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Microbiology & Plant Science & Animal Science EDITORIAL

The Innovation Life

# Taxonomy and beyond: From dark taxa to bright approaches—The four pillars of a disciplinary renaissance

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Received: July 21, 2026; Accepted: October 19, 2026; Published Online: October 20, 2026; https://doi.org/10.59717/j.xinn-life.2026.100275

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Citation: Su P.-W., Li B., Ren J.-L., et al. (2027). Taxonomy and beyond: From dark taxa to bright approaches—The four pillars of a disciplinary renaissance. *The Innovation Life* **5**:100275.

Taxonomy, in brief, aims to name all organisms and furthermore classify their relationships. This aim seems to categorize the fundamental essence of this discipline. In today's scientific era highlighting the applicability of research together with the utilization of advanced technologies, this basic discipline has long been overlooked. Nevertheless, it is precisely the fundamental scientific nature of taxonomy that makes it indispensable for applied research. Simply, you have to know what the research subject is. On the other hand, our knowledge of life on Earth will continuously accumulate and be revised, which serves as the core data to constantly calibrate and refine its classification systems. This inherently dictates that taxonomy, while keeping its core task, must evolve with the advancement of technologies as has happened before. Thus, the central issue is not the uselessness of taxonomy, but recognizing scientific trends and contemplating how to achieve a taxonomic renaissance.

Undoubtedly, taxonomy has made extraordinary achievements, especially over the past few decades. Yet a new era is dawning. To adapt, we argue that a systematic reorientation is urgently needed and accordingly propose four pillars to fuel taxonomic renaissance, namely: I. special environments and II. crucial lineages corresponding to dark taxa—the research subjects, and III. integrative biology and IV. cutting-edge technologies related to bright approaches—the research means (Figure 1).

## PILLAR I. SPECIAL ENVIRONMENTS

The first priority for illuminating dark taxa is to explore special environments, such as hydrothermal vents, high-altitude regions, subterranean aquifers, abyssal benthic zones, glacial forelands, acid mine drainages and so on. These habitats may not harbor abundant biodiversity, but normally give rise to highly unique, endemic species.[1] Fortunately, the latest technologies help overcome the previous poor accessibility to sampling in these habitats. Moreover, secondary concealed habitats resulting from human activities also provide opportunities for discovering dark taxa. Notably, besides these natural or man-made environments, the organisms themselves can also be consid-

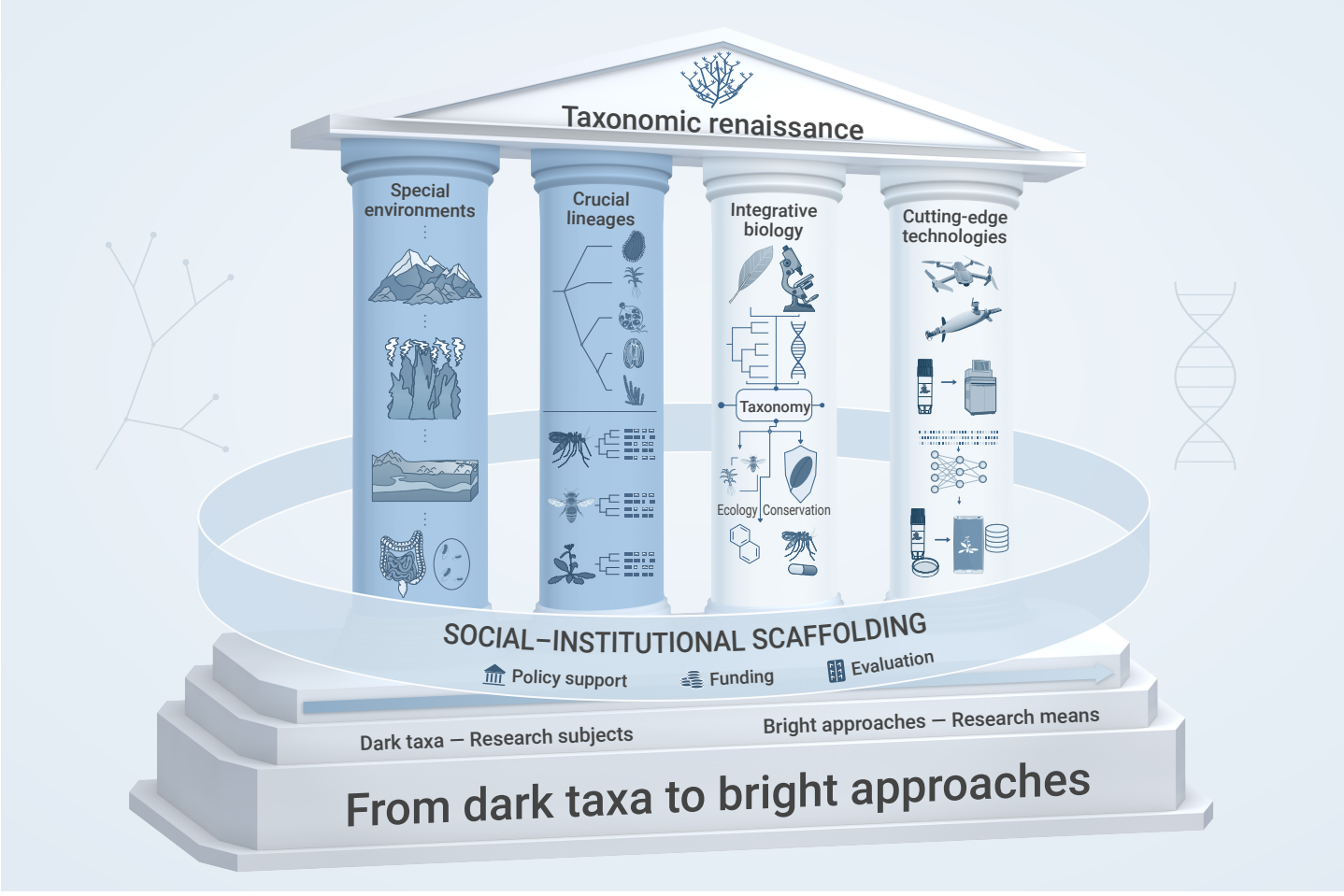


**Figure 1. Four pillars from dark taxa to bright approaches assisting taxonomic renaissance.**

ered special environments. For instance, the intestines of different animal species and the endosphere of various plant species provide unique niches for microorganisms. This means that taxonomists, focusing on different groups, should work together to clarify species diversity across kingdoms.

## PILLAR II. CRUCIAL LINEAGES

While illuminating dark taxa, taxonomy is better to prioritize crucial lineages from evolutionary and economic perspectives. Two axes stand out: early-branching clades (protists, sponges, ctenophores, early land plants, and basal fungi) and economically important groups (pollinator complexes, disease vectors, crop wild relatives, and medicinal organisms).

Early-branching clades are dark, because they are morphologically simple and lack diagnostic traits. For instance, sponge species diversity may be almost double the described count, and protistan phylogeny remains unsettled. In addition, the diversity of basal fungi is still largely unknown, although thousands of new fungal species have been described per year over recent decades. The knowledge of their diversity and phylogenetic positions determines our understanding of trait origin and diversification scenarios (e.g., neurons and multicellularity).[2,3] Such dark taxa are more available from special environments in comparison with other organisms. Meanwhile, economically crucial groups in common environments cannot be omitted. These groups are dark because of cryptic species. The mosquito *Anopheles gambiae* complex contains at least eight morphologically identical species with vastly different vectorial capacities, while some species in the fungal genus *Fusarium*, containing numerous plant pathogens, can only be distinguished by molecular sequencing. The accurate identification of these crucial dark taxa is thus pivotal to epidemiology and quarantine.

## PILLAR III. INTEGRATIVE BIOLOGY

Whether illuminating dark taxa or discovering common species, taxonomy should cease being a mere name factory and become an entry point for hypothesis testing as a hub for broader biological interests. Evolutionary biology, either macroevolutionary phenomena or microevolutionary dynamics, relies on taxonomy as its only rigid coordinate system, because a stable phylogeny is the premise of any claim of homology or convergence. Ecology and conservation biology also depend on accurate species delimitation, enabling the identification of conservation priority areas for organisms. Integrating evolution and conservation biology, Evolutionary Distinctiveness and Global Endangerment (EDGE) has become a prevailing method to determine what taxa deserve higher conservation priority.[4] Therefore, taxonomy plays pivotal roles in helping provide scientifically grounded theory and practical information for policy makers on biodiversity conservation. Regarding applied fields, functional biology and biomedicine need taxonomic precision to avoid rediscovering known compounds or targeting wrong vector species. In this light, taxonomy is no longer a terminal output, but is a central node through which various biological narratives converge. Its impact is measured not only by new species described following the comparison with type specimens deposited in museums, but also by the cross-disciplinary questions it enables, which proves its irreplaceable value.

## PILLAR IV. CUTTING-EDGE TECHNOLOGIES

With the rapid scientific advancement, the concrete new technologies must be used by taxonomists to facilitate the development of taxonomy. Drones and unmanned underwater vehicles with Light Detection and Ranging (LiDAR) can enter previously inaccessible environments to perform sampling. Furthermore, environmental DNA (eDNA) sequencing can simultaneously generate molecular data, including barcoding and genomes from innumerable unculturable taxa. In association with artificial intelligence-machine learning (AIML), the environmental and molecular data may help simulate the appropriate growth conditions for making unculturable taxa culturable. In addition, AIML also has abilities to recognize subtle differences among various species via images, which endows it with expert-level or even higher species identification accuracy and description standardization.[5] Besides data acquisition and processing, the new technologies also can help taxonomists share data via cloud-based, open-edit taxonomic databases linked to digitized museum specimens (3D scans, microscopic images from various microscopes and molecular sequences), turning static collections into living, globally accessible resources. Taxonomy thus shifts from an individual expert's craft to a collaborative, testable, computational science.

It is noteworthy that these bright approaches do not replace traditional research methods of taxonomy. Instead, they rely on data generated from traditional methods, and then amplify the data and promote these methods. eDNA sequences require reference barcodes to be annotated, AIML needs accurately identified training sets, and taxonomic databases anchor to type specimens. Furthermore, it should be recognized that technological advances also brought new positive challenges for taxonomy, including how to describe dark taxa solely using DNA and identify species using AIML trained on geographically biased data, among other challenges. Therefore, the traditional and cutting-edge technologies have to work together, making taxonomy more rigorous and more inclusive.

## CONCLUSION

Taxonomy was once dismissed as a sunset discipline, but it is now poised at its most exciting dawn. Instead of just naming the known, taxonomy is navigating the unknown—across the harshest environments, through the most cryptic clades, into every biological field, and with every available instrument. That is the true meaning of Taxonomy and Beyond. Its renaissance will not be a solitary revival, but a collective awakening: a renewed understanding that all life sciences need a precise coordinate system. That blueprint rests on the four pillars: special environments and crucial lineages as the foundation, integrative biology and cutting-edge technologies as the vault—together lighting our way from dark to light.

The four pillars are not sequential, but form a positive-feedback loop. Special environments (I) yield crucial lineages (II); resolving those lineages (II) drives integrative biology (III); exploring integrative biology (III) depends on cutting-edge technologies (IV); and new technologies (IV) open further environments (I) and reveal more cryptic lineages (II). Each pillar amplifies the others. This synergy is the engine of the disciplinary renaissance. Moreover, policy support from funding and evaluation systems plays a pivotal role in promoting these four epistemic pillars as a form of social-institutional scaffolding. It is not nostalgia for Linnaean times, but a re-engagement with the oldest biological questions—"How many species are there on Earth?" and "What determines species diversity?"—equipped with the most powerful approaches of the 21st century.

Finally, *The Innovation Life* would like to provide a platform for taxonomy papers assisting the disciplinary renaissance.

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## FUNDING AND ACKNOWLEDGMENTS

The research was financed by the National Natural Science Foundation of China (32470003, W2521084 & 32300370), National Science & Technology Fundamental Resources Investigation Program of China (2023FY101300), and Biological Resources Programme, Chinese Academy of Sciences (CAS-TAX-24-018). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

## DATA AND CODE AVAILABILITY

No new data were created or analyzed in this study.