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Amphibian conservation, land-use changes and protected areas: A global overview

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ABSTRACT

Amphibians are undergoing a global conservation crisis, and they are one of the most underrepresented groups of vertebrates in the global network of protected areas (PAs). In this study, we evaluated the ability of the world's PAs to represent extant amphibian species. We also estimated the magnitude of the human footprint along the geographic distributions of gap species (i.e., those with distributions totally outside PAs). Twenty-four percent of species (n = 1535) are totally unrepresented, and another 18% (n = 1119) have less than 5% of their distribution inside PAs. Nearly half of all species with ranges under 1000 km^2 do not occur inside any PA. Furthermore, more than 65% of the distribution of gap species is in human-dominated landscapes. Although the Earth's PAs have greatly increased during the last ten years, the number of unprotected amphibians has also grown. Tropical countries in particular should strongly consider (1) the importance of using amphibians to drive conservation policies that eventually lead to the implementation and management of PAs, given amphibians' extinction risk and ability to act as bioindicators; (2) the effectiveness of national recovery plans for threatened amphibian species; and (3) the need for increased funding for scientific research to expand our knowledge of amphibian species. Meanwhile, data-deficient amphibian species should receive a higher priority than they usually receive in conservation planning, as a precautionary measure. Throughout this paper, we point out several challenges in creating more comprehensive amphibian conservation strategies and opportunities in the next decade.

1. Introduction

Amphibians are undergoing a global conservation crisis characterized by widespread species extinctions and population declines (Butchart et al., 2010; IUCN, 2013), with more than 41% of the living amphibian species currently considered to be threatened (Pimm et al., 2014). Although this is a difficult topic to address (Collins and Halliday, 2005; Scheffers et al., 2012), forecasts of extinction risks in the group are not optimistic (Hof et al., 2011; Sodhi et al., 2008; Wake and Vredenburg, 2008). Threats include the synergistic effect of many extinction drivers, such as habitat fragmentation and degradation, diseases and climate change (Stuart et al., 2004; Gardner et al., 2007; Becker and Zamudio, 2011; Hof et al., 2011). For all of these reasons, amphibians have become a high-priority group for which conservation efforts have become focused (Pous et al., 2010; Urbina-Cardona and Flores-Villela, 2010; Trindade-Filho et al., 2012; Nori et al., 2013; Nori and Loyola, 2015).

Protected areas (PAs) cover about 13% of the Earth's terrestrial surface (Bertzky et al., 2012), but several studies have revealed the relative inefficiency of PAs in representing biodiversity in general (Rodrigues et al., 2004a,b; Venter et al., 2014; Butchart et al., 2015; Nori and Loyola, 2015; Sánchez-Fernández and Abellán, 2015). Amphibians are the group with the most species whose geographic ranges are totally outside of the world's PAs. In particular, previous research revealed that 17% of these species live completely outside of PAs (Rodrigues et al., 2004b). Recent studies have further shown that most threatened amphibian species are inadequately represented in PAs worldwide (Venter et al., 2014). In Europe, PAs do not represent amphibian species significantly better than would be expected by chance (Sánchez-Fernández and Abellán, 2015). In addition, many amphibian species have restricted geographic ranges, highlighting the importance of choosing a scale that can be used to develop more accurate conservation strategies for this group (Cushman, 2006). Amphibians are rarely considered in conservation policy decisions (Rodrigues et al., 2004b), and in some regions, priority areas for amphibian conservation do not spatially match the priority areas for other vertebrate groups (Urbina-Cardona and Flores-Villela, 2010). Therefore, the underrepresentation of amphibians in conservation decisions involving PAs is much more problematic for range-restricted species that inhabit highly human-modified landscapes.

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Considering the global panorama of amphibian conservation, previous studies were undertaken over 10 years ago (Rodrigues et al., 2004a,b). However, these studies left out many details regarding amphibian conservation (e.g., the degree of protection at lower taxonomical levels within the group). Today, more information about the distribution of many amphibian species is currently available (including 862 additional species), and the area of the planet's PAs has greatly increased in the last ten years, from 11% to more than 13% of the world's surface (IUCN and UNEP-WCMC, 2013). Consequently, it is now possible to incorporate other useful information into analyses, such as the different types of land use within species' geographic ranges.

The overview presented above suggests that, currently, there is a gap in information regarding amphibian representation inside the global network of PAs and that, at the global scale, existing information is out-of-date and lacking useful, specific details to support conservation strategies. These reasons have motivated the present study, in which we provide both a new and comprehensive overview of the global PA network's ability to protect amphibian species and new information about the overlap of amphibian geographic distributions with different types of human land use. Additionally, we consider different taxa, conservation statuses and geographic regions, making special distinctions for gap species and range-restricted species.

In particular, we aim to: (1) determine the proportion of represented amphibian species inside the world's PAs in different management categories (according to the IUCN) for each taxonomic family by separately evaluating all species and range-restricted species; (2) assess the number of species unrepresented or poorly represented in PAs and those species' locations; (3) assess the proportion of each amphibian species' total distribution represented in PAs; (4) estimate the number of gap species per unit area for each continent and country; (5) estimate the magnitude of human-modified landscapes inside the geographic ranges of gap species; and, finally, (6) evaluate the conservation status of gap species, especially the status of range-restricted species that inhabit human-modified environments.

2. Methods

2.1. Data

We obtained shape files for terrestrial PAs around the globe from the World Database of Protected Areas website (IUCN and UNEP-WCMC, 2013). We selected only those PAs with "designated" status (i.e., we did not consider "inscribed," "non-reported," or "proposed" PAs) from all six management categories defined by the IUCN (I to VI), totaling 126,280 PAs. Some PAs are not represented in the WDPA database, including subregional and private PAs; we did not include these areas in our study. It would be important to include these PAs in future studies with similar analyses at regional scales.

To build the amphibian dataset, we downloaded vector files of range maps for the 6316 species available in the IUCN database (IUCN, 2013), which includes 86.5% of all extant amphibian species, according to Frost (2014). These vector maps were generated and/or validated by experts in each taxonomic group. They are available in the shapefile format and contain the known range of each species, depicted as polygons. Our results did not include taxonomic changes arising from the inclusive phylogenetic analysis of Brachycephaloidea (=Terrarana) undertaken by Padial et al. (2014). Overall, the range maps accurately represent the known distribution of most of the species included (Ficetola et al., 2013), and they are useful and appropriate for global extent analyses. However, their use implies the need to assume commission and omission errors (mainly the former) in species distributions, especially in the tropical areas of South America and Asia (Ficetola et al., 2013).

We also compiled data on each species' current conservation status (IUCN, 2013) and its taxonomic order and family (Frost, 2013; downloaded from Amphibian Species of the World 5.6, available at http://research.amnh.org/vz/herpetology/amphibia/). Using ArcGis 10.2, we joined this information with the range map of each species. We obtained information about human impact on natural environments from the "Anthropogenic Biomes of the World (v. 1)" website (http://ecotope.org/anthromes/v1/guide/). Ellis and Ramankutty (2008) proposed these biomes using different sources of information, such as land use and human population density. The database offers 21 different categories of anthropogenic biomes in raster files. For this study, using a reclassification tool in ArcGis 10.2, we regrouped those 21 categories into four. Our categories have a decreasing order of human population density: (a) highly urbanized areas with up to 440 persons/km^2, (b) rural villages and sparsely urbanized areas with up to 210 persons/km^2, (c) crop areas with up to 6 persons/km^2 and (d) wild areas with no persons/km^2. These categories were modified from Brum et al. (2013), where more details can be found. For another source of human influence on the landscape, we extracted information on deforestation between 2000 and 2012 for each country from Hansen et al. (2013).

2.2. Analyses

For each amphibian family, we calculated the percentage of species (a) unrepresented in PAs (i.e., gap species), (b) only represented in PAs under categories I to IV, which have specific conservation objectives, and (c) represented in PAs under categories V and VI, which have no strict biological conservation goals. We replicated these analyses considering only species with geographic ranges smaller than 1000 km^2 (i.e., range-restricted species; see Rodrigues et al., 2004a). There were 2323 total range-restricted species, nearly 37% of our database.

We have calculated, shown and discussed the percentage of overlap between each species distribution and PAs. Hereafter, we refer to those species whose ranges fall totally outside of PAs as "unrepresented" or "gap" species. Following our reasoning, "represented" species are those whose geographic distribution overlaps with PAs. To determine both the number and location of gap species, we superimposed the PA range polygons onto the geographic range map for each species, and by implementing the "select by location tool" in ArcGis 10.2, we selected those species that overlapped with at least one PA. Then, we inverted this selection in order to select from all the gap species. The location of each species was graphically represented as the centroid of their distribution.

Then, using ArcGis 10.2, we overlaid the polygons of gap species with the political boundaries of countries and quantified the number of species occurring in each country. Using this information, we were able to calculate the number of gap species per unit area for each country. In order to determine the percentage of representation per species, first we calculated the area of each species' range and the area of that range that overlaps with PAs. Finally, we calculated the proportion of each species' range that is protected.

Finally, to determine the magnitude of human influence for each gap species' range, we calculated the percentage of each range occupied by each of our four anthropogenic biome categories. We did this by implementing the zonal statistic tool of ArcGis 10.2. In addition, we retrieved each gap species' IUCN threat status. We also investigated the criteria IUCN used to classify these species under a given threat category: critically endangered (CR), endangered (EN) and vulnerable (VU). We calculated the percentage of species assigned to each threat category and mapped them worldwide; we also replicated this analysis both for gap species having more than 50% of their distribution ranges overlapping human-modified environments and for species with very restricted ranges (i.e., smaller than 1000 km^2).

3. Results

The majority of described amphibian species are indeed represented in PAs: 4781 species (75.69%). Furthermore, we found that 64% of amphibian species (n = 4045) are represented in at least one PA under categories I to IV, while 11.6% (n = 732) of amphibian species can be found only within PAs under categories V and VI. The remaining 24.4% of species (n = 1535) are totally unrepresented in the global network of PAs (Figs. 1–3).

Eighteen percent (n = 1119) of amphibian species have less than 5% of their distribution represented in PAs, and 22% of those (n = 240) have less than 1% of their ranges protected. Many species (37%, n = 2350) have between 5% and 25% of their distribution protected, but only 662 species (10.5%) have more than 50% of their ranges protected. Of these most-protected species, the majority (n = 449) is range-restricted (Fig. 2).

The only amphibian family totally unrepresented in PAs is the monotypic Nasikabatrachidae (Frost, 2013). All other families have at least half of their species represented in at least one PA (Fig. 1a). Among range-restricted species, 49% (n = 1145) are represented in at least one PA, and 33.7% (n = 784) occur in PAs with categories I to IV. A total of 51% of range-restricted species (n = 1180) are not represented in any PA. Our results show that range-restricted species from the families of Nasikabatrachidae, Conrauidae, Rhinatrematidae, Hemisotidae and Ascaphidae are completely unprotected today. On the other hand, five families have all of their range-restricted species represented in at least one PA, and the families Leiopelmatidae, Limnodynastidae, Proteidae and Sooglossidae are totally represented in PAs of categories I to IV (Fig. 1b).

North America has 232 species (94% of those occurring there) represented in at least one PA, 84% of which are in PAs with categories I–IV. Europe has 88% of its species (n = 82) represented in at least one PA, with 84% of those in PA categories I–IV. The scenario is worse for Latin America, which has 26% gap species (n = 832), and Asia, which has 20% gap species (n = 283). Ecuador, Colombia, Peru, Panama, Guatemala and Papua New Guinea are the countries with the highest number of gap species per unit of area (Fig. 3). Independent of country borders, the areas with the greatest number of gap species are located in the Andean mountain region (Peru, Ecuador and Colombia); southern Mexico; eastern Brazil; Papua New Guinea and Indonesia; and parts of Madagascar, Cameroon and southern India (see centroids in Fig. 4).

On average, the degree of spatial congruence between human-modified landscapes and the geographic ranges of gap species is 65.4%. Nevertheless, this congruence is highly variable among regions. Africa has the largest proportion of species affected by human-induced alterations, and only 16% of its gap species' ranges were free of human influence. Oceania, despite having one of the largest percentages of gap species, also has the lowest level of human influence on species' ranges, with 75% of its gap species' ranges falling outside human-modified landscapes. Rural villages and sparsely populated areas were the most common anthropogenic units inhabited by gap species on this continent (Fig. 5).

Considering all gap species, 51% are currently classified as Data Deficient (DD), 16% as CR, 15% as EN and 7% as VU, according to the IUCN (2013). Of the 585 threatened gap species (i.e., those classified as CR, EN or VU), 424 (72%), were assigned to a threat category based on IUCN's criterion B1, which considers species' extent of occurrence; 8.5% were assigned based on criterion B2, which considers species' area of occupancy; and 13% were considered threatened under criterion D2, which considers species' restricted areas of occupancy or locations (for further details, see the IUCN categories at www.iucnredlist.org). When considering only species that occur in areas with high human influence, according to Ellis and Ramankutty (2008), we found similar results: 47% of these species are categorized as DD, 20% are CR, and 18%

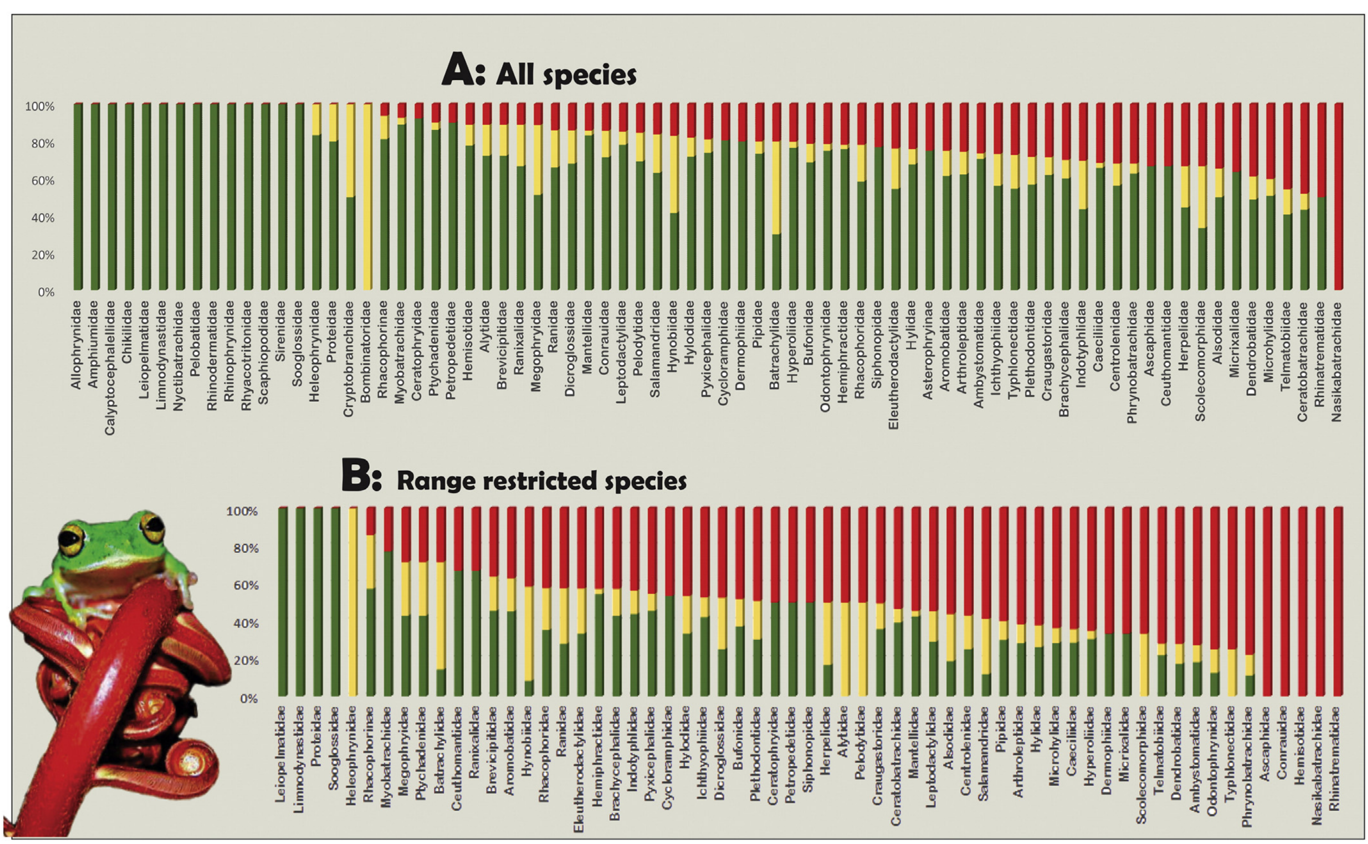

Fig. 1. Percentage of amphibian species in each family for range-restricted species and for all species. Green bars stand for the percentage of species found in at least one protected area (PA) under strict protection (IUCN category I–IV), yellow stands for species found in PAs under sustainable use (IUCN category V–VI), and red stands for the percentage of unprotected species in each family. Amphibian species: *Pseudophilautus femoralis*. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

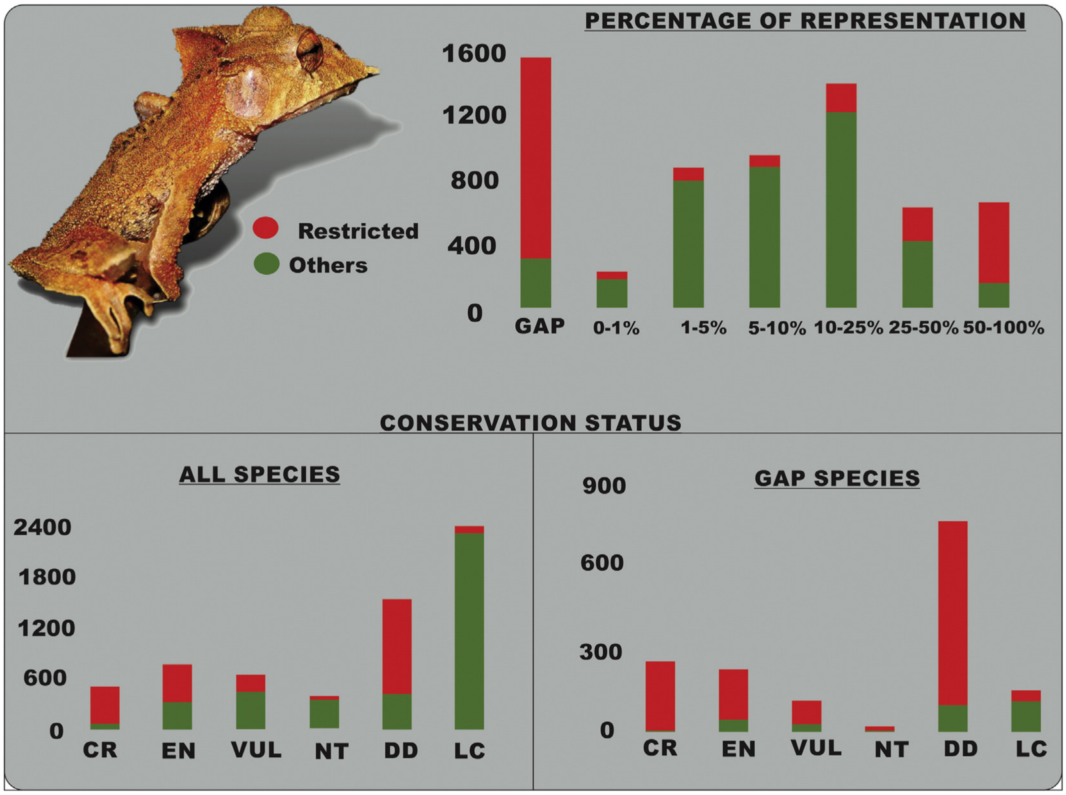

Fig. 2. Histograms showing the percentage of the distribution of the species included in PAs for each species (A) and the number of species assigned to each IUCN status when considering all species (B) and only the gap species (C). All the histograms discriminate range-restricted species. Amphibian species: *Hemiphractus bubalus*.

are EN. This pattern is also similar for range-restricted gap species: 55% of these species are DD, 19% are CR, and 15% are EN (Figs. 2 and 4).

4. Discussion

Our analyses revealed that almost 25% of all extant amphibian species, more than 1500 in all, still remain totally outside PAs. Furthermore, for some other species, only a small proportion of their total geographic range lies within PAs. Continents harboring an abundance of gap species (such as Latin America, Asia and Africa; Fig. 3) are being highly impacted by human activities (Fig. 5). It is important to highlight that our maps do not consider mining and industrial development, activities that are deemed harmful for amphibians (Becker and Zamudio, 2011). The ongoing modification of landscapes by humans could negatively and irreversibly affect the survival of many taxa (Laurance et al., 2012). Therefore, the overview presented here has critical implications for both conservation actions and policy.

Despite the increase in the extent of terrestrial PAs in the last decade (about 10% more area designated as protected and 13,000 additional PAs), the proportion of amphibian species falling totally outside of PAs has also increased. This pattern could be due to the increase in taxonomic description of new amphibian species (especially those with a limited distribution), the split of widely distributed taxa into new species, and the lack of available information on amphibian ecology and natural history (for a general discussion on this topic, see Diniz-Filho et al., 2013; Oliver et al., 2013). However, this pattern also emphasizes that only a few designated PAs provide an effective safeguard against extinction for amphibians (Rodrigues et al., 2004a,b). In recent years, additional private reserves not included in the WDPA database have been established with the sole purpose of conserving amphibians (see the Methods section); however, as threatened amphibian species are often not the focus of conservation planning, this group is currently not adequately represented (Venter et al., 2014).

It is worth noting the particular situation faced by amphibians in central and western Africa (see also Nori and Loyola, 2015). In this region, on average, 84% of gap species have geographic ranges that overlap with human-modified landscapes. Considering future scenarios of global change (Pereira et al., 2010; Dobrovolski et al., 2011; Hof et al., 2011), opportunities to conserve species in highly disturbed regions could be increasingly diminished due to the expansion of agricultural areas and continued human modification (Faleiro et al., 2013; Nori et al., 2013; Dobrovolski et al., 2014). The implementation of conservation planning protocols that consider amphibians is therefore urgently needed in these areas. Postponing the implementation of these protocols could delay and threaten the protection of many amphibian gap species. Finally, while considering future scenarios, it is important to highlight that our analyses consider only the current distributions of species; however, it is known that global climate change is already affecting biodiversity distribution patterns (Garcia et al., 2014). Hence, these changes might have a strong effect in the representativeness of PAs (Araujo et al., 2004; Ferro et al., 2014; Lemes et al., 2014; Loyola et al., 2014). Thus, ideally, the mentioned conservation planning protocols should incorporate the uncertainty associated with this particular threat in order to generate accurate and lasting policies.

While widely distributed families have, on average, a large percentage of species that currently occur in at least one PA, those families with species restricted to only a few regions exhibit extensive variation (from 0% to 100%) in terms of protection by at least one PA. This result could either be due to chance, given that these families contain a relatively small number of species, or it could be linked to the degree of human impact and the level of protection found in species' native regions. This pattern is explained by the fact that well-represented range-restricted families (i.e., those with bounded geographic coverage and a great proportion of their species overlapping in PAs) are endemic to countries or regions with large PAs, such as those found in the Amazon rainforest (Allophrynidae), North America (Amphiumidae, Rhyacotritonidae, and Sirenidae) or the Andean-Patagonian Forest (Calyptocephalellidae,

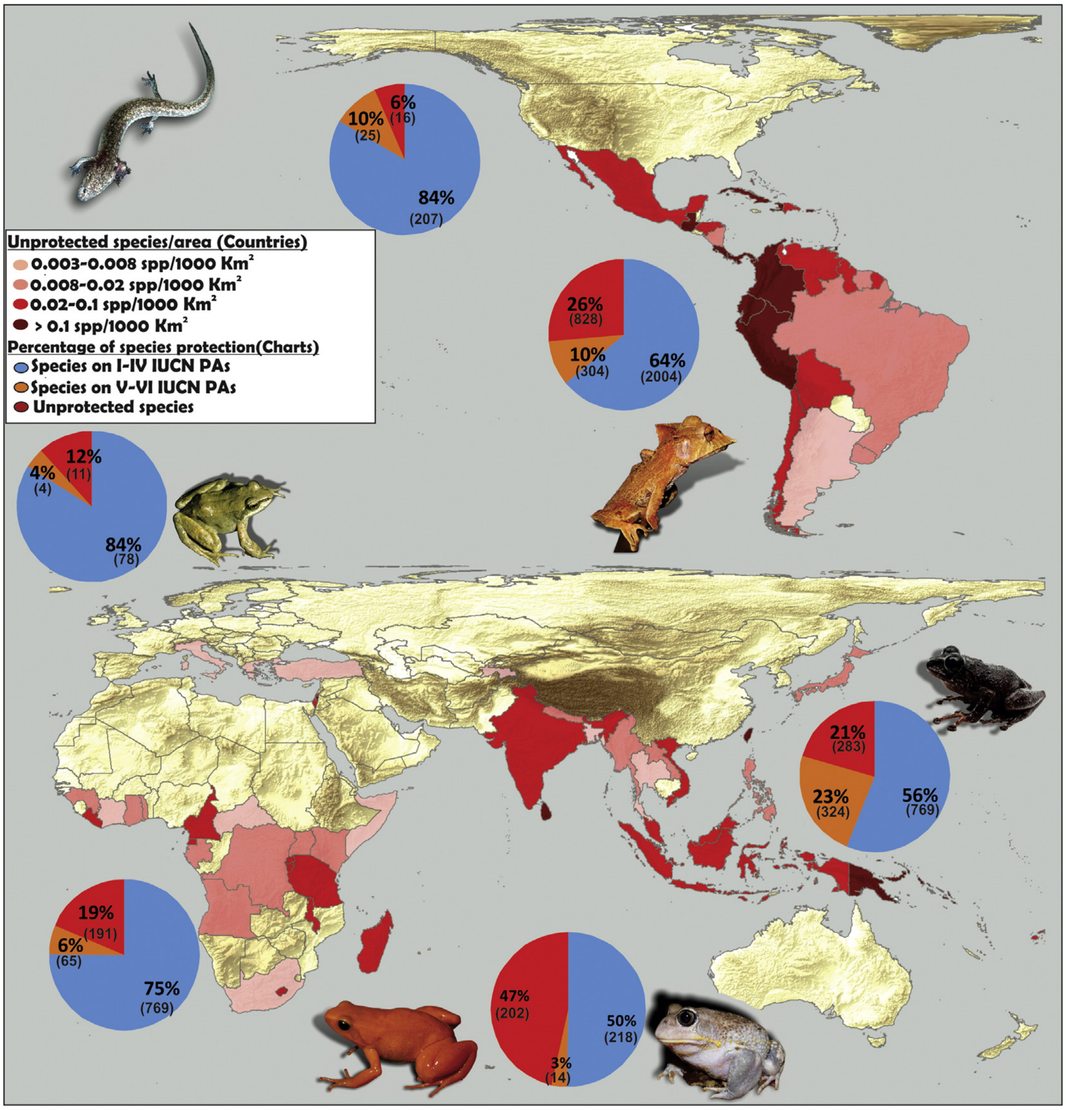

Fig. 3. Map showing the number of unprotected species per unit area in the world's countries and pie charts with the percentage of species occurring in different protected area management categories. This figure is illustrated with an amphibian species from each region: *Eurycea latitance* (North America), *Hemiphractus bubalus* (Latin America), *Rana pyrenaica* (Europe), *Mantella aurantiaca* (Africa), *Helioporus australiacus* (Oceania) and *Philautus umbra* (Asia).

Rhinodermatidae). However, families with the largest percentage of gap species are endemic to regions with little relationship between the extent of PAs and amphibian species richness, such as the Western Ghats in India (Nasikabatrachidae and Micrixalidae), the tropical Andes (Rhinatrematidae and Telmatobiidae) and Southeast Asia (Ceratobatrachidae) (Frost, 2014; IUCN, 2013; IUCN and UNEP-WCMC, 2013). Range-restricted species (and families) are highly vulnerable (Villalobos et al., 2013) and therefore must be considered in conservation policies (Rosenfield, 2002; Whittaker et al., 2005).

In most countries that harbor a great number (and density) of gap species, recent trends are not compatible with amphibian conservation. For example, countries with tropical and subtropical forests in Asia (including Indonesia and Thailand), Africa (including Angola, Zambia and Congo), and Latin America (including Nicaragua and Bolivia) have also recently suffered exceptionally high deforestation rates (Hansen et al., 2013; see also Fig. 4). In addition, unfortunately, these countries have experienced only a small increase in the extent of their PAs during the same period (IUCN and UNEP-WCMC, 2013; see Supplementary Fig. S1). Regions with the largest number and density of gap species are located in species-rich countries that have areas identified as high priority for conservation on the global scale (Mittermeier et al., 2004; Brooks et al., 2006). Given the high irreplaceability of many PAs in these regions, scientists have proposed a high level of protection and encouraged global recognition for 137 current PAs as World Heritage sites (Le Saout et al., 2013). Combining the results presented here with those of previous studies (e.g., Rodrigues et al., 2004a,b), we suggest that conservation efforts should be mainly focused on strategically expanding the network of PAs in these species-rich countries, based on the known conservation gaps, to ensure the protection of many gap species.

According to the IUCN Red List of Threatened Species, many gap species are highly threatened, and most of them are also range-restricted (Fig. 2). However, our findings may be highly influenced by the narrow distributions of these species. It is also noticeable than 45% of gap species are currently classified as DD species by the IUCN and that many of these species inhabit highly disturbed environments. Unfortunately, DD species are generally ignored or considered as species of least concern in conservation policies, plans and recommendations (e.g., Rodrigues et al., 2004a; Trindade-Filho et al., 2012; Le Saout et al., 2013) even though many researchers have devoted their efforts to showing that this could be a wrong decision (Trindade-Filho et al., 2012; Morais et al., 2013; Howard and Bickford, 2014; Nori and Loyola,

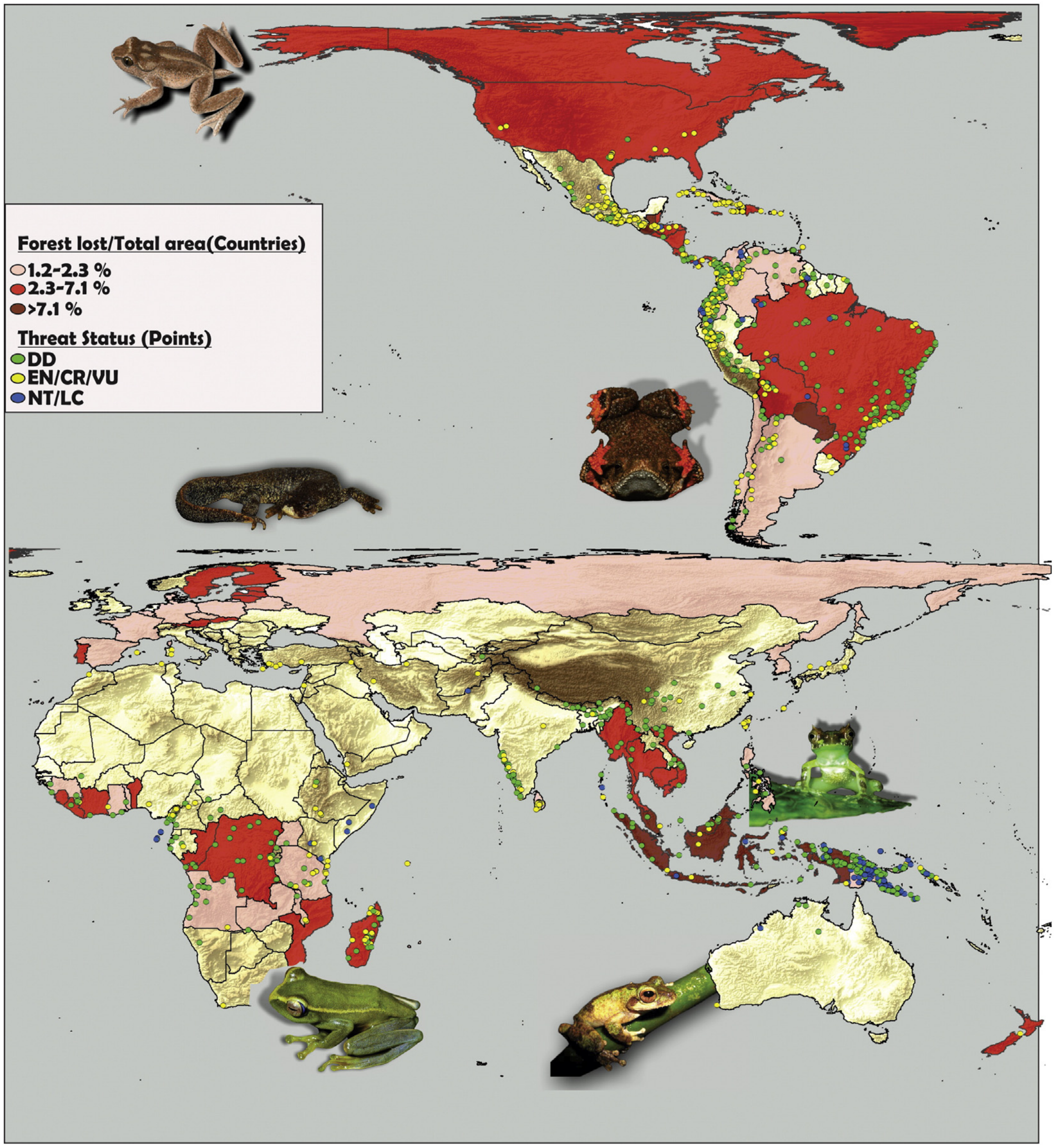

Fig. 4. Map showing the location (centroid of species' distribution) of unprotected species, their conservation status and the recent deforestation in each country. This figure is illustrated with an amphibian species from each region: *Ascaphus montanus* (North America), *Melanophryniuscus krauczuki* (Latin America), *Calotriton arnoldi* (Europe), *Gracixalus supercornutus* (Asia), *Litoria myola* (Oceania) and *Boophis andohahela* (Africa).

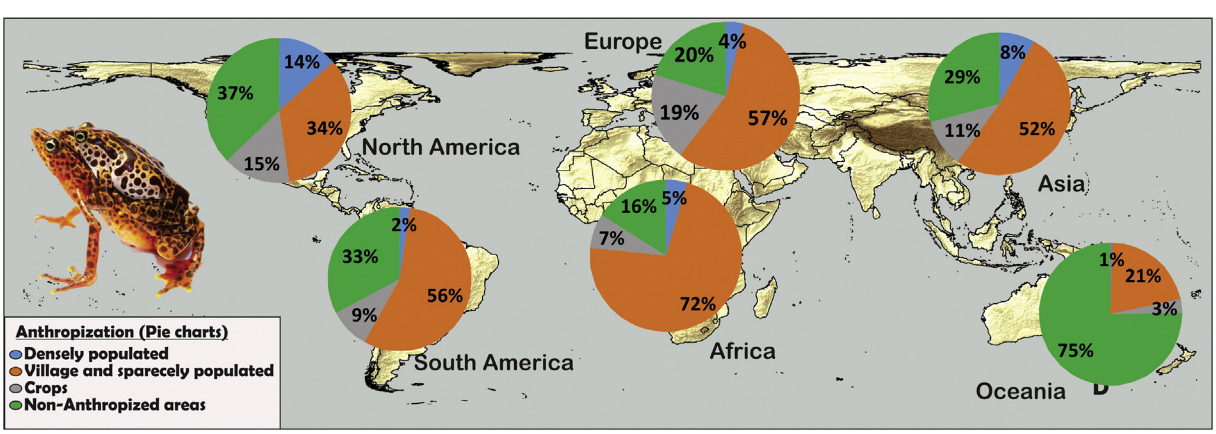

Fig. 5. Percentage of spatial overlap between species' geographic range and different types of human land use and the rate of deforestation per unit area in the world's countries. Amphibian species: *Atelopus certus*.

2015). Information regarding the geographic range of many DD species is likely to be incomplete, and we were not able to discriminate between DD species that have been recently assessed and those that are DD due to taxonomic problems. Hence, it is essential to increase our knowledge of many biological aspects of these species (such as taxonomy, systematics, demography, ecology, natural history and threats) in order to generate adequate conservation policies (see Diniz-Filho et al., 2013).

We identified several key regions (such as part of the tropical Andes, Southeast Asia and central Africa) in which the combined effect of deficits in the PA network and steady human influence will inevitably aggravate the current crisis scenario for amphibians. Urgent conservation policies, including governmental and social initiatives aimed at strategically expanding current PA networks, are needed (Ochoa-Ochoa et al., 2009). Fortunately, many opportunities are available. The 10th United Nations Convention on Biological Diversity Conference of the Parties, which took place in October 2010 in Nagoya (Japan), resulted in an impressive revised and updated Strategic Plan for Biodiversity Conservation that will last until 2020. The Parties made the bold commitment to protect at least 17% of terrestrial and inland waters protected by 2020 (Butchart et al., 2010).

Major gaps in PA coverage preclude the protection of many species and ecosystems, not just those of amphibians (Butchart et al., 2010; Jenkins and Joppa, 2009; Le Saout et al., 2013). Thus, this international agreement to expand the global network of PAs is timely. Nearly 13.6% of the terrestrial land area is currently protected (Le Saout et al., 2013), although the effectiveness of this protection has been disputed (e.g., Jenkins and Joppa, 2009). Hence, there are still large opportunities to achieve such a target by filling the gaps in the network. The scientific community is working tirelessly to take firm and decisive steps in order to achieve these targets (Pimm et al., 2014; Rodrigues et al., 2004a; Venter et al., 2014). The efforts of the scientific community must be accompanied by bilateral or multilateral institutions (e.g., World Bank and UNEP) and NGOs, which will be indispensable when filling these gaps, making it possible to develop improved policies for conservation of amphibians and other groups in a human-altered world.

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