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# Is parasite taxonomy really in trouble? A quantitative analysis

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ABSTRACT

In recent years, several authors have warned that the number of trained experts in parasite taxonomy and systematics is declining rapidly, and that the whole field is at risk. However, to date there has been no quantitative analysis to support these claims. Here, we provide the first such assessment, focusing on helminths parasitic in fish as an example, and using a representative dataset comprising over 2000 helminth species described in the past two decades. Based on standard indices of inequality, we demonstrate that a small group of highly prolific taxonomists are associated with the vast majority of new species descriptions, indicating that the research output in parasite discovery is concentrated in the hands of a small number of individuals. This situation has not improved over time. Furthermore, there has been no turnover over time, i.e., no replacement of the most prolific taxonomists: the individual researchers ranking among the most prolific describers of new parasite helminth species in the past decade were generally also the most prolific in the decade before that. Finally, based on the year in which these most prolific taxonomists published their first species description, we estimate that a large proportion of them are in the latter stages of their career. Inequalities in research output are the norm across scientific disciplines. However, persistent inequality in the number of species description per author, coupled with the same individuals ranking as most prolific over time and a majority of them in late career, all combine to support earlier claims that parasite taxonomy may well face a crisis in the form of an impending loss of taxonomic expertise.



## 1. Introduction

Since the turn of the millennium, many researchers have voiced concerns regarding the loss of taxonomic expertise as funding and training opportunities for early-career researchers are increasingly allocated to other branches of biology (de Carvalho et al., 2005; Agnarsson and Kuntner, 2007; Britz et al., 2020; Engel et al., 2021). In particular, alarm bells have been sounded regarding the growing shortage of qualified taxonomists, a key reason for the 'taxonomic impediment' that impacts ecologists and conservation biologists working to understand community-level phenomena in a rapidly changing world (Wheeler et al., 2004; de Carvalho et al., 2005; Pearson et al., 2011; Britz et al., 2020; Engel et al., 2021). The same concerns have been raised more specifically for parasite taxonomy, with many authors arguing that the number of trained experts in parasite taxonomy and systematics is not just failing to keep up with the number of new species being uncovered, but is actually dwindling (Brooks and Hoberg, 2000, 2001; Poulin, 2014; Cribb, 2016). If true, this situation would indeed be worrying, as the number of undescribed parasite species is likely to exceed the number currently described, and the effort necessary to describe the rest will require a large and active taxonomic workforce (Carlson et al., 2020).

In spite of all these alarming commentaries, there has been no quantitative analysis to support the presumed decline in the number of parasite taxonomists. Some have even argued that because the total number of distinct authors associated with the descriptions of new parasite species published per year has been growing, the number of taxonomists may actually be increasing (Costello et al., 2013). However, since many of these authors are only involved with very few descriptions, and over short time spans of 2–3 years, they are more likely to be graduate students or one-off collaborators rather than dedicated, career taxonomists (Poulin and Presswell, 2016). It has also been reported that taxonomic resolution, i.e., the extent to which parasites are identified down to species level, has decreased on average in recent studies of parasite ecology compared with older ones (Poulin and Leung, 2010). This may simply be due to a lack of collaboration between parasite ecologists and taxonomists, however. So what actual evidence is there that taxonomic expertise is in decline within parasitology?

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Here, we approach this question by quantifying the degree to which contributions to new species descriptions are unequally divided among taxonomists, and how this inequality has changed over time. If a few individuals account for a disproportionately large number of new species descriptions, it would suggest that the field is at risk: if these few prominent experts leave the work force for one reason or another, the loss of taxonomic expertise would be substantial. The risk would be exacerbated if these few prolific individuals were in the latter stages of their career, as their retirement would be imminent. In contrast, if the output of new species descriptions is shared more equally among active taxonomists, the whole field has much less to fear from the retirement of a few individuals.

Using a large dataset based on descriptions of new species of parasitic helminths recovered from fish hosts in the past two decades, we (i) test for temporal changes in the degree to which taxonomic contributions are unequally distributed among authors, (ii) assess the temporal stability in the identity of the most prolific taxonomists, and (iii) determine how long the most prolific taxonomists have been active, to estimate their career stage. We focus on parasites of fish, although our findings are likely to apply more generally to all parasites. We then use our results as a quantitative basis to assess whether the field of parasite taxonomy and systematics is heading for trouble.

## 2. Materials and methods

We extracted information from the dataset compiled by Poulin et al. (unpublished data), which included data on all new species descriptions of trematodes, cestodes, monogeneans, nematodes, and acanthocephalans published between 2000 and 2020, inclusively, in the following eight journals: *Acta Parasitologica* (data from 2000 to 2005 missing for this journal), *Comparative Parasitology*, *Folia Parasitologica*, *Journal of Helminthology*, *Journal of Parasitology*, *Parasitology International*, *Parasitology Research*, and *Systematic Parasitology*. We then added data for descriptions published in 2021 in these same journals, to update the dataset. These eight journals capture a large proportion of published descriptions, and provide a large enough sample for analysis.

We focused exclusively on parasites described from fish hosts (including elasmobranchs), since they account for almost two-thirds of new species described in the past two decades. For each species description, in addition to the name of the new species we recorded the following information: (i) the higher taxon to which the parasite belonged (trematodes, cestodes, monogeneans, nematodes, or acanthocephalans); (ii) the year of publication; (iii) the names of all authors of the description; and (iv) the journal in which it was published.

The dataset covered the last 22 years, but for analysis it was broken down into two 11-year time periods: 2000–2010 and 2011–2021. For each subset (five taxonomic groups X two time periods = 10 subsets), we ranked the taxonomists from the least prolific to the most prolific, based on the number of descriptions in which they appear as author, and being careful to distinguish among authors with the same surname. Some species descriptions were included in the counts for two or more taxonomists, when these were co-authors of those descriptions. We only considered the 25 most prolific taxonomists per subset (20 for acanthocephalans, for which there were fewer species described), since beyond that top-rated group other taxonomists have only contributed to very few descriptions per subset; these probably represent students or one-off contributors to a taxonomic study, rather than committed taxonomists.

For each subset of taxonomists, we quantified inequalities among taxonomists in the number of species described using Lorenz curves and Gini coefficients. These are widely used in economics to measure the degree of income inequality (Cowell, 2000), and have also been used in parasitology to quantify inequalities in body sizes or fecundity among individual parasitic worms (Shostak and Dick, 1987; Poulin and Latham, 2002; Hanelt, 2009). A Lorenz curve is generated by plotting the cumulative number of species described against the cumulative number of taxonomists considered, when they are ranked from least to most prolific. In the hypothetical case where they have all described the same number of species, we would obtain a straight line; the more concave the actual curve, the more pronounced the inequalities in productivity among taxonomists. The Gini coefficient provides an index of this inequality, by measuring the departure from perfectly equal productivity, i.e., the ratio of the area between the ideal straight line and the observed Lorenz curve to the total area under the straight line. It is computed using the following double summation:

$$1 - \frac{2\sum_{i=1}^{N}\left(\sum_{j=1}^{i} x_j\right)}{\bar{x}N(N+1)}$$

where $x$ is the number of species descriptions to which taxonomist $j$ has contributed (with taxonomists ranked from least prolific, $j = 1$, to most prolific, $j = N$), and $N$ is the number of taxonomists, i.e. 20 for acanthocephalans and 25 for the other taxa. The Gini coefficient has a minimum value of zero when the observed curve lies on top of the straight line, that is, when all taxonomists have described the same number of parasite species. As inequalities in productivity among taxonomists increase, the coefficient tends toward a value of one; it would equal one in the extreme case where all species descriptions have been published by a single taxonomist.

We then examined whether there was some temporal consistency in the number of descriptions published or the ranking of the most prolific taxonomists among time periods. This analysis considered only authors (i) whose name appeared in the lists of top 25 (20 for acanthocephalans) most prolific taxonomists for a particular helminth taxon in both time periods, and (ii) who were involved with at least two species descriptions in each time period. A few researchers featured in the lists of most prolific taxonomists for more than one helminth group, however only three met the stricter criteria above for two different helminth groups; these three were counted twice, since they had parallel taxonomic activities in these two different helminth groups. We computed the Spearman's correlation coefficient between the number of descriptions published by the 42 authors who met the above criteria in 2000–2010 versus 2011–2021. A positive correlation would indicate stability over time, with the most prolific taxonomists in one time period also dominating the other time period, whereas a negative correlation would suggest a turnover, with the most prolific individuals in one time period being replaced by others in the following period.

Finally, we estimated the duration of the taxonomic career of the most productive individuals, again using only the 42 taxonomists who met the above criteria, i.e., who made the top 20/25 list for one parasite group in each time period and described at least two species in each time period. We conducted name searches on the Web of Science database, using the surname of each taxonomist and all plausible combinations of given names and initials. For each taxonomist, we recorded the year in which they published their first species description (not necessarily their first scientific article), whatever the parasite taxon, and including the period prior to the year 2000 (i.e. before the start of our dataset), to estimate the full duration of their period of taxonomic activity. This served to indicate whether or not the vast majority of the greatest and most prolific experts in parasite taxonomy are in the latter part of their career.

## 3. Results

The dataset included 2017 species descriptions published between 2000 and 2021 (see Supplementary Table S1). For all helminth taxa, there were more species described in the 2011–2021 period than in the preceding one (Table 1). And in both time periods, monogeneans accounted for the most new species described, and acanthocephalans for the fewest (Table 1). For any given helminth taxon in either time period, there were a few highly prolific taxonomists, with some having their names associated with over 100 new species described for a particular taxon in one time period (see Supplementary Table S2).

There were marked inequalities in productivity among taxonomists, as indicated by Lorenz curves that depart from an ideal straight line (Fig. 1). The inequality was most pronounced for nematodes, and least pronounced for monogeneans. Except for trematodes, inequalities in output among taxonomists were less pronounced in the past decade, 2011–2021, than they were in the previous one, 2000–2010 (Fig. 1). The Gini coefficients confirm this, showing a small decrease from 2000–2010 to 2011–2021 in all taxa except trematodes (Fig. 2).

For all five helminth groups, the taxonomist who was the most prolific in 2000–2010 remained the top-ranked taxonomist in 2011–2021. These were Drs. Omar Amin (acanthocephalans), Janine Caira (cestodes), Delane Kritsky (monogeneans), Thomas Cribb (trematodes) and František Moravec (nematodes). There was also consistency among the top five or top 10 most prolific taxonomists over time, with those individuals featuring in the top five or 10 list in one time period generally also appearing the top five or 10 list in the other time period (see Supplementary Table S2). This is evident from the positive correlation (Spearman's correlation coefficient, $r_s = 0.624$, $N = 42$, $P = 0.0001$) between the number of descriptions published by taxonomists across the two time periods (Fig. 3). Note that this correlation considers only taxonomists who made the top 20/25 list in each time period and described at least two species in each time period.

Among the 42 most prolific taxonomists considered in the above correlation, 71% published their first parasite species description before the year 2000, when our coverage of the literature begins (Fig. 4). In fact, of the five individuals named above and each ranking as the most prolific taxonomist for one of the five helminth groups, all published their first parasite species description in 1985 or earlier. On average, the 42 most prolific taxonomists first published species descriptions 30 years before 2021 (range 10–54 years), indicating that a large proportion are in the latter stages of their career.

## 4. Discussion

Inequality in knowledge production among active researchers has long been recognised as a universal pattern across all scientific disciplines (Allison, 1980; Kyvik, 1989; Xie, 2014; Kwiek, 2015). Highly skewed distributions of research output typically result in fewer than 10% of all authors in a discipline accounting for well over 50% of published articles. The reasons why some individuals are more productive than others are complex; they include individual characteristics relating to personality and work habits, as well as external factors such as variation among institutions in teaching and administrative loads or in the level of support provided to researchers (Fox, 1983; Ramsden, 1994; Prpić, 1996; Teodorescu, 2000; Kwiek, 2015). Regardless of the underlying reasons, inequality in research output seems to be an intrinsic feature of modern science. Here, we show that it certainly applies to parasite taxonomy. More specifically, we found that productivity in parasite taxonomy is strongly concentrated in the hands of a small number of researchers. Although the situation has improved slightly (except for trematodes) in the past decade compared with the previous one, the inequality in output of new species descriptions remains pronounced, putting the whole field at risk of collapse should the small number of highly prolific taxonomists cease their activities, for one reason or another.

**Table 1**
Number of parasite species descriptions from each higher taxon published in each time period.

| Parasite taxon | Time period | | TOTAL |
|---|---|---|---|
| | 2000–2010 | 2011–2021 | |
| Acanthocephalans | 22 | 71 | 93 |
| Monogeneans | 318 | 403 | 721 |
| Cestodes | 187 | 208 | 395 |
| Trematodes | 196 | 296 | 492 |
| Nematodes | 141 | 175 | 316 |
| TOTAL | 864 | 1153 | 2017 |

For instance, for all major taxa of helminth parasites infecting fish, the top-ranked taxonomist in terms of new species described accounts for a substantial proportion of biodiversity discovered from 2000 to 2021. For nematodes, František Moravec on his own accounts for 65% (205 out of 316) of new species described from fish in the past two decades; similarly, Thomas Cribb accounts for 38% (188 out of 492) of described trematode species, and Janine Caira for 34% (133 out of 395) of described cestode species. These percentages go up substantially if we consider the top three most prolific taxonomists, instead of just the single most prolific individual. The loss of their expertise would likely result in a major reduction in the rate at which new species are described, and therefore slow down the completion of the inventory of parasite diversity on Earth.

Our findings also reveal that the output of new species descriptions in the 2000–2010 period by the top tier of taxonomists correlates well with their output in the 2011–2021 period. This positive correlation indicates that their rankings remain generally unchanged, with no significant "changing of the guard" taking place in the past two decades. Some researchers appearing in the lists of top 20 or 25 most productive researchers are former students of the highly prolific individuals heading the lists, suggesting that there may be a passing of the torch through mentorship. However, in most cases the names of these former students disappear from new species descriptions in later years, indicating that they have not remained active in the field of taxonomy. The lack of turnover among the most prolific taxonomists is even more concerning given that most of them began their taxonomic activities (based on their publication record) decades ago. Most are therefore at a late career stage, and even if they pursue their activities for some years beyond the usual retirement age, parasite taxonomy is inevitably facing the impending loss of a large number of leading experts in coming years. Ironically, the number of new species described per year has been increasing steadily in the past two decades (Costello et al., 2013; Poulin, 2014; Poulin and Presswell, 2016); the current productivity of taxonomists is not the issue, but the remaining research lifespan of the most prolific ones certainly is. The disproportionate contribution by a small number of late-career taxonomists to the discovery and description of new species is a key factor that has been overlooked in recent estimates of how long it would take to complete the global inventory of parasite biodiversity (Carlson et al., 2020).

Of course, the contributions of taxonomists to parasitology extend beyond finding and describing new species (i.e., alpha taxonomy). One cannot simply assess the whole field based solely on new species descriptions, because taxonomists do much more than that (see Brower and Schuh, 2021). Among their published outputs,

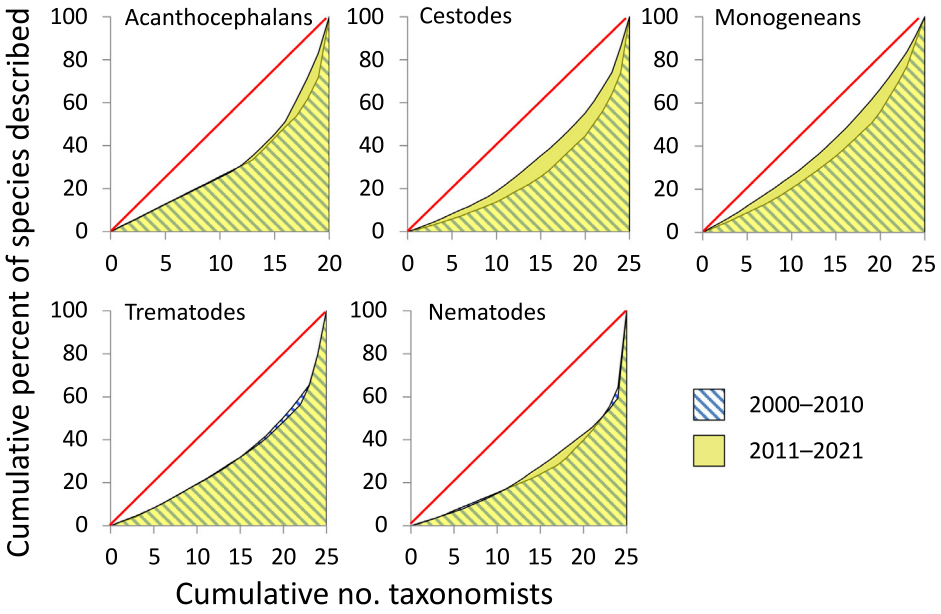


**Fig. 1.** Lorenz curves capturing inequalities in the productivity of taxonomists, showing the cumulative number of species described plotted against the cumulative number of taxonomists, when the latter are ranked from least to most prolific. Curves are plotted separately for each major helminth taxon, and for each of the two time periods investigated. Only the top 25 (20 for acanthocephalans) most prolific taxonomists are considered. The cumulative number of species described is shown as a percentage, to standardise the scale across datasets. The more a curve departs from the hypothetical case where all taxonomists have described the same number of species (straight red line), the more pronounced the inequalities in productivity among taxonomists.

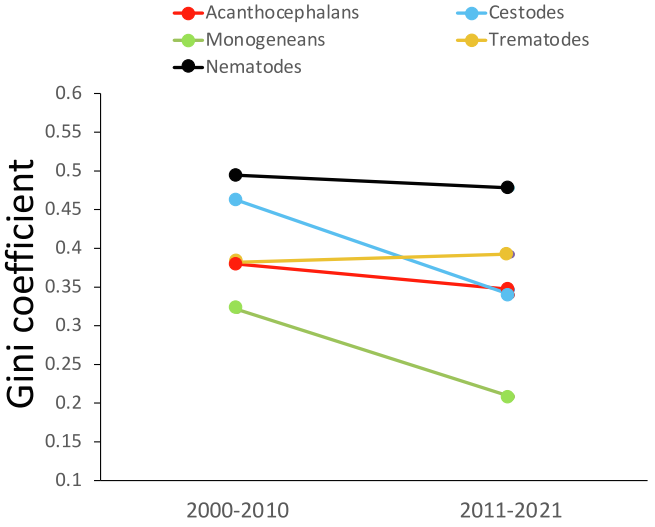


**Fig. 2.** Gini coefficients measuring inequalities in the productivity of taxonomists, in both time periods and for each of the major helminth taxa.

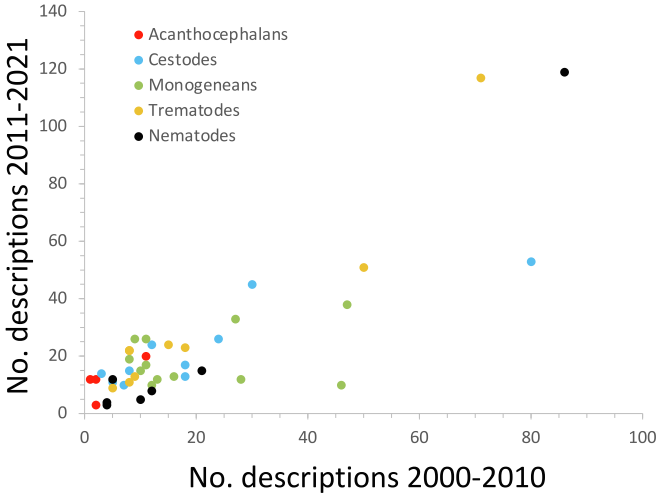


**Fig. 3.** Number of species descriptions published in the 2011–2021 period versus those published in 2000–2010, for the 42 most prolific taxonomists (in the top list for a given helminth group in each time period, and author of at least two species descriptions in each time period).

there are also re-descriptions of previously known but poorly or incompletely characterised species, as well as revisions of earlier classification schemes, or reconstructions of the phylogenetic history of species. However, the present focus on new species descriptions most likely provides an accurate assessment of contributions to the discipline and inequality in overall productivity among researchers in the field.

It is important to point out that the present analysis was conducted at a gross taxonomic level, and the results are likely more variable at a finer taxonomic level. For instance, many of the most prolific taxonomists identified here specialise on one or a few families within a higher taxonomic group, with descriptions of new species in other families coming from a range of authors rather than being dominated by one or two authors. Equally, the highly prolific taxonomists may be focusing their efforts on describing species from only certain geographical regions, with other regions receiving equal attention from several taxonomists. Therefore, the imminent risk of losing taxonomic expertise may affect some helminth families or some geographical areas much more than others. Nevertheless, our findings still reveal that parasite taxonomy is facing a crisis, whether globally or not.

Our dataset has some limitations in the context of our study. Firstly, we assessed the contributions of various authors by the quantity of species descriptions they published, and not their quality. There is substantial variation in the quality of parasite species descriptions in the peer-reviewed literature (Poulin and Presswell, 2016). However, the quality of the taxonomic work of individual

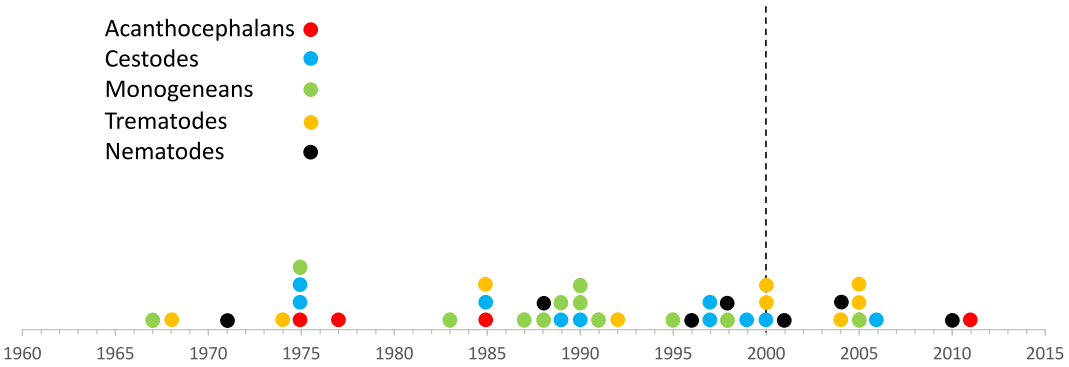


**Fig. 4.** Year in which each of the 42 most prolific taxonomists (in the top list for a given helminth group in each time period, and author of at least two species descriptions in each time period) published their first species description, relative to the year 2000 (broken line) in which our data coverage began. Each point represents one taxonomist, with different symbols for each of the five major helminth taxa.

researchers cannot easily be assessed since the vast majority of descriptions are produced by teams of authors. We assumed that quality and quantity were correlated, as the peer-review process should ensure that most published species descriptions meet the standard criteria established by the taxonomic community. Secondly, authors of species descriptions are not necessarily taxonomists; some may be included as authors because they contributed in other ways, for example by providing the material or conducting genetic analyses. Some may even be included by default, merely due to their seniority within a research unit and with no meaningful input into the species description, a truly deplorable practice. However, we assumed that such contributors were unlikely to have co-authored a large number of species descriptions. Therefore, by focusing strictly on the most prolific subset of authors, we are probably including only researchers with genuine taxonomic expertise. Finally, our focus on parasites of fish means that the contribution of taxonomists whose output crosses host taxonomic boundaries, that is, researchers who also describe parasites of host taxa other than fish, may have been underestimated. Nevertheless, in the context of fish parasites, our conclusion that new species descriptions are highly concentrated in the hands of a few researchers remains valid.

Overall, our findings suggest that the output of new species descriptions in parasite taxonomy has been concentrated among very few researchers, more so for some parasite taxa than others. These few prolific taxonomists have remained mostly the same for two decades, with little turnover, and most are in the latter stages of their career. Although we do not have the full data to back this up, it is likely that a similar situation occurred last century; names such as Harold Manter and Satyu Yamaguti come to mind as members of a small group of highly productive fish parasite taxonomists dominating the mid-1900s, with no obvious successors until the cohort of prolific researchers identified in the present study. We are not aware of comparable data for other invertebrate taxa, though we expect a similar situation to apply to them. Our analysis suggests an impending crisis, for which solutions have been proposed (e.g., Godfray, 2002; Pearson et al., 2011; Wägele et al., 2011; Boxshall, 2020; Britz et al., 2020). These include, among many others, increasing funding allocations for taxonomic research, establishing formal traineeships in parasite taxonomy, and promoting the recruitment of taxonomists to permanent positions at universities, museums and other research institutions. Our results provide the first solid empirical support for the many earlier warnings that parasite taxonomy is in peril (Brooks and Hoberg, 2000, 2001; Poulin, 2014; Cribb, 2016), reinforcing the alarm call for urgent action.

## Acknowledgements

We thank the many parasite taxonomists whose hard work and concerns voiced over many years have inspired this study.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpara.2022.03.001.

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