GfÖ Ecological Society of Germany, Austria and Switzerland

Basic and Applied Ecology 11 (2010) 709–713

Basic and Applied Ecology

www.elsevier.de/baae

Overcoming the Linnean shortfall: Data deficiency and biological survey priorities

Daniel Brito*

Universidade Federal de Goiás, Instituto de Ciências Biológicas, Departamento de Ecologia, Laboratório de Ecologia Aplicada e Conservação, Caixa Postal 131, Goiânia, GO 74001-970, Brazil

Received 14 May 2010; accepted 15 September 2010

Abstract

Knowledge of biodiversity is woefully inadequate. Only a fraction of the planet's species has been described by science (the "Linnean shortfall"). Even for described species, scientists often have only fragmentary information about their distributions (the "Wallacean" shortfall). These shortfalls in biodiversity knowledge place serious limitations on the ability to conserve biodiversity in the face of the ongoing extinction crisis. Here, I test the hypothesis that data deficiency may be used to guide surveys and inventories to regions that would increase the probability of discovering new species. I compiled global distribution maps for all Data Deficient amphibian species (species described up to 2004) and constructed a Data Deficiency (DD) surface (the DD surface was based on distribution information obtained from the IUCN Red List). Then, I compared the type-locality sites of new amphibian species descriptions (species described between 2005 and 2009) with the DD surface in order to check if new species discoveries were significantly more abundant within the DD surface or not. Even though the amphibian DD species surface covers only 8% of Earth's land area, 79% of the amphibian species discovered between 2005 and 2009 were within the DD surface. The results suggest that directing surveys towards areas of known data deficiency will likely result in the discovery of species new to science, helping to address the Linnean shortfall. Incorporating DD information from the IUCN Red List may provide an efficient methodology for strategically targeting surveys and inventories, maximizing the chances of obtaining high conservation benefits from them, and helping minimize the costs associated with such endeavours.

Zusammenfassung

Die Kenntnis der Biodiversität ist von trauriger Unzulänglichkeit. Nur ein Bruchteil der Arten dieses Planeten wurden wissenschaftlich beschrieben (das "Linneische Defizit"). Selbst bei den beschriebenen Arten verfügt die Wissenschaft oft nur über fragmentarische Informationen zu ihrer Verbreitung (das "Wallacesche Defizit"). Diese Wissendefizite schränken die Fähigkeit, Biodiversität angesichts des gegenwärtigen Artenschwundes zu schützen, erheblich ein. Hier überprüfe ich die Hypothese, dass fehlende Information (Data Deficiency: DD) genutzt werden könnte, um Erkundungen und Bestandsaufnahmen in solche Regionen zu lenken, in denen die Wahrscheinlichkeit neue Arten zu entdecken hoch ist.

*Tel.: +55 62 3521 1728; fax: +55 62 3521 1728.
E-mail address: brito.dan@gmail.com.

1439-1791/$ – see front matter
doi:10.1016/j.baae.2010.09.007

Ich stellte globale Verbreitungskarten für alle Amphibienarten (bis zum Erstbeschreibungsjahr 2004) mit unzulänglich bekannter (DD) Verbreitung zusammen und konstruierte eine DD-Oberfläche. Diese DD-Oberfläche basierte auf den Verbreitungsangaben in der IUCN Roten Liste. Dann verglich ich die Typusfundorte von neuen Amphibienbeschreibungen (2005 bis 2009) mit der DD-Oberfläche, um zu überprüfen, ob neu entdeckte Arten signifikant häufiger innerhalb der DD-Oberfläche auftraten oder nicht.

Obwohl die DD-Oberfläche der Amphibienarten nur 8% der Landfläche der Erde einnimmt, fanden sich 79% der von 2005 bis 2009 neu entdeckten Arten innerhalb der DD-Oberfläche.

Die Ergebnisse legen nahe, dass der Ansatz, Erkundungen in Gebiete mit bekannt geringem Wissensstand zur Artverbreitung zu richten, wahrscheinlich zur Entdeckung neuer Arten führen wird und damit helfen kann, das Linneische Defizit anzugehen.

DD-Informationen aus der IUCN Roten Liste zu berücksichtigen, könnte eine effektive Methode sein, Erkundungen und Bestandsaufnahmen strategisch zu planen. Hierdurch könnten die Aussichten, aus ihnen einen hohen Naturschutznutzen zu ziehen, maximiert und die mit solchen Vorhaben verbundenen Kosten minimiert werden.

Keywords: Amphibia; Conservation priorities; Data Deficient; Inventories; Linnean Shortfall; Surveys

Introduction

Biodiversity faces a crisis with extinction rates estimated to be as high as those of the five mass extinctions of Earth's history (Pimm, Russell, Gittleman, & Brooks 1995). However, our understanding of the natural and anthropogenic processes associated with this event is severely impaired due to our lack of knowledge on the very core of the crisis: How many species are there? Where are they?

Our knowledge about biodiversity is plagued by the so-called Linnean and Wallacean shortfalls (Brown and Lomolino 1998; Lomolino 2004; Whittaker et al. 2005; Possingham, Grantham, & Rondinini 2007). The first refers to the fact that most species living on Earth are not formally described. Even 300 years after the birth of Linnaeus, taxonomy has described only a small fraction of our planet's species (Novotny et al. 2002). The second refers to the fact that, for the majority of taxa, geographical distributions are also poorly understood and contain many gaps. Indeed, the lack of knowledge about species and their distributions has always been considered an obvious problem for reserve design (Polasky et al. 2000; Gaston & Rodrigues 2003; Brooks, Fonseca, & Rodrigues 2004a; Fagan, Kennedy, & Unmack 2005).

Detailed knowledge about species and their distributions is of paramount importance for conservation for a number of reasons. For example, in order to have its conservation status assessed by the International Union for Conservation of Nature (IUCN), a species must have a formal scientific description (a Latin name) (Mace & Lande 1991; IUCN 2001). Estimates suggest there are between 5 and 30 million of species on Earth (Novotny et al. 2002). However, the total number of species actually named and recorded is approximately 2.0 million (Mace et al. 2005). Further, current rates of species description average 15,000 species per year (Stork 1993), and approximately 90 of these are amphibians. However, only 47,677 species have had their conservation status assessed against the IUCN Red List of Threatened Species (IUCN 2009), and to make matters worse, 6557 are considered Data Deficient (DD, i.e., information is insufficient to make a conservation status assessment) (IUCN 2009).

Species identification and distribution data are also fundamental to identify sites of global conservation significance (Eken et al. 2004). However, this dependence on species distribution data presents significant problems because new data change species threat status, and because there are inaccuracies and incompleteness in species distribution maps (Nelson, Ferreira, Silva, & Kawasaki 1990; Reddy & Davalos 2003). Over the last few years, increasing attention has been paid to the incorporation of uncertainty into conservation planning; for example, the likelihood that landscape dynamics and global climatic changes cause distributional shifts (Meir, Andelman, & Possingham 2004). However, the lack of knowledge about a group has only rarely been explicitly incorporated into site selection models. A simulation study on anurans from the Cerrado biome in Brazil (Bini, Diniz-Filho, Rangel, Bastos, & Pinto 2006), provides compelling evidence of how much difference the incompleteness of biodiversity sampling makes to conservation planning.

There are two main approaches to address this problem. The first is to rely on environmental surrogates of biodiversity in conservation planning. Many such approaches have been proposed, including ecoregions (Olson et al. 2001; Olson & Dinerstein 2002), assemblage diversity (Araújo, Densham, & Williams 2004), environmental diversity (Bonn & Gaston 2005); and environmental cluster analysis (Trakhtenbrot & Kadmon 2005). These surrogates are attractive in that they can be mapped from space using remote sensing technology (Turner et al. 2003). However, they face a serious limitation in that biodiversity is not evenly distributed across environmental space (Brooks, Fonseca, & Rodrigues 2004b; Ferrier et al. 2004; Rodrigues et al. 2004).

The second approach to tackling the Linnean and Wallacean shortfalls is to intensify field studies to collect species data (Brooks et al. 2004a). Such work is underway through numerous museums, herbaria, and universities around the world, and increasingly in non-governmental organizations, due to significant funding (e.g., through NSF's Biological

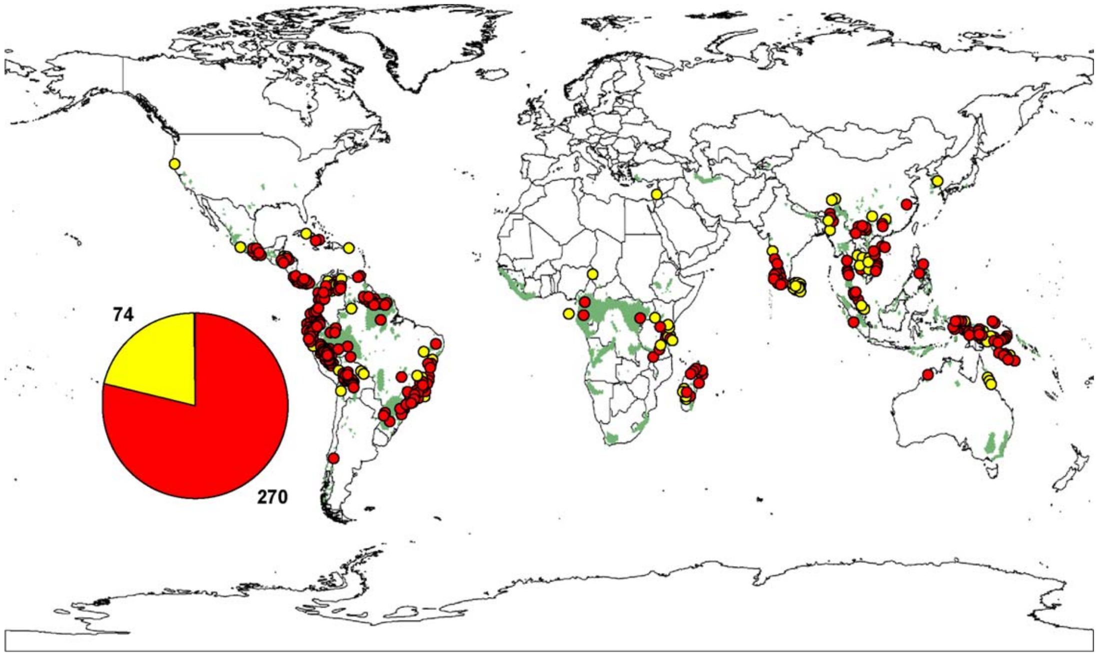

Fig. 1. Data Deficiency (DD) surface (light grey/green) and the type localities of new amphibian species described between 2005 and 2009. Species whose type locality falls within the DD surface are shown in dark grey/red and those falling outside the DD surface are shown in white/yellow.

Surveys and Inventories program). However, resources are still insufficient to come anywhere close to completing a global survey of life, so this approach requires prioritization of survey effort. At which sites would new records of threatened species contribute most to minimizing extinctions? At which sites would surveys do the most to reduce existing biases in our knowledge of priority species distributions?

The small amount of novel work focused on this topic to date has been restricted to the use of environmental surrogates alone to guide survey effort (Funk, Richardson, & Ferrier 2005). While the best guidance available up to now, this approach suffers from the same limitations of environmental surrogates generally – biodiversity is not evenly distributed across environmental space. Such data deficiency places serious limitations on our ability to conserve biodiversity. Yet strategic use of such information about what we do not know may be able to accelerate our acquisition of biodiversity knowledge.

Here, I analyze global data for amphibians in a novel way, in order to test the hypothesis that data deficiency may be used to guide surveys and inventories to regions that would increase the probability of discovering new species.

Material and methods

Amphibian populations are declining throughout the world (Stuart et al. 2004), and 25% (1597 out of 6285) of all amphibians are listed as Data Deficient (IUCN 2009). I compiled distribution maps for all Data Deficient amphibians (IUCN 2009). Geographic distribution polygon(s) of the Extent of Occurrence (see IUCN 2001 for a definition) for each species were obtained from the Global Amphibian Assessment database (IUCN 2009). The maps are in the form of polygons that join known locations. A species' distribution map can consist of more than one polygon where there is an obvious discontinuity in suitable habitat. Then, I overlaid all maps in order to obtain an amphibian DD species surface. I only used species described up to 2004 to construct this DD surface map.

I also compiled a list of all new amphibian species discovered in the years 2005–2009 (IUCN 2009; Frost 2010), and obtained the coordinates of the location from which each species was described. Then, I compared the type-locality sites of new amphibian species descriptions with the DD surface in order to check if new species discoveries were significantly more abundant within the DD surface or not.

Results

The amphibian DD species surface covers only 8% of Earth's land area (Fig. 1). Yet, of the 344 amphibian species discovered between 2005 and 2009, 270 (79%) were discovered within the DD surface, (Fig. 1) substantially more than expected according to the DD surface coverage in relation to Earth's terrestrial surface ($\chi^2 = 2276.9$; $p < 0.001$).

Some DD regions were particular rich in new species: tropical Andes, Tumbes-Chocó-Magdalena, Atlantic Forest, Guyanan Shield, Mesoamerica, Madagascar, Western Ghats, the mountains of south-west China, Indo-Burma, Philippines, Sundaland, New Guinea and the East Melanesian Islands (Fig. 1). Amphibian surveys and inventories directed not only to these regions, but also to some DD regions that have been under-sampled until now, such as northern and western Amazon, the Congo Basin, the Guinean Forests of West Africa, Maputaland-Pondoland-Albany and Wallacea (Fig. 1), might result in significantly reducing the global Linnean shortfall for amphibians.

Discussion

A precise knowledge on global biodiversity patterns is a pressing concern for determining anthropogenic impact upon life on earth (Purvis & Hector, 2000; Mace, Gittleman, & Purvis 2003; Wilson 2003). The ability to design effective conservation strategies can be greatly increased by an accurate knowledge of what species exist and their distributions (Jones, Purvis, Baumgart, & Quicke 2009). As a consequence, recently several methods and frameworks are being developed with the objective of tapping into this yet unknown portion of biodiversity (e.g. Jones et al. 2009).

Even though studies based on biodiversity data need accurate information on species, some studies show that this information is frequently biased, mainly as a consequence of aggregated survey patterns in which taxonomists repeatedly select localities that are historically recognized as having greater values of biodiversity (Dennis & Thomas 2000; Sastre & Lobo 2009). This suggests that taxonomists tend to concentrate their efforts in the localities that guarantee success in the collection of as many species as possible (Sastre & Lobo 2009).

The results suggest that directing surveys towards areas of known data deficiency will likely result in the discovery of species new to science, helping to address the Linnean shortfall. It seems that the Data Deficient label, applied to a taxonomic entity (species) also reflects spatial knowledge deficiency. These first global findings are in accordance with earlier works at regional scales suggesting that the probability of new species discoveries increases in areas with low biodiversity knowledge (Bini et al. 2006), and that it should be possible to target fieldwork towards redressing this (Raxworthy et al. 2003). Balmford and Gaston (1999) show that government agencies and non-governmental organizations should invest in high-quality biodiversity inventories before designing protected area networks. As such surveys may be expensive (Balmford & Gaston 1999). A survey directed towards localities previously recognized as having higher species richness values is unpromising for discovering the true species richness distribution of a territory (Sastre & Lobo 2009). Results show that incorporating DD information from the IUCN Red List provides an efficient methodology for strategically targeting surveys and inventories, maximizing the chances of obtaining high conservation benefits from them, and helping minimize the costs associated with such endeavours. The method presented here provides another tool that may help the scientific community to better understand species diversity and distribution.

Acknowledgements

I would like to thank Thomas Brooks and Will Turner for valuable comments and suggestions in an earlier draft of the manuscript. Daniel Brito's work is funded by CNPq (project # 305631/2009-8).

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