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Short communication

Threat-dependent traits of endangered frogs

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ABSTRACT

Numerous studies have investigated life-history and other traits of endangered species for conservation purposes. These studies typically look for universal traits independently of the reasons why species are threatened. The usefulness of such analyses is limited if the traits are actually threat-dependent, but whether that is the case is currently unknown. We investigated if two traits of anurans – snout-vent length and habitat breadth – are threat-dependent, using the threats *human consumption* and *pet trade* as case examples. Analysing a unique global dataset (1041 species with data on snout-vent length and 4103 species with data on habitat breadth), we show that the traits of endangered anurans are strongly threat-dependent. For instance, while snout-vent length is similar between threatened and non-threatened frogs when not discriminating between threats, distinct differences become apparent when considering the reasons why the species are threatened: frogs threatened by human consumption have large body sizes, whereas those threatened by the pet trade are small. Thus at least for frogs, searching for universal traits of endangered species independently of the reasons why they are threatened does not seem to be rewarding. Instead, we need to better understand the relationship between the traits of endangered species and the reasons why they are threatened. This will help better predicting which species will become more critically endangered (or can recover) if certain threats will increase (or decrease) in their magnitude in the future.

1. Introduction

Human-induced changes have caused the decline or extinction of a vast range of species worldwide, and there is mounting evidence that we are in the midst of the sixth mass extinction (Novacek, 2009; Wake and Vredenburg, 2008). To predict and prevent further loss of biological diversity, some conservation ecologists aim at understanding which life-history and other traits render certain species more vulnerable than others (reviewed in Fisher and Owens, 2004). However, these studies typically investigate the traits of *all* endangered species and do not consider *why* they are endangered, e.g. due to habitat loss, invasive species, pollution, or direct exploitation by humans. As a result, we do not know whether particular threats act selectively on species traits. There are some recent studies connecting threat with traits of species, but to our knowledge these are restricted to mammals (see Collen et al., 2011; González-Suárez et al., 2013; Kosydar et al., 2014).

We addressed this question with a focus on anurans (frogs and toads) which form the largest taxonomic group within amphibians, the most threatened vertebrate taxon (Stuart et al., 2004; Wake and Vredenburg, 2008). To our knowledge, previous analyses of the traits of endangered frogs (e.g. Cooper et al., 2008; Sodhi et al., 2008) could show, for example, a correlation between snout-vent length of anurans and threat status, but did not investigate whether this trait might be related to the factors threatening frogs. Thus, we have indication of snout-vent length to be linked to threat status but do not know which specific threat is selecting on body size. The most severe threats to anuran species are land-use change, contaminants, invasive species, climate change, and commercial use (Collins, 2010).

Our study focuses on the different types of commercial use of anurans. These types of threats are used as case examples with the aim of understanding if the traits of endangered anurans can be threat-specific or if they are independent of the reasons why the species are threatened. Many frog species are traded for human consumption or pet trade, by millions of individuals yearly. In the years 2000–2004 alone, 26 million living amphibians were imported to the U.S., including 172 non-native species (Jenkins, 2007). While the traffic constitutes a powerful vector for the chytrid fungus *Batrachochytrium dendrobatidis* (Picco and Collins, 2008), a number of amphibian species are directly

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threatened by human exploitation. This is because only few of them are reared in aquariums or farms, and most are taken from the wild.

2. Methods

We compiled data on threat status (from the IUCN Red List, IUCN, 2014), body size (measured as snout-vent length), and habitat breadth (measured as the number of different habitats where each species has been discovered). We found data on snout-vent length of adult frogs for 1041 species; these data were extracted from the literature (sources, meta-data, details about excluded species and the full dataset are provided in the online Appendices S1, S2). We performed two types of analyses: one was restricted to species where data on snout-vent length included both sexes or came from more than one data source – the results of this analysis are in the main article; the other analysis included all collected data on snout-vent length – the results of this analysis are available in the online Appendix S1. Data on habitat breadth for 4103 species were taken from the IUCN Red List (IUCN, 2014). We calculated our habitat breadth metric by summing up all habitat categories the species was detected in according to the IUCN. For the analyses, we split the species into nested groups according to their threat categories (see Fig. 1 for categories, sample sizes and test results). All species with unknown threat status or defined as data deficient were excluded from the analysis. A total of 125 species were excluded from the snout-vent length analysis, one species from the habitat number analysis (more information in the online Appendix S1).

Anurans are exploited by humans in many ways: for religious purposes, medicine or research, but by far most species are threatened by the pet trade or human consumption. We thus restricted our detailed analyses to these two threats. The three species threatened by both human consumption and pet trade were excluded from the analyses (details and species names in the online Appendix S1).

For both snout-vent length and habitat breadth, we performed Kolmogorov-Smirnov tests with 100,000 bootstrap simulations and Bonferroni-Holm correction, and calculated Hedges' g effect sizes for the four pairwise comparisons. All analyses were conducted using R version 3.2.3 (R Development Core Team, 2015). Kolmogorov-Smirnov tests were performed with the command ks.boot() of the "Matching" package (Jasjeet, 2011). Hegde's g effect sizes were calculated using the cohen.d() command of the package "effsize".

3. Results

We found that when comparing all threatened with non-threatened anurans, i.e. when not considering the reasons why the species are threatened, there are no big differences in body size (Fig. 1; Th + vs. TH −: $D = 0.08$, $p = 0.085$, $g = -0.12$). On the other hand, anurans threatened by direct human exploitation (either religious purposes, medicine, research, human consumption or pet trade) are larger than other threatened species (EX + vs. EX −: $D = 0.24$, $p < 0.05$, $g = 0.64$). Threatened anurans used as a food source are distinctly larger than those threatened due to other means of human exploitation (Con + vs. Con −: $D = 0.84$, $p < 0.001$, $g = 2.11$). And, finally, species collected for the pet trade are distinctly smaller than those threatened due to other means of human exploitation (Pet + vs. Pet −: $D = 0.72$, $p < 0.001$, $g = -1.6$). The results for the complete dataset on snout-vent length, that is including species with reduced data reliability, were qualitatively similar (online Appendix S1).

All distributions of snout-vent length of species in the nested categories are shown in Fig. 2A. For clarity, the log of snout-vent length is displayed; statistical tests were performed with untransformed values. Test results are easily comprehensible by comparing the plots from the top to the bottom: The second histogram shows a marginal change in distribution and shift in mean between all vs. threatened species. Species directly exploited by humans show a bimodal distribution in body size (third histogram from above), which is composed of large, consumed species and small species collected for the pet trade. We find, for example, the large-bodied critically endangered species *Leptodactylus fallax* (mountain chicken or giant ditch frog) with its snout-vent length of 210 mm at the right end of the consumed species distribution (histogram 4). The small endangered *Andinobates virolinensis* (Santander poison frog) with its snout-vent length of 16.8 mm is located at the low tail of the distribution of species collected for the pet trade (histogram 5).

We also found that threatened anurans have a narrower habitat range than non-threatened anurans (Fig. 1; Th + vs. TH −: $D = 0.41$, $p < 0.001$, $g = -0.88$). Anurans threatened by direct exploitation

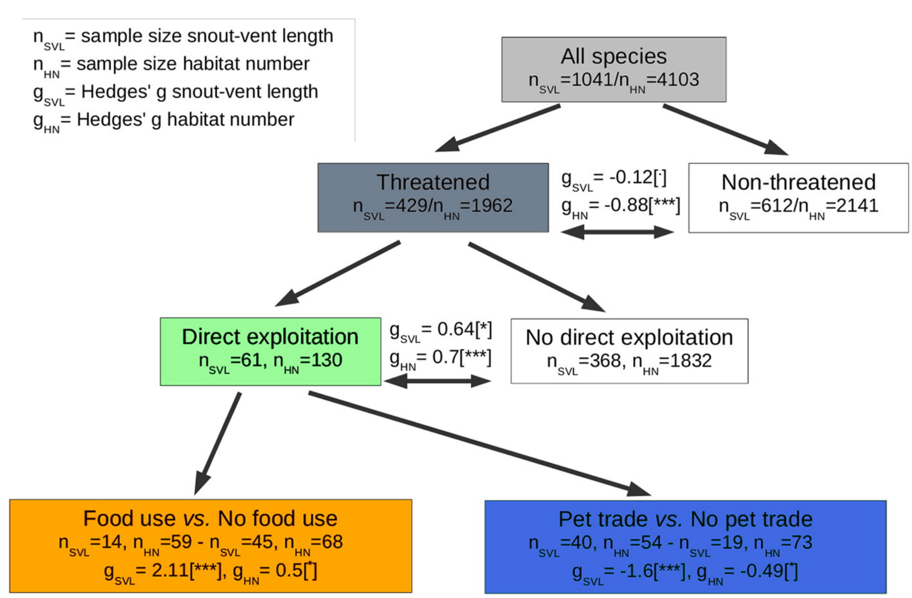

Fig. 1. Numbers of species in different threat categories with Hedges' g effect sizes and levels of significance of pairwise comparisons using bootstrap Kolmogorov-Smirnov tests (***$p < 0.001$; **$0.001 \le p < 0.01$; *$0.01 \le p < 0.05$; •$0.05 \le p < 0.1$).

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