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Taxonomy in the post-2020 Framework for Biodiversity: underpinning the 2050 Vision for Living in Harmony with Nature

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Biodiversity - the genetic, species, community and ecosystem variety of life on Earth - is the living fabric of our planet. As the products of millions of years of evolution, biological species form a global ecological system that encompasses all living beings and their interactions with each other as well as the elements of the atmosphere, geosphere, hydrosphere and lithosphere, collectively known as the biosphere. Human impacts on the biosphere, either direct or indirect, can destabilize or even destroy habitats or ecosystems and their inherent biodiversity components, something that may also lead to species extinctions. The equitable and responsible use of the world's biological resources is essential for the well-being of the planet. This can only be achieved in a sustainable manner when it is based on a solid and comprehensive understanding of biodiversity: on how to protect it, how to manage it, how to nurture it, and how to respect it.

The 2050 Vision for Biodiversity, focused on the theme *Living in harmony with nature,* seeks to ensure that, by 2050, biodiversity is valued, conserved, restored and wisely used with the aim of maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people. In the Strategic Plan for Biodiversity 2011-2020, the role of knowledge in supporting the 2050 Vision is recognized in Aichi Biodiversity Target 19: *By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied*. As the global community considers the framework that will succeed the Strategic Plan beyond 2020, the fundamental importance of taxonomy in framing the transformational change needed to bring the 2050 Vision within reach must be explicitly acknowledged and incorporated within this framework of targets and actions in the years ahead.

1. Taxonomy underpinning biodiversity discovery and understanding

Taxonomy underpins the CBD and its successful implementation, on a species by species, habitat by habitat, ecosystem by ecosystem, country by country and region by region basis. From the perspective of preserving global biodiversity, the crucial importance of taxonomy and systematics and thus, of species discovery, species description, species documentation and species classification in an evolutionary framework has been recognized, alongside the significance of the scientific expertise needed in order to describe, document, classify and understand life on Earth (https://www.cbd.int/gti). As highlighted by the Global Taxonomy Initiative and its work programme, significant steps were needed in order to fully address the complex issues surrounding, firstly, the creation and delivery of information necessary to support conservation and sustainable use of biological diversity, including, critically, understanding and documenting this diversity.

Taxonomy is a fundamental science for understanding biodiversity and ecosystem functioning, as it scientifically documents and seeks to understand the natural world at different taxonomic (species, genera, families) as well as biological levels (community, habitat, ecosystem). Information obtained from biological and palaeontological specimens permits researchers to understand evolutionary events and to reconstruct the history of life on Earth. Taxonomic and systematic research provides species concepts, single and stable names for biological units, insights into evolutionary processes and interpretative perspectives on the complex evolutionary history of the Tree of Life. As such it is the scientific pillar that supports a variety of other scientific disciplines as well as a significant number of key activities and industries such as conservation, agriculture, horticulture, forestry and fisheries, eco-tourism and pharmaceuticals. The data that taxonomists and geodiversity or biodiversity scientists provide plays a fundamental role in providing the baseline information for addressing societal challenges and informing environmental policy and decision making.

One of the main focuses remains species discovery that is intrinsically linked to the need to ensure that the taxonomic expertise to do this is available, maintained and enhanced on a global scale. The encouragement of the use of integrative taxonomy techniques, the sharing and linking of geodiversity and biodiversity knowledge, capacity building and ongoing education and outreach activities which encourage natural human curiosity about the living world and support the sharing of scientific, indigenous and lay-knowledge on the living planet, are also fundamental elements that need to be considered in the achievement of objectives and targets post 2020.

Successful CBD implementation beyond the horizon of 2020 requires the prioritization of taxonomy as a discipline that is essential for understanding biodiversity, particularly for ensuring its sustainable and equitable use. Governments can achieve this objective at a number of different political, scientific and social levels, provided that they coordinate both priorities and progress.

2. Biodiversity information and the biodiversity knowledge network

Researchers in biodiversity have long had a culture of curating and annotating data — from identifying specimens to correcting and cleaning up entire downloaded datasets. These efforts are a key part of the data validation process: even with the best automated tools, identifying and correcting most errors still requires an expert, human eye. Yet these annotations are not always made available to the original data owners, and even when they are, there may be neither the resources nor the mechanisms in place to incorporate them. As a result, mistakes get replicated or have to be repeatedly corrected, duplicating effort, while there is little incentive for researchers to continue to

correct and annotate records more widely. Data aggregators generally encourage users to report mistakes; various communities have developed systems of data curation, including amateur networks to curate citizens' observations and, in some cases, expert curation for aggregated data. However, too often these are *ad hoc* and isolated efforts and require special engagement on the part of the contributors, especially if they want to make corrections in many different sites, while data providers or publishers may not feel confident in trusting changes submitted over the Internet.

Data needed to reliably document, support and contribute to CBD implementation, requires mobilizing information, expertise (also technological competences), knowledge and funds, that increasingly need to be coordinated to avoid duplication of initiatives and guarantee the efficient use of the available resources, both human and technical. There is a broad need for coordination between individual institutions and projects to ensure that data clean-up efforts can be recognized and valued, and to set in place incentives so that annotations are made and fed back into the system. Combining incentive-driven mechanisms with tools to facilitate fitness-for-use and annotation will drive progress towards making distributed data curation the norm.

Increased linkages and alignment between data management systems can also simplify efforts to curate digital knowledge and deliver multiplier effects from the contributions of taxonomists and other experts. A key priority should be development and adoption of a shared identity management system for contributors, whether professionals or citizen scientists, so that they can have a common identity and contribution history across platforms — particularly the key data networks and publishers.

International organizations, and increasingly international networks, play a key role in connecting experts, providing access to existing information and fostering a comprehensive understanding of what is known is known versus not known, thus supporting scientific progress and future research efforts. Networking is crucial to support access to data and exchange between people, and existing global and regional organisations provide the framework for collaboration beyond political borders, social boundaries and cultural differences. From 2020 onwards, global coordination of efforts to document, aggregate and link biodiversity knowledge will be an essential step forward, one that will be crucial for supporting CBD implementation.

3. Molecular genetics and genomics

Biodiversity is delimited, detected and described primarily using two main types of data: the first based on the study of variability in morphology-anatomy and the establishment of stable taxonomically informative characters, supported by traditional taxonomic

methods, the Codes of nomenclature and the Linnaean (Latin binomial) classification and naming system; and, the second on molecular evidence, primarily DNA, with an array of sequence clustering methods and naming systems that applied in particular groups of organisms. Molecular genetics and genomics are particularly useful where traditional approaches alone are not easily applicable or are too slow. Although taxonomy relies principally on human expertise to adequately find, interpret, compare and identify species, and to link them to the currently described organisms, there are exciting new opportunities opening for integrative taxonomy up as technologies develop.

There is a practical need for establishing a biodiversity knowledge network through a single taxonomic environment and scientific name space that provides an integral view of life on Earth. Information collated and connected in this way can be more easily interpreted by users and applied at different political or geographical scales, as well underpinning scientific research efforts. Initiatives that handle global taxonomic data and names, both from the point of view of conventional Linnaean classification and based on molecular evidence, are working together on delivering centralized data access for CBD Parties and other stakeholders on an open access basis. For molecular systems to be integrated and interlinked within this common space, national and global efforts to build reference libraries of sequence clusters (Operational Taxonomic Units as molecular proxies to species and other taxa) as well as eDNA initiatives (metabarcoding, molecular ecology) that detect and quantify biodiversity at large scales and high speeds, offer exciting opportunities for biodiversity discovery and need to be supported. Population genetics techniques and molecular phylogenies complement morphology-anatomy based taxonomic efforts. As technologies evolve and become more widely affordable and accessible, genomics will increasingly drive our understanding of the physiology and functioning of individual organisms, of communities and of the biosphere. Integrated global biodiversity data coming from citizen science, monitoring and natural history collections and new large data streams, such as remote sensing and molecular data, need better linking to the pool of existing data. Taxonomy and nomenclature of morphologically and molecularly delimited taxa and of operational taxonomic units need to work together for an integrated, up to date view of global biodiversity.

4. Capacity building, training and outreach

Natural science institutions in Europe and North America hold a significant proportion of the world’s natural history collections that represent a large proportion of the species that have been described to date. Recognizing and addressing the unbalanced global landscape between biodiversity rich countries and countries that are rich in collections and linked expertise is the first step towards facilitating capacity building in the

appropriate places. Collaboration on best practices, capacity building programmes, mobility of expert initiatives, joint collaborative scientific discovery projects and the integration of scientific data driven by local knowledge into policy and decision making processes will play a crucial role in underpinning efforts to understand biodiversity and its sustainable use. Indigenous communities are critical stakeholders in this, as in all aspects of the successful implementation of the CBD. By understanding what user communities need from taxonomy and biodiversity knowledge, results from scientific studies can be better interpreted by scientists for different audiences and user communities.

Training provided by taxonomists is increasingly relevant in addressing both the taxonomic impediment addressed in the GTI and for successful CBD implementation. Comprehensive, widely accessible and tailored training programmes will become increasingly pertinent as e-learning facilitates training across borders, providing an economically viable and ecologically sound solution to information exchange and knowledge transfer. The expertise gained by the researchers and the knowledge contained in collections conform to the tandem on which modern taxonomy is being built, together with the information technologies that support the entire process. Transversal disciplines are being born in the light of the internet of things, big data and artificial intelligence. Those tools are to be the mechanisms helping the experts to ensure the adequate and precise flow and track of information, storage and enhancement of data, the accessibility to science where, when by whom it may be needed. Together this will support taxonomy as the backbone of natural sciences, helping to tackle environmental challenges such as the impacts of climate change in a thorough manner and based on open science.

Outreach activities across the stakeholder community will be essential in ensuring both understanding of the importance of biodiversity, and of its sustainable management in an ever changing world. Engagement of the public in scientific endeavours via citizen science initiatives potentially contribute to stimulating interest in the living world, delivering data for scientific studies, enhancing scientific literacy in society and engaging people more actively in sciences such as taxonomy.

Actions for incorporating taxonomy into the post-2020 biodiversity framework to support the global vision for 2050

- Recognition of taxonomy as a fundamental scientific discipline, with associated financial support given for the development of taxonomy-based scientific enterprises and citizen-science activities
- Support of taxonomists and the expertise of both geodiversity and- biodiversity scientists via the establishment of coordinated taxonomy-based training programmes, certifications and funding mechanisms
- Identification of bottom-up needs and requirements with respect to species discovery and biodiversity knowledge (respond to the question “What do the user communities actually need?”)
- Facilitation of capacity building and multi-way information exchange in support of taxonomy and taxonomic expertise
- Coordination of outreach campaigns on geodiversity and biodiversity and sustainable development with the scientists who can interpret the outcomes of taxonomic research
- Engagement of stakeholders in taxonomic discovery and the interpretation of the living world
- Creation of cross-cutting and global taxonomy initiatives that focus on sampling and studying living material as well as using the world’s natural history collections by involving taxonomic experts, amateurs, engaged citizen’s, students and school children in documenting the natural world
- Support for coordinated initiatives that enable contributions and annotations from biodiversity domain experts to be persistently incorporated in aggregated open data systems, thus improving their quality and usefulness
- Development of integrated information systems that enable the seamless linking of taxonomic data derived from anatomical-morphological and molecular sources of evidence, respectively
- Address taxonomic bias and prioritize taxonomy, nomenclature, and the biological understanding of functionally critical taxa and guilds
- Creation of monitoring programmes for critical taxa or invasive taxa, using taxonomic expertise, field observations and biodiversity data aggregated through a globally coordinated system
- Scale up capacity building activities empowering individuals and institutions in all regions to benefit from the opportunities provided by a strong and developing taxonomic research sector and relevant communities of practitioners and users.