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Progress and prospects in taxonomy: what is our goal and are we ever going to reach it?

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Abstract. Based on percentages of undescribed species collected during intensive recent sampling campaigns in South America, tropical Africa, and the Caribbean, the current global total number of pholcid species is estimated to range from about 4,000 to 5,000. With the current rate of descriptions of about 570 pholcid species per decade, this suggests that a global inventory of the family could be completed within a few decades. However, I argue that a complete (or near-complete) inventory is neither realistic nor necessary and that knowing the majority of species of a particular group will answer most questions on that taxon's biology, while being a manageable task. At current rates of description, the majority of pholcid species might be known within 10–20 years.

Keywords: Spiders, Pholcidae, global diversity, description rate, taxonomic impediment, extrapolation

There is a wide range of positions about the progress and prospects of taxonomy. One extreme is characterized by a rather pessimistic view, based on the fact that taxonomists have described no more than about 5–20% of global diversity in over 250 years (e.g., Stork 1997; Guerra-García et al. 2008; Hamilton et al. 2010); on the impression that all sorts of fundamental prerequisites are increasingly difficult to access, including funds, academic positions, and permits for collecting and export (e.g., Gaston & May 1992; Wilson 2004; Haas & Häuser 2005; Amato & DeSalle 2012; Bebber et al. 2013; de Carvalho et al. 2013; Löbl & Leschen 2013; Sluys 2013); on the insight that modern taxonomy is not only solving problems but also creating new ones, as by the current explosion of DNA sequences in online repositories not linked to described species (Samyn & De Clerck 2012); on the awareness that we live in an 'age of extinction' (e.g., Stork 1997; Amato & DeSalle 2012; Mora et al. 2013); and on the uneasy suspicion that taxonomy makes us feel we 'know' a species after describing it while in fact we know almost nothing about most described species (e.g., Lawton 1993).

On the other extreme there is a confident 'yes, we can' position, based on impressive numbers of species described every year, on supposedly increasing rates of species description by increasing numbers of taxonomists, and on the ongoing development of infrastructure and technology (e.g., Janzen 2004; Joppa et al. 2011; Wheeler et al. 2012; Costello et al. 2013a, b).

The present paper challenges these extremes but primarily intends to address the problem at a much smaller scale, dealing with a single family of spiders, the Pholcidae. This is simply a result of my own emphasis on and experience with this group for almost two decades. I do not pretend that the results can or should be easily extrapolated to other spiders or even beyond (for recent thoughts at that scope, see Agnarsson et al. 2013; Platnick & Raven 2013). Acknowledging the need for clearly achievable goals that are both realistic and relevant (Godfray 2002), I aim at a picture that is as close to reality as possible, in an effort to avoid both debilitating hopelessness and overly enthusiastic confidence.

ESTIMATING GLOBAL SPECIES DIVERSITY

In the early days of arachnology, the pioneering French-American zoologist Nicolas Hentz published a remarkable statement, saying that "…when the work is accomplished, and all nature is described by man, the number of species included in the common word *spider* will be truly amazing. … It is obvious that the number of species throughout the world will amount to more than *two thousand*…" (Hentz 1841: his italics). Current estimates of global spider diversity (76,000–170,000: Coddington & Levi 1991; Platnick 1999; Agnarsson et al. 2013; Platnick & Raven 2013) are obviously closer to reality, but the wide range of estimates also shows that we still have to build on incomplete data and make extrapolations based on debatable assumptions. A variety of methods have been proposed to estimate species diversity, each with its strengths and weaknesses, including ratios from known to unknown faunas; extrapolations from samples; relationships of body size and species number; rates of species description; species turnover; and expert opinion (e.g., Stork 1997; Mora et al. 2011; Scheffers et al. 2012).

The approach used here is similar to that in Hodkinson & Casson (1991), who employed percentages of new species collected during intensive sampling events (the "known to unknown ratio" method in Mora et al. 2011). In contrast to previous studies using this approach, I try to avoid two pitfalls: 1) by comparing results from mega-transects in different regions I hope to minimize the potential impact of unjustified extrapolation from regional to global species richness; 2) by focusing on Pholcidae I limit the results to a relatively small taxon (currently about 1400 nominal species), avoiding further assumptions needed for extrapolating to total spider or even total species richness.

The estimates below are based on a series of 15 recent collecting trips to Brazil, the Caribbean and tropical Africa (for details see http://www.pholcidae.de/expeditions.html). The primary aim in each of these expeditions was to collect a maximum of pholcid species present at each locality. For this reason, common and easy species were deliberately ignored after an initial period and the effort was increasingly focused on more cryptic and 'difficult' species. This method obviously impedes an analysis of species abundances within and among localities, but it is likely to collect most or all species with considerably less effort than a strict quantitative approach in ecologically structured sampling.

Atlantic Forest mega-transect.—In five expeditions (2003–2011), 17 localities in Brazil's Atlantic Forest were visited over

Figure 1.—Localities in Brazil's Atlantic Forest visited between 2003 and 2011, resulting in a total of 89 pholcid species, 71 of them new to science.

a transect of 2,000 km (Fig. 1). Species accumulation curves for total and new species do not seem to slow down in the addition of new species over time. The percentage of new species remained relatively constant over the transect, with a final value of 80% (71 of 89) (Fig. 2).

Tropical Africa mega-transect.—In six expeditions (2008–2013), about 75 localities across tropical Africa were visited over a transect of 6,000 km (Fig. 3). Even though species diversity per locality and levels of endemism were lower than in Brazil, the species accumulation curves for total and new species are similar (Fig. 4). The percentage of new species remained relatively constant over the transect, with a final value of 74% (87 of 117) (Fig. 4).

Comparative data on Caribbean islands.—About 45 localities on Cuba, Haiti and the Dominican Republic were visited in four expeditions (1999–2012). The total percentage of new species was similar to those in Brazil and Africa: 78% (62 of 80).

Preliminary conclusions.—The three intensive sampling events over large geographic areas resulted in similar percentages of new species (Brazil: 80%, Africa: 74%, Caribbean: 78%). I see no reason to expect significantly different percentages for other megadiverse regions like Southeast Asia or other parts of tropical South America. For regions that are better studied (e.g., Europe, North America), percentages are likely lower, but their relatively low pholcid diversity suggests little impact on the total numbers. Extrapolation based on numbers of described species before major description of new taxa collected during the above sampling events (~1,000 species as of 2008) suggests a global total of about 4,000–5,000 pholcid species. Whether these numbers are closer to reality than the quick-and-dirty expert opinion I offered in May 2012 (6,770 species: published in Agnarsson et al. 2013), only the future can show (the illusory precision resulted from the fact that my rough guess of 5,500 undescribed species was added to the number of nominal species known at that time).

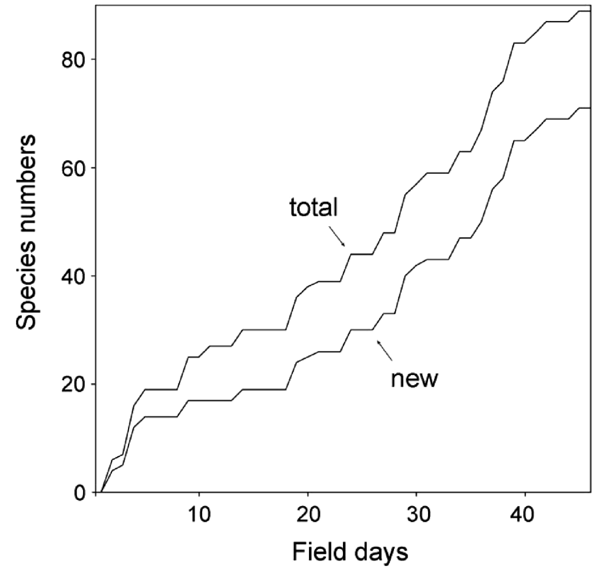

Figure 2.—Species accumulation curves for total and new pholcid species collected at the Brazilian Atlantic Forest localities shown in Fig. 1 during 46 days of fieldwork.

RATES OF DESCRIPTION

The species accumulation curve of Pholcidae from Linnaeus to present shown in Fig. 5 primarily reflects the increasing specialization of taxonomists on ever fewer and/or smaller taxa. One remarkable feature of the curve is its fairly steady exponential increase. Four phases can be distinguished, with increasing rates but decreasing duration: 1757–1889 (132 years, 2 species/decade); 1890–1970 (81 years, 31 species/decade); 1971–1999 (29 years, 110 species/decade); 2000–present (14 years, 572 species/decade). Apart from the trivial conclusion that an average rate over the last 250 years is misleading for extrapolation, the curve suggests that even current rates may not be a solid basis for extrapolation.

A PLEA FOR THE MAJORITY

Recent contributions on the subject almost universally imply that nothing less than naming and cataloguing *all* [my emphasis] life on Earth is a major and unquestioned goal of taxonomy (e.g., Carbayo & Marques 2011; Wheeler et al. 2012; Bebber et al. 2013; Costello et al. 2013a; Didham et al. 2013). For groups such as plants and vertebrates this may be a feasible goal. For megadiverse arthropod groups, however, aiming for the majority of species rather than a complete or near-complete inventory of global diversity seems an attractive and justified approach for three reasons:

1) I strongly agree with May (2004) that collecting new species in the field will remain the rate-limiting step in taxonomy. The more species we collect and describe, the higher will be the percentage of 'difficult' species among those that remain undescribed; i.e., species that are rare, cryptic, small, limited to poorly accessible areas, etc. (Mora et al. 2011; Scheffers et al. 2012). Finding these species will require increasing numbers of specialists (generalist collectors inevitably tend to recollect the 'easy' species) in increasingly difficult areas (e.g., the landmine-infested forests in Angola; see http://www.sac-na.org/

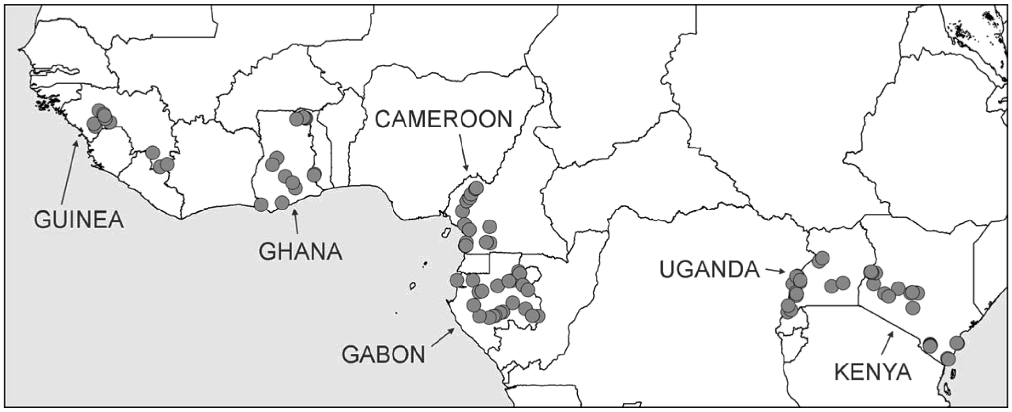

Figure 3.—Localities in tropical Africa visited between 2008 and 2013, resulting in a total of 117 pholcid species, 87 of them new to science.

surveys_angola.html), spending increasing amounts of time and money (at some point the seemingly absurd estimate of Carbayo & Marques 2011 of US$ 48,500 per species may become realistic), and facing increasing bureaucratic hurdles on the way to the field and back. It is a mystery to me how Wheeler et al. (2012) could unequivocally agree with the statement that "a comprehensive mission to discover … the species of the biosphere is feasible". These authors call for an "aggressive expansion of collections", remaining silent about what this means and how it works.

2) As I will suggest below, aiming for the majority of species may result in a much less intimidating period of time necessary to achieve the goal (and thus help avoid the feeling of hopelessness).

3) I propose that knowing half of all species of each taxon will get us very far in providing the basis for answering our questions about all aspects of nature ranging from molecules to ecosystems. The half of the species described first from a particular taxon will probably include most species a non-specialist will ever encounter in the field, it will likely be a good representation of the geographic range and the morphological and molecular variation within the taxon, it will allow estimation of biases (such as biases in collecting effort, or the bias for widespread species: see below) and it will probably reflect the basic patterns of the group's natural history and point out the most promising aspects for further in-depth studies in and beyond taxonomy.

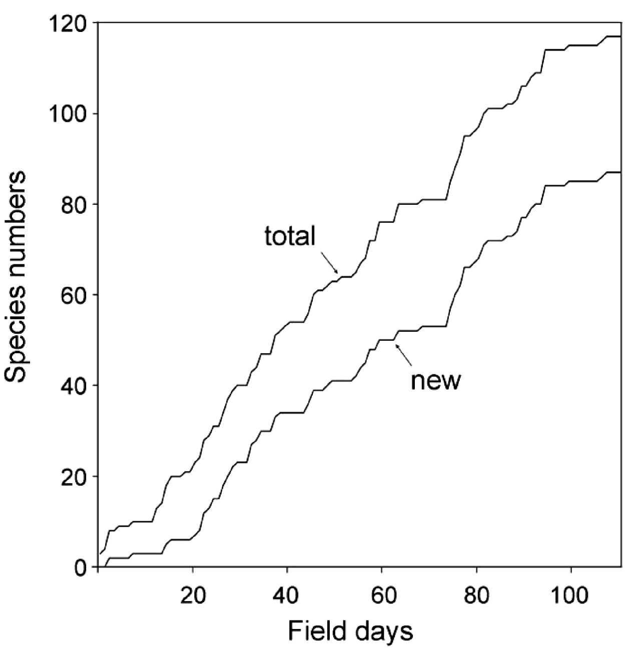

Figure 4.—Species accumulation curves for total and new pholcid species collected at the African localities shown in Fig. 3 during 106 days of field work.

CONCLUSION – IT NEED NOT TAKE HUNDREDS OF YEARS

In a recent paper on tropical arthropod species richness estimation, Hamilton et al. (2010) concluded that "… 66%–77% of arthropod species are yet to be described … [and that it] will take hundreds of years to complete at the current rate

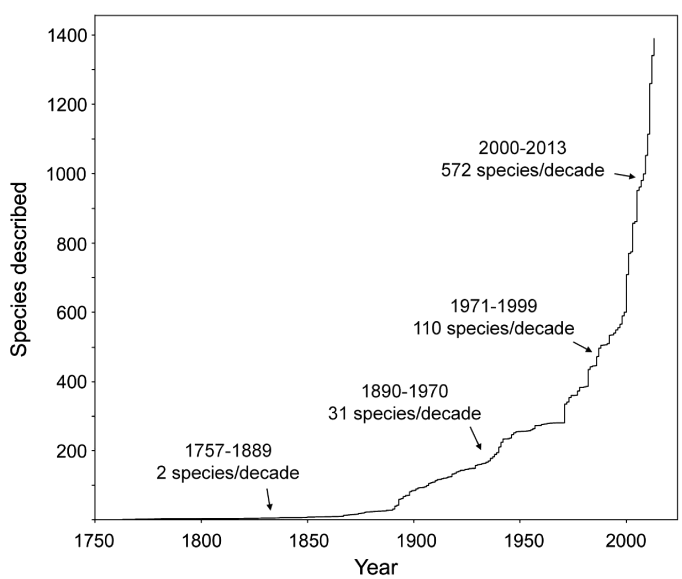

Figure 5.—Cumulative curve of currently valid described pholcid species up to September 2013.

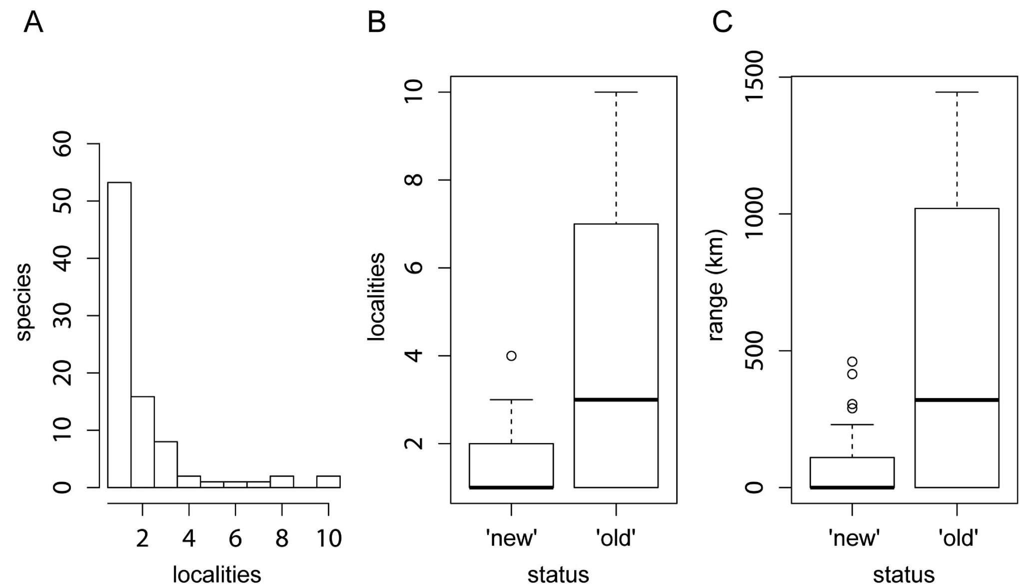

Figure 6.—Atlantic Forest transect. A. Histogram showing that a large majority of species was found at only one or few of the 17 localities sampled. B, C. Boxplots showing that 'new' species (i.e., undescribed species as of December 2003, the date of the first trip) have significantly smaller ranges [both in terms of numbers of localities ($P = 0.004$) and with respect to maximum distances between localities ($P = 0.003$)] than 'old' species. Synanthropic species are excluded.

…". A year later the authors (Hamilton et al. 2011) corrected their numbers, resulting in an even more disillusioning 86%–89% of undescribed species (almost identical numbers are reported in Mora et al. 2011). The numbers presented above for Pholcidae suggest that in groups with 'active' taxonomists (see below) it may take much less than hundreds of years. At the current rate of about 570 species per decade it may take no more than 40–60 years to 'complete' a global total of 4,000–5,000 pholcid species. Taking into account the predicted difficulties in finding the ever rarer species and aiming for the majority reduces the time necessary to an encouraging 10–20 years.

What do I mean by 'active' taxonomists? Available estimates of the numbers of taxonomists worldwide (6,000–47,000; Wilson 2004; Haas & Häuser 2005; Costello et al. 2013b) and species described per year (8,000–18,000, depending on the number of synonyms; Wheeler et al. 2012; Costello et al. 2013a; Mora et al. 2013) suggest an average of only about 0.2–3.0 newly described species per taxonomist per year. Taxonomy of course is not only about describing new species, and I am not questioning the overall scientific productivity of taxonomists (about a fifth of taxonomists work on the relatively well-known tetrapods: Gaston & May 1992). However, the numbers suggest that only a small fraction of taxonomists actually invest a considerable amount of time in species descriptions (cf. Evenhuis 2007; Bebber et al. 2013). The fact that 20% of all spiders newly described in the last decade belong to just two of the currently 112 families (Oonopidae and Pholcidae: see Platnick 2013) illustrates the point for this particular group. On a broad scale we will probably never get even close to the 100 species per taxonomist and year envisioned by Wheeler et al. (2012). However, the number is realistic in individual cases counting on the support staff proposed by these authors. Supporting such 'active' taxonomists may be among the most promising approaches against the taxonomic impediment (cf. Bebber et al. 2013; Sluys 2013).

In all the above, the involvement of several factors, each of which is estimated or predicted with error, obviously results in rough orders of magnitude rather than precise numbers. Technical advances that may increase rates of description are as difficult to predict as future changes in the conceptual framework (e.g., allowing for intraspecific genitalic variation may drastically decrease species numbers in many arthropod groups). Numbers of synonyms and cryptic species are equally difficult to estimate, and may affect the time necessary to reach whatever level of completeness we aim at (e.g., Bickford et al. 2007; de Carvalho et al. 2013). Another possibly confounding factor is the distributional range of undescribed species. On average, widespread species are likely to be discovered and described sooner than local endemics (e.g., Agnarsson et al. 2013; Essl et al. 2013), and Fig. 6 illustrates this point for the Atlantic Forest data on Pholcidae. This non-linear relationship between described and undescribed species means that the method used above may underestimate true species richness.

Extinction, on the other hand, may ironically help taxonomists reach the goal sooner than expected. Estimates of extinction rates vary mostly between about 1% and 10% per decade (Stork 1997; Costello et al. 2013a; Mora et al. 2013). Since forest loss is probably the single major factor driving current extinctions (Stork 1997) and Pholcidae are most diverse in pristine forests and have a high percentage of locally endemic species (e.g., Huber 2011, 2013; see also Fig. 6), their rate of extinction is probably at the higher rather than the lower end. Although the effect is relatively moderate at 1% per decade (about 200–250 species less in 50 years, assuming 4,000–5,000 current species), it is quite significant at 10% (about 1,600–2,000 species less in 50 years). Although it may be hard to see a realistic chance to stop the ongoing extinction in the near future, I am optimistic that a concentrated focus on manageable tasks and a renewed effort by trained taxonomists to actually describe species can get taxonomy very far in a very reasonable period of time.

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