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Editorial

Taxonomy in crisis: Addressing the shortage of taxonomists in a biodiversity hotspot era

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Abstract

In the era of biodiversity crises, where the extinction rates are accelerating at an unprecedented pace, taxonomy—the science of classification, description, and identification of organisms—stands as a critical tool for understanding and preserving the natural world. Yet, paradoxically, this field is in crisis. The shortage of trained taxonomists has become a significant bottleneck in biodiversity research and conservation efforts, especially in regions designated as biodiversity hotspots, which are home to the most unique and endangered species on the planet. This editorial explores the implications of this crisis, the challenges facing taxonomy today, and the steps needed to ensure the discipline can continue to play a pivotal role in safeguarding Earth's biodiversity. Taxonomy provides the foundational knowledge necessary for a variety of scientific disciplines and conservation efforts. Accurate species identification is the first step toward understanding ecosystem dynamics, species interactions, and evolutionary relationships. Without a robust taxonomic framework, it becomes impossible to prioritize conservation efforts effectively. Conservation strategies depend heavily on identifying species at risk of extinction, protecting endangered habitats, and managing invasive species—all tasks that rely on precise taxonomic data.

In the era of biodiversity crises, where the extinction rates are accelerating at an unprecedented pace, taxonomy—the science of classification, description, and identification of organisms—stands as a critical tool for understanding and preserving the natural world (Cowie *et al.*, 2022; Löbl *et al.*, 2023). Yet, paradoxically, this field is in crisis (Agnarsson and Kuntner, 2007). The shortage of trained taxonomists has become a significant bottleneck in biodiversity research and conservation efforts, especially in regions designated as biodiversity hotspots, which are home to the most unique and endangered species on the planet (Aronne *et al.*, 2023; Engel *et al.*, 2021). This editorial explores the implications of this crisis, the challenges facing taxonomy today, and the steps needed to ensure the discipline can continue to play a pivotal role in safeguarding Earth's biodiversity.

Taxonomy provides the foundational knowledge necessary for a variety of scientific disciplines and conservation efforts (Dubois, 2003; Sandall *et al.*, 2023). Accurate species identification is the first step toward understanding ecosystem dynamics, species interactions, and evolutionary relationships (Kürzel *et al.*, 2022; Ruppert *et al.*, 2019). Without a robust taxonomic framework, it becomes impossible to prioritize conservation efforts effectively. Conservation strategies depend heavily on identifying species at risk of extinction, protecting endangered habitats, and managing invasive species—all tasks that rely on precise taxonomic data (Ribeiro *et al.*, 2016).

In biodiversity hotspots, where ecosystems are characterized by high species endemism (species found only in specific regions) and extreme vulnerability to anthropogenic pressures, the role of taxonomists is even more crucial (Esperon-Rodriguez *et al.*, 2024; Kier *et al.*, 2009). These regions, such as the Amazon rainforest, the Western Ghats of India, and the Coral Triangle, are home to a large proportion of Earth's biodiversity (Al-Asif *et al.*, 2022; Gardner *et al.*, 2010). Understanding the diversity of life in these areas requires comprehensive taxonomic assessments to identify species that may be new to science, catalog those at risk, and implement conservation measures (Braby and Williams, 2016; Gallagher *et al.*, 2021). Yet, the shortage of taxonomists in these areas creates a vacuum in knowledge, putting many species at risk of going extinct before they are even discovered (Engel *et al.*, 2021; Löbl *et al.*, 2023; Petrović, 2022).

The term "taxonomic impediment" refers to the shortage of taxonomic expertise and the lack of comprehensive taxonomic information, which hinder the progress of biodiversity research and conservation (Ebach *et al.*, 2011; Engel *et al.*, 2021). This problem is exacerbated by a variety of factors including,

a. Aging workforce: Taxonomy, particularly in its traditional form, is seen by many as a declining field. The majority of practicing taxonomists belong to an older generation, with fewer young scientists entering the field. As these taxonomists retire, the loss of accumulated knowledge and expertise is significant, and the gap left behind is not being filled fast enough (Lücking, 2020).

b. Lack of funding: Taxonomy, often considered a "basic" science, receives comparatively less funding than other fields like genomics, medicine, or environmental science. The lack of financial

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support for taxonomic research and training has dissuaded many young scientists from entering the field, as they are drawn to disciplines with more stable career prospects (Tahseen, 2014).

c. Shift in scientific trends: The rise of molecular techniques and the surge in interest in fields such as genomics and bioinformatics have, in some ways, overshadowed traditional taxonomic methods. While molecular taxonomy (e.g., DNA barcoding) offers powerful tools for species identification, it does not replace the need for experts who understand the morphological, ecological, and behavioral aspects of organisms—critical components of species classification (Tsaballa *et al.*, 2023).

d. Educational barriers: Taxonomy as a discipline is not widely emphasized in modern biology curricula. University programs offering specialized courses in taxonomy have dwindled, leaving fewer opportunities for students to receive formal training in the field. Furthermore, taxonomic research often requires extensive fieldwork, access to museum collections, and long-term study—elements that can be challenging to fit into the fast-paced, results-driven environment of modern academia (Irfanullah, 2002; Wilson, 2004).

The consequences of this taxonomic impediment are far-reaching. Biodiversity data becomes incomplete or inaccurate, slowing conservation efforts and policy-making. Moreover, the lack of taxonomists hampers our ability to respond to emerging global challenges, such as the spread of invasive species and the effects of climate change on species distributions. Without precise taxonomic knowledge, many ecosystems could be irreversibly altered before we even understand what is being lost (Dar *et al.*, 2012; Engel *et al.*, 2021; Löbl *et al.*, 2023).

Biodiversity hotspots are defined by two key criteria: they must contain at least 1,500 species of vascular plants as endemics, and they must have lost at least 70% of their original habitat. These regions are home to nearly 50% of the world's plant species and over 42% of terrestrial vertebrates, despite covering only 2.3% of Earth's surface (Kobayashi *et al.*, 2019; Reid, 1998). The biodiversity within these hotspots is under immense pressure from deforestation, urbanization, agricultural expansion, and climate change. The role of taxonomy in these regions cannot be overstated, yet the shortage of taxonomists is felt most acutely here (Aukema *et al.*, 2017).

For example, in the Amazon rainforest—a biodiversity hotspot with thousands of species yet to be described—the shortage of taxonomists has slowed the process of species identification. This not only hampers conservation efforts but also limits our understanding of how environmental changes, such as deforestation, impact the ecosystem as a whole (Decaëns *et al.*, 2018; Guayasamin *et al.*, 2024). The situation is similar in marine biodiversity hotspots, such as coral reefs in the Coral Triangle, where the loss of taxonomic expertise has made it difficult to assess the true impact of coral bleaching and ocean acidification on marine life (Harvey *et al.*, 2018; Huang *et al.*, 2018). Without taxonomists working in these regions, we risk losing species before they are even discovered. Many endemic species, which are found only in specific regions, could vanish due to habitat loss or climate change, and without taxonomic studies, their extinction might go unnoticed (Lees and Pimm, 2015; Löbl *et al.*, 2023). While the challenges facing taxonomy are significant, there are innovative solutions that can help address the current crisis. Some of these approaches involve leveraging new technologies, while others focus on reinvigorating traditional taxonomic methods and promoting collaboration across disciplines.

1. DNA barcoding and genomic tools: DNA barcoding, a technique that uses a short genetic sequence from a standardized region of the genome to identify species, has revolutionized taxonomy. This method allows for the rapid identification of species, even from minimal or degraded samples, which is particularly useful in biodiversity hotspots where many species are difficult to collect or observe in the wild. Coupling DNA barcoding with next-generation sequencing technologies can help overcome some of the bottlenecks in species identification. However, these tools should complement rather than replace traditional taxonomic methods (Kress and Erickson, 2008; Odah, 2023).

2. Citizen science and public engagement: Citizen Science initiatives have gained popularity as a way to involve the public in scientific research. In taxonomy, platforms such as iNaturalist and eBird have allowed amateur naturalists to contribute valuable data on species observations. Engaging the public in taxonomic research can help bridge the gap created by the shortage of professional taxonomists. Furthermore, increased public awareness of the importance of taxonomy can drive demand for more educational programs and funding for taxonomic research (Aristeidou *et al.*, 2021).

3. Digital taxonomy and artificial intelligence: The use of artificial intelligence (AI) in species identification is another promising area. AI algorithms, trained on large datasets of species images and descriptions, can assist in the identification of species from photographs or specimens. While still in its infancy, digital taxonomy has the potential to streamline the classification process and make it more accessible to researchers in biodiversity-rich regions with limited access to taxonomic expertise (Bartlett *et al.*, 2022).

4. Capacity building and training: Addressing the shortage of taxonomists will require a concerted effort to build capacity in the field. This includes providing more funding for taxonomic research, creating specialized training programs, and encouraging interdisciplinary collaborations between taxonomists, ecologists, and conservationists. Developing taxonomic expertise in biodiversity hotspots should be a priority, with local universities and research institutions playing a key role in training the next generation of taxonomists (Sandall *et al.*, 2023; Smith and Figueiredo, 2009).

5. Global collaboration and data sharing: The creation of global databases such as the Global Biodiversity Information Facility (GBIF) and the Catalogue of Life has made taxonomic data more accessible to researchers worldwide. These platforms promote data sharing and collaboration, allowing taxonomists to work together across borders. Strengthening international collaborations can help mitigate the effects of the taxonomic crisis, particularly in regions where expertise is lacking (Luo *et al.*, 2021; Sandall *et al.*, 2023).

The current shortage of taxonomists presents a serious challenge to biodiversity research and conservation efforts, particularly in biodiversity hotspots where many species are at risk of extinction. The taxonomic crisis is driven by a combination of factors, including an aging workforce, lack of funding, and shifting scientific priorities. However, through the use of new technologies, public engagement, capacity building, and international collaboration, it is possible to address this crisis and ensure that taxonomy remains a vital tool for understanding and preserving the natural world. As we move further into the Anthropocene—a geological epoch defined by human impact on Earth's ecosystems—the need for taxonomic expertise has never been greater. It is essential that we recognize the importance of taxonomy in biodiversity conservation and take the necessary steps to support and revitalize this critical field. The future of many species, particularly those in biodiversity hotspots, depends on it.

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The authors declare no competing interests.

Authors' contribution

Abdulla-Al-Asif and **Sayali Nerurkar** contributed to the conceptualization and writing of this editorial. Both authors has read and approved the final version of the published editorial.

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