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The original descriptions of reptiles and their subspecies

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Abstract

By August 2017 an estimated 13,047 species and subspecies of extant reptiles have been described by a total of 6,454 papers and books which are listed in a supplementary file. For 1,052 species a total of 2,452 subspecies (excluding nominate subspecies) had been described by 2017, down from 1,295 species and 4,411 subspecies in 2009, due to the elevation of many subspecies to species. Here we summarize the history of these taxon description beginning with Linnaeus in 1758. While it took 80 years to reach the first 1,000 species in 1838, new species and subspecies descriptions since then have been added at a roughly constant rate of 1000 new taxa every 12-17 years. The only exception were the decades during World Wars I and II and the beginning of this millennium when the rate of descriptions increased to now about 7 years for the last 1,000 taxa. The top 101 most productive herpetologists (in terms of "taxon output") have described more than 8,000 species and subspecies, amounting to over 60% of all currently valid taxa. More than 90% of all species were described in either English (68.2%), German (12.7%) or French (9.3%).

Key words: lizards, Sauria, snakes, Serpentes, crocodiles, Crocodylia, turtles, Testudines, language, bibliography

Introduction

Systematic biology is the backbone of biology in that it describes the taxa and their relationship which then serve as objects of research in all other areas such as ecology, evolution, physiology, or molecular biology. While there has been some discussion about which species concepts describe biological diversity best, there is agreement that taxa need to be described or defined and named.

The aim of this paper is to compile all original descriptions of extant non-avian reptiles (i.e. lizards, snakes, turtles, tuataras and crocodilians but not birds). We have compiled a list of original species descriptions previously (Uetz 2010) which included 9,084 species of extant reptiles that were described by a total of 4,579 papers and books. Here we expand this analysis to all currently accepted subspecies, which resulted in a much expanded list of 13,047 species and subspecies that were described in a total of 6,454 publications. Given that many recent authors reject the concept of subspecies and either synonymized them with existing species as mere variants or elevate them to full species, we treat species and subspecies equivalently for the sake of this analysis.

Material and methods

The species list and references of this study were taken from the Reptile Database (Uetz *et al.* 2017). On 17 Aug 2017, the database contained 10,594 species, of which 1,052 contained 2,452 subspecies (excluding their nominate forms), or 13,047 taxa total, as well as their original references. The species list and bibliography is available for download at http://www.reptile-database.org/data/originaldescriptions2017.xlsx.

This database of taxa is not an "official" list. In particular, the database has been somewhat conservative when it comes to species concepts and tends to favor a biological species concept over evolutionary concepts that are purely based on diagnosable lineages. However, we followed the primary literature in elevating many of the 4,411 subspecies (of 1,295 species with subspecies) present in the 2009 version of the database (Uetz 2010). Given that in

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the vast majority of cases no reproductive isolation has been shown, there is often no objective basis to consider a taxon as a species or subspecies. Hence both are treated equivalently here.

This list of 13,047 taxa will be incomplete by the time this paper is published, given that about two new species are described every week. However, the overall statistics should remain relatively stable for some time, even with a ~1% growth rate that reptile taxonomy has seen in the past. In any case, future descriptions will be logged into the Reptile Database and continuously updated.

Note that a number of taxa were described by authors as parts of other author's works. For example, Zug and Vindum described *Calotes htunwini* in (Zug *et al.* 2006). In these cases only the actual describers are considered as authors, here "Zug & Vindum", not "Zug *et al.*".

Language analysis. In order to identify the language of a publication, a list of key/value pairs was made in Python, with keys being the language and the values being terms from these languages (e.g. for **French**: les, note, sur, un, nouveaux, des, ou, avec, histoire, deux, une, les; **English**: *the, new, on, a, of, and, to, contribution, from, natural, lizard, reptiles, description, two, an, taxonomic, is, descriptions*; **German**: *neue, zu, der, und, die, durch, aus, zoologisch, zur, reise, einer, eine, über*; **Spanish**: *una, nueva, nuevos, sorbe, las*; **Portuguese**: *estudos, uma, nova*. The terms were read into Python and then iterated over the book or article title and if any or all the words from the title matched the words in the associated list a language was assigned to that article title. Further verification was completed by manually inspecting the pairing of the language and publication title (or the actual paper if the title was not informative).

The descriptions

Not surprisingly, the 19th century was a century of discovery with some of the highest numbers of discoveries. For instance, in 1854, 1863, and 1887, more than 120 taxa were described in each of these years (**Fig. 1**). Such numbers were only reached again in the 21st century, although they have been consistently surpassed during the past 10 years.

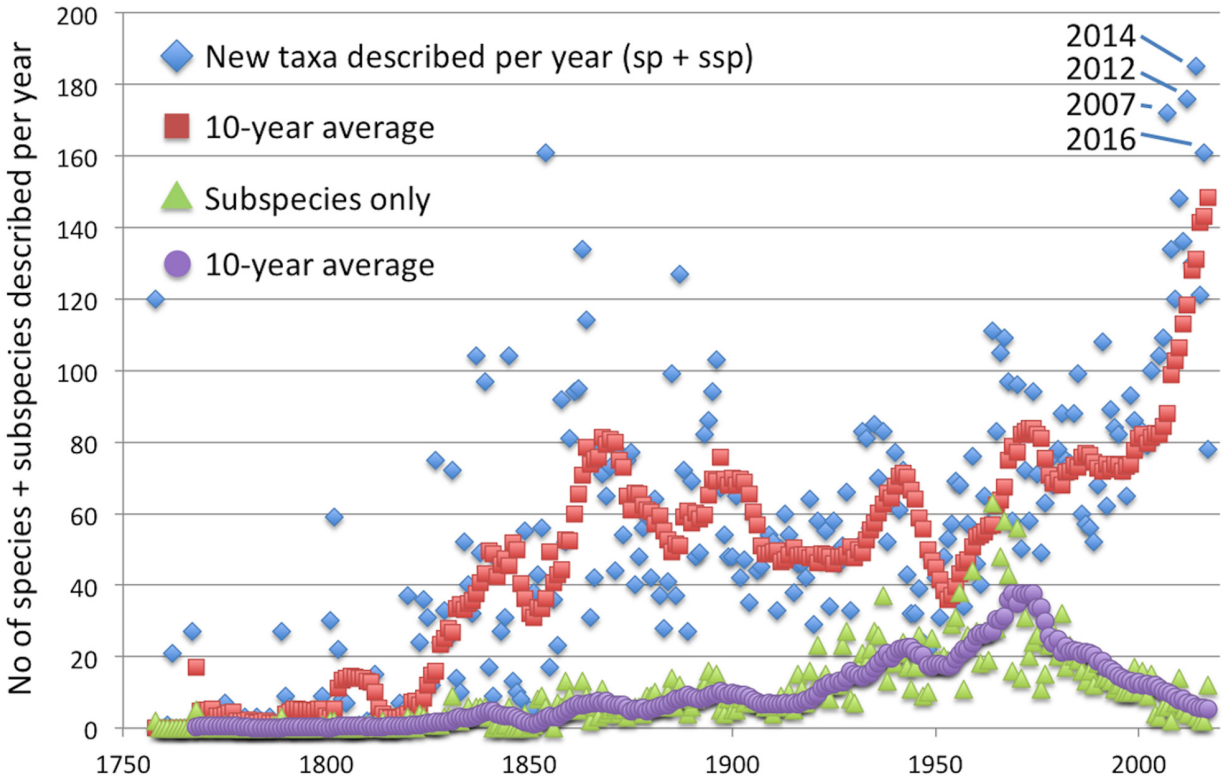

FIGURE 1. Reptile species and subspecies descriptions over 260 years. Only currently accepted species are considered. Blue diamonds represent the number of species described each year. Red squares represent average species numbers over the previous 10 years. Green triangles represent new subspecies only. Purple circles are average subspecies descriptions over the past 10 years.

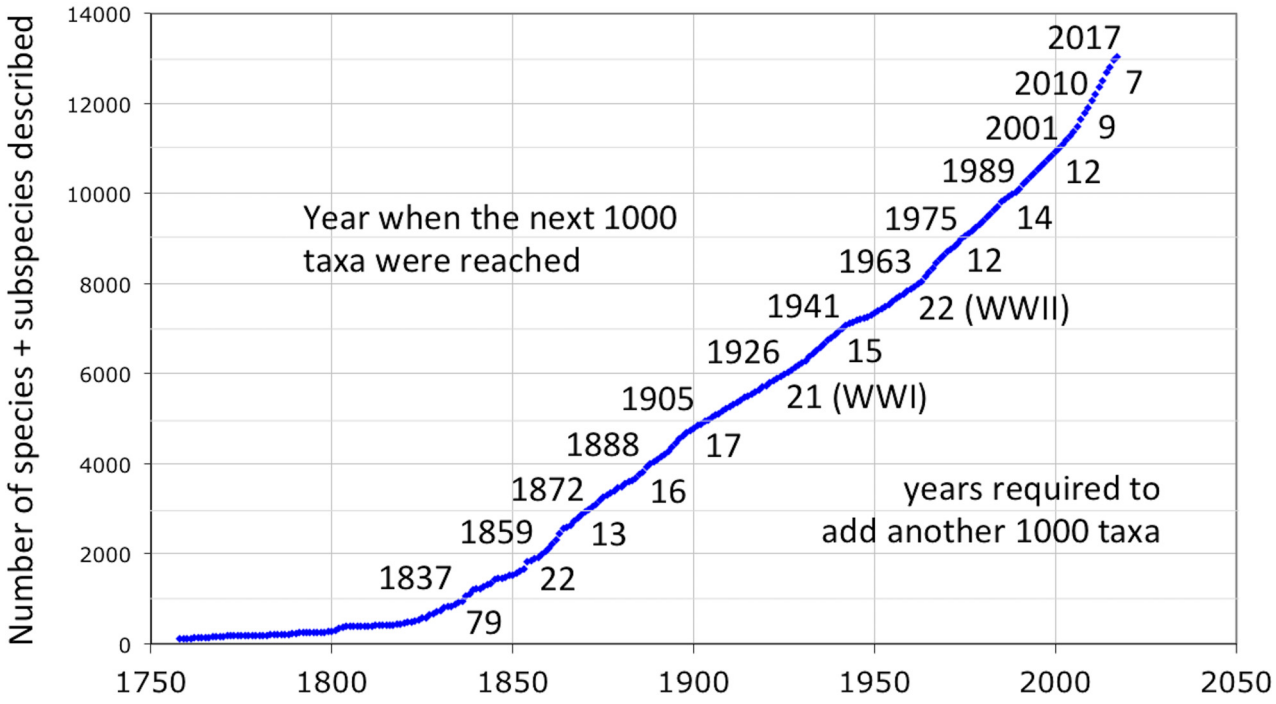

FIGURE 2. Cumulated (total) number of species. The numbers to the left of the line indicate the years when milestones of multiples of 1000 taxa (species plus subspecies) were reached. The numbers to the right indicate the time span between these milestones. Numbers refer only to species and subspecies still recognized today.

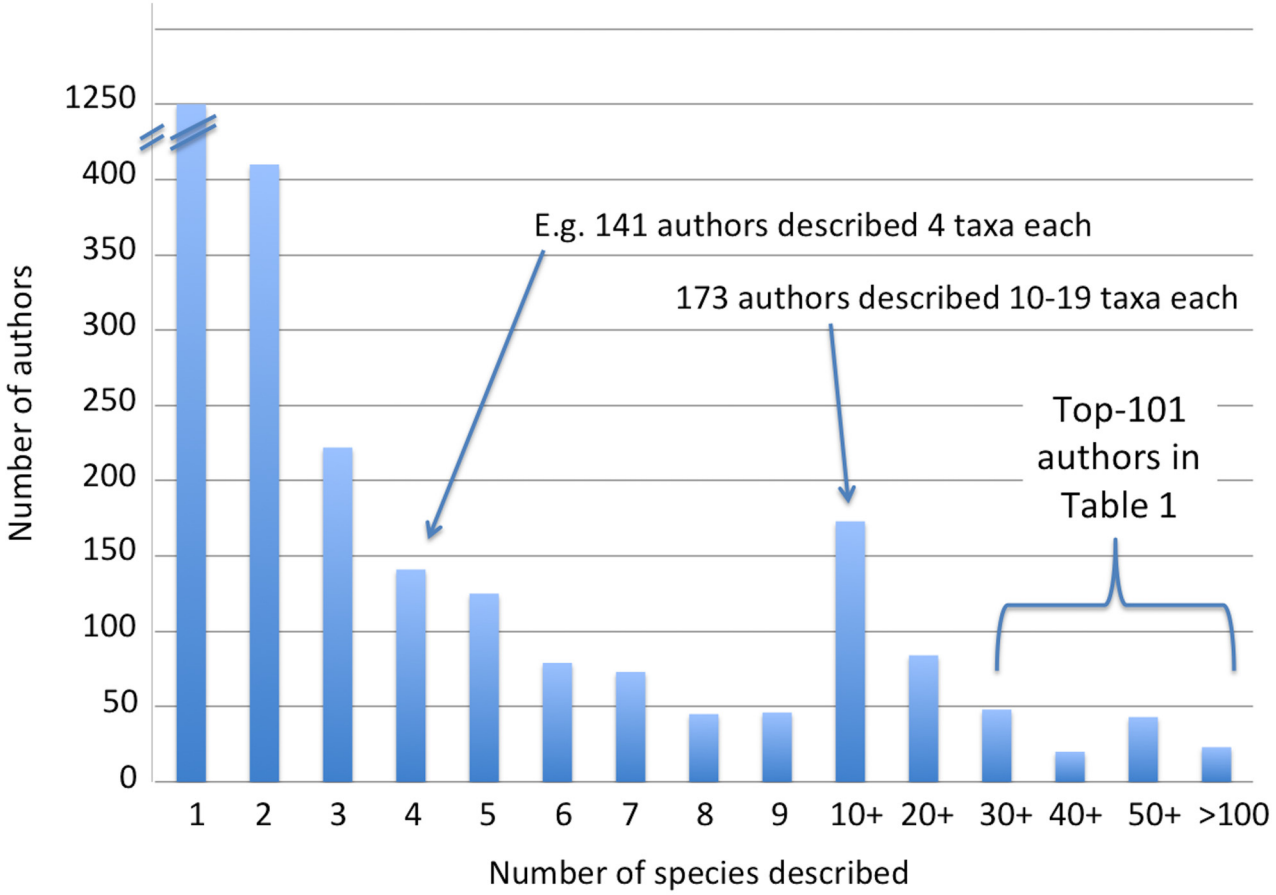

FIGURE 3. Species described per author. Less than 10 species are indicated separately while bins of 10 to 19 taxa etc are indicated by 10+ etc. For instance, 1250 authors have described only 1 taxon that is still considered valid.

Somewhat surprising, however, is the fact that descriptions have been also fairly consistent when tracked over longer periods, such as decades: to add another 1,000 taxa to existing species and subspecies it has taken herpetologists consistently about 15 years from the mid-19th century to the 21st century. The only notable exceptions were the decades during World War I and II (**Fig. 2**).

The authors

As emphasized in our 2010 analysis (Uetz 2010), reptile alpha-taxonomy has been dominated by a few highly productive individuals over long periods of time. Our 2010 list found 40 individuals who described at least 50 species, together amounting to more than half of all reptile species recognized at the time (Uetz 2010). This time we considered both subspecies and species and found 66 authors who have described at least 50 species or subspecies that are still considered valid (**Fig. 3**). In fact, the 13,047 taxa were described by a total of about 2,786 authors, although that number is likely higher, as we identified authors with the same last name only for the top-101 authors (authors 99-101 had the same number of taxa; **Table 1**). In order to get into this list of the top-101, someone had to have described at least 36 (still valid) taxa.

The list is still led by a large margin by George Albert Boulenger (1858-1937) who described 659 reptile taxa that are still recognized today (573 species in 2010), in addition to many amphibians and fish. Remarkably, about 37% of the top-100 are alive, often remaining productive. Two living authors have described more than 100 taxa, namely Aaron Bauer and Lee Grismer, with currently 164 and 126 reptile taxa.

TABLE 1. Top-101 authors and the number of taxa they described. Only authors who described more than 35 taxa (species or subspecies still valid) are considered. Authors that share their last name with others that have described new taxa are indicated by their initials. Authors who are still **alive** are highlighted in **bold**. A complete list of authors and their references with new (sub-) species is provided in Electronic Supplementary **Table S1**.

#	Author	Taxa	#	Author	Taxa
1	BOULENGER	659	23	LAURENT	101
2	COPE	385	24	JAN	97
3	GÜNTHER, A.	364		**THOMAS, R.**	97
4	GRAY, J. E.	335	26	**BÖHME**	92
5	PETERS, W.C.H.	306	27	SCHLEGEL	90
6	SCHWARTZ	299	28	**GARRIDO, O.H.**	88
7	DUMÈRIL, A.M.C.	266	29	**HEDGES**	86
8	BIBRON	238	30	STEJNEGER	84
9	STORR	232	31	**WOOD JR**	81
10	SMITH, H. M	199	32	**KÖHLER, G.**	79
11	**BAUER**	164		BAIRD	79
12	WERNER, F.	152	34	BROWN, W.C.	78
13	TAYLOR	150	35	**RODRIGUES**	77
14	LINNAEUS	141	36	GIRARD	75
15	MERTENS	133	37	SMITH, M.A.	73
16	**GRISMER, L.L.**	126	38	**ZIEGLER**	71
17	SCHMIDT, K.P.	118		HALLOWELL	71
18	DUMÈRIL, A.H.A.	114		PARKER, H.W.	71
19	BARBOUR	112	41	**BROWN, R.M.**	70
20	BOETTGER	108	42	**SADLIER**	69
21	BROADLEY	106	43	**GREER**	68
22	LOVERIDGE	102	44	SMITH, A.	67

.....continued on the next page

TABLE 1. (Continued)

#	Author	Taxa	#	Author	Taxa
45	MOCQUARD	66		DAREVSKY	47
	BOCOURT	66		**VENCES**	47
47	WILLIAMS	65	75	**WALLACH**	46
	PAUWELS	65		LANZA	46
49	ANDERSON	64		NGUYEN, T.Q.	46
50	DIXON	63	78	**SILER**	45
51	BOCAGE	58	79	DOMERGUE	44
	WIEGMANN	58	80	**CAMPBELL, J.A.**	43
	ORLOV	58		COCHRAN	43
54	DUNN	57	82	BEDDOME	42
	MÜLLER, L.	57		**DIESMOS**	42
56	VAN DENBURGH	56	84	**BRANCH**	41
57	DAUDIN	54	85	**ABDALA**	40
58	STERNFELD	53		**ARNOLD**	40
59	CEI	52	87	**DOUGHTY**	39
	COUPER	52		**VOGEL**	39
	GARMAN	52		FISCHER	39
62	**RAXWORTHY**	51		BLANFORD	39
	SUMONTHA	51	91	BLYTH	38
	HEWITT	51		ANGEL	38
65	AMARAL	50		SHREVE	38
	FITZSIMONS	50	94	**MUIN**	37
67	**GRISMER, J.L.**	49		**DAS**	37
	NUSSBAUM	48		**INGRAM**	37
	BOIE	48		NIKOLSKY	37
	STEINDACHNER	48		KLAUBER	37
	GLAW	48	99	TANNER, W.W.	36
72	**ROZE**	47		**ANUAR**	36
				HORNER	36

The language of new taxa

When Carl von Linné kicked off zoological taxonomy with his *Systema Naturae* (Linnaeus 1758), he used Latin to describe new species. Surprisingly, Latin has never been the dominant language in reptile taxonomy except for Linné's *Systema* which contained 141 of the 264 descriptions published during the 18th century (53.4%). After 1800 only 107 taxa were described in Latin. Nevertheless, this makes Latin the 5th most often used language in reptile alpha-taxonomy with 310 species total. While German initially dominated as language in the 19th century, English quickly took over and is now almost exclusively used to describe new taxa (**Fig. 4**). Overall, we found that 8,901 (out of 13,047) taxa were described in English, 1,660 in German, 1,214 in French, and 1,272 in some other (or unknown) language (**Table 2**). To complicate matters, some titles do not reflect the actual language used for a description and thus a few papers may have been misclassified. For instance, some authors used two languages in the same paper, e.g. Otto Boettger used German titles and introductory text in some papers but then described new species in Latin within these papers (e.g. Boettger 1888).

TABLE 2. The most common languages in which new taxa were described (1758–2017), across 13,047 taxa and 6,454 publications (see Electronic **Supplementary Table S1** for complete list).

Language	Publications	% Publications	Number of taxa	% Taxa
English	4,678	72.48	8,901	68.22
German	751	11.64	1,660	12.72
French	415	6.43	1,214	9.3
Spanish	225	3.49	329	2.52
Portuguese	92	1.43	166	1.27
Italian	86	1.33	201	1.54
Russian	81	1.26	121	0.93
Latin	39	0.6	310	2.38
Dutch	24	0.37	30	0.23
Chinese	17	0.26	32	0.25
Unknown / other	46	0.71	83	0.64
Total	**6,454**	100	**13,047**	100

Availability of original descriptions and their digitization

Efforts have dramatically increased to support open access publishing to make the scientific literature freely accessible (Tennant *et al.* 2016). Nevertheless, there are journals and other publications that are not accessible online, e.g. the *Bulletin of the Maryland Herpetological Society*. Some journals may be ordered online as paper copies but are not available in digital formats, e.g. many herpetocultural journals that occasionally publish taxonomic papers (e.g. *Reptilia*).

In addition to online publications, serious efforts are under way to digitize the older scientific and popular literature and make it available online. The most important ones are the Biodiversity Heritage Library (BHL) operated by the Internet Archive, and Google Books which is now also incorporated into other web sites including the BHL. In addition, there are many national efforts to digitize the intellectual heritage of these countries, e.g. the French national library (Gallica) or the Europeana project (Europeana Foundation 2017).

According to the Berne Convention on Copyright, EU countries and the United States typically grant copyright protection for 70 years after the death of an author, hence the year 1923 was chosen as the cut-off date for the BHL. More recent publications are thus often not accessible online. Although we did have a list of journals that are available online in our 2010 list we did not have URLs for individual articles. This has changed dramatically, so that an estimated 4,482 of the 6,452 original descriptions are now available online. Unfortunately, a significant number of these sites are commercial. Many journals ask for an open access fee, including Magnolia Press, the publisher of Zootaxa. Other services such as JSTOR or BioOne require a (paid) membership or subscriptions to access journals.

The future of species descriptions

While it is a welcome achievement to put species descriptions online, most such publications do not go beyond traditional printed papers, except that they are online. This is unfortunate, given that digital technologies could improve publications in many ways that are barely used today. For instance, space is not limiting any more, and neither is color, so much more detailed descriptions could be made mandatory, especially with the generous use of illustrations and data tables. Images can now be embedded in 3D and the resolution of micro-CT-scanning even allows us to publish detailed anatomical data in 3 or 4 dimensions (the latter when ontogeny or other processes are included).

The Reptile Database aims to improve this situation by providing diagnoses and hopefully soon more detailed descriptions of taxa together with detailed images. Copyright issues have prevented that but there is an active discussion on whether scientific illustrations should or can be subject to copyright laws at all (Egloff *et al.* 2016).

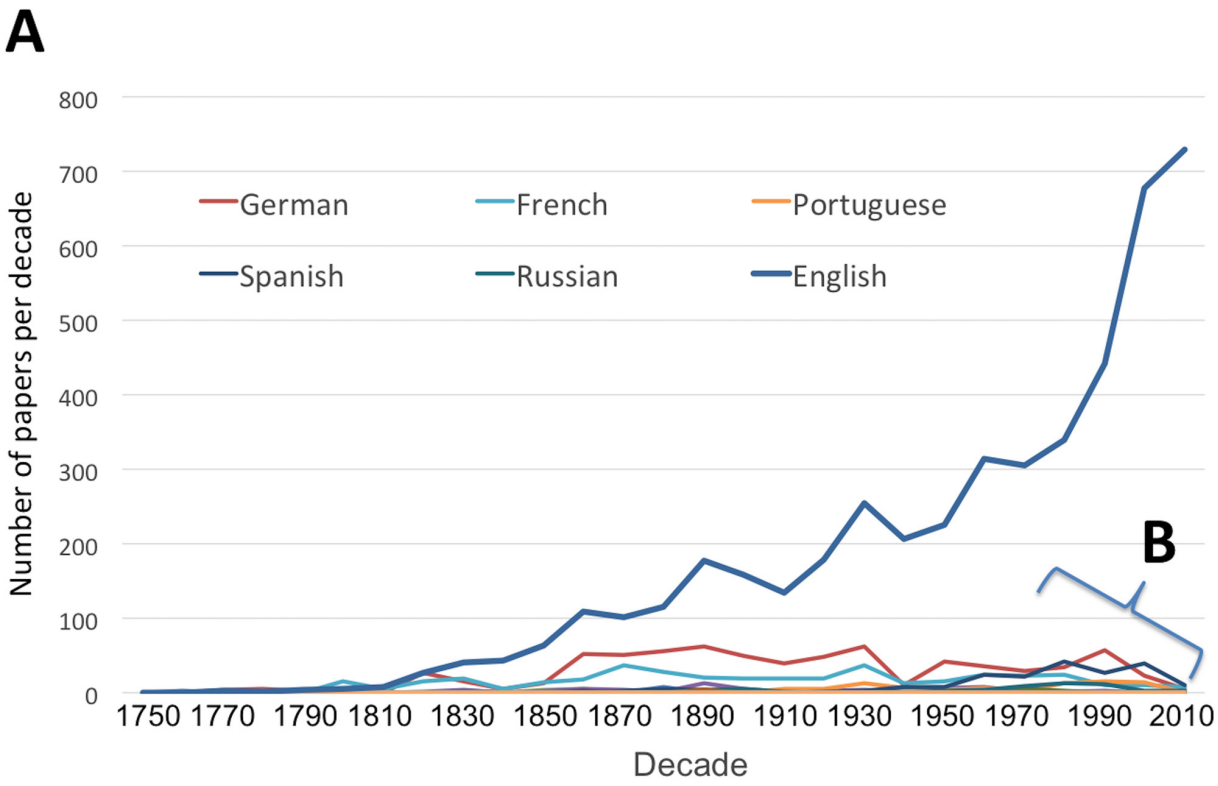

FIGURE 4. The language of species descriptions. (A) Major languages used to describe new taxa over the history of reptile taxonomy, including English. **(B)** As in (A) but with English excluded.

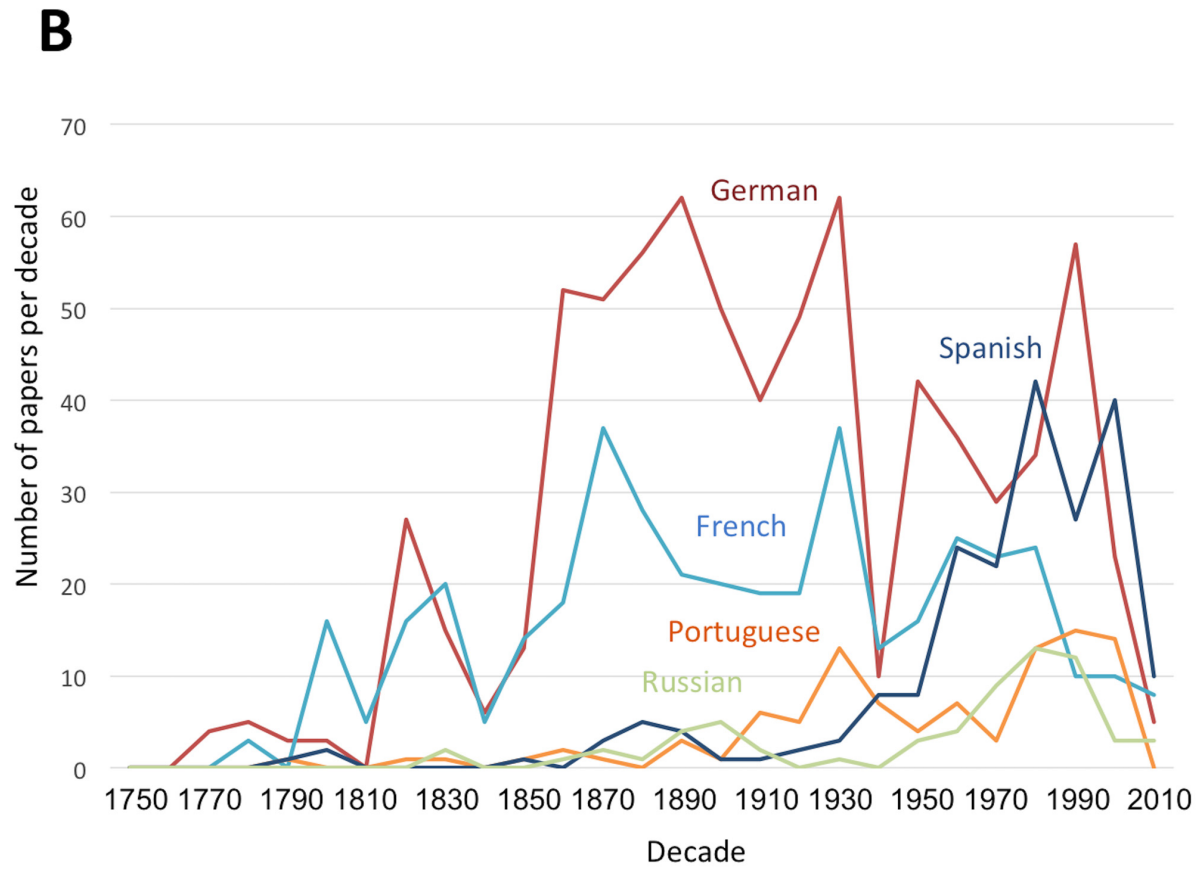

FIGURE 4B.

In addition, the Reptile Database has started to link species descriptions to anatomical databases such as Morphosource (Boyer 2017) and to the NCBI taxonomy and GenBank which provide DNA and genome sequences which will increasingly supplement and possibly replace morphological descriptions – at least when sequences will allow us to predict morphology.

Acknowledgements

Numerous volunteers and authors provided original reptile descriptions, especially Mario Schweiger. Roy McDiarmid and Nicholas Vidal kindly allowed us to use the herpetological library at the National Museum of Natural History (Smithsonian Institution) and the Muséum National d'Histoire Naturelle (Paris), respectively. The Reptile Database is a member of the Catalogue of Life/Species2000 consortium and acknowledges previous support by the European Union (project 238988, 4D4Life—Distributed Dynamic Diversity Databases for Life). The Society for the Study of Amphibians and Reptiles (SSAR) supported the establishment of a US mirror site of the Reptile Database.

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Note added in proof: Since this paper was accepted about 100 new taxa have been added to the Reptile Database (Feb 2018 release). New taxa and their original references are listed in the Reptile Database and its downloadable checklist at http://www.reptile-database.org/data/

Electronic Supplementary Table 1. All currently recognized species by the Reptile Database and their original references. (Column A) (sub-) species, (B) author, (C) year, (D) ssp = subspecies, nom = nominate subspecies; (E) duplicate references, lines with " yes" can be deleted to obtain non-redundant list of references, (F-H) **Publication**: (F) author(s), (G) title, (H) source, (I) language, (J) Ref# = Reptile Database internal reference number.
Available at http://www.reptile-database.org/data/originaldescriptions2017.xlsx