are already threatened under IUCN, and the later is of special concern given that highland species are particularly susceptible to a warming climate.

Dr. Rui Cerqueira's contribution to the understanding of ecological biogeography and distribution modeling in Brazil is undeniable. His vision of distribution is aligned to what is recently called "distribution ecology", an approach that understand distribution as referring to differences between places either in individual residence times, population abundances, species occurrences, or probabilities of use, depending on ecological scales and levels of organization (Cassini 2013). This broad view of the species' distribution issue can be appreciated in Cerqueira's contribution to diet, water balance and populations studies, discussed in this volume (Vieira *et al.* this volume, Gentile and Kajin this volume). Dr. Rui Cerqueira has formed a crew of researchers on ecological biogeography and distribution modeling, as can be attested by his diverse co-authorship, which is carrying on his legacy on this exciting and rapidly expanding scientific field.

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MATERIAL AND METHODS

Scientometric and bibliometric analysis quantify and assess trends and characteristics in scientific production in a particular science area. These analyses can be a useful tool for evaluating the results of scientific activity, providing a synoptic overview of the research area, contributing, therefore, to the understanding of the state of the art within a scientific field (Verbeek *et al.* 2002, Tian *et al*. 2008). We provide a quantitative characterization of scientific activity related to "Species Distribution Modeling" and "Species Distribution Modeling in Brazil", by performing a scientometric analysis of data retrieved from three scientific publication databases: (i) Web of Science (WoS) from Thompson Institute for Scientific Information - ISI (http://isiwebofknowledge.com), (ii) Scopus from Elsevier (http://www.hub.sciverse.com), and (iii) Scientific Electronic Library Online (SciELO) from FAPESP/ CNPq/BIREME/OPAS/ OMS consortium (http://www.scielo.org). The WoS is the most detailed and accurate scientific database of peer-reviewed articles published in English, besides being the most used for scientometric analysis (Verbeek *et al.* 2002, Falagas *et al.* 2008, Gavel and Iselid 2008). On the other hand, the Scopus database covers a larger number of journals that publish articles in languages other than English (Falagas *et al.* 2008, Gavel and Iselid 2008). The SciELO database, although much less comprehensive, covers South American journals that are not indexed by WoS or Scopus. We search databases for articles published from 1945 through 2012, using "species distribution model*", "ecologic* niche model*" or "potential distribution model*" and "Brazil*" as the keywords to search parts of titles, abstracts, or keywords. We combined articles retrieved from the three databases and, after filtering to remove replications and articles not related to ENM/SDM, we analyzed the retained articles in terms of publication year and authorship.

In addition, we also used the Lattes platform to search for Rui Cerqueira's publications on Biogeography (not ENM/SDM). The Lattes Platform is an information system maintained by the National Council for Scientific and Technological Development (CNPq) that manages science and technology information about individual researchers and institutions working in Brazil (Mena-Chalco and Cesar-Junior 2009). The Lattes Platform is a valuable tool to obtain information on individual researchers, as all researchers and institutions are required by the CNPq to maintain their records up to date.

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