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Taxonomy in Biological Science and Its Basic Role in Species Conservation

Mohd Shoeb[1] ,Yogesh Kumar Gupta[2]
[1]Department of Zoology, Gandhi-faiz-e-Aam-P.G.College Shahjahanpur (UP)
[2]Department of Zoology,Swami Kalyananad Mahavidyhyalay,Neoradev,Hardoi(UP)

ABSTRACT
Taxonomy and species conservation are often assumed to be completely interdependent activities. However, a shortage of taxonomic information and skills, and confusion over where the limits to 'species' should be set, both cause problems for conservationists. There is no simple solution because species lists used for conservation planning (e.g. threatened species, species richness estimates, species covered by legislation) are often also used to determine which units should be the focus of conservation actions; this despite the fact that the two processes have such different goals and information needs. Species conservation needs two kinds of taxonomic solution: (i) a set of practical rules to standardize the species units included on lists; and (ii) an approach to the units chosen for conservation recovery planning which recognizes the dynamic nature of natural systems and the differences from the units in listing processes that result. These solutions are well within our grasp but require a new kind of collaboration among conservation biologists, taxonomists and legislators, as well as an increased resource of taxonomists with relevant and high-quality skills.
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INTRODUCTION
Taxonomy is the science of classifying organisms. At no time there has been a greater need for taxonomists than now when the crisis facing biodiversity is escalating. Dicision 11/8 of the second meeting of the Conference of Parties to the Convention on Biological Diversity (CBD) identified the lack of sufficient taxonomists as a significant impediment for implementing the decisions of the convention at national as well as international levels.. Over the past half a billion years the world lost perhaps one species per million species each year including everything from mammals to plants and today the annual rate of extinction is estimated to be 1000 to 10000 times faster [1]. This is really a matter of grave concern for all those who think that our biodiversity is precious and should be protected. It is also known now that centinelan extinctions take place on many
regions of the world today and not merely a thing of the past which happened in that cloud forest of the Western Ecuador in 1978-1980. Besides we are quite ignorant of the real magnitude of the world's biodiversity. The audit of biodiversity today is far short of a reality. Though opinions on the biodiversity of the world differ from 5-100 million [1] species, a 'best guess' or mid way on the road, places it at 14 million living species today [2].
The primary way basic information about animals and plants is organized and stored is by taxonomic categories (typically species) [another way is by subject, such as vision or food and feeding]. It is important to understand (1) why good taxonomic databases are essential for studying biodiversity, (2) what taxonomy entails, (3) why a hierarchical classification is useful, and (4) why classifications and names change, thereby making it more difficult to accumulate and keep track of information for many purposes from conservation management to inventories, to species entering commerce, etc.
Taxonomists have two important tasks: to name organisms and to classify them. The system of hierarchical classification and a two-word system for naming species began with Linnaeus in 1758. The system was codified in 1842 [3], and it became the system used by all zoologists worldwide from 1843 to the present, with changes and improvements along the way. (The present Code which all zoologists follow is discussed in Appendix A of the *Catalog*). The two-word name for species consists of a generic name and a specific name. A genus may contain more than one species, and species are placed together in a genus

based on perceived genetic affinity (as determined mostly by morphological differences and similarities, although biochemical techniques are providing new, additional information). (Subspecies are sometimes used to define smaller categories within a species). Taxonomists discover or describe species (1) by assembling specimens through fieldwork and/or by borrowing from museum collections, (2) by studying variation, (3) by grouping the specimens into species categories, (4) by comparing these with previously described species, (5) then naming the new species following specific rules [4, 5] and (6) by publishing the information in scientific journals and books. Monographs contain thorough treatments of all the species in a larger group, such as a genus or family, and monographs represent the latest summary of information for that group.

Taxonomy is as old as the language skill of mankind. It has always been essential to know the names of edible as well as poisonous plants in order to communicate acquired experiences to other members of the family and the tribe. Since my profession is that of a systematic botanist, I will focus my lecture on botanical taxonomy. A taxonomist should be aware of that apart from scientific taxonomy there is and has always been folk taxonomy, which is of great importance in, for example, ethnobiological studies. When we speak about ancient taxonomy we usually mean the history in the Western world, starting with Romans and Greek. However, the earliest traces are not from the West, but from the East. Eastern taxonomic works were not known to the Western world until the Middle Ages and could thus not influence the progress of Western sciences. In the Eastern world, one of the earliest pharmacopoeias was written by Shen Nung, Emperor of China around 3000 BC. He was a legendary emperor known as the Father of Chinese medicine and is believed to have introduced acupuncture. He wanted to educate his people in agriculture and medicine and is said to have tasted hundreds of herbs to test their medicinal value. The pharmacopoeia *Divine Husbandman's Materia Medica* included 365 medicines derived from minerals, plants, and animals.

Classifications are useful because they contain information about relationships. For example, when a chemical suitable for a pharmaceutical product is found in one species, biochemists can quickly learn from classifications of the close relatives (e.g., other species in the same genus or the sister-species that might contain similar or even better chemicals. All species in the same genus should share many behavioral, biochemical, ecological and biological properties because they are closely related evolutionarily. The effect of pollution on a species at one location should be similar to the effect on a close relative living in a different area. Those in the same family (next primary category up) similarly share many but fewer features. Classifications thereby have predictive value. Since the late 1960s, most taxonomists have used cladistic methods of forming classifications (i.e., Henning's method), basing them on shared advanced (new) features. This approach results in cladograms or trees that reflect ancestry as well as relatedness of individual taxa.

The changing nature of classifications and scientific names (because of changing ideas of relationships and because of technical [nomenclatural] rules changes) makes it almost impossible to know under which species, genus, or even family names one will find pertinent information in the prior literature or in specimen collections. For example, in 1989 both the genus name and specific name of the rainbow trout were changed (see Smith and Stearley 1989). Thousands of publications cite *Salmo gairdneri* as the name of the rainbow trout; now we call it *Oncorhynchus mykiss*. The genus name was changed from *Salmo* to *Oncorhynchus* partly based on fossil evidence because the Pacific trouts were thought to be more closely related to the Pacific salmon than to the Atlantic salmon [the name carrier or type of *Salmo*]. Pacific trout and salmon are now classified as *Oncorhynchus*. The species name *gairdneri* was changed to *mykiss* when it was thought that *mykiss* from Kamchatka, Russia, was the same as *gairdneri*; since *mykiss* was described first, that name had priority for use over *gairdneri*.

Another major activity of taxonomists is to make synonymies that summarize prior accumulated knowledge about species. Unfortunately, scientific names change for several reasons, which makes inventory especially difficult since information about a single species may be found under several scientific names. Names change because:

1. One species may have been described more than once (such as from different geographical areas, from different sexes, from atypical specimens, or from a lack of knowledge of earlier descriptions). As these duplicates are discovered, the first described name is selected as the valid name, often resulting in a name change, such as for the rainbow trout.
2. Scientists may differ on what species to include in a particular genus, or species are moved to different genera based on perceived relatedness. This results in the first half (generic) of the name changing; sometimes the ending of a scientific name also changes since, if it is an adjective, it must agree (decline) in gender with the genus.
3. Sometimes names are changed for technical reasons.

Another problem is that scientific names are frequently misspelled in scientific publications, in collection records for museum holdings, and by abstracting services. Often a name is misspelled because the spelling as originally presented was not verified by subsequent workers. Although, there are current arguments about how to incorporate fossils into classifications, and especially how to treat them in higher taxa, the present system probably will continue for many years. Numbering taxa has not worked either. Often common names are more stable than scientific names, and they can be useful in some groups.

CONSERVATION PLANNING AND MANAGEMENT

To form a basis for considering the role of taxonomy in conservation, I use a simple representation of the cycle of conservation activities. The starting point is the observations of the species or populations that indicate attention is needed. Ideally, these observations are formalized into some kind of systematic monitoring programme, but in fact much biodiversity assessment is opportunistic and sporadic [6]. Depending on the context, the observations could be of the status of a single population or species, or could be of suites of species organized by locality, higher taxonomic grouping, biome, region, etc. At local scales, monitoring is likely to be through direct or indirect measures of population status, but at broader scales, the species level dominates most assessments. Once observations or monitoring indicate that there is a problem that needs addressing, the next step will involve an analysis of the factors involved, their relationships to one another and the conservation status of the species or population. At this stage, good experimental methods are needed to draw out causes and effects of rare or declining species, so as to best design strategies that will reverse the trend [7]. This stage may take some time to complete but it should lead to the design and development of solutions. There is an enormous range of possible solutions, which will vary according to their place in the causal chain and the degree to which they are local and practical versus distal and strategic. To take some extreme examples, the solutions for a declining population of a rare bird species might involve either or both of gazetting critical habitat and managing that habitat for its suitability for the species, to lobbying for the species to be added into lists that carry legal weight ensuring protection. On a broader level, analyses might indicate that species are especially threatened in certain habitats (e.g. coastal ecosystems), or facing a particular threat (e.g. marine capture fisheries), or belonging to particular taxa (e.g. amphibians). In this case an analysis of causation and of efficient conservation strategies is called for. The various prioritization schemes and strategies developed by conservation organizations and agencies are a response to these broader assessments of need, as well as the organization's particular focus or mandate. They may include species- or area-based priority setting systems as well as responses that address the anthropogenic drivers of change. The solutions then become embedded in a conservation plan for the species, taxon or region. The existence of a plan is far from a guarantee that actions will follow. A series of alternative enabling activities, ranging from fund-raising, through raising awareness and lobbying, to drafting and implementing legislation are almost always necessary. At international levels this could include listing the species or population under one of the multilateral intergovernmental environmental agreements (e.g. CITES, Ramsar—the wetlands agreement, the Convention on Migratory Species, etc.) or international management agreements (e.g. fisheries agreements, trade agreements, International Whaling Commission). At national level, various countries have lists of species that are afforded protection (e.g. federal Endangered Species Acts in the USA and in Canada, the Biodiversity Action Plan species in the UK). At local levels the responses are most likely to involve direct action on the ground, for example habitat protection and management, but in very many instances the placing of the species on one of these important lists may be a prerequisite to effective direct actions to protect or restore the species. Over the past 20 years, largely as a consequence of influential national legislations such as the Endangered Species Act in the USA, there has been substantial work done on the design and implementation of species recovery plans, and general agreement that this level of analysis is required if actions are to be effective over the medium or long term.

(a) *Taxonomic issues for listing species*

Lists here refer to all kinds of species lists including those that form the basis of national and international legislation, and those that are used in local and regional planning. There are many examples. CITES has lists of species that are covered by the Articles of the Convention—those species listed in appendix I are prohibited in international trade, whereas those listed in appendix II are controlled in trade. The IUCN produces a regular list of species most at risk of extinction in the short term—the Red List, and changes in the length of the list are used to indicate changing patterns and intensity of threat over time, between higher taxa and among regions. Species richness and the proportion of species threatened with extinction can be calculated for countries, ecoregions and within countries and used for priority setting aimed at diverting conservation funds appropriately [8, 9]. Regions of the world with exceptionally high species richness and evidence of threat are recorded as biodiversity hot spots, and extra conservation resources are focused on conservation in those areas [10]. Among birds, significant conservation choices are made on the basis of areas where there are many sympatric species with restricted ranges [11]. In some areas of the world (especially in Australia and South Africa) the choices over land areas to protect in reserves or parks are based on algorithms that systematically optimize areas of high complementarity or irreplaceability by comparing lists of species from different areas [12].

Variations on all the same processes are played out within countries—there are lists of species protected in national legislation, lists of species recommended for protection, recovery planning and special protection. There are also national lists of rare and threatened species [13]. Without doubt, species need to be named and identified formally if they are to benefit from the conservationists' sets of legislative and planning tools. Unfortunately, all lists of species, and species richness measures generally, are extremely vulnerable to changes in species definitions. As the species concept becomes narrower, or species are split for whatever reason, the length of the list increases. The units making up the list can also alter radically. Whether this is a problem or not depends on the role that entities in the list are expected to play. For example, conservationists concerned with mega-faunal diversity and the clear evidence that large bodied taxa are being lost at a disproportionately high rate are unlikely to be reassured that the list of large mammals is also growing as we add one or two more species of African elephants [14], tigers [15] or gorilla. But at the same time, those seeking to conserve elephants, tigers and gorillas across their geographical and biological range may find it easier to achieve when there are more distinct units that have been given the rank of species. In reality, when the lists are lengthened by simply splitting previously recognized species, rather little diversity is added. To take another example, the list of species controlled in trade by CITES will grow longer as these new species are added, leading to some practical difficulties with implementation, but the impact of the Convention overall is unaffected because the set of organisms given protection is exactly the same.

(**b**) ***Units for conservation action***

The design and implementation of conservation actions on the ground is critically important for conservationists. All the legislative and policy work done to get species named and listed will be wasted unless the conservation and recovery plans developed as a result are well designed and implemented. So, ideally, once a species has been identified, its precarious conservation status determined, and its name included on lists that lead to actions to restore it, the real business of conservation can begin. Listing a species does no more than draw attention to it. Effective management now depends upon understanding the processes causing its decline, developing effective control and management strategies and implementing whatever actions are called for.

(**c**) ***Distinguishing between processes***

The role of taxonomy in species conservation has become complicated by the fact that conservationists are confusing the two different processes of listing and priority setting, versus recovery planning and *in situ* conservation actions. Recognizing that these are distinct and have different demands will be necessary before we can determine what kind of taxonomy conservationists need. The general discussion in § 3a,b has outlined the issue but a specific case study illustrates this confusion. The shiitake mushroom (*Lentinula edodes*) is a wild species with a broad natural distribution through East Asia to Tasmania and New Zealand, but it is under intense cultivation across Asia, expanding rapidly into other parts of the world. It is now the world's third largest mushroom industry. This industry is expanding in a way that may threaten the future of the wild species. Loss of natural habitats, harvesting of wild mushrooms at an unsustainable rate, and the introduction of non-native strains into cultivated areas are all increasing problems. Loss of genetic diversity is also occurring within the industry so the destinies of the wild and cultivated forms are closely interrelated.

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