Linnaeus 300: Tips for tinkering morphological taxonomy

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The morphological taxonomy is exclusively the product of intellectualness of Linnaeus, a primary tool relied by global taxonomists presently to unfold the hidden biodiversity. There is no immediate, alternative and widely applicable system to tackle the taxonomic impediment in current biodiversity crisis. It has many remarkable inherent defects and appreciable evergreen merits. It is becoming an endangered science in India. We have suggested some practicable suggestions to improve this system, which are pertained to improving the content of taxonomic publications, methods of collection, preservation and storage of type specimens and taxonomic records and preparation of user-friendly identification resources for nonspecialists.

We know many 'fathers' in different branches of biology. But Carl Linnaeus can be considered as the 'grandfather' of taxonomy. The whole conceptual foundation of taxonomy is solely the product of his intellectual labour. He made original contributions and invested inexhaustible energy to make taxonomy more efficient and creditable. He was the 'first' in the history of biology in the following aspects: (i) Proposed and used morphological criteria for discriminating species from one another; (ii) Framed a classification system with different hierarchies to catalogue the discriminated species; (iii) Proposed binomial nomenclature for scientifically naming all classified species and (iv) Described and named nearly 7000 plants, an unbroken record in the history of taxonomy. Even though his morphological approach is extensively used, analysed and debated methodology, it has stood the test of time well. We still indispensably require it even in the era of DNA taxonomy. This is the reason why even after 300 years, the world's leading science journal, *Nature* released a special issue (March 2007, **446**) on the 300th anniversary of his binomial nomenclature and system of classification in 2008. There are many scholarly articles in this issue; particularly a commentary entitled 'Linnaeus in the information age' by H. C. J. Godfray (Oxford University). It deals with hard problems faced by Linnaean taxonomists in modern times and offers some solutions. This special issue of *Nature* inspired us to think about the present status of Linnaean taxonomy in our country and the measures needed to reform it.

The most illustrious feature of life is its diversity. This concept of biodiversity forms the crux of modern ecological research. Morphological taxonomy conceived and developed by Linnaeus is the primary tool used by global taxonomists to unfold the unaccountable biodiversity of the biosphere. It is a most primitive methodology primarily relying on morphological characteristics for discriminating species and placing them in suitable taxonomic hierarchy. It has survived for 300 years and some quarters are still going strong due to current interest in the concept of biodiversity. India is endowed with great natural diversity of fauna and flora. It is one of the world's twelve megadiversity countries. Over 125,000 species have been taxonomically catalogued from India. It is also one of the Vavilovian centres of diversity of wild crops and livestock[1]. Scientific documentation of this immeasurable diversity is certainly an immense task for India. Gadgil[2] had critically pointed out the major weaknesses with reference to taxonomic classification of our biowealth. They are briefly: (i) Only 20% of the native species have been described so far; (ii) Most work is done by British and Western taxonomists; (iii) Most type specimens of these species are not available in Indian depositories, and (iv) Taxonomy as a vital discipline of biology is not properly introduced in the curriculum in higher education. The vital link between the biodiversity inventory and the present status of morphological taxonomy in our country has been analysed by many workers[3–6]. These reports have mainly emphasized the urgent measures needed to improve the reliability and efficiency of morphological taxonomy as well as major problems associated with it. Meanwhile a number of perennial issues regarding the reliability of morphological taxonomy await further analysis to reach applicable solutions. Here, we first briefly summarize the merits and demerits of morphological taxonomy and then list some vital suggestions for strengthening its reliability in future biodiversity inventories.

Morphological taxonomy has some evergreen merits. It is being practised and refined for a long period, nearly 300 years in the history of biology. Majority of living organisms in the earth have been already keyed and named on the basis of this system. Thus a rich collection of preserved specimens is available in global museums and regional depositories as reference records for analysis and revisionary works. Many professional taxonomists are also maintaining the preserved taxa of their interest as personal collections. Even though this system is severely criticized with solid evidences for its reliability, so far no other system of classification has replaced it completely even for one group of taxon. As a positive response to criticisms, morphological keys are being ameliorated using current data from morphological as well as non-morphological criteria. A fraction of morphometric data generated by this system is also suitable for statistical scrutiny and better taxonomic resolution. More importantly, it offers an immediate solution for documenting the species richness of tropical megadiversity countries such as India. It enjoys priority in our country, where applied researches are limited; they indispensably require accurate species resolution to ensure economic outcomes of project or technology such as biocontrol of weeds and pests. Many local taxonomists have also been encouraged by their foreign counterparts by providing exotic keys, holotype loans and co-authorship in publications; some catalytic factors responsible for survival of this primitive system. In Western countries, new-generation taxonomists hope to adopt the 'DNA barcodes' for species discrimination, similar to barcodes in the retail industry[7–10]. In

this context also, we lack hi-tech instrumentation, funds and trained manpower for molecular taxonomic research. According to Narendran[3], we lack basic facilities even for morphological taxonomy, particularly trained manpower. This limited number of global taxonomists when compared to millions of anonymous species that await description in future, has been well discussed earlier[11,12]. To make matters worse, it has been also censused that the number of taxonomists capable of identifying tropical biota morphologically is limited[12].

Linnaean taxonomy also has some inherent defects. As a vital branch of biology, it is not ideally blended with the curriculum of higher education in India. In the past, morphological taxonomists were considered to be incapable of analytical thoughts and deductive logic[3]. This area of research lacks prestige and adequate funding. It has failed and continues to fail in luring major funding and in producing applicable outcomes[13]. It is well known that construction of morphological keys is a difficult and laborious process in many groups (e.g. bruchid beetles)[14]. In some taxa, only certain stages of the life cycle provide significant traits of taxonomic value (e.g. nymphal traits in Membracidae)[15]. Many experts ignore the request of identification of specimens from non-specialists and our national depositories are not helpful in loaning type materials[3]. There are controversies among many taxonomists regarding the traits selected as keys as well as in 'splitting and lumping' higher taxa categories in many groups of organisms. The pace at which major revisionary work is being done in many taxa is extremely slow, against the urgent taxonomic demands. For most of the taxa, we are still using keys developped by Western taxonomists earlier, by deliberately ignoring local and regional variations in our life-forms. Our taxonomists do not update even such conventional keys by including other kinds of variations as supporting keys. In general, globally taxonomists prepare their publications by adopting some 'typical conventional format', which makes it uninteresting to other biologists. Qualitative reproducible data considering chromosomal[16], molecular biological[17,18] and behavioural[19] criteria indicate the unreliability of the morphological approach of species resolution. The urgent need for compilation and inclusion of nonmorphological data in species discrimination has tremendously increased with advances in molecular evolution. This kind of integration of ecobehavioural, physiological, cytogenetic and biochemical approaches towards better discrimination of species is termed as the multidimensional concept of species. In fact, morphological taxonomy mostly produced a scatter of taxon descriptions in taxa selected according to the preferences of the taxonomists. Many groups studied painfully for decades using the morphological approach have limited practical value in the Indian perspective (aquatic insects in biomonitoring). More preciously, the status of the species at present is being characterized by variations in nucleotide sequences of the selected genes (e.g. rRNA genes and cytochrome oxidase-I). Taxonomy now has more value rather than merely description and naming, two major objectives of the Linnaean system. To summarize, Templeton[20] from an in-depth analysis has concluded that speciation can occur in the absence of visible variations in morphology; on the contrary, morphological variations in many taxa are uncorrelated with speciation.

A perusal of the preceding account would show that our dependency on morphological taxonomy as a major tool for classifying, naming and documenting our biowealth is unavoidable as the problem has no immediate, alternative solution. Even contemporary molecular taxonomists, now acknowledge Linnaean taxonomy as a starting point for their billion-dollar projects. We conclude our analysis by listing some practicable suggestions that deserve special attention in future to improve the reliability of morphological taxonomy.

First with reference to the content of taxonomic publications, the following kind of new records and revisionary work in morphological taxonomy should be given preference in future:

- Based on fresh holotype specimens rather than old museum collections.
- Provides accurate information such as map of collection site, depository and specimen accession number.
- Type materials deposited in national depositories rather than kept as personal collections.
- Supported by SEM data on significant, minute taxonomic parts.
- Confirmed by molecular biological and biochemical data, when erecting new hierarchies below family (genera, species and subspecies).
- Adapted keys of local or regional variations rather than broad global variations from exotic keys.
- Based on description of all life stages rather than only one life stage (especially in insects).
- Based on morpho-traits that can be easily recognized by non-specialists or end-users.
- Based on type materials available in Indian depositories rather than international museums.
- Recorded from unexplored habitats.
- Provides details on dissection and mounting procedures to trace minute parts.
- Concludes with well-designed keys and illustrations that are suitable for direct and rapid use in the field by non-specialists by a few easily recognizable traits.
- Differentiates closely related genera or species by minimum of unambiguous traits that a non-specialist can easily and quickly utilize.
- Deviates from conventional format in any form to serve the purpose; easy identification without help from specialists.
- Considers human welfare/economic value rather than merely phylogenetic value.
- Provides cytogenetic and behavioural data to support species status (in vectors, pests and natural enemies).

The following suggestions are made to improve the collection, preservation and storage of specimens as well as taxonomic records:

- Preservation of specimens by advanced methods (e.g. cryopreservation of fungi, pollen grains, insect eggs).
- Collection of data on minute taxonomic traits using SEM.
- Storage of all taxonomic data in quickly transmittable e-version.
- Deposition of paratypes of rare or regionally important species in national depositories.
- Upgrading our museums and depositories in terms of infrastructure, trained manpower and reference literature[3].
- Inclusion of taxonomy in curriculum of higher education and establishment of 'schools of taxonomy' in our universities.

- Taxonomy 'training camps' for non-specialists by experts of ZSI and BSI, at least with respect to difficult taxa.
- Regular expeditions to sanctuaries and parks to explore new forms of life.
- On-line identification services by ZSI and BSI to identify digitized specimens/photographs (so called 'cybertaxonomy').
- Employing 'parataxonomists' in specimen collection, preparation, preliminary sorting into morphospecies and making a database with other relevant information[21,22].
- Training interested amateur taxonomists, biology students, school teachers and others in parataxonomy, especially those living in and around biodiversity-rich areas[23,24].

According to Godfray[13], excellent identification resources (field guides, monographs and taxonomists themselves) exist for different taxa at different geographical areas. But these resources are generally often absent for many taxa in diversity-rich tropical regions. We feel that the voluminous records published by ZSI and BSI on our fauna and flora are valuable treasures to 'specialists', but are of no help to end-users or non-specialists, who often experience difficulty in identifying their specimens. So these 'biostock registers' can be converted into:

- Simplified user-friendly keys[25].
- Field guides with figures and colour photographs[26,27].
- Pictorial glossaries for terminologies used in keys, especially in the case of difficult taxa.
- Photographs and keys for fauna and flora in the existing sanctuaries, parks and reservoirs of our country.
- Identification pamphlets about rare/threatened flora suitable for use among the 'ecosystem people' (tribals) to prevent over-exploitation and indiscriminate destruction.
- Packages of illustrated keys to identify dominant flora and fauna of the reserves, parks and sanctuaries, to exclude them from 'species list' while exploring biodiversity.
- Creating Indian database (similar to gene banks in Western countries) on our flora and fauna, with details on not only taxonomy but also their ecology, genomics and phylogeny.
- Collection and documentation of keys used by tribals to identify biota in biodiversity-rich areas; for instance, a recent field guide of keys used by Kurumbas and Irulas for plant identification in the Nilgiris Biosphere Reserves[28].

Recently, Godfray[13] has summarized the steps that should be faithfully followed by morphological taxonomists to save their ancient science in this information age, which nowadays totally depends on 'webs and nets'. Some of his conclusions are worth mentioning here: (i) Taxonomists must clearly understand the relationships and interfaces of their science with other branches of biology; (ii) Their project proposals must be aimed at the needs of the user communities; (iii) Must integrate morphological criteria with modern molecular biological techniques. (iv) Taxonomic information should be made accessible to others. In summary, morphological taxonomy is becoming an 'endangered science' in India. It urgently needs revolutionary changes to play a vital role in biodiversity documentation. It requires adequate funds and trained manpower as in the case of molecular taxonomic projects in Western countries[9]. We have no alternative and the sooner this is done, the better are the prospects of biodiversity inventory and its sustainable utilization in India. We urge all 'disciples' of Linnaeus in India to consider objectively the pertinent issues and combine their efforts to make morphological taxonomy a truly applied science.

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