Received: 3 February 2018 | Revised: 15 August 2018 | Accepted: 20 August 2018
DOI: 10.1111/jbi.13435

RESEARCH PAPER

WILEY Journal of Biogeography

Global priority areas for amphibian research

Javier Nori[1] | Fabricio Villalobos[2,3] | Rafael Loyola[4]

[1]Instituto de Diversidad y Ecología Animal (IDEA-CONICET) and Centro de Zoología Aplicada, Universidad Nacional de Córdoba, Córdoba, Argentina

[2]Laboratorio de Macroecología Evolutiva, Red de Biología Evolutiva, Instituto de Ecología, A.C. Xalapa, Veracruz, México

[3]Laboratório de Ecologia Teórica e Síntese, Departamento de Ecologia, Universidade Federal de Goiás, Goiânia, Goiás, Brazil

[4]Laboratório de Biogeografia da Conservação, Departamento de Ecologia, Universidade Federal de Goiás, Goiânia, Goiás, Brazil

Correspondence
Rafael Loyola, Departamento de Ecologia, Universidade Federal de Goiás, Avenida Esperança s/n, Campus Samambaia, CEP 74.690-900, Goiânia, Goiás, Brazil.
Email: loyola@ufg.br

Funding information
Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 308532/2014-7, 437167/2016-0, 465610/2014-5; Fundação Grupo Boticário de Proteção à Natureza, Grant/Award Number: PROG_0008_2013; Financiadora de Estudos e Projetos, Grant/Award Number: 01.13.0353.00; Fondo para la Investigación Científica y Tecnológica, Grant/Award Number: PICT-2013-1607

Editor: Walter Jetz

Abstract

Aim: Lack of biological information is a silent but strong impediment for planning how to rescue amphibians from extinction. Currently, 24% of all amphibian species are assigned to the Data Deficient (DD) category of IUCN. Here, we aim to identify priority areas for amphibian research that could help gather information on these species and overcome such knowledge gap.

Location: Global.

Taxon: Amphibians.

Methods: We mapped the distribution of 1578 DD amphibian species and then defined priority research areas as those areas with high and complementary concentration of amphibian DD species that could be considered important areas for studying (and therefore conserving) such species. To evaluate the performance of the proposed priority research areas, we calculated the percentage of species overlapping these areas, considering all amphibian DD species; recently described species and geographically restricted DD species. We also determined the proportion of priority research areas falling inside each continent and country of the world. Finally, we estimated the level protection of these species and of human pressure on natural ecosystems found within our priority research areas.

Results: We showed that gathering biological information of species from just 0.4% of the world area could clarify the conservation status of more than 80% of DD amphibians. Most identified priority research areas overlap with regions under high human pressure and only a small percentage of DD amphibian species might cope with those altered conditions.

Main conclusions: Knowledge shortfalls represent a major issue for amphibian conservation globally, however, the picture could radically change if research efforts and investments are geographically strategically distributed. This study brings the first application of a complementary-based tool, which has been originally designed and implemented in conservation planning, aimed at generating information that help researchers to fill knowledge gaps as efficiently as possible.

KEYWORDS
complementary-based assessment, conservation policy, data deficient, knowledge gaps, threatened species

1 | INTRODUCTION

Knowledge shortfalls in biological sciences imply noteworthy constraints for biodiversity conservation (Bini, Diniz-Filho, Rangel, Bastos, & Pinto, 2006; Diniz-Filho, Loyola, Raia, Mooers, & Bini, 2013; Hortal et al., 2015; Jarić, Courchamp, Gessner, & Roberts, 2016). On the one hand, a great portion of biodiversity remains totally unknown (Bini et al., 2006; Mora, Tittensor, Adl, Simpson, &

Worm, 2011). On the other hand, many essential components of species existence such as geographical distribution, phylogenetic relationships or population dynamics, remain uncertain for most described species (Diniz-Filho et al., 2013; Hortal et al., 2015). These knowledge gaps are the main reasons why an important proportion of vertebrate species are currently assigned as Data Deficient by the IUCN.

Data Deficient (DD) species are those for which there is insufficient information to apply IUCN criteria and assign them (or not) to a given threat category. Over the last years, several authors have pointed out that these species could actually be under high pressure and even under actual threat (Howard & Bickford, 2014; Jetz & Freckleton, 2015; Luiz, Woods, Madin, & Madin, 2016; Morais et al., 2013; Nori & Loyola, 2015; Ocampo-peñuela, Jenkins, Vijay, Li, & Pimm, 2016) and have proposed cautionary measures to appropriately consider these species in conservation strategies and policies (Jarić et al., 2016; Trindade-Filho et al., 2012).

The case of amphibians is emblematic as they are the most threatened vertebrates worldwide (Hoffmann et al., 2010; Stuart et al., 2004). More than 30% of extant amphibian species are threatened (Jenkins, Pimm, & Joppa, 2013; Nori et al., 2015; Pimm et al., 2014) and the global network of protected areas is inefficient to protect them appropriately (Nori et al., 2015; Rodrigues et al., 2004; Sánchez-Fernández & Abellán, 2015; Venter et al., 2014; Watson, Dudley, Segan, & Hockings, 2014). On top of this, more than 40% of the remaining (i.e. non-threatened) amphibians are currently assigned as DD, with most of them facing different threats (Howard & Bickford, 2014; Morais et al., 2013). Many species-rich areas and taxa continue to be poorly studied (Brito, 2008) and consequently, amphibian DD species are usually ignored in conservation planning and policy (Nori & Loyola, 2015).

At the global scale, amphibian species richness is geographically concentrated (Jenkins et al., 2013). Thus, it is expected that geographically focused strategic research efforts could have a massive implication for the conservation of the entire group (Edges, 2002; Morais et al., 2013; Nori & Loyola, 2015). Here, using data on the known distribution of DD amphibian species and applying systematic conservation planning tools, we identify strategic areas for amphibian research, which would provide the best return on research investment per area to fill the enormous knowledge gap attached to these imperiled animals and thus contribute to their conservation.

2 | MATERIALS AND METHODS

2.1 | Species data

We downloaded digital range maps (extent of occurrence maps) for 6476 amphibian species available at the IUCN database (IUCN, 2017). Then, we selected only those maps corresponding to Data Deficient (DD) species, which resulted in a final data set of 1578 species, which corresponds to 24% of all extant amphibians (Frost, 2014; see Supporting Information Appendix S1). On the basis of these species range maps, we used the letsR package in R (Vilela & Villalobos, 2015) to generate a presence-absence matrix of species across cells of a global grid with a resolution of 0.5° of latitude-longitude. Finally, we generated individual raster files representing the distribution of each species using the raster package in R (Hijmans et al., 2015). Given the large number of species and the global extent of analysis, as well as the bias associated with the source of the distributional data (which precludes working at fine spatial resolutions; Ficetola et al., 2014), we decided to run the analyses at a spatial resolution of 0.5°. Furthermore, using range maps at finer resolutions would increase even more the biases related to overinterpretation of the limited information contained in these maps (e.g. commission and omission errors; Hurlbert & Jetz, 2007; Peterson, 2017).

2.2 | Spatial prioritisation

We used Zonation 4.0 (Moilanen et al., 2014), a systematic conservation planning decision support tool, to determine priority research areas for DD amphibian species. Such conservation planning tools are conventionally used for determining regions where conservation action could be undertaken (Ciarleglio, Wesley Barnes, & Sarkar, 2009; Di Minin, Veach, Lehtomäki, Pouzols, & Moilanen, 2014; Margules & Pressey, 2000). Here, we used Zonation to identify areas where research should be conducted to fill the knowledge gap on amphibian species. Of course, these areas could later be considered important for conservation and thus for establishing additional conservation interventions within these regions. Zonation allowed us to generate a complementarity-based ranking of priority areas over the entire globe, in this case, all of the pixels with a presence of at least one DD amphibian species. In other words, we defined priority research areas as those areas with high and complementary concentration of DD amphibian species that could be considered important areas for studying such species.

The ranking is produced by iteratively removing the pixel that leads to the smallest aggregate loss of value, in this particular case calculated on the presence of DD species. Pixels value was calculated on the basis of the additive-benefit function cell removal rule. This removal rule has the heuristic interpretation of minimising the expected extinction rates via feature-specific species-area curves (Di Minin et al., 2014). In general, this rule gives high values to those cells of high species richness in a complementary way by maximising the number of represented species in high priority areas as much as possible. The additive benefit function, however, can push priorities towards areas with a higher number of DD species. Nonetheless, the complementary-based criterion will avoid the selection of redundant pixels regarding species composition, independently of their species richness. Consequently, it is expected that our results differ from a simple map of richness of DD species. Given that all species were considered in the same conservation status (IUCN, 2017), for the Zonation analyses we assigned positive equal weights of 1 to all of them. In addition and given the simplicity of the analyses (without negative features, interactions, masks, etc.), all other parameters were kept as default: warp factor = 10; edge removal = 1; BLP = 0; etc. (see Moilanen et al., 2014 for details).

The ranking value of each pixel could be interpreted as its relative priority in terms of the 'knowledge shortfall' for amphibian species. Consequently, our top priority areas are those regions for which biological information about DD species is imperative to fill the knowledge gaps as efficiently as possible. After generating the ranking of pixels, we determined the top 5%, 10% and 20% priority pixels (i.e. 0.42%, 0.84%, and 1.67% of the world's terrestrial area, respectively).

2.3 | Additional analyses

To evaluate the performance of our proposed priority research areas, we calculated the percentage of species overlapping priority areas, considering: (a) all amphibian DD species; (b) recently described species, that is, those described after 2004 (year of the major comprehensive amphibian assessment; Stuart et al., 2004), and only DD species described after this year; and (c) all geographically restricted DD species (i.e. those species whose geographic range sizes fell within the first quartile—smallest ranges—of the geographic range size frequency distribution of all DD species). If the distribution of these restricted species (with distributional ranges smaller than 0.0032°) overlapped a priority pixel, we assumed that its type locality should be within that pixel.

Furthermore, using the map tools package of R, we determined the proportion of the top 5%, 10% and 20% priority research areas falling inside each country and continents of the world. We also determined the level of human pressure on natural ecosystems found within our priority research areas. To do this, we downloaded the Human Footprint Index 2.0 raster (WCS & CIESIN, 2005), which is a complex index created from nine global data layers covering human population pressure (population density), human land use and infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers), varying between 0 (non-anthropogenic areas) and 100 (maximum value of Human influence) and a global land cover raster (Latham, Cumani, Rosati, & Bloise, 2014) and overlaid them with our priority research areas for amphibian conservation to quantify (a) the average value of Human Footprint Index, (WCS & CIESIN, 2005) and (b) the extent of human dominated or pristine landscape inside priority areas.

Finally, we overlapped priority research areas with the global network of protected areas (PAs; IUCN & UNEP, 2017) to identify PAs of special interest for amphibian research. We considered 131,537 designated PAs. We selected and listed all PAs overlapping with top 0.42% of the world surface in terms of research (our top 5% of priority research areas).

To estimate the percentage of DD species that are tolerant to anthropogenic environments and occur within priority areas of each continent, we downloaded the habitat information of each DD species from the IUCN website (http://www.iucnredlist.org; accessed on 27 March 2018) and reclassified species as tolerant (those able to inhabit artificial areas such as crops or urbanised areas) and non-tolerant (those which only inhabit well-preserved habitats). Then, we assigned each species' habitat information to their distributional maps and used them to identify all species (tolerant and non-tolerant to anthropogenic environments) overlapping with priority research areas of each continent (considering the 5%, 10% and 20% of priority pixels). On the basis of this information, we were able to quantify the percentage of species within priority areas that are considered able to inhabit human modified habitats (see Supporting Information Appendix S1).

Last, to evaluate how knowledge on DD amphibian species has accumulated over time, we quantified the percentage of DD species discovered between 1900 and 2011 (IUCN 2017) that occur within our identified priority research areas. We grouped this information for the Atlantic rain forest, Tropical Andes, East of Africa and Madagascar and Southeast Asia because these are the areas with the highest research and conservation priorities in the world.

3 | RESULTS

The top 5% of priority research areas covered 0.42% of the world's terrestrial area and overlapped with 80% of DD amphibians' distributions. The top 0.84% of the world's terrestrial area (i.e. 10% of priority research areas) harboured 90% of all DD amphibians (Table 1). Within the top 1.68% of the world's land, virtually all DD species (98%) were found (Figure 1).

Regarding all recently described species (i.e. considering all amphibian species described after 2004), the top priority 0.42% of the world overlapped with 59% of these species, the top 0.84% with 76% and the top 1.68% with 85% of all amphibian species respectively. Considering only recently described DD species, the top 0.84% of the world overlapped with 99% of these species and the priority 0.42% with 76% of them. When only restricted DD species were considered, the priority 0.42% of the world overlapped with 75% of these species, and the top 0.84% with 98% of restricted DD amphibians (Table 1).

Priority research areas are heavily concentrated in tropical regions, mainly in the Tropical Andes and the Atlantic rain forest in South America as well as Southeast Asia, East of Africa and Madagascar (Figure 1). Almost half (48.4%) of top 0.42% of the world is concentrated in only five countries: Brazil, Peru, Colombia, Papua

TABLE 1 Number and percentage of amphibian species overlapping with priority research areas considering all DD species, range restricted DD species, DD species discovered after 2004, and all amphibians discovered after 2004

		0.42% of the world (top 5%)	0.84% of the world (top 10%)	1.6% of the world (top 20%)
All DD species	Number	1264	1433	1551
	Percentage	80	91	98
Restricted range species	Number	298	389	397
	Percentage	75	98	100
Recently described DD species	Number	262	341	345
	Percentage	76	99	100
Recently described amphibians species	Number	422	544	608
	Percentage	59	76	85

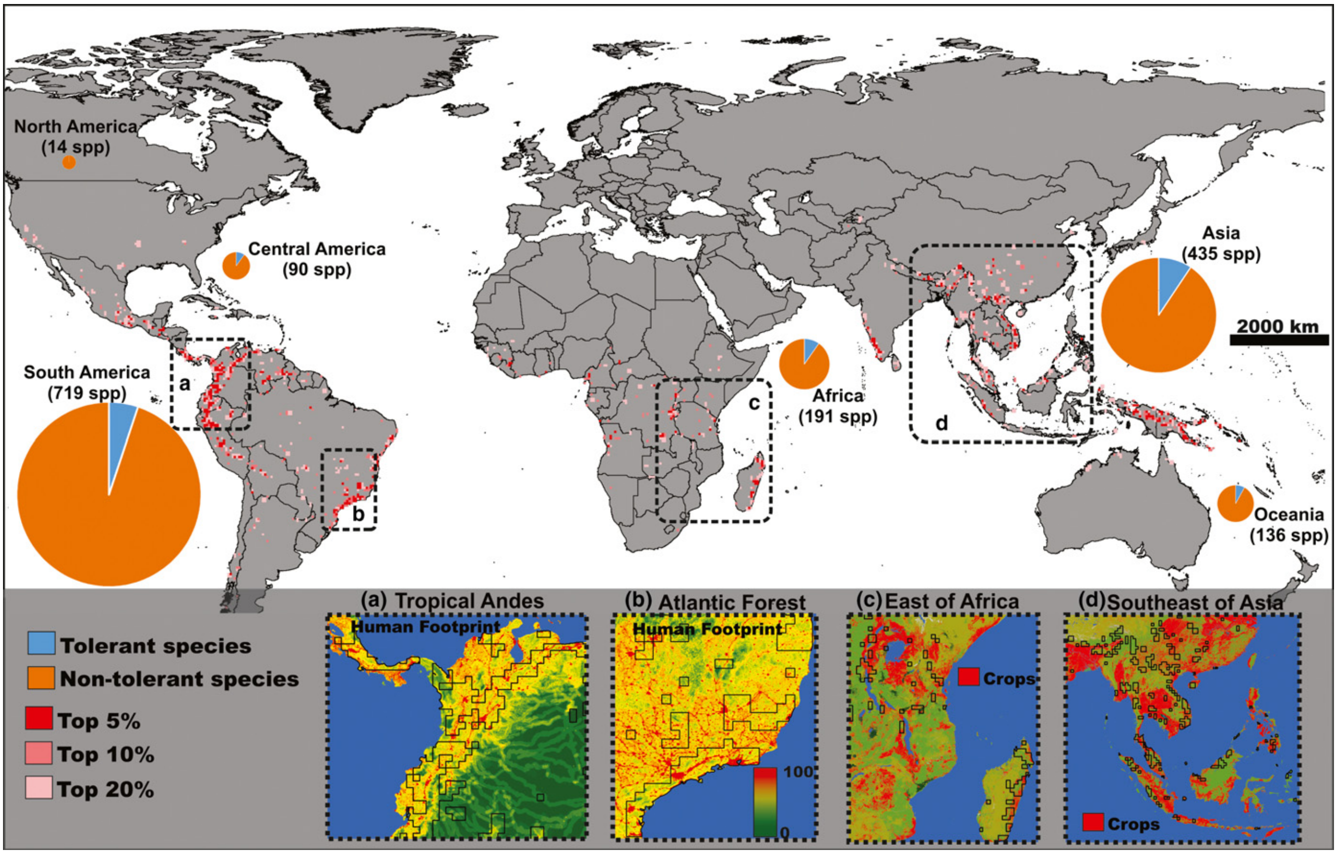

FIGURE 1 Global priority areas for amphibian research. Priorities are shown by red pixels covering the top 5–20% of land. Pie charts show the percentage of Data Deficient amphibian species that are tolerant or non-tolerant to human-modified landscapes in each continent. Diameter of the chart represent the number of DD species considered on each continent. Insets show overlap between priority areas (outlined in black) and Human Footprint Index (a–b) and crops (c–d) in the most important nucleus of priority research areas

New Guinea and Indonesia (Supporting Information Appendix S2). These priority research areas also overlapped with 980 protected areas, from which only 248 belong to IUCN categories I–IV, that is, those established with strict conservation purposes (for a detailed list, see Supporting Information Appendix S3).

Overall, priority research areas for amphibian DD species were located in human-disturbed areas. Average values of Human Footprint Index in the top priority 0.42%, 0.84% and 1.68% area were 24.8, 25 and 26.2, respectively (see WCS & CIESIN, 2005, for details of the meaning and units of these values). In addition, priority research areas in the Brazilian Atlantic rain forest and the Tropical Andes, overlapped with areas with high values of Human Footprint Index (Figure 1a,b). We also found high overlap of priority research areas and agriculture in Southeast Asia, East Africa and Madagascar (Figure 1c,d).

Only 10% of the DD species overlapping priority research areas (i.e. the 98% of the total number of DD species included in our analyses) are able to inhabit human-modified habitats. This percentage is quite conservative among continents (from 9% for South America to 15% for Asia), except in North America where none of the 19 DD species within priority areas are able to inhabit human-disturbed habitats (Figure 1). The number of DD species described in Atlantic rain forest, Tropical Andes, and Southeast Asia have exponentially increased in the last four decades (at least doubled; Figure 2; IUCN, 2017). Instead, description rates of DD species in East Africa and Madagascar, were quite constant over this period (18% of DD species described between 1971 and 1980 and 20% between 2000 and 2011; Figure 2).

4 | DISCUSSION

While knowledge shortfalls represent a major issue for amphibian conservation globally (Howard & Bickford, 2014; Morais et al., 2013; Nori & Loyola, 2015), we have shown that the gloomy picture for amphibian conservation could radically change if research efforts and investments are geographically strategically distributed. By applying a complementary-based tool originally developed for conservation planning in a novel way, we propose that gathering biological information of species from 0.42% of the world's terrestrial area can help to clarify the conservation status of more than 80% of amphibian species currently categorised as Data Deficient.

Most priority research areas are concentrated in regions where published studies on amphibians are scarce such as the Neotropical, Afrotropical and Indomalayan regions (see also Brito, 2008). These poorly studied regions need to receive more attention from the scientific community as well as more research funds. Most of these funds are currently concentrated in few developed countries that are already

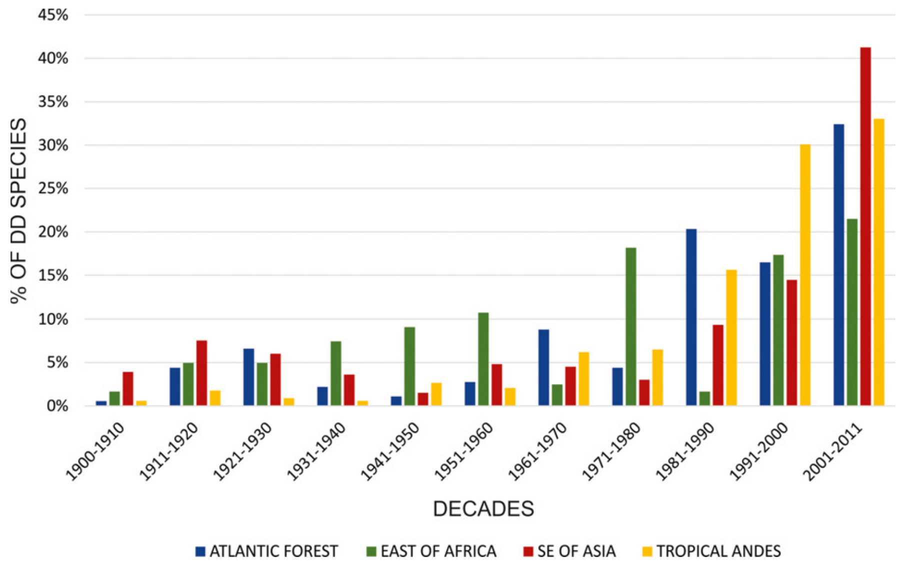

FIGURE 2 Percentage of DD species (*Y* axis) discovered on 10 years periods (*X* axis) on the most important priority research regions: Atlantic rain forest, East of Africa and Madagascar, Southeast of Asia and Tropical Andes

holding a large body of knowledge on the amphibian diversity. Targeting or transferring funds to poorly studied regions would help to solve a major problem regarding amphibian conservation. This problem is associated with the lack of knowledge on species and targeting research in these priority areas could help to appropriately determine the conservation status of amphibian DD species (see also Brito, 2008). While researchers fill this gap, those species can be considered in conservation assessments and planning, which would ultimately favour a more comprehensive conservation strategy of all amphibian species.

It is important to notice that given the spatial scale and the data used on species distribution, our results should be interpreted as an initial, broad-scale assessment of areas with both research and conservation value for amphibians worldwide. Indeed, priority areas identified here can guide future research efforts while providing the best return on research investment per area that can ultimately translate into effective conservation actions. Therefore, we encourage researchers and decision makers to address the knowledge-gap problem in the identified priority research areas at higher spatial resolution, using detailed species distribution and taxonomic knowledge to generate robust information for decision-making. It is also important to acknowledge that our data were gathered at the beginning of 2017 (IUCN, 2017) and thus they did not include taxonomic changes and species discovered during the last 2 years (243 species described in 2017–2018; AmphibiaWeb, 2018). Of course, given the trends of amphibian species discovery (e.g. amphibian taxonomy being far from complete; Rodrigues et al., 2010), our results will always be subjected to such taxonomic impediment. Nevertheless, the current amphibian crisis (Nori et al., 2015; Stuart et al., 2004) urges us to conduct research with the available information while also trying to complete it. Such efforts can bolster by focusing on priority research areas as the ones we have identified here.

The poor attention that decision-makers generally give to poorly known species (Bland et al., 2017; Jarić et al., 2016; Trindade-Filho et al., 2012) and the threats that presumably most DD amphibians are facing (Howard & Bickford, 2014; Nori & Loyola, 2015; Nori et al., 2015), suggests that many DD amphibians could become extinct even before we assign them into a threat category. Even worse, the large spatial congruence between priority research areas and sites where most restricted species have been discovered suggests that several species may still be unknown to science and could become extinct even before we ever know about their existence (Lees & Pimm, 2015; Rodrigues et al., 2010).

Despite the worrying global picture, there are still opportunities for global amphibian conservation as suggested by the important regional variation in current human impact within our identified priority research areas. For instance, given its topographic and climatic features, the largest set of priority research areas located in Tropical Andes is not compatible with many intensive productive activities (Hansen et al., 2013; Latham et al., 2014). Therefore, regardless of the human impact in the area being quite high, the Tropical Andes is the best conserved priority set of areas. Unfortunately, there are counterexamples such as the priority research areas located in Southeast Asia, which are mostly covered by intensive crops and located in places with currently high deforestation rates (Richards & Friess, 2016). In such areas with high human pressure, it is imperative to fill knowledge gaps at higher spatial resolutions, using more accurate information on species distributions, and maybe including crops as a mask in prioritisation analyses to determinate priority areas compatible with the persistence of most DD species before it is too late. Between these two extremes, there are other areas for research and with high conservation value such as the Atlantic rainforest, in Brazil. While a great portion of the Atlantic rainforest is currently covered by pasture and agriculture (Hansen et al., 2013), most priority research areas identified within this region are located in the Serra Do Mar forest, which is currently relatively well preserved and the focus of important conservation efforts (Alves-Pinto et al., 2017; Lemes & Loyola, 2013; Loyola, Lemes, Brum, Provete, & Duarte, 2014; Zwiener et al., 2017).

We found a distinction between different types of priority areas where research focus should be allocated. On the one hand, we detected priority regions such as Eastern Africa and Madagascar where DD species' description rates are rather constant over the time, suggesting that DD amphibians are yet underestimated and that resource allocation for expeditions and taxonomical research in these regions should be prioritised. On the other hand, in most priority research regions such as the Tropical Andes or Atlantic rainforest, the number of DD species has remarkably increased over the last decades, which suggests that much more funds are needed to gather biological information from already discovered DD amphibians. This finding further implies that resource allocation for ecological studies on DD species could prevent many extinctions in the near future.

Protected areas overlapping priority research areas are strategic places for research investment aimed at increasing biological knowledge of amphibians. However, two important issues should be remarked. First, most of these PAs (75% of them) do not have specific conservation goals (categories V and VI of IUCN). Hence, the long-term survival of DD amphibians within these PAs is far from being guaranteed. Second, several high priority research areas (such as those in the South American Atlantic rainforest, central west of Africa or west of Mexico) are heavily threatened by human pressures (Hansen et al., 2013; Jones et al., 2018; Watson et al., 2014) and have a really poor coverage of PAs (IUCN & UNEP, 2017).

This study represents the first application of a complementary-based tool, which has been originally designed and implemented in conservation planning, aimed at generating information that allows us to fill knowledge gaps as efficiently as possible. Applied in this context, the novel use of a well-known efficient method could help maximising resource allocation for gathering biological information about poorly known species. Accordingly, we propose that such application should be considered and undertaken for different biological groups and at different geographical scales, as the new information that can be generated will be valuable not only in terms of conservation, but for basic research in other disciplines of science.

ACKNOWLEDGEMENTS

We thank three anonymous reviewers for their time and comments on this paper. J.N. thanks FONCyT (PICT-2017-2666) and SECyT-UNC for financial support and J. Lescano for discussion of the initial idea. F.V. thanks INECOL for support and A. Lira-Noriega and O. Rojas-Soto for discussions. R.L. research is funded by CNPq (grant 308532/2014-7) and O Boticário Group Foundation for Nature Protection (grant PROG_0008_2013). This paper is a contribution of the INCT in Ecology, Evolution and Biodiversity Conservation founded by MCTIC/CNPq/FAPEG (grant 465610/2014-5).

ORCID

Fabricio Villalobos http://orcid.org/0000-0002-5230-2217
Rafael Loyola http://orcid.org/0000-0001-5323-2735

REFERENCES

Alves-Pinto, H. N., Latawiec, A. E., Strassburg, B. B. N., Barros, F. S. M., Sansevero, J. B. B., Iribarrem, A., … Silva, A.C.P. (2017). Reconciling rural development and ecological restoration: Strategies and policy recommendations for the Brazilian Atlantic Forest. *Land Use Policy*, *60*, 419–426. https://doi.org/10.1016/j.landusepol.2016.08.004

AmphibiaWeb. 2018. https://amphibiaweb.org/. University of California, Berkeley, CA, USA. Accessed 4 June 2018

Bini, L. M., Diniz-Filho, J. A. F., Rangel, T. F. L. V. B., Bastos, R. P., & Pinto, M. P. (2006). Challenging Wallacean and Linnean shortfalls: Knowledge gradients and conservation planning in a biodiversity hotspot. *Diversity and Distributions*, *12*, 475–482. https://doi.org/10.1111/j.1366-9516.2006.00286.x

Bland, L. M., Bielby, J., Kearney, S., Orme, C. D. L., Watson, J. E. M., & Collen, B. (2017). Toward reassessing data-deficient species. *Conservation Biology*, *31*, 531–539. https://doi.org/10.1111/cobi.12850

Brito, D. (2008). Amphibian conservation: Are we on the right track? *Biological Conservation*, *141*, 2912–2917. https://doi.org/10.1016/j.biocon.2008.08.016

Ciarleglio, M., Wesley Barnes, J., & Sarkar, S. (2009). ConsNet: New software for the selection of conservation area networks with spatial and multi-criteria analyses. *Ecography*, *32*, 205–209. https://doi.org/10.1111/j.1600-0587.2008.05721.x

Di Minin, E., Veach, V., Lehtomäki, J., Pouzols, F.M., & Moilanen, A. (2014). A quick introduction to Zonation. pp. 1–30.

Diniz-Filho, J. A. F., Loyola, R. D., Raia, P., Mooers, A. O., & Bini, L. M. (2013). Darwinian shortfalls in biodiversity conservation. *Trends in Ecology & Evolution*, *28*, 689–695. https://doi.org/10.1016/j.tree.2013.09.003

Edges, S.B.L.H. (2002). New snake of the genus Tropidophis (Tropidophiidae) from eastern Cuba. *Society*, *36*, 157–161.

Ficetola, G. F., Rondinini, C., Bonardi, A., Katariya, V., Padoa-Schioppa, E., & Angulo, A. (2014). An evaluation of the robustness of global amphibian range maps. *Journal of Biogeography*, *41*, 211–221. https://doi.org/10.1111/jbi.12206

Frost, D.R. (2014) Amphibian Species of the World: an Online Reference. Version 6.0. American Museum of Natural History, New York, USA.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., … Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, *342*, 850–853. https://doi.org/10.1126/science.1244693

Hijmans, R. J., Etten, J., Cheng, J., Mattiuzzi, M., Sumner, M., Greenberg, J. A., … Shortridge, A. (2015). Package: raster.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., … Stuart, S. N. (2010). The impact of conservation on the status of the world's vertebrates's vertebrates. *Science*, *330*, 1503–1509.

Hortal, J., de Bello, F., Diniz-Filho, J. A. F., Lewinsohn, T. M., Lobo, J. M., & Ladle, R. J. (2015). Seven shortfalls that beset large-scale knowledge of biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *46*, 523–549. https://doi.org/10.1146/annurev-ecolsys-112414-054400

Howard, S. D., & Bickford, D. P. (2014). Amphibians over the edge: Silent extinction risk of Data Deficient species. *Diversity and Distributions*, *20*, 837–846. https://doi.org/10.1111/ddi.12218

Hurlbert, A. H., & Jetz, W. (2007). Species richness, hotspots, and the scale dependence of range maps in ecology and conservation. *Proceedings of the National Academy of Sciences*, *104*, 13384–13389. https://doi.org/10.1073/pnas.0704469104

IUCN (2017). IUCN red list of threatened species. *Version*, *2017*, 3.

IUCN & UNEP (2017). *The World Database of Protected Areas (WDPA)*. Cambridge, UK: UNEP-WCMC. www.protectedplanet.net.

Jarić, I., Courchamp, F., Gessner, J., & Roberts, D. L. (2016). Potentially threatened: A Data Deficient flag for conservation management. *Biodiversity and Conservation*, *25*, 1995–2000.

Jenkins, C. N., Pimm, S. L., & Joppa, L. N. (2013). Global patterns of terrestrial vertebrate diversity and conservation. *Proceedings of the National Academy of Sciences*, *110*, E2602–E2610. https://doi.org/10.1073/pnas.1302251110

Jetz, W., & Freckleton, R. P. (2015). Towards a general framework for predicting threat status of data-deficient species from phylogenetic, spatial and environmental information. *Philosophical transactions of*

the Royal Society of London. Series B, Biological sciences, *370*, 20140016. https://doi.org/10.1098/rstb.2014.0016
Jones, K. R., Venter, O., Fuller, R. A., Allan, J. R., Maxwell, S. L., Negret, P. J., & Watson, J. E. M. (2018). One-third of global protected land is under intense human pressure. *Science*, *360*, 788–791. https://doi.org/10.1126/science.aap9565
Latham, J., Cumani, R., Rosati, I., & Bloise, M. (2014). Global Land Cover SHARE (GLC-SHARE) database Beta- Release Version 1.0.
Lees, A. C., & Pimm, S. L. (2015). Species, extinct before we know them? *Current Biology*, *25*, R177–R180. https://doi.org/10.1016/j.cub.2014.12.017
Lemes, P., & Loyola, R. D. (2013). Accommodating species climate-forced dispersal and uncertainties in spatial conservation planning. *PLoS ONE*, *8*, e54323. https://doi.org/10.1371/journal.pone.0054323
Loyola, R. D., Lemes, P., Brum, F. T., Provete, D. B., & Duarte, L. D. S. (2014). Clade-specific consequences of climate change to amphibians in Atlantic Forest protected areas. *Ecography*, *37*, 65–72. https://doi.org/10.1111/j.1600-0587.2013.00396.x
Luiz, O. J., Woods, R. M., Madin, E. M. P., & Madin, J. S. (2016). Predicting IUCN extinction risk categories for the World's Data Deficient groupers (Teleostei: Epinephelidae). *Conservation Letters*, 1–9.
Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature*, *405*, 243–253. https://doi.org/10.1038/35012251
Moilanen, A., Pouzols, F.M., Meller, L., Veach, V., Arponen, A., Leppänen, J., & Kujala, H. (2014). Spatial conservation planning methods and software ZONATION. User Manual. 288.
Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G. B., & Worm, B. (2011). How many species are there on earth and in the ocean? *PLoS Biology*, *9*, 1–8.
Morais, A. R., Siqueira, M. N., Lemes, P., Maciel, N. M., De Marco, P., & Brito, D. (2013). Unraveling the conservation status of Data Deficient species. *Biological Conservation*, *166*, 98–102. https://doi.org/10.1016/j.biocon.2013.06.010
Nori, J., Lemes, P., Urbina-Cardona, N., Baldo, D., Lescano, J., & Loyola, R. (2015). Amphibian conservation, land-use changes and protected areas: A global overview. *Biological Conservation*, *191*, 367–374. https://doi.org/10.1016/j.biocon.2015.07.028
Nori, J., & Loyola, R. (2015). On the worrying fate of Data Deficient amphibians. *PLoS ONE*, *10*, e0125055. https://doi.org/10.1371/journal.pone.0125055
Ocampo-peñuela, N., Jenkins, C.N., Vijay, V., Li, B. V, & Pimm, S.L. (2016). Incorporating explicit geospatial data shows more species at risk of extinction than the current Red List. *Conservation Ecology*, *2*, e1601367.
Peterson, A.T. (2017). Problems with reductive, polygon-based methods for estimating species' ranges: Reply to Pimm et al. 2017. *Conservation Biology*, *31*, 948–951. https://doi.org/10.1111/cobi.12929
Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., … Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, *344*, 1246752. https://doi.org/10.1126/science.1246752
Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proceedings of the National Academy of Sciences*, *113*, 344–349. https://doi.org/10.1073/pnas.1510272113
Rodrigues, A. A. S. L., Andelman, S. S. J., Bakarr, M. I. M., Boitani, L., Brooks, T. M., Cowling, R. M., … Ian, X. (2004). Effectiveness of the global protected area network in representing species diversity. *Nature*, *428*, 640–643. https://doi.org/10.1038/nature02422
Rodrigues, A. S. L., Gray, C. L., Crowter, B. J., Ewers, R. M., Stuart, S. N., Whitten, T., & Manica, A. (2010). A global assessment of amphibian taxonomic effort and expertise. *BioScience*, *60*, 798–806. https://doi.org/10.1525/bio.2010.60.10.6
Sánchez-Fernández, D., & Abellán, P. (2015). Using null models to identify under-represented species in protected areas: A case study using European amphibians and reptiles. *Biological Conservation*, *184*, 290–299. https://doi.org/10.1016/j.biocon.2015.02.006
Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., & Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science (New York, N.Y.)*, *306*, 1783–1786. https://doi.org/10.1126/science.1103538
Trindade-Filho, J., Carvalho, R. A., Brito, D., Loyola, R. D., de Carvalho, R. A., Brito, D., & Loyola, R. D. (2012). How does the inclusion of Data Deficient species change conservation priorities for amphibians in the Atlantic Forest? *Biodiversity and Conservation*, *21*, 2709–2718. https://doi.org/10.1007/s10531-012-0326-y
Venter, O., Fuller, R. A., Segan, D. B., Carwardine, J., Brooks, T., Butchart, S. H. M., … Watson, J. E. M. (2014). Targeting global protected area expansion for imperiled biodiversity. *PLoS Biology*, *12*, e1001891. https://doi.org/10.1371/journal.pbio.1001891
Vilela, B., & Villalobos, F. (2015). letsR: A new R package for data handling and analysis in macroecology. *Methods in Ecology and Evolution*, *6*, 1229–1234. https://doi.org/10.1111/2041-210X.12401
Watson, J. E. M., Dudley, N., Segan, D. B., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, *515*, 67–73. https://doi.org/10.1038/nature13947
WCS & CIESIN (2005). *Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Footprint Dataset (Geographic)*. NASA Socioeconomic Data and Applications Center (SEDAC), New York, USA.
Zwiener, V. P., Padial, A. A., Marques, M. C. M., Faleiro, F. V., Loyola, R., & Peterson, A. T. (2017). Planning for conservation and restoration under climate and land use change in the Brazilian Atlantic Forest. *Diversity and Distributions*, *23*, 955–966. https://doi.org/10.1111/ddi.12588

BIOSKETCHES

Javier Nori is a professor and researcher at Universidad Nacional de Cordoba and CONICET, Argentina. His research focuses on the study of spatial patterns of vertebrate diversity aiming to generate guidelines to inform conservation decisions. He is especially interested in the conservation of amphibians, reptiles and South American environments.

Fabricio Villalobos is a full researcher at Instituto de Ecología A.C. in Mexico. His research focuses on geographical patterns of biodiversity integrating tools and concepts from macroecology and evolutionary biology.

Rafael Loyola is associate professor at the Federal University of Goiás, Brazil. He leads the Conservation Biogeography Lab, which focuses on delivering scientifically validated evidence, analysis and synthesis to support conservation decision and policy-making, especially in Brazil.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Nori J, Villalobos F, Loyola R. Global priority areas for amphibian research. *J Biogeogr*. 2018;00:1–7. https://doi.org/10.1111/jbi.13435