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An assessment of funding and publication rates in Herpetology

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Currently, herpetofauna worldwide is facing enormous threats; the number of threatened species is increasing at an alarming rate and many species have gone extinct. Despite efforts of institutions and researchers to understand and address the causes of declines and raise awareness of herpetofauna conservation, there has been no systematic study to evaluate the allocation of funding for basic and applied research relevant to conservation, relative publication rates, and the relationship of these measures to a degree of threat among herpetological groups. This study addresses this gap and identifies strengths and weaknesses of herpetological research and conservation over the last 10 years (2008-2018). Frogs had the highest grant-publication index (1384), followed by lizards (695), turtles (678), snakes (461.5), salamanders (366.5), crocodiles (164), caecilians (25.5), worm lizards (23) and tuatara (10). Nonetheless, when the grant-publication index is divided by the number of threatened and data-deficient species within each group, it demonstrates that, proportionally and in ascending order, salamanders, snakes, lizards, worm lizards, frogs and caecilians are in most need of knowledge and on-going funding for their conservation and survival. I was able to document a continued shift in attention in herpetological research owing to the emergence of chytridiomycosis and the global decline of amphibians. Despite some caveats, these findings should represent a proxy for the allocation of research and conservation effort on herpetofauna worldwide. I suggest priorities for research and how to better direct efforts to herpetofauna conservation.

Keywords: amphibians, extinction, IUCN Red List, literature representation, natural history, reptiles

INTRODUCTION

Although amphibians and reptiles are not closely related in an evolutionary sense, they are often studied together, because as ectotherms they share many physiological, behavioural and ecological similarities (Vitt & Caldwell, 2014). Major extinction events in the past have reduced global diversity of amphibians and reptiles several times, only to be followed by relatively rapid diversification events within some of the surviving groups (Vitt & Caldwell, 2014). Currently, scientists recognise a contemporary extinction of species and populations of similar magnitude to those in the past, known as the sixth mass extinction (Wake & Vredenburg, 2008; Barnosky et al., 2011). Human activities, such as co-opting resources, fragmenting habitats, introducing non-native species, spreading pathogens, killing species directly and changing global climate are playing major roles in these extinctions (Barnosky et al., 2011). Amphibians and reptiles are affected by these globally threatening processes, and a global decline of herpetofauna is underway (Gibbons et al., 2000; Stuart et al., 2004; Hoffmann et al., 2010; Böhm et al., 2013).

An emerging amphibian chytrid fungal disease, chytridiomycosis, has been responsible for massive die-offs of amphibians worldwide (Rovito et al., 2009; van Rooij et al., 2015). Combined with deforestation, chemical pollution, stochastic events and climate change, scores of amphibian species have gone extinct and 2421 species are currently listed as threatened (Gibbons et al., 2000; Stuart et al., 2004; IUCN, 2019). Reptiles are enduring declines similar to those experienced by amphibians in terms of taxonomic breadth, geographic scope, and severity (Gibbons et al., 2000; Sinervo et al., 2010), although on a global scale threat levels seems to be more severe in amphibians (Böhm et al., 2013). As with amphibians, causes of reptile declines are known with certainty in some cases, suspected in many, and unknown in others (Gibbons et al., 2000). Likely, overharvesting and habitat loss and fragmentation are the leading threats in the global decline of reptiles (Gibbons et al., 2000; Böhm et al., 2013).

Appreciation of the dire situation for herpetofauna has initiated efforts to investigate and conserve amphibians and reptiles around the globe, led by researchers, governments (Towns et al., 2001; McCarthy et al., 2012), zoos (Conde et al., 2011), and conservation organisations (see Appendix). Although awareness

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within the conservation community of herpetofauna biology, research and protection has increased recently (Gibbons et al., 2000; Urbina-Cardona, 2008; Ohmer & Bishop, 2011; Böhm et al., 2013; Roll et al., 2016), in addition to some studies that have dealt with publication rates (Gibbons, 1988; McCallum & McCallum, 2006; Urbina-Cardona, 2008; Christoffel & Lepczyk, 2012; Lovich & Ennen, 2013) and funding (Gibbons, 1988) in herpetology, there is still a lack of understanding on how current funding allocation and conservation publication outputs vary among herpetological taxonomic groups worldwide, and the relationship between funding levels and degree of threat. Such data are important to detect any bias arising from perceptions of need not related directly to actual levels of threat, and to realign priorities to better balance effort across need. To fill this gap, I gathered information on grants, publications and degree of threat among groups of amphibians (frogs, salamanders and caecilians) and reptiles (turtles, lizards, snakes, worm lizards, tuatara and crocodiles) as reported in conservation journals. I asked the following questions: (1) How is funding and generation of knowledge of strategic and tactical value distributed across taxonomic groups over the last 10 years (2008-2018)?, and (2) Does funding and the generation of knowledge reflect the level of threat faced by particular taxonomic groups? In answering those questions, I provide an improved understanding of the distribution of resources across herpetofauna to assist in setting priorities for conservation and research.

METHODS

Herpetological keywords

I searched for keywords that would cover amphibian and reptile classes, orders and families, including synonyms. For amphibians, I searched for "amphibian", "amphibia", "anura", "frog", "toad", "caudata", "urodela", "salamander", "newt", "gymnophiona" and "caecilian". For reptiles, I searched for "reptile", "testudines", "chelonian", "chelonia", "turtle", "freshwater turtle", "terrapin", "cooter", "marine turtle", "sea turtle", "tortoise", "squamata", "lizard", "gecko", "iguana", "chameleon", "monitor", "snake", "serpent", "viper", "rattlesnake", "worm lizard", "legless lizard", "amphisbaenia", "rhyncocephalia", "tuatara", "crocodylia", "crocodilian", "crocodile", "alligator", "caiman", "gavial" and "gharial". For general keywords such as "amphibian" or "reptile", the records were subsequently examined to verify to which group they belonged. In some instances, some search engines were sensitive to "(s)", and consequently the keywords were searched both in singular and plural. These keywords were used in searches in several funding agencies databases and the search engine Scopus for scientific publications, as detailed below.

Funding

I searched herpetological keywords for funding in herpetology across grants for basic and applied research, and grants specific for on-ground conservation, from 2008 to 2018, during which time all the funding agencies were operating and results could be compared. For example, I searched databases from five funding agencies within North America, Australia, United Kindgom and the European Union, which cover basic and applied research in the field of herpetology. They were the National Science Foundation (NSF; available from https://www.nsf.gov/awardsearch/ [accessed on 14th May 2019]); Australian Research Council (ARC; available from http://www.arc.gov.au/grants-dataset-information [accessed on 14th May 2019]); Research Councils UK (RCUK; available from http://gtr.rcuk.ac.uk/ [accessed on 14th May 2019]); Natural Sciences and Engineering Research Council of Canada (NSERC; available from http://www.nserc-crsng.gc.ca/ase-oro/index_eng.asp [accessed on 31st May 2019]); and BiodivERsA (available from http://www.biodiversa.org/database/ [accessed on 31st May 2019]). The grants were subsequently filtered for herpetological keywords and the taxonomic group to which they belonged to, and to exclude keywords that had no link with biological research.

For on-ground conservation grants specifically, I searched the databases of six conservation agencies, five of which fund mainly conservation initiatives in the developing world: Conservation Leadership Program (CLP; available from http://www.conservationleadershipprogramme.org/our-projects/supported-projects/ [accessed on 3rd June 2019]); Rufford Small Grant Foundation (RSG; available from http://www.rufford.org/category [accessed on 3rd June 2019]); Whitley Fund for Nature (WFN; available from https://whitleyaward.org/winners/ [accessed on 5th June 2019]); The Mohamed bin Zayed Species Conservation Fund (MBZSCF; available from https://www.speciesconservation.org/case-studies-projects/ [accessed on 9th May 2019]); and National Geographic Society (NGS; available from https://www.nationalgeographic.org/funding-opportunities/grants/what-we-fund/our-focus/ [accessed on 9th May 2019], searched on the wildlife focus area, which covered both research and conservation categories). I also included another agency that funds projects on species recovery and habitat protection in the United States of America and developing countries: National Fish and Wildlife Foundation (NFWF; available from http://www.nfwf.org/whatwedo/grants/search/Pages/Grant-Search.aspx [accessed on 17th June 2019]). Additionally, I searched for grants specific to freshwater turtles and tortoises awarded by the Turtle Conservation Fund (TCF; available from http://www.turtleconservationfund.org/announcements/ [accessed on 9th May 2019]), to highlight this additional source of major funding to this taxomonic group.

Publications

I chose four leading conservation journals (*Conservation Biology*, *Biological Conservation*, *Biodiversity and Conservation*, and *Animal Conservation*), four high impact journals (*Nature*, *Science*, *Proceedings of the National Academy* of *Science of the United States of America*, and *Global Change Biology*), and six major herpetological journals (*Herpetologica*, *Amphibia-Reptilia*, *Journal of*

Herpetology, *Copeia*, *The Herpetological Journal*, and *African Journal of Herpetology*). The first two groups are broad in scope and not specific to any taxa, while the last one is specific to amphibians and reptiles. The goal was to cover the specialised literature in addition to conservation topics, cutting-edge research, and issues related to herpetology in these journals. The search engine Scopus was used to identify articles containing herpetological keywords in the title, abstract, and keywords from 2008 to 2018, which matched the period of funding searched for in this investigation. Scopus was chosen owing to the ability to organise the information and export it in several file formats, in addition to its accuracy in finding herpetological keywords.

A grant-publication index was calculated for each taxon by summing the number of grants (basic and applied research plus on-ground conservation) and the number of publications (conservation, high impact, and herpetological journals) and dividing by two. This index was created to summarise the efforts in both allocation of resources (grants) and biological and conservation knowledge (publications) for herpetofauna.

Threat category

The threat category for each class, order, family, genus and species was obtained from IUCN Red List of Threatened Species (IUCN, 2019) for threatened (critically endangered - CR, endangered - EN and vulnerable - VU) amphibians and reptiles. In addition, the number of data-deficient (DD) species was also recorded. The data were subsequently organided into total (absolute) number of threatened (CR, EN, VU) and data-deficient species (DD) per lower taxonomic group (i.e. frogs, salamanders, caecilians, turtles, lizards, snakes, worm lizards, tuatara and crocodiles). In addition, percentages were obtained by dividing the number of threatened species and the number of data-deficient species by the total number of species in each lower taxonomic group (number of species for amphibians, Frost, 2019; for reptiles, Uetz et al., 2018). To answer the question if funding and knowledge reflect the level of threat faced by herpetological taxonomic groups, giving the unequalness of size of taxonomic groups, the grant-publication index was divided by the absolute number of threatened and data-deficient species in each taxonomic group.

RESULTS

Considering an overall picture in terms of funding and publications, amphibians have received slightly more basic and applied research funding (US$ 212,629,001.29) than reptiles (US$ 200,813,308.73; Table 1, 2), but reptiles attracted more on-ground conservation grants and had a slightly greater publication record (n = 831 and n = 2330, respectively) compared to amphibians (n = 542 and n = 2010, respectively; Table 3, 4).

When considering lower taxonomic levels, frogs led with the highest grant-publication index (1384; Fig. 1). Lizards (695), turtles (678), and snakes (461.5) also had an above average grant-publication index (mean = 423 ± [SD] 450.3 [range, 10–1384], n = 9). On the other hand, salamanders (366.5), crocodiles (164), caecilians (25.5), worm lizards (23) and tuatara (10) had below average values (Fig. 1, Table 1, 3, 4). With regard to on-ground conservation grants, turtles (37.8 %) and frogs (32.7 %) received the greatest number, followed by lizards (9.2 %), snakes (8.2 %), salamanders (6.1 %), and crocodiles (5.1 %) (Table 3). Caecilians (0.7 %), worm lizards (0.2 %) and tuatara (0 %) have received little or no on-ground conservation funding from the agencies analysed in this study (Table 3). Publications were highest in number for frogs (34.4 %), followed by lizards (20.2 %), snakes (14.6 %), turtles (13.8 %), and salamanders (11.3 %). The other taxonomic groups showed below average values (mean = 482.2 ± [SD] 492 [range, 16–1494], n = 9; Table 4).

Proportionally, tuatara (100 %), turtles (46.2 %), crocodiles (45.8 %), salamanders (38.7 %) and frogs (30.1 %) are the most threatened groups of herpetofauna, while lizards (12.9 %), worm lizards (8.7 %), snakes (7.5 %), and caecilians (6.1 %) are the least (Table 5).

Nonetheless, when dividing the amount of funding and knowledge (grant-publication index) by the absolute number of threatened species, crocodiles, tuatara, and turtles are proportionally considered better funded and studied groups, while caecilians, snakes, worm lizards, salamanders, lizards, and frogs less so (Fig. 2a). If data-deficient species are also considered, crocodiles, tuatara, and turtles proportionally continue to be the most funded and studied groups of herpetofauna, whilst salamanders, snakes, lizards, worm lizards, frogs, and caecilians the least (Fig. 2b).

Table 1. Number of basic and applied science grants for herpetological research and conservation during 2008 to 2018.

Class	Order	Group	NSF	ARC	RCUK	NSERC	BiodivERsA	Total	Projects %
Amphibia	Anura	Frogs	284	52	96	266	127	825	43.4
Amphibia	Caudata	Salamanders	99	0	12	41	7	159	8.4
Amphibia	Gymnophiona	Caecilians	9	0	0	5	2	16	0.8
Reptilia	Testudines	Turtles	88	8	6	86	50	238	12.5
Reptilia	Squamata	Lizards	243	30	14	64	36	387	20.3
Reptilia	Squamata	Snakes	98	10	12	50	9	179	9.4
Reptilia	Squamata	Worm lizards	2	1	0	2	1	6	0.3
Reptilia	Rhynchocephalia	Tuatara	4	0	0	0	0	4	0.2
Reptilia	Crocodylia	Crocodiles	53	6	3	14	12	88	4.6

NSF - National Science Foundation; ARC - Australian Research Council; RCUK - Research Councils UK; NSERC - Natural Sciences and Engineering Research Council of Canada; Projects % - percentage of grants among herpetological groups

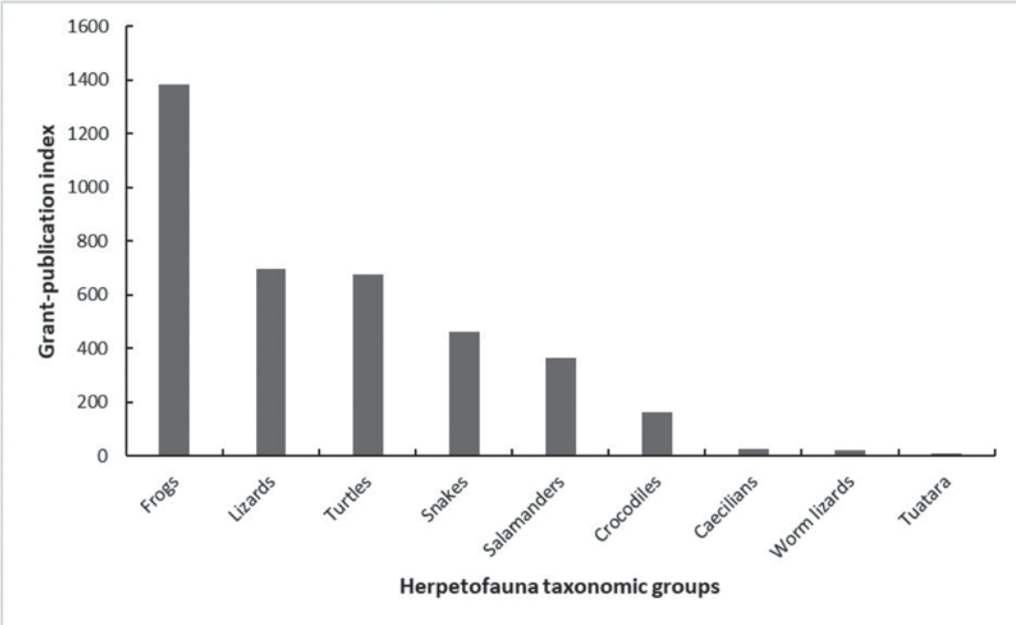

Figure 1. Grant-publication index (during 2008-2018, see Methods) across herpetological taxonomic groups.

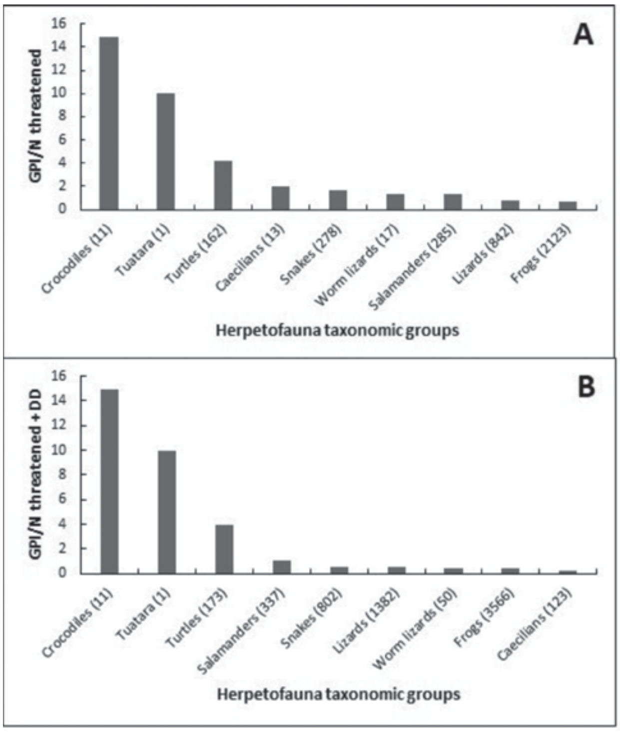

Figure 2. Grant-publication index (during 2008-2018, see Methods) divided by the total number of threatened species (critically endangered, endangered, vulnerable - IUCN), and threatened and data-deficient species (DD), in amphibians and reptiles. In parentheses, total number of threatened species in each group **(A)**, and threatened and data-deficient species **(B)**.

When a finer resolution was used for turtles, dividing up tortoises, marine and freshwater turtles, marine turtles had the highest percentage of threatened species (85.7 %) and attracted more on-ground conservation funding (52.5 %), but had a smaller publication rate (34.4 %) and less basic and applied research funding (31.9 %) compared to freshwater turtles (40.1 %, 27.5 %, 43.7 %, 61%, respectively) and tortoises (70 %, 20 %, 21.9 %, 7.1 %, respectively). And when the grant-publication index is divided by the total number of threatened species within the turtle subgroups, marine turtles (47.5) are largely better funded and studied than tortoises (3.09) and freshwater turtles (2.51; Table 1, 3, 4, 5). Additionally, considering funds specific for freshwater turtles and tortoises through the Turtle Conservation Fund (see Methods), of a total of 192 proposals, 67.2 % were granted to freshwater turtles and 32.8 % to tortoises.

DISCUSSION

Although setting priorities to protect and fund the most threatened taxa should be the norm, current research on vertebrates show that conservation efforts and biological research are generally biased toward large-bodied and charismatic mammals (Sitas et al., 2009), and common bird species (Roberts et al., 2016), leaving most threatened taxa with little or no biological data to inform their conservation (Roberts et al., 2016). Here, I show that funding and publications are not uniformly distributed among herpetological groups, with frogs, lizards, turtles, and snakes at the forefront of grants awarded and conservation knowledge (i.e., grant-publication index), whilst salamanders and crocodiles are in an intermediate position, and caecilians, worm lizards and tuatara are at the bottom. Even though some of the most threatened groups of herpetofauna showed a small grant-publication index, when the absolute number of threatened and data-deficient species is considered, it demonstrates that, proportionally and in ascending order, salamanders, snakes, lizards, worm lizards, frogs and caecilians are in most need of continued knowledge and on-going funding for their conservation and survival. Potentially, the main driver of the findings in the present study is the description of the chytridiomycosis

Table 2. Amount of funding for basic and applied science grants for herpetological research and conservation during 2008 to 2018*.

Class	Order	Group	NSF	ARC	RCUK	NSERC	Total	Funding %
Amphibia	Anura	Frogs	$90,632,022.00	$16,890,638.80	$34,782,850.17	$6,505,562.76	$148,811,073.73	36.0
Amphibia	Caudata	Salamanders	$51,794,459.00	$0.00	$6,788,856.12	$639,463.24	$59,222,778.36	14.3
Amphibia	Gymnophiona	Caecilians	$4,492,686.00	$0.00	$0.00	$102,463.20	$4,595,149.20	1.1
Reptilia	Testudines	Turtles	$32,600,709.00	$1,804,096.00	$1,388,084.60	$2,045,102.24	$37,837,991.84	9.2
Reptilia	Squamata	Lizards	$75,737,365.00	$8,617,134.40	$4,031,933.77	$1,371,951.24	$89,758,384.41	21.7
Reptilia	Squamata	Snakes	$46,914,666.00	$2,758,161.70	$4,296,841.80	$843,004.92	$54,812,674.42	13.3
Reptilia	Squamata	Worm lizards	$1,476,018.00	$184,800.00	$0.00	$66,880.00	$1,727,698.00	0.4
Reptilia	Rhynchocephalia	Tuatara	$1,626,934.00	$0.00	$0.00	$0.00	$1,626,934.00	0.4
Reptilia	Crocodylia	Crocodiles	$13,225,972.00	$1,257,900.00	$217,721.18	$348,032.88	$15,049,626.06	3.6

* BiodivERsA was not included as the database did not contain grant amounts. All the values were converted to US dollars for comparisons. NSF - National Science Foundation; ARC - Australian Research Council; RCUK - Research Councils UK; NSERC - Natural Sciences and Engineering Research Council of Canada; Funding % - percentage of funding among herpetological groups

Table 3. Number of on-ground conservation grants for herpetology during 2008 to 2018.

Class	Order	Group	CLP	RSG	WFN	NFWF	MBZSCF	NGS	Total	Projects %
Amphibia	Anura	Frogs	22	127	3	124	165	8	449	32.7
Amphibia	Caudata	Salamanders	3	13	1	37	30	0	84	6.1
Amphibia	Gymnophiona	Caecilians	0	4	0	0	5	0	9	0.7
Reptilia	Testudines	Turtles	15	169	9	208	115	3	519	37.8
Reptilia	Squamata	Lizards	1	40	1	9	72	4	127	9.2
Reptilia	Squamata	Snakes	1	31	1	42	36	1	112	8.2
Reptilia	Squamata	Worm lizards	0	1	0	0	2	0	3	0.2
Reptilia	Rhynchocephalia	Tuatara	0	0	0	0	0	0	0	0.0
Reptilia	Crocodylia	Crocodiles	5	36	1	7	21	0	70	5.1

CLP - Conservation Leadership Program; RSG - Rufford Small Grant Foundation; WFN - Whitley Fund for Nature; NFWF - National Fish and Wildlife Foundation; MBZSCF - The Mohamed bin Zayed Species Conservation Fund; NGS – National Geographic Society; Projects % - percentage of grants among herpetological groups

outbreak in late 1990s and the recognition of the global decline of amphibians (Stuart et al., 2004; Ohmer & Bishop, 2011). The breadth and scope of this fungal disease in amphibians is so extensive and fatal (Daszak et al., 2003; van Rooij et al., 2015), that it may have prompted a response by the scientific community to understand the mechanisms involved in the disease (Daszak et al., 2003), which could still reflect the last ten years (2008-2018) of research funding, by the number of publications and basic and applied grants to amphibians in this study, especially for frogs. It has been noted that new scientific discoveries, as in the case of chytridiomycosis, spark ideas and hypotheses which may draw a disproportionate amount of funding and both scientific and public attention (Ohmer & Bishop, 2011). A three-fold increase in scientific knowledge about amphibians was also observed by the number of manuscripts published in wildlife research journals from the 1990s to the 2000s (Christoffel & Lepczyk, 2012). This may be viewed, together with the findings in the present study, as a shift in attention in herpetological research, where previously reptiles (n = 29) had received almost six times more grants than amphibians (n = 5) during 1987-1988 by U.S. funding agencies, and reptiles (n = 42 and n = 6) were more commonly featured than amphibians (n = 27 and n = 1) in general ecology and wildlife ecology journals during 1983-1988, respectively (Gibbons, 1988). Also, over a 30-year period (1980-2010), reptile publications (n = 202) were much more commonly featured than amphibians (n = 95) within six wildlife research journals (Christoffel & Lepczyk, 2012), as number of papers per taxomonic group followed the order: turtles (n = 84), squamata (lizards and snakes; n = 78), frogs (n = 57), crocodiles (n = 30), salamanders (n = 19), and worm lizards, tuatara and caecilians had no studies (Christoffel & Lepczyk, 2012). Interestingly, I showed that proportionally to the total number of frogs in risk of extinction, continued funding and conservation knowledge are needed to protect frogs worldwide (Table 3, Fig. 2), and help to halt the effects of chytridiomycosis. Although frogs had the highest grant-publication index, they did not secure the greatest number of on-ground conservation grants. Turtles, especially marine turtles, have received the majority of on-ground conservation funding by the agencies examined in this study. This could be due to the high degree of threat faced by marine turtles (85.7 % threatened; IUCN, 2019), their global distribution, in addition to their charismatic profile (McClenachan et al., 2012), helping to yield public attention and funding. Even though freshwater turtles and tortoises face an unprecedent threat worldwide (40.1 % and 70 %, respectively; IUCN, 2019), they do not garner the same levels of funding specific for conservation, and compared to the number of threatened species, they are

Table 4. Publication rates in herpetology in leading conservation journals (Conservation Biology, Biological Conservation, Biodiversity and Conservation, Animal Conservation), high impact journals (Nature, Science, Proceedings of the National Academy of Science of the United States of America, and Global Change Biology), and major herpetological journals (*Herpetologica*, *Amphibia-Reptilia*, *Journal of Herpetology*, *Copeia*, *The Herpetological Journal*, and *African Journal of Herpetology*) during 2008 to 2018.

Class	Order	Group	C. J. (n, %[1])	H.I.J. (n, %[1])	H.J. (n, %[1])	Total (n, %[2])
Amphibia	Anura	Frogs	263 (39.8)	249 (35.1)	982 (33.1)	1494 (34.4)
Amphibia	Caudata	Salamanders	65 (9.8)	75 (10.6)	350 (11.8)	490 (11.3)
Amphibia	Gymnophiona	Caecilians	4 (0.6)	3 (0.4)	19 (0.6)	26 (0.6)
Reptilia	Testudines	Turtles	190 (28.7)	62 (8.7)	347 (11.7)	599 (13.8)
Reptilia	Squamata	Lizards	68 (10.3)	142 (20.0)	666 (22.4)	876 (20.2)
Reptilia	Squamata	Snakes	42 (6.4)	123 (17.3)	467 (15.7)	632 (14.6)
Reptilia	Squamata	Worm lizards	3 (0.5)	2 (0.3)	32 (1.1)	37 (0.9)
Reptilia	Rhynchocephalia	Tuatara	7 (1.1)	2 (0.3)	7 (0.2)	16 (0.4)
Reptilia	Crocodylia	Crocodiles	19 (2.9)	51 (7.2)	100 (3.4)	170 (3.9)

C. J. - Conservation Journals; H.I.J. - High Impact Journals; H.J. - Herpetological Journals; n = number of publications; %[1] = percentage within journal group; %[2] = total percentage

Table 5. Number of threatened and data-deficient amphibians and reptiles worldwide (CR – critically endangered; EN – endangered; VU – vulnerable; DD – data-deficient; IUCN 2019).

Class	Order	Group	CR	EN	VU	Total threatened*	DD	N.Species**	Threatened %	DD %	TDD %***
Amphibia	Anura	Frogs	567	924	632	2123	1443	7062	30.1	20.4	50.5
Amphibia	Caudata	Salamanders	79	111	95	285	52	736	38.7	7.1	45.8
Amphibia	Gymnophiona	Caecilians	1	8	4	13	110	212	6.1	51.9	58.0
Reptilia	Testudines	Turtles	50	45	67	162	11	351	46.2	3.1	49.3
Reptilia	Squamata	Lizards	175	346	321	842	540	6512	12.9	8.3	21.2
Reptilia	Squamata	Snakes	56	115	107	278	524	3709	7.5	14.1	21.6
Reptilia	Squamata	Worm lizards	5	8	4	17	33	196	8.7	16.8	25.5
Reptilia	Rhynchocephalia	Tuatara	0	0	1	1	0	1	100.0	0.0	100.0
Reptilia	Crocodylia	Crocodiles	7	0	4	11	0	24	45.8	0.0	45.8

* CR + EN + VU
** Number of species per group obtained for amphibians (Frost, 2019) and reptiles (Uetz et al., 2018) *** Threatened species (%) + DD species (%)

almost 19 and 15 times, respectively, less studied and funded than marine turtles. In terms of funding specific for tortoises and freshwater turtles only, tortoises are two times less funded than freshwater turtles. This suggests that even though turtles as a taxonomic group are well studied and funded (Fig. 2), proportionally, the majority of these resources are channelled to marine turtles. Contrary to examples of marine turtle recoveries (Balazs & Chaloupka, 2004), freshwater turtles and tortoises have shown no sign of resilience in the wild, and overharvesting and habitat degradation are currently the main threats (van Dijk, 2000; Turtle Taxonomy Working Group, 2014; Nijman & Shepherd, 2015).

It has been noted that there is a decrease in number of manuscripts published on natural history and field ecology studies in herpetological journals, which are essential to comprehend the crisis facing many herpetofauna (McCallum & McCallum, 2006). There is also evidence that changes in the priorities by funding agencies could play a role, owing to the rise of modern molecular and mathematical techniques, such as the case of the National Science Foundation establishing programmes to boost systematics training after a steep decline in this research area (McCallum & McCallum, 2006). Perhaps such trends in the decrease of field studies and increase in cutting-edge research being funded by agencies could be reflected in the present findings, in terms of grant-publication index, where several groups have fallen behind frogs, lizards, turtles and snakes, especially the more cryptic groups, such as worm lizards and caecilians (Fig. 1). Additionally, it is interesting to note that there were several similarities in the order and proportion of publications in herpetological, conservation and high impact journals among groups in this study (Table 4).

One major finding was that researchers conducting studies on frogs, turtles, lizards and snakes publish at similar rates in herpetological and high impact journals, whilst in conservation journals, frogs, turtles and lizards tend to be the most featured groups (Table 4). In the case of the least published groups, tuatara had more studies featured in conservation journals, worm lizards were more featured in herpetological journals than high impact and conservation ones, while caecilians were similarly featured in all journal groups (Table 4). Considering that many species in the data-deficient category could be classified as threatened (Morais et al., 2013; Howard & Bickford, 2014), it is alarming that worm lizards and caecilians are facing increasing threats (Gower & Wilkinson, 2005; Colli et al., 2016) but are not adequately funded or studied (Fig. 2b, Table 4), consequently they should be considered as high priority. Potential reasons for their inattention by funders and researchers may be that worm lizards and caecilians are mainly found in developing countries where there is less funding for research (Fazey et al., 2005), and their cryptic habits make them harder to sample (Gower & Wilkinson, 2005; Colli et al., 2016).

Besides common threats for amphibians (Gibbons et al., 2000), salamanders are not only exposed to the chytrid fungus *Batrachochytrium dendrobatidis*, which has caused mortalities in all amphibian orders (van Rooij et al., 2015), but also by another chytrid fungus which is specific to salamanders and newts (*B. salamandrivorans*; Martel et al., 2013; van Rooij et al., 2015). Both *B. dendrobatidis* and *B. salamandrivorans* have been linked to the decline and are recognised as a conservation threat to several salamander species (Cheng et al., 2011; Martel et al., 2014). In the present study, I show that salamanders are highly threatened (Table 5) and in need of more funding for research, on-ground conservation and recovery programmes (Fig. 1, 2).

Among Squamata, lizards have the highest grant-publication index and on-ground conservation funding. Lizards (12.9 %, IUCN, 2019) are slightly more threatened than worm lizards (8.7 %, IUCN, 2019) and snakes (7.5 %, IUCN, 2019), nonetheless when the number of threatened and data-deficient species is considered in relation to the grant-publication index, these three groups are still in need of more conservation funding and attention (Fig. 2b). Life-history traits of many lizards, such as high fecundity, short generation times, and high population densities can make them less susceptible to declines from anthropogenic factors as they may be able to rebound quickly (Todd et al., 2010). However, lizard species characterised by endemism, restricted geographic ranges, large body size, late maturity and long lives are more prone to population declines and endangerment (Todd et al., 2010). Despite snakes not presenting an overall high degree of threat, studies have indicated that several species not listed as threatened share ecological traits of threatened groups (Reed & Shine, 2002), or could have their status reviewed from data-deficient to threatened (Maritz et al., 2016). In addition, extinction risk may be underestimated owing to a lack of population information (Böhm et al., 2013).

Crocodiles and tuatara are considered the most studied and funded groups of herpetofauna, in relation to the number of threatened species they possess (Fig. 2). Even though they are relatively well researched and have some success stories in terms of recovery (Nelson et al., 2002; Gibbons et al., 2000; Todd et al., 2010), they are still highly threatened and have particularities that deserve monitoring. For example, tuatara is the sole remnant of the order Rhynchocephalia and is endemic to New Zealand (Daugherty et al., 1990; Hay et al., 2010). According to the present study, tuatara is the most threatened group of herpetofauna, has the lowest grant-publication index, and did not procure any on-ground conservation grants included in this study. It is possible that the grant-publication index and conservation grants are underestimated for tuatara for two reasons. First, tuatara is a species that endemic to New Zealand, unlike other herpetological groups that have greater global distribution. Second, on-ground conservation agencies analysed for this study fund mainly projects in developing countries. In fact, most of tuatara funding and recovery plans are sponsored by the New Zealand goverment (Towns et al., 2001). On the other hand, tuatara risk of extinction is high as many populations live on small islands and are declining despite absolute protection (Daugherty et al., 1990). Despite intensive hunting pressure on crocodilians during the mid to late 20th century, protection measures and management programmes were established during the 1970s, and for most species for which habitat loss was not a signicant threat factor, there were many cases of population recovery (Thorbjarnarson, 1999; Gibbons et al., 2000; Todd et al., 2010). Nonetheless, for some species, viable populations are no longer extant in the wild, such as the Siamese crocodile (Platt & Ngo, 2000), or have scattered and isolated populations, such as the Indian gharial (Gad, 2008) and Chinese alligator (Thorbjarnarson et al., 2002). Potentially, a limitation in the present study was that certain taxa lend themselves more to addressing fundamental questions in ecology and evolution (e.g. short-lived taxa compared with long lived taxa). Consequently, frogs and lizards (Hopkins, 2007; Losos, 2009) could attract more funding (e.g. basic and applied science grants) compared to turtles, crocodiles and tuatara, for example. However, on-ground conservation grants should be independent of this aspect. Perhaps another caveat was that the funding metrics were based on agencies in developed countries and six conservation grant providers focusing mainly on developing countries. This should be a concern for herpetological groups with restricted distribution, as previously discussed in the case of tuatara. Even though the bulk of herpetofaunal biodiversity is found in tropical regions in developing areas of the world (Stuart et al., 2004; Böhm et al., 2013), the majority of groups are distributed globally and the collaborative nature of research projects, nationally and internationally, among universities (Grueber & Studt, 2011; Suresh, 2012), and the range of projects supported by on-ground conservation agencies in several countries investigated in this study, should represent an appropriate coverage of herpetological research. For example, within the NSF grants for both amphibians and reptiles investigated in this study, 5.8 % were specifically targeted to the Office of International Science and Engineering (OISE), which fosters international collaboration. Still, many more grants from different NSF programmes researched here involved the study of herpetofauna in developing and tropical countries.

Another aspect to be mentioned is that countries such as the U.S., Canada, Australia, Costa Rica and South Africa have specific policies to protect critical habitat, establish recovery programmes and mandate work to prevent extinction in threatened species (Waples et al., 2013).

Though some of the countries where funding agencies investigated here operate do not have mechanisms such as the Endangered Species Act (Waples et al., 2013), the majority of countries do have national laws to protect threatened species (www.bagheera.com/endangered-species-laws/), hence national red lists and the IUCN Red listing are important mechanisms for researchers and wildlife managers to attract funding to study and protect threatened wildlife (Rodrigues et al., 2006). The bulk of the research output investigated here was not necessarily being directly funded by the grant agencies searched in this study. Investigators funded by the research funding agencies are expected to promptly have their results disseminated and published, while the on-ground conservation agencies only encourage the grantees to have their results published, and this difference can account for some of the diferences in publication rates. Despite this fact, the intention was to have a systematic approach to understand funding levels and knowledge within herpetofauna groups, and by examining a diverse set of granting bodies and journals, this should generally represent a reliable overview of grants and knowledge for amphibians and reptiles worldwide.

CONCLUSIONS

This manuscript aimed to demonstrate strengths and weaknesses in herpetological research and conservation (as represented by fourteen research journals, five research funding agencies, and six on-ground conservation agencies) and shed some light on the groups needing action. I was able to substantiate a continued shift in attention in herpetological research owing to the emergence of the chytridiomycosis as other authors have (e.g. Christoffel & Lepczyk, 2012), the imbalance of funding and scientific information among groups and that degree of threat does not always translate into enough grants and publications.

The main message of this manuscript is that funding should increase as a whole for herpetofauna conservation and biology. This argument is based on the degree of threat faced by several groups of amphibians and reptiles, which is comparatively, more than birds (ca. 13 %), mammals (ca. 21–25 %), and cartilaginous and bony fishes (ca. 17–31 %; Turtle Taxonomy Working Group, 2014). Research, funding and management efforts of amphibians and reptiles have historically lagged behind those of other vertebrates which have a high economic value or are considered pests, such as games species of large mammals, birds and fishes (Gibbons, 1988; Christoffel & Lepczyk, 2012). Making studies more representative at the current insufficient level of funding will not have as substantial an impact as increasing funding generally. By securing more funding for herpetofauna from funding agencies, governments, universities, NGO's and citizen science programmes, it would be possible to continue research on high quality projects on more commonly studied taxa; protection of highly threatened groups of herpetofauna, such as tuatara, crocodiles and marine turtles; and more focus on groups that proportionally have fewer funds and less knowledge in relation to the overall number of threatened and data-deficient species, such as caecilians, frogs, worm lizards, lizards, snakes, and salamanders (Fig. 2b), in addition to tortoises and freshwater turtles.

Another example to be followed by governments is of employing herpetologists as done by the U.S. Department of the Interior, where science can foster knowledge and protection of amphibians and reptiles (Lovich et al., 2012). Also, it is important to consider more research on the usefulness and effectiveness of species of reptiles and amphibians as "umbrella" and/or "flagship" species (Simberloff, 1998; Rondinini & Boitani, 2006; Kalinkat et al., 2017), considering their ecological similarities and shared habitats (Vitt & Caldwell, 2014). Finally, a follow-up study could investigate which categories of projects are being funded in herpetology. For example, a break down into categories (such as behaviour; ecology; distribution; disease; conservation evidence; evolution; physiology) could help to understand which study areas are currently more active and where more attention should be focused.

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APPENDIX

List of conservation organisations involved in herpetological conservation worldwide: Amphibian Survival Alliance, Partners in Amphibian and Reptile Conservation, Amphibian and Reptile Conservation Trust, Save the Frogs!, Turtle Survival Alliance, Turtle Conservancy, The Nature Conservancy, Conservation International, Wildlife Conservation Society, World Wildlife Fund, Durrell Wildlife Conservation Trust, and Disney Conservation Fund, among others.

Priorities for research and action are determined by a range of agencies, in particular the IUCN Species Survival Commission networks, such as Amphibian Specialist Group, Anole Lizard Specialist Group, Boa and Python Specialist Group, Chameleon Specialist Group, Crocodile Specialist Group, Iguana Specialist Group, Marine Turtle Specialist Group, Monitor Lizard Specialist Group, Sea Snake Specialist Group, Snake and Lizard Red List Authority, Tortoise and Freshwater Turtle Specialist Group, and the Viper Specialist Group.

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