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Taxonomy in Trouble—An impediment to Life on Earth

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The preamble to the Convention on Biological Diversity (CBD 1992) states that the contracting parties were aware 'of the general lack of information and knowledge regarding biological diversity and of the urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures'; but over three decades on, not much had happened to prove the above statement wrong. To this day, the exact number of species, particularly the faunal component present on the Earth, remains one of the biggest mysteries and challenges for mankind. Linnaeus (1758), the first official taxonomist, documented 4,236 species of animals. The list of species was expanded to 418,600 by Möbius (1898), to 1,071,000 by Mayr (1969), and to 1,552,319 by Zhang (2011), the most recent comprehensive data review. This figure is likely to account for less than 12% of all species, as Mora *et al.* (2011) estimated that 86% of existing species on Earth and 91% of species in the ocean still await description, or 'not even one-tenth of the estimated species on Earth' (Hochkirch 2016). Even worse, we are only in the discussion phase of creating an authoritative list of those we have named (Garnett *et al*. 2020). From the second half of the 18th century to the end of the 19th century, the named list of animal species grew at the rate of about 3,000 species per year. During the 20th century, we recorded roughly 10,000 new animal species per year. The rate of species description has remained relatively stable over the past several decades, fluctuating between 15,000 and 20,000 species each year, despite the existence of numerous undiscovered species housed in herbaria and museums (Bebber *et al.* 2010). At the present pace, we would take about 350 to 500 years to explore our animal diversity. This void in our basic knowledge is exacerbated by the imminent threat of a sixth mass extinction event (Barnosky *et al.* 2011, Kolbert 2014), which is projected to occur by the year 2200 (Monastersky 2014). Notably, these estimates lack robust taxonomic support, being either indirectly substantiated, such as through evaluations of habitat loss, or derived from incomplete inventories. Nevertheless, it is clear that millions of species, facing an imminent threat of extinction, will leave no fossil record and will disappear along with all they could have taught us about their roles in the biosphere, evolutionary history, and adaptations for survival (Wheeler 2020).

Taxonomy

The only science dealing with discovering, naming and describing species, and classifying them in a hierarchical system, is Taxonomy. The primary aim of Taxonomy, and that of a taxonomist, is to establish the nominal taxa (a biological entity at the appropriate taxonomic rank, e.g. family, genus, species) in as much correlation as possible with the natural taxa. 'Taxonomists define the unique properties of taxa and also the properties certain taxa have in common with each other' (Mayr 1969).

Why taxonomy is important

Taxonomy is the fundamental generator of primary biological data. The output of taxonomic research is, in effect, a public library of data on biodiversity. This data is available for use in all other biological sciences. However, as previously noted, we have only described about 10% of our total biological resources.

We can think of biological studies on one or more species, whether behavioural or conservation aspects, ecological significance, medical importance, economic impacts, agricultural aspects or otherwise, as a vertical expansion of biological sciences. Whereas, the output of taxonomic research, by increasing the number of described species or otherwise describing hitherto undescribed facets of biodiversity, is the horizontal expansion of the dataset on which other biological sciences are able to work. As the data produced by taxonomic research expands, so other biological sciences

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have more information with which to work. Taxonomy works as a basement on which research in other biological sciences depends. As the outputs from taxonomic research increase, the possibilities of related research in other biological sciences increase proportionally. Much of today's progress in biology is fundamentally built upon the foundational contributions of taxonomists from the 18th, 19th, and early 20th centuries, whose classification systems and species descriptions continue to underpin modern research. However, relying solely on this historical legacy without continued investment in taxonomy is akin to attempting to harvest fruit from a tree that is no longer being nurtured.

The link between taxonomic research and benefit to (including for these purposes' prevention of harm to) mankind may not always be immediately obvious, but it is too important to be ignored. Taxonomy serves humanity in much the same way that food webs and chains function from producers to top consumers. I consider taxonomy equivalent to the producer in a trophic pyramid, with the common man as the top consumer and other biological sciences occupying the intermediate trophic levels.

Taxonomy has great potential to benefit mankind, indirectly, in conjunction with other sciences. I present just one, among numerous, examples of practical or potential practical applications of taxonomic discovery. In 2022, it was announced that *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae: Xyleninae), a pest species of moth, native to the US but spreading elsewhere, was being used to produce a protein-based inactivated vaccine against COVID-19. Spike proteins were being synthesised in a cell line derived from ovaries of this species (Gorski 2022). Taxonomy tells us that there are about 40 known species of *Spodoptera* worldwide. Could ovarian cells from (or other parts of) a related species assist more efficiently than those of *S. frugiperda*? Could cell lines from one or more species of *Spodoptera* be used in other vaccines? Without taxonomy, it would not be possible to investigate such questions.

For conserving biodiversity, Vane-Wright (2005) identified four structural challenges: i) uncertainty regarding the extent of diversity at all hierarchic levels of biological organization, ii) the unequal spatial distribution of biodiversity, iii) the significance of these uncertainties and heterogeneities for conservation, and iv) the need to recognize and accommodate different values systems in setting goals for conservation action. Taxonomy is primarily required to address at least the first two challenges. Similarly, Thomson *et al.* (2018) note that: 'without a robust taxonomic paradigm, that is based on science and unconstrained by unnecessary and counterproductive bureaucracy, conservation efforts will ultimately suffer, potentially leading to devastating and irreversible impacts on global biodiversity'.

Godfray (2002) puts the case this way: 'without taxonomy, nobody would be sure of the identity of the organisms they were interested in, or whether they belonged to the same or different species as the organisms studied by others. Without taxonomy, there would be no meaningful genome projects, and medical science, for one, would be seriously compromised. Without taxonomy, there could be no systematics, the related but distinct business of arranging species' names into an order that reflects their evolutionary relationships. Without taxonomy, we could not begin to understand biodiversity and the related issue of conservation'.

The importance of taxonomy can be summarised as follows: Encouragement of taxonomy is fundamental for biological sciences. Deterrence of taxonomy is detrimental to biological sciences.

Where is the problem

The priorities of research are shifting far away from taxonomy and most of academia is interested in the products of taxonomy, rather than taxonomy itself. For example, conservation biologists often view taxonomic procedures, starting from collections to taxonomic revisions, with scepticism and rarely acknowledge good taxonomic works, but nevertheless use the inventories created only by that taxonomy. In a similar vein, numerous ecologists, conservationists, and other biologists often overlook the contributions of taxonomists, who provided them with a well-defined, delimited species, their model organism, to work upon. Furthermore, the evolving concepts of species and their interrelations are often underestimated by many. Carvalho *et al*. (2005) argued that this phenomenon should not be viewed as a shortcoming of systematics, but rather as a limitation of those who perceive taxonomy merely as a service for naming biodiversity.

Taxonomy is now broadly, though fallaciously, considered as an 'old fashioned', non-evolutionary, and descriptive science. However, 'the process of describing new taxa necessitates a high level of theoretical, empirical, and epistemological rigor' (Carvalho *et al*. 2005). Further, to understand the practical approach of naming species, which may sometimes get overlooked in debates about theoretical concepts, is that what are defined as species are populations with enduring phenotypic features that distinguish them from other populations (Christenhusz 2020, Costello 2020). 'Taxonomic principles are rarely found in biology textbooks or classrooms; taxonomists are not replaced in kind. And natural history museums, once world centers of taxonomic discovery, pursue more fashionable areas of biology in search of funding and recognition' (Wheeler 2020).

'Taxonomy is starved of funds, whereas the arms of biology that rely fundamentally on it attract both money and publicity' (Godfray 2002). It seems extraordinary that the scientific world is spending billions of dollars in the hunt for life outside our planet, and also for the excavations, investigation and restoration of extinct species while the science responsible for the exploration of life presently existing on the earth is struggling for funds, particularly when 'the extinction rate of species may be as high as 11 to 690 per week (Monastersky 2014), and, in case of invertebrates, the estimated range of extinction is 1 to 100 per day' (Hochkirch 2016). The higher estimates of extinction rate is nearly double the number of species that we are describing today. 'In any other scientific field, a rate of knowledge around or below 10% (which is clearly the case if the inaccuracy of some current data is taken into account) would be considered "poor" and "insufficient", and its identification would be likely to prompt sudden awareness of the need to support and develop this domain of research, but, despite several cries of alarm concerning the inadequacy of our inventory of living organisms, such an awareness is still largely lacking, even among professional biologists' (Dubois 2003). Over 20 years later, the statements of Godfray and Dubois remain true and the situation is exacerbating, not improving.

There is a fundamental taxonomic paradox, 'at a time when the opportunities for taxonomic research to provide data for the benefit of other biological sciences have never been greater, and taxonomy is still left with at least 90% of its basic objectives not achieved, it is ironic that taxonomy is increasingly perceived as an outdated field of study which is not worth funding or pursuing'.

A few of the reasons responsible for the situation can be the low impact factor of taxonomic journals resulting in lack of researchers to carry forward the legacy, lack of funding, lack of glamour (Salvador *et al.* 2022), poor image of taxonomists among other biologists (Godfray 2002), lack of trained taxonomists, lack of recognition of taxonomy as a robust science, and unnecessary restriction in collection and storage of specimens (Engel *et al*. 2021). Taxonomists have not succeeded in organizing themselves as a cohesive group, even to defend for their professional interests. In contrast, specialists in most other scientific fields, including various branches of systematics, have formed associations that publish journals and function as lobbying entities to advance their disciplines and support their members. However, taxonomists have not established such a framework; there is no international or national scientific society dedicated specifically to the promotion and protection of taxonomy. Consequently, taxonomists are either unrepresented or significantly underrepresented in both official and unofficial organizations that influence scientific policies, funding, and the establishment of priorities (Dubois 2003). Taxonomic vandalism is another serious cause of concern (Wüster *et al.* 2021).

Further, I have observed that many present-day taxonomists are struggling to uphold the principles of taxonomy in its truest form. They appear to be losing confidence in the discipline, and/ or are gravitating towards biological sciences that offer greater financial support and visibility. 'Since the 1940s, taxonomists have frequently conflated their objectives with those of more contemporary and well-funded disciplines' (Wheeler 2008). The ambiguity surrounding the objectives of taxonomy is nowhere more evident than in the differentiation between studies of species and speciation. The former pertains to taxonomy and is concerned with the patterns of similarities and differences among species. In contrast, the latter falls under the purview of population biology, which examines the processes involved in speciation (Wheeler 2020).

Consequently, this results in diminishing career opportunities in the field of taxonomy, and ultimately causes a decrease in the number of taxonomists and hinders advancements in taxonomic research. This will lead inexorably to impediments in the advancement of other biological sciences.

Way forward and possible solutions

In order to return taxonomy to the recognition of being the fundamental provider of biological data, we must think differently. We need to understand the importance of taxonomy in correct terms. Trying to explain the significance of taxonomy by reference to a direct relationship between taxonomy and benefit to the common man is unwarranted. Except in a few cases (e.g. legal issues), taxonomy is not a science directly benefiting the common man. In actuality, taxonomy is a bedrock on which ecology, ethology, genetics, evolutionary biology, conservation biology, economic biology, and likewise all the other branches of biological sciences and also citizen science, flourish and work for the common man. Taxonomy prepares a path along which ecologists, ethologists, evolutionary biologists, conservation biologists, citizen scientists and other biologists travel. Unfortunately, taxonomy is rarely discussed in economic terms. Perhaps this is because most "powers that be" know, but refuse to acknowledge, the consolidated economics of all the biological sciences is the economic value of taxonomy.

Taxonomy requires prioritising for description of the undescribed before the undescribed disappear without a trace.

On the lines of our forefathers who discovered about 70% of the known biological data in the form of species on which today's biological sciences are progressing, we need to think about the generation of similar biological data that we will be leaving behind for successive generations to work upon. The wisdom of proper spending on searching for and describing life on earth needs to be understood if we want to keep the biological sciences working for humanity in the next century. Investment in taxonomy is a long term and indispensable need, which keeps the biological sciences progressing for the survival of our coming generations. It is essential to establish long-term strategies and initiatives, accompanied by sustained financial support and a clear vision of the final outcomes.

- Taxonomy needs to be understood as an essential tool for generating basic biological data. It should be acknowledged as a rigorous science by policy makers. Until and unless countries are able to identify all their own species, carry out comprehensive inventories, and sustain their own biodiversity information systems; they will be at a disadvantage when negotiating access to their biodiversity and genetic resources. Governments should earmark separate funds and establish independent ministries or departments with the sole objective of primary data generation for the biological sciences.
- The Rio Earth Summit of 1992 has probably done more harm to the field of taxonomy than it provided benefits, primarily by the implementation of various legislations. The constraints on collection, the restrictions on the exchange of materials and the supposed restrictions on DNA sampling of genetic resources are negatively affecting the advancement of taxonomy. A taxonomist, throughout their entire career, will not collect a number of specimens that approaches the quantity of specimens killed by a few hundred cars in a single night on a tropical road, or by the streetlights illuminating any city in the tropics during one night, or by a farmer during one time spray on a few hectares, or by the cutting of trees for construction of a few hundred kilometres of road. Conservation biology is fundamentally reliant on a robust taxonomic foundation. But sadly, most of the conservation related policies are based on incomplete and out-dated inventories, resulting in the failure of these programmes. Taxonomy and taxonomists should be supported, encouraged, and facilitated to make collections, their transportations and interpretations for the robustness of the datasets based on which conservation biology as well as other biological sciences may progress on the right path.
- Impact factors don't work for taxonomy (Ellis 2002), where the author calculated the mean age of taxonomic references as 61 years and the median age as 36 years. Taxonomic articles typically experience a low citation rate in their initial years, but they remain valuable and are referenced for decades or even centuries to come (Löbl *et al*. 2023). It is therefore unproductive to evaluate taxonomists based solely on a restricted timeframe of previous years. In fact, reputable scientific journals focused on biological sciences, regardless of their impact factor, should allocate space for essential taxonomic research in recognition of all they have gained from its outcomes. This approach will enhance the significance of taxonomic studies and bolster researchers' confidence in the field of taxonomy.
- Taxonomy has infrequently been regarded as a legitimate academic discipline and has seldom been included in university curricula. Therefore, it is urgently required to recognise taxonomy as an independent academic discipline with a separate curriculum.
- Most importantly, human resources must be strengthened, trained and retained in the field of taxonomy through generous and long term funding.

Conclusion

Taxonomic impediments are being discussed broadly (Engel *et al*. 2021), but in actuality, it is currently side-lined, underfunded, and undervalued (Löbl *et al*. 2023). I am quite sure that, if by this time, we had calculations of the carrying capacity of our Mother Earth in real terms and accorded the right policies in action based on sufficient knowledge about our actual species diversity, their interactions, and their role in the ecosystem, we would have been living in a far better world. The immeasurable knowledge gap between estimated and named species, which can only be filled by the science of taxonomy, will finally lead to the horizontal expansion crisis in biological sciences. Without a doubt, if taxonomy dies and taxonomists disappear, the entire biological scientific network will collapse without sustained support and growth.

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