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Perspective

The Silent Extinction of Species and Taxonomists—An Appeal to Science Policymakers and Legislators

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Abstract: The science of taxonomy, albeit being fundamental for all organismic research, has been underfunded and undervalued for about two generations. We analyze how this could happen, particularly in times of a biodiversity crisis, when we have increased awareness amongst the population and decision makers that knowledge about species we share the planet with is indispensable for finding solutions. We identify five major issues: the habit of holding taxonomy in low esteem; the focus on inappropriate publication metrics in evaluating scientific output; the excessive focus on innovative technology in evaluating scientific relevance; shifting priorities in natural history museums away from their traditional strengths; and changing attitudes towards specimen collecting and increasing legislation regulating collecting and international exchange of specimens. To transform taxonomy into a thriving science again, we urgently suggest significantly increasing baseline funding for permanent positions in taxonomy, particularly in natural history museums; reviving taxonomic research and teaching in universities at the tenured professor level; strongly increasing soft money for integrative taxonomy projects; refraining using journal-based metrics for evaluating individual researchers and scientific output and instead focusing on quality; installing governmental support for open access publishing; focusing digitizing efforts to the most useful parts of collections, freeing resources for improving data quality by improving identifications; requiring natural history museums to focus on collection-based research; and ending the trend of prohibitive legislation towards scientific collecting and international exchange of taxonomic specimens, and instead building legal frameworks supportive of biodiversity research.

Keywords: taxonomy; science policy; biodiversity research; natural history museums; universities; red tape

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1. Introduction

"Although often ignored or belittled, the role of taxonomy in biological research and in other fields like ecology and biodiversity management is central. To paraphrase a famous sentence, nothing makes sense in biology if the organisms studied are not identified and named, as their taxonomic placement in special units, the taxa, provides irreplaceable information on their characters, relationships, and evolution. Misidentification or misnaming of organisms may have unfortunate consequences not only on the accuracy of biological works and on their repeatability, but also in domains like medicine, pharmacology, breeding, agriculture, conservation biology, ecosystem management and climatology." (Dubois et al. 2013 [1])

It has long been recognized that the threat to populations and species and their extinction rates have reached an alarming level [2,3]. The general concern in an increasing part of society is boosted by the latest figures of the International Union for the Conservation of Nature (IUCN), documenting that 28% of all assessed species are threatened with extinction [4]. This is a disturbingly high figure, but what does it mean? A total of 150,388 species have been assessed, of which 20,835 species are data deficient. In Insecta, the coverage is, as expected, even smaller: only 12,441 insect species have been assessed, of which 3217 are data deficient. Less than 130,000 assessed species, including less than 10,000 insect species, is a dismally small portion of the whole biodiversity of this planet.

The authors of this paper, who have been involved for a combined 220 years in the painstaking recording and documentation of biodiversity, wonder what portion of the whole species diversity might be threatened by extinction and what the absolute number of threatened species would be. In fact, nobody knows the number, or even the magnitude, of species currently still living on Earth. Estimates are based on extrapolations from local assessments, have high uncertainty, and vary enormously [5–8]. Estimates for the Australian beetle fauna, for instance, vary between 80,000 and 100,000 species, which is four to five times the known species number [9]. Based on expert opinion, we might expect 704,000 to 972,000 marine eukaryote species, with only one fourth to one third described so far [10]. For the whole animal kingdom, estimates fluctuate between two and eighty million, with a wide consensus of a minimum of five to eight million currently living species [11,12]. Our ignorance of the diversity of species we share the planet with is astonishing and gets almost surreal when we look at microorganisms with estimates between six million and one trillion species (or basic evolutionary units) [13]. While we have good figures for the known marine eucaryote diversity [10], we do not know the overall number of described species on the planet. While the Catalogue of Life lists over 2 million species of all organism groups [14], this number is skewed by unknown quantities of unresolved synonymies and yet unconsidered described species.

Anyway, after almost three centuries of taxonomic research, we are still far from the conclusion of our endeavor. At the same time, the interaction of global factors like climate change and environmental pollution with direct local destruction by, e.g., the development of housing, mineral resources, or agriculture, leads to an ever-accelerating loss of natural habitats worldwide and, in turn, to a reduction in species diversity and abundance of non-human organisms. Considering the overwhelmingly high number of yet-to-be-discovered species that appear to be destined for silent extinction, recording and studying the still-existing diversity of life on our planet should be one of the priorities of modern biology [15–18].

It would make sense that this task received support commensurate with its importance, but in reality, we find the opposite. It is taxonomists who discover, diagnose, and classify the basic entities of biodiversity, creating the frame of reference for most organismic biologists, such as evolutionary biologists, parasitologists, and ecologists, but also for practitioners, such as foresters, farmers, and conservationists. Without taxonomists, threatened species could not be identified, and species lists were not provided, leading to hampered conservation efforts [19,20]. Without taxonomists, time and money might be wasted in misled control efforts targeting the wrong species [21] or just by publishing worthless studies [22]. Without taxonomists, medically important model species could be misidentified or misinterpreted, as in the case of the medicinal leech [23]. Without taxonomists, datasets used by other scientists lead to erroneous or imprecise results [24]. Yet taxonomy, natural history museums, and herbaria have long been undersupported and underfunded both in the northern [25–30] and in the southern hemisphere [31,32]. Underfunding taxonomy inevitably leads to persisting knowledge gaps [33] or, if sustained, even loss of knowledge.

Until about two generations ago, the work of taxonomists was highly regarded; taxonomy was taught at many universities, and natural history museums boasted a wealth of comprehensive taxonomic expertise [34–36]. It was recognized that without robust taxonomy, fields like ecology, biogeography, or phylogenetics lack their foundation. Many productive taxonomists achieved leading positions in academic institutions and were supported by technical staff. Natural history museums, with their large collections, were held in high esteem. It was recognized that they not only preserve the archives of life in a sustained way but also document the distribution of species in space and time and the variability of populations. Museum specimens are not only indispensable for comparative studies but also form the foundation for a universal nomenclature that allows unequivocal communication about life on Earth [37], bridging cultural, linguistic, and national differences. Every described species and every higher taxon have been diagnosed or defined according to the knowledge, techniques, and capabilities of the time. With growing knowledge, newly recognized species and characters, and progressing analytical technology, these old hypotheses need to be revisited and reevaluated, which is impossible without preserved voucher specimens.

Nonetheless, taxonomy is currently sidelined and undervalued [3,38]. Emphasizing the large descriptive component, taxonomy frequently is not considered proper science and can supposedly be performed by amateurs [27,39,40], similar to the intertwined but broader field of natural history [40,41]. While "descriptive" in science is often considered a pejorative, being the argument for paper rejections by high-impact journals and disdained by parts of academia, it is still the indispensable foundation for most sciences, including biodiversity research [42,43]. Evidence still needs to be described. Nevertheless, many, if not most, universities' curricula neglect taxonomy. The number of professors of taxonomy is paltry compared to other fields of biology that rely on robust taxonomy. Taxonomy is rarely taught these days and is generally not accepted as a topic of doctoral dissertations [44,45]. In England and the United States, financial support for taxonomic projects decreased at least from the 1990s [46,47], with short-lived exceptions, such as the Planetary Biodiversity Inventory (PBI) [48] or the Partnerships for Enhancing Expertise in Taxonomy (PEET) programs [49] of the National Science Foundation. An erosion or taxonomic knowledge and taxonomic education has been happening for a long time at universities in Germany [50], Switzerland [51], Austria [52], and likely most countries that were traditional taxonomic strongholds. The expression "taxonomic impediment" has become omnipresent globally [53]. We note a profound paradox: the public and politics are touched by the declining diversity of life, whereas the discoverer of this diversity and the institutions documenting it often receive insufficient support or even experience obstructions [54]. This paradox is not new. Thirty years ago, Claridge [55] noted, "The astonishing paradox then is that at a time when it is widely agreed that much more taxonomic research is urgently needed, research and training are at a low level and funding is completely inadequate." Little has changed.

Large-scale initiatives, such as the Catalogue of Life, Global Biodiversity Information Facility, and the Consortium of European Taxonomic Facilities, or national programs, such as "Biodiversität: Forschung für die Artenvielfalt" of the German Federal Ministry of Education and Research give the impression that taxonomy receives efficient support. In reality, these initiatives are rather distant from the painstaking descriptive day-to-day taxonomic work. They do facilitate information retrieval, flow, and dissemination but are often still of limited use [56–58], and the taxonomic baseline work remains largely unsupported. Some programs, such as the ongoing Synthesis of the European Union [59], facilitate access to collections and are undoubtedly useful. The Biodiversity Heritage Library [60] and similar projects, such as the German AnimalBase [61], provide easy access to an increasing portion of the historical literature, saving taxonomists uncountable (albeit enjoyable) library hours. The NSF program PEET [48] did train young taxonomists, but all these initiatives did and do not touch the fundamental problem of taxonomy: the low and decreasing number of permanent positions for taxonomists that would allow multi-year revisions and comprehensive work [49,62,63].

Citizen science (lately, sometimes re-christened community science) initiatives are often propagated as solutions, providing taxonomy and species-focused research with relevant data. While we value such projects, they can only provide a small fraction of the data needed for taxonomic research, mainly distributional and phenological data for easily recognizable species in accessible places [64]. One of us had great success with mapping the easily recognizable Japanese Beetle in Colorado with the help of a couple hundred citizen scientists [65]. For the identification of most insects, however, the involvement of expert taxonomists is necessary, including the large and important group of private scholars, amateurs who educated themselves for many years to become respected specialists for particular taxa. Without their competence and their scientific publications over more than 150 years, our taxonomic knowledge would be much more fragmentary. Giving them access to ample support and funding should be a top priority [45,66,67], but it is not.

The following examples are symptomatic of the current state of taxonomy:

- From Hungary, a well-researched European country with a long taxonomic tradition, 35,650 animal species (excl. "Protozoa") are recorded. For 15,250 of these (42.7%), there is no taxonomic expert in the country; for another 33.7% (12,010 species), there are only one or two, often retired experts. Currently, Hungarian taxonomists can reliably identify only 23.6% (8410 species) of the Hungarian fauna (B. Páll-Gergely, pers. comm.).
- In Great Britain, the number of authors of taxonomic publications and the number of publications has decreased constantly and significantly since the mid 20th century [68].
- Many biodiversity publications do without species identifications, relying on identification to higher taxa, which admittedly can be justified in cases [69], or naively relying on "morphospecies" sorting [70], containing serious misidentifications (references withheld, but see [71,72]), or, more often, the reliability of taxonomic identifications cannot be validated because of insufficient documentation of methods and sources [73,74].
- Authors of database or citizen science-based analyses sometimes do not even mention the potential of misidentification [75,76], hence overlooking or neglecting the elephant in the analysis.
- Countless species collected by expeditions in poorly known and highly diverse regions of the planet remain unstudied while accessible in museums. For instance, after 38 years, only about a quarter of the insects of the British research endeavor in 1985 in Dumoga-Bone National Park, Sulawesi, have been identified (M.V.L. Barclay, pers. comm.).

How could it happen that taxonomy is no longer respected as a solid fundamental science [63,77–79]; that we ended up with a severe global deficit of taxonomists in times of a biodiversity crisis [47,78–81]; and that fieldwork is hampered by increasing red tape [22,26,82–84]? It is high time to reflect on these developments and their causes. We have identified the following issues that we will discuss in detail:

- Low appreciation of taxonomy;
- Publication metrics as a crooked yardstick of scientific performance;
- Focusing on technology;
- Priorities in natural history museums;
- Ideology and legislation.

2. Low Appreciation of Taxonomy

At its beginnings three centuries ago, taxonomy was an exclusively descriptive activity. Since then, it has developed into a highly integrative field of biological sciences [63]. While "dry" descriptions of specimens remain an integral and essential part of taxonomic studies, taxonomy has become so much more. Taxonomists are often involved in determining the ecological role of species in ecosystems, their evolution, biology, and habits. It is incomprehensible that taxonomy is still reproached for morphological descriptions [40,85] when descriptive approaches in other fields, such as medical research (e.g., pathological descriptions) or astronomy, are apparently acceptable.

Another misunderstanding seems to be grounded in the wide use of identification keys. If they are well composed, users see simple theses and antitheses (e.g., one or two denticles on the tibia), which leads easily to results and might create the impression of effortless, unscientific work. Users overlook that creating user-friendly identification keys involves the selection of the few least intraspecifically variable characters that can easily be seen and correctly interpreted out of an immense number of characters of a biological species. It is often true that the easier the key is to use, the more effort its construction requires. Frequently, taxonomy is simply equated with identification, which is comparable to confounding a medical diagnosis with medical research. When mingling in ecological circles, the exclamation, "But this is only identification!" (implying not real science), was heard all too often (FTK., pers. obs.). The "unsatisfactory level of recognition [taxonomy] has in academia" is widely experienced in the taxonomic community [86].

Another common misunderstanding relates to the purpose of taxonomic discovery. For some, the taxonomic goal is naming species [87,88], but names are only labels that enable the exchange of information [89,90]. The eminent mycologist Keith A. Seifert questions: "Does the act of naming a sequence provide new information that is not already inherent in the sequence itself? I would say not." [91]. The naming process, nomenclature, is a technical complex of rules and not science. Having a lot of names for questionable or largely undescribed taxa just for the sake of having names is not necessarily advantageous. The proponents of metabarcoding (see Section 4) do not even bother with names and consider it sufficient to know the number of species in a sample. To cite Keith A. Seifert again, "In modern ecology, when you have a substrate in your hand that contains DNA sequences of a thousand species, half of them unknown, have you discovered 500 new species or have you picked up a handful of dirt?" [91]. To present results with the highest predictive power and to provide the most exact and reproducible descriptions of biota, communities, and assemblages, taxonomy needs to be involved. It is taxonomy that discovers and describes the millions of leaves (species) on the tree of life, which should get named when they are sufficiently diagnosed.

3. Publication Metrics as Crooked Yardstick of Scientific Performance

The Institute of Scientific Information (ISI) was founded in 1958 by Eugene Garfield. Garfield and Irving H. Sher created the Journal Impact Factor in the 1960s "to help select journals for the Science Citation Index" [92], the main product of ISI, which meanwhile has evolved into the "Journal Citation Review" of Clarivate Analytics. The Journal Impact Factor is defined as the number of citations within a given year of items published by a journal in the preceding two years divided by the number of citable items published by the journal in those two years. It is the average number of citations a paper of a journal attracts in the two years following its publication. It ranks the journals of the selected pool according to the attention they attract in the two years after publication and was used increasingly by libraries to decide which journals to keep and which subscriptions to cancel. However, the pool of journals selected to be assigned an Impact Factor is rather small. The journals containing the papers indexed by "Zoological Record" since 1864, which represent the major part of all taxonomic and faunistic publications, are largely not considered [77]. Later, papers published in a journal with a higher Impact Factor were often considered to be of a higher quality. The short-term attention a journal attracts was seen as equivalent to the quality of every single paper published by this journal and, in turn, to the scientific ability and skills of the authors. This assumption turned out to be erroneous [93], but still, the Journal Impact Factor has been used in many countries for evaluating the performance of scientists [94–96]. Researchers publishing in journals with higher Impact Factors are considered better scientists. This continues to happen despite the early warning of the Impact Factor's creator [97] and his persistent follow-ups, e.g., [94], clearly stating that neither single papers nor authors should be evaluated by cumulative journal citation counts.

Besides the general inapplicability of Journal Impact Factors for the evaluation of authors, taxonomy-specific citation patterns worsen the situation even more. In a spot check of a few larger monographs, Krell [98] found the mean age of taxonomic references to be 61 years. Köhler [99] found a similar high age, 47.7 years, for cited references in coleopterology. Given that the Impact Factor considers citations only from the two years following publication, taxonomy has a huge disadvantage when this metric is used for evaluation. Additional metrics are currently in use, e.g., the H-index, that are researcher-related, not journal-based. Such indices appear to be more appropriate for evaluating individuals but have their own issues and are based on the belief that quantity equals quality. While they may influence career success and budgets, they do not consider that taxonomic results generally have a low citation rate in the first years but continue to be used and referred to for decades, or even centuries, to come.

The internet facilitated another problem for journals that traditionally published taxonomic content. Journals of learned societies, local natural history associations, natural history institutions, or privately funded specialist journals experience competition from a wave of new, electronically or mainly electronically published journals. Electronically published journals are cheaper to produce and can easily offer open-access models that provide higher visibility, which, in turn, as many authors believe, leads to more citations. Evidence for such correlation is ambiguous [100–102], but it is still a selling point.

A huge and growing number of online journals of low to no quality, the so-called predatory journals, emerged in the last two decades as money-making enterprises [103]. Taxonomy has largely been spared by this wave, but the number of papers suffering from immediately obvious misidentification, even at the family level, impossible results, or erroneous claims is increasing. An early report on this phenomenon relates to Indian ichthyology [104]. We can at least breathe a little sigh of relief that papers in predatory journals attract very few citations [105]. While largely neglected, they are still a nuisance and, for the uninitiated, outright harmful.

The financial implications of modern, metrics-driven publishing also put taxonomy at a disadvantage. Open-access publishing, where authors pay fees to make their works available for free to everybody, leading to the desired exposure, comes at a high price. Publishing processing fees in a reputable journal with a decent Impact Factor can be substantial. PLoS Biology requests USD 3000–5300, and PLoS ONE charges USD 800–1850, the latter attracting 20,000 new authors every year [106]. A large proportion of taxonomic research is performed by private scholars or retirees without funding, by professional researchers on institutional shoestring budgets, or on the side of ecological or phylogenetic projects. Paying high processing fees for publication is not an option. The fees for predatory journals are lower, often attracting authors in good standing from poorer countries or countries that are less highly regarded in traditional peer review, depriving them of the experience of a publication process that improves their papers and leaving them with the stain of having published in a predatory journal.

Focusing on publication metrics has resulted in the paradigm of science shifting from "discovering new things and making them known" to "publishing as much as possible in the journals with the highest Impact Factors." It has also led to a struggle for the existence of traditional scholarly journals of societies or institutions that some already lost. At the same time, the "publish or perish" mantra leads to an inflation of publications. Salami-slicing strategies, i.e., publishing multiple papers of least publishable units from one study, are facilitated by the rising number of journals competing for publications and satisfy research assessments focusing on quantity. The gold standard in taxonomy is revisionary work. Extensive revisions take a long time and result in only one publication after several years. Would it not be better for one's academic CV to publish several dozen single species descriptions as separate papers in the same time period? Long, comprehensive revisionary studies have become a disadvantage for a scientific career because the number or resulting papers is low, the time invested is high, and the number of expected citations in the immediate, career-relevant period post-publication is most likely very low. Considering the last point, working on neglected groups with few taxonomists involved turns out to be a disadvantage. It is a great advantage to choose a popular group with numerous colleagues who can potentially cite your work. Hence, it is no wonder that we maintain large knowledge gaps in neglected groups, particularly in parts of the world with an overwhelmingly large biodiversity and underwhelming financial resources. Under such circumstances, the focus on better-known groups such as Lepidoptera [107] is understandable.

As long as we focus on quantity and metrics, taxonomy will continue to lose out. Which early-career biologist would invest years in studying old literature in many languages and specimens from institutions all over the world, only to have a few publications in their CV and then struggle to find permanent employment? Revisionary taxonomic work on species-rich groups is unattractive and unfeasible to execute when in term-limited employment. Rushing revisions at the end of a contract does not help the quality of such fundamental works, and publishing incomplete revisions is unwise and potentially harmful.

The problems are systemic and extend across many scientific disciplines well beyond taxonomy, from mathematics to geology, and have been called out innumerable times [108–113]. Fortunately, stronger voices have emerged in favor of an improved research evaluation. Criticism of too much focus on publication metrics finds its way into well-supported international declarations, such as DORA, the San Francisco Declaration on Research Assessment [114], or national policy statements implementing DORA, such as

- The Dutch universities' "Room for everyone's talent, toward a new balance in the recognition and rewards of academics" [115];
- The new research assessment reform in China moving away from "Science Citation Index worship" [116];
- Or the new CV format of the Swiss National Science Foundation that devalues publication metrics [117].

Also, an increasing number of UK universities and funders implement DORA principles into their policies [118]. These are all good developments that can only help the recognition taxonomists receive in the future.

4. Focusing on Technology

Science has always adopted new technologies. Taxonomy is no exception. X-ray microscopy [119], phase-contrast synchrotron X-ray microtomography [120], micro-CT scans [121], or genomic and other molecular technologies [122,123], often combined with morphological studies [124], provide great examples of technologically advanced taxonomic approaches. Bioacoustical characters also provided an important data source for entomo-taxonomy, e.g., the drumming signals of stone flies, the mating calls of cicadas, or the sounds of grasshoppers. In ornithology, songs have been important characters for taxonomic decisions for a long time [125]. Good taxonomists have always integrated different approaches, character systems, and technologies that were at their disposal [38].

Technology, however, should be a means to gain knowledge, not the goal itself. Advanced technology is not necessarily an indicator of the quality of taxonomic analyses. Over seventy years ago, Hennig [126] had already noted that the way of data analysis is much more important than by which technology these data were gathered. Popper [127] stressed that hypotheses must be intersubjectively testable and falsifiable. This is the main criterion of a scientific hypothesis, not by which means or methods it was conceived. While these propositions are widely accepted, they often seem to be forgotten when taxonomic work is assessed. At the end of the 20th century, a good taxonomic study was expected to contain a cladistic analysis. Currently, molecular methods have taken over the place of comparative morphology. Molecular methods are a treasure trove for studies of phylogenetic relationships, phylogeography, polymorphic species, diagnosing cryptic species, or for the taxonomic assignment of preimaginal stages, but are most efficient and revealing in an integrative approach.

DNA taxonomy, as proposed by Tautz and colleagues [128], found many followers because of its simple approach but also attracted criticism right from the beginning [129,130]. DNA taxonomy, particularly when relying on a short "barcode" sequence, is still widely considered a questionable approach and inferior to an integrative taxonomy that combines several techniques and approaches [131–134]. The core of the problem is the enticement to replace the use of complex morphological characters with a simple technology [135]. This limited approach has even been presented as revolutionary progress for tackling the planet's undescribed biodiversity and saving time and money and has led to the description of hundreds of new species based on 2% differences in a single gene, largely without considering even obvious phenotypical differences [88,136]; see also [63,137,138]. Using short DNA barcodes as the sole identification tool without solving issues of calibration might easily lead to incorrect identifications and artificial classifications. Proponents of metabarcoding often go a step further and do without species identification altogether and count "operational taxonomic units" instead [139,140]. As a result, we obtain the number of units but do not know which species there are and what portion of those units represent species at all. Moreover, the numbers metabarcoding reveals can be significantly lower than the actual number of species in a sample [141]. After all, the DNA barcodes of only a small fraction of all species are known. For example, of the 400,000 described beetle species, only 4% of the species have associated DNA barcodes [9]. From a limited sample of beetles Stork and Hine examined, 53% were known only from one locality, and 13% were just from one single specimen [142]. Even in the unlikely case that these numbers turn out to overstate the rarity or collectability of species, this example shows that achieving a very high barcoding rate in invertebrates is challenging and probably, with current collecting restrictions, not achievable.

We do not dismiss technological progress and new methods at all. Novel methods and techniques attract funding and new blood, provide novel sets of data, and are generally a positive development [143]. As always, the problem is not the methods or techniques themselves. There is nothing wrong with new techniques or molecular approaches per se. The big mistake is overemphasizing newer techniques to the detriment of long-established, tested, and proven methods. However, we also notice positive developments: the integrative approach in taxonomy is on the rise [144], which gives us hope that taxonomy will have a future as a scientific endeavor.

5. Priorities in Natural History Museums

Natural history museums are the places that hold collections that document the biological diversity of our planet, past and present. These specimen collections are fundamental to our understanding of life forms and biotic processes [145]. They show the changes and influences of ecological conditions on flora and fauna over time and enable reconstruction and modeling evolution. While the number of specimens in these collections is constantly increasing, the number of curators and technical staff is still generally decreasing [146], often dramatically [36,81]. This tendency is caused by the underrating of natural history collections by decision makers and by part of the scientific community, combined with the lack of understanding of the epistemological function of voucher specimens, which provide the only basis for reproducibility in organismic research [40,147,148].

The current priority for natural history collections is not, as one would expect, the discovery of novelties in nature but the digitization of already existing specimens, with the justification of providing access to the whole scientific community and even to the public [149]. Scientists can find interesting material in databases, helping particularly smaller and mid-sized collections that would not regularly be approached with loan requests. The general public, however, is unlikely to profit much from lists of millions of little flies or dung beetles. They would rather have a selection of remarkable specimens, as exhibited in traditional museum exhibits in the past. While scientists can find specimens they want to study, they might still have to consult the specimen on loan, as even with high-quality photography, not all the relevant characters will be available online. Moreover, the identification of many museum specimens is doubtful, wrong, or outdated [150,151] because we do not have enough taxonomists to provide up-to-date identifications for even the existing museum specimens. Transcribing wrong identifications into online databases can lead to the dissemination of wrong information but can also initiate feedback by users, helping to correct such mistakes. The uncritical use of collection databases for scientific studies is dangerous and discouraged, but it happens. "Indeed, not all scientific users understand that globally aggregated data always need filtering and post processing, as well as dealing with data gaps" [152]. Targeted digitization and high-quality photographic documentation of, e.g., type material, historical material, or reliably identified specimens can be extremely useful for the scientific community, having easy access, and for the preservation of the specimens, avoiding shipment. This is obvious to people working with collections but not necessarily to decision makers who expect universal digitization efforts and promote this as great progress to mitigate the taxonomic impediment without supporting data quality, i.e., taxonomy, at the same time. A huge investment of funds and time is targeted to an effort that is certainly useful but might not serve the most urgent needs of collections and taxonomy.

Distortion in valuating traditional scientific research activities forces museums to find new ways and priorities that can better secure support from administrations and the public. The result has been, for decades, a shift from collection-focused biodiversity research (taxonomy) to more fashionable topics. This happens despite the immeasurable potential of natural history to produce stories that the general public understands and appreciates. We see a declining number of natural history museums that still focus long-term on biodiversity studies in understudied areas and publish their fieldwork results, e.g., the Naturkundemuseum Erfurt in Germany (directed by one of the coauthors, M.H.). This is a largely missed opportunity that will never come again.

6. Ideology and Legislature

The preservation of the still extant life in nature is one of the most important tasks of humankind, particularly in times of a biodiversity crisis, changing climate, and accelerating destruction of habitats worldwide. Legislatures in all parts of the world support this task and introduced numerous regulations with the best intentions, nationally and internationally. These regulations help the preservation of nature in many ways but have also resulted in prejudices against any collecting of animals and plants. They often hamper scientific collecting by increasing bureaucratic hurdles, which may put off researchers [153] if not prevent research at all [79,154]. The fundamental difference between tiny, fast-reproducing invertebrates and large, slowly reproducing vertebrates is often bluntly ignored [67]. As a result, it became difficult, or even impossible, to collect in some countries, and comprehensive projects considering the fauna or flora of multiple countries become increasingly unworkable, although collecting is the foundation for all taxonomic research [79,155,156].

The absurdity of many bureaucratic regulations can be easily demonstrated by many examples. The size and health of populations are influenced by many factors, one of them being predation. A single colony of the Greater mouse-eared bat (*Myotis myotis*) in Switzerland consumes over two million arthropods per year [157]. They predate the arthropods in their territory year after year without any damaging influence. Songbirds are another group of efficient predators. A pair feeds their chicks 450 insects per day, which equals a full insect drawer in a collection, which adds up to seven breeding pairs of songbirds killing as many insects in one season as one insect collector in a lifetime [158]. Nyffeler and Birkhofer [159] estimate that spiders globally kill about 400 to 800 million metric tons of insects per year. They consume approximately 10^{15} arthropods in one year, whereas the number of specimens collected by humans during the last 200 years and preserved in museums is closer to 10^9. And then, we must consider the inadvertent consequences of human activities that do not even deliberately target insects. According to Gepp [160], road traffic in Austria kills 14×10^{15} animals annually, which is millions of times more specimens than in all scientific collections worldwide combined. This happens not only in Austria. Road traffic kills an estimated 20 million butterflies and moths per week in the State of Illinois [161]. Baxter-Tilbert and colleagues [162] extrapolate that up to 187 billion pollinators are killed on North American roads per year. These astronomical numbers are likely to be dwarfed by the losses caused by the destruction of habitats and the application of insecticides in agriculture and urban areas. Restricting scientific collecting of invertebrates for the purpose of species conservation appears dishonest. It results in the obstruction of research while having no noticeable impact on conservation efforts apart from preventing the creation of crucial knowledge.

An example of this bold statement might be the European Apollo, a butterfly that has been strictly protected by law for almost a century and has been and still is in dramatic decline all the same [163,164]. The bureaucracy that allowed "Flurbereinigung" (land consolidation), destruction of river meadows and flood plains, or the generous application of fertilizers and pesticides in agriculture obstructs the collecting of specimens by entomologists. Making collecting difficult or illegal alienates the upcoming generation from the study of natural history, which is counterproductive to efficient nature conservation [45]. Moreover, even most Red List species cannot be reliably identified without studying specimens. Photography, often suggested as a replacement for collecting, has limited use [165]. To assess the species diversity of an area, to assess the conservation value, or to suggest a particular management scheme, we must collect, prepare, and identify first.

The "red tape" for collecting affects even more severely tropical and subtropical countries, where biodiversity is very rich but poorly known [84,154]. Habitats are getting destroyed on an industrial scale. Scientists can point out this development but can rarely influence it and never stop it. Scientific priority should be to collect as many samples of moribund fauna and flora as possible and preserve them in well-curated collections—as an invaluable source of information for current and future research when a large proportion of taxa will no longer be present in nature. Ironically, an international framework aiming at just and equitable access to genetic resources and the sharing of benefits gained from genetical resources seems to develop into a severe hindrance to taxonomic research and international collaboration. The Nagoya protocol [166], signed by 136 states and the European Union and ratified by most, does not distinguish between commercial and non-commercial use. It does, however, distinguish between monetary and non-monetary benefits, such as local capacity building or contributions to the local economy. Most of those non-monetary benefits still require funding, and most taxonomy is performed unfunded. As countries may equate benefits with monetary resources, and every organism contains genetic information, benefit sharing might be difficult for unfunded taxonomy, and collecting without the required—but difficult to obtain—paperwork is an offense and can result in jail time. Consequently, researchers shift their interests to areas where they can work without too much red tape and without the risk of prosecution ([153]; I.L., pers. experience), resulting in the neglect of threatened and biodiversity-rich biota. The authors of the Nagoya protocol, but more so national implementations, seem to have disregarded that even underfunded taxonomy results in publications that are accessible, useful sources of information for biodiversity-rich countries. Moreover, the myth of ubiquitous commercially exploitable compounds from animals and plants [167] has raised unrealistic expectations about the profitability of biodiversity research even if the industry itself focuses increasingly on efficient laboratory research instead of tediously bioprospecting, as Ehrenfeld had already noted in 1988 [168]. Sensible national implementation of international frameworks, such as the Nagoya or Rio Protocols, is urgently needed to avoid the further decline of taxonomy and related fields.

7. Suggestions

Our own experiences convince us that recording and understanding the species with which we share the planet touch a broad audience. Natural history is a welcome topic for public presentations, telling stories that people understand and appreciate. Countless volunteers, citizen scientists, or amateur researchers try to fill gaps in our knowledge [169–171] despite often frustrating and unsupportive circumstances. From 2000 to 2014, European taxonomists described 3968 rove beetle (Staphylinidae) species. Twenty-four professional, paid taxonomists described 519 species; the remaining, almost 3500, were published by 44 unpaid retired and unpaid amateur taxonomists [172]. We still have a workforce contributing significantly to the grand challenge of discovering, describing, and understanding Earth's biodiversity, albeit collecting by amateurs is declining [173]. We must make sure that this workforce is nourished, supported, and replenished, not obstructed or even criminalized. This is in line with a recent community exercise of the Royal Entomological Society of London that determined the priorities for action in entomology in the coming decades, which included taxonomic training, funding, early career development, and integration, amongst others [174]. Additionally, we see the necessity to change legal and societal attitudes to create welcoming conditions for basic biodiversity research if we want to discover and understand the undescribed species of the planet before they become extinct.

Our suggestions are as follows:

- To significantly increase financial support and the number of paid non-term-limited positions in taxonomy in general and particularly in natural history museums, which house in their collections reference material of already described, but also of still undiscovered species—"Biodiversity research requires more boots on the ground", as E.O. Wilson [175] aptly stated;
- To immediately revive taxonomic research and teaching at universities at the tenured professor level to secure the education of the next generation of taxonomists;
- To strongly increase funding for integrative taxonomic research to build the foundation for the usefulness and general applicability of genetic barcoding;
- To refrain from using metric evaluation at the journal level (Journal Impact Factors) for evaluating the quality of researchers and their work;
- To provide governmental support for scholarly journals that provide open access without charging authors large article processing fees;
- To focus digitization efforts on parts of collections that experts consider useful instead of binding scarce resources in all-embracing digitization endeavors of large collections as a whole;
- To require natural history museums to focus on collection-based research;
- To end the trend of prohibitive legislation towards scientific collecting and international exchange of taxonomic specimens; a supportive legal framework is paramount for achieving a realistic idea of the global species diversity, a solid foundation for efficient nature observation, deciding upon sustainable management strategies in ecosystems, and securing a new generation of motivated scientists targeting all aspects of biodiversity research.

These are straightforward strategies to provide a sustained workforce documenting and analyzing the biodiversity of our planet in times of peril. We are perfectly able to study and potentially rescue major parts of our organismic diversity on Earth if we want.

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