Some conceptual and practical issues in taxonomic research

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Issues concerning taxonomic research are dealt with in the Indian perspective and with reference to 'Flora of India'. Diverse species concepts and their interpretation introduced high subjectivity in taxonomic research as species being the unit of classification. Taxonomic authenticity cannot be added to our 'treatments' unless these concepts are understood in their entirety. Thoroughness in these concepts reduces variance in fixing the limits of species due to subjectivity. Different species concepts are reviewed in this light. Discrepancies in the application of infra-specific categories are also stressed. Variability in a tropical species and the difficulties in its assessment are emphasized. Synonymy and the rule of priority are considered known hindrances to the progress of taxonomic research. In view of limited taxonomic expertise, it is emphasized that our energies should orient towards 'Flora of India' in preference to local or regional floras. It is also viewed that specimens available to us are not put to full use in revisionary works. The lack of accessibility of specimens of different herbaria and old literature including illustrations are identified constraints in revisionary works. Organized information base of specimens of different herbaria, image database of both types and illustrations and their connectivity through WAN or availability through creation of a website and more effective documentation units in all taxonomic research centres are some suggested measures to overcome these problems. These measures ensure quality outputs and expeditious completion of the 'Flora of India' project.

THE living world is composed of more or less distinct entities which are called species. They represent an important level of integration in living nature. This recognition is fundamental since species occur as different units existing in nature. They are not only distinct from one another in ways that are recognizable but variations among them are essentially discontinuous. In other words, they are not graduated from one to another through intermediate forms.

Discontinuity of variations – The basis for limits of taxa

Variations in the plant world are either continuous or discontinuous. Continuity in variation without break does not signal anything to taxonomists. Obvious dissimilarities and natural and undeviating breaks enable taxonomists to draw delimitations among different groups of plants. The course of evolution promoted those plants which possess the combination of features advantageous and suited to their habitat and way of life. The present-day combinations of features in living plants are those that have been successful in the course of evolution[1]. The gaps between groups represent kinds of plants that have failed to evolve in the course of evolution, or, if they did evolve, have by now become extinct or have not been found by us so far. The gaps or discontinuities in variation thus represent combinations of these probabilities. On tracing some novelty, a taxonomist would first study the subject in detail and place it first in the family that it represents followed by the genus and finally taking it to the nearest (allied) species. He takes it nearer to the one which shows similarity in majority characters but differs from it in certain other characters discontinuously, which qualifies it as a new species. In other words, he is trying to place it in one of those gaps of variation or discontinuities in variation which is not yet filled. A taxonomist firmly believes that biologically there exist different kinds of species and that each species generates a kind of population. This notion is in contrast to the nominalistic concept which believes in the existence of individuals and not species. Equally important is the conviction he harbours that these species must be resolvable and recognized properly, placed and named into the existing functional binomial system of nomenclature. It is worth reconsidering diversity in concepts concerning species which have a bearing in taxonomic research.

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Species concepts

The *typological species concept* envisages that individuals of a species are assumed to have two sets of properties, essential ones and accidental ones. Essential features are the defining characteristics of a given species. The essence is deduced by observing a number of individuals and experiencing regularity, steadiness and universality (appearing unfailingly irrespective of collection locality). Accidental features vacillate more inconsistently depending on habitat factors and vary from one individual to another and hence are not gist of the species[2]. Taxonomists recognize species on a morphological basis. The justification for this practice is based on the assumptions that (1) morphological divergence parallels reproductive isolation, and (2) the presence of morphological gaps in sets of characters implies that groups of organisms separated by such gaps are reproductively isolated. Besides, identification based on morphology is practical while handling a large number of species.

An outgrowth of the typological–morphological concept is the *phenetic species concept.* Phenetic classifications are based on overall similarities where the constituent groups describe the distribution among organisms of as many features as possible including those which are not used in the original classification[3,4]. This concept identifies discrete groups of organisms and however makes no claim to infer evolutionary relationships. A definition based on this concept is: 'A species is a group of organisms not itself divisible by phenetic gaps resulting from concordant differences in character states (except for morphs such as those resulting from sex, caste, or age differences), but separated by such phenetic gaps from other such groups'[5].

The other concept widely popular is the *biological species concept* which is based on reproductive isolation between groups of organisms. Biological species are groups of interbreeding natural populations that are reproductively isolated from other such groups. Reproduction preserves the basic traits of the species and propagates it by successively continuing to reproduce like individuals. Proponents of this concept believe that reproductive isolation is a key to the process of speciation and hence the biological species presents the actual organization of organisms in nature. The biological species can explain genetic continuity in dealing with organisms that reproduce sexually. Similarly, the typological and phenetic concepts are easier to apply and are of more practical utility. The problem associated with the above concepts is that they cannot explain dynamism (mutability) in the species. This dynamism in the species can be brought in when species are considered as units of selection.

A *selection species concept* holds that a species is a system of genetically similar individuals and populations of it maintained as a cohesive unit by a set of selection pressures that balance the disruptive forces imposed by environmental or genetic factors. This system maintains a steady state through time as long as all forces are equally balanced. An imbalance in environmental and/or genetic forces acting on a population changes the selection pressures on that population, resulting in morphological, behavioural, ecological, physiological and genetic divergence from the cohesive species unit. Depending on the rate of change in selection pressures, reproductive isolation between diverging bisexual populations may proceed gradually or rapidly until the ability to interbreed is lost. However, a change in selection pressures, induced by shifts in environmental or genetic forces before the ability to interbreed is lost, may restore full reproductive compatibility. Taken as a system, the species may have its characters/character states evaluated at a given time (time zero). This can serve as an initial approximation of a species unit. For purposes of identification, such an initial approximation is adequate. The follow-up evaluations at subsequent times would produce refined estimates of the first approximation and also an insight into balance of disruptive and stabilizing forces, and the cohesiveness of a given species unit[6]. Hence this concept emphasizes dynamics in species and conveys considerable plasticity for evolution with changing times.

Now the essence lies, as Corner[7] rightly puts it: 'The human mind strives for generalizations, but I doubt if there can be any unified theory of species'. In nature, certain species exhibit total discreteness in contrast to fluidity exhibited by certain others. Both rigidity and fluidity co-exist in the plant world of the tropics, a reflection to the process of selection and evolution of a species through various influences of nature. Further, many other species present problems of unique nature. Possibly different concepts independently or together explain different species, their nature and behaviour. In certain cases, these concepts may prove insufficient to explain the intricacies of graduation/distinction of one to another. A taxonomist has to evaluate and understand thoroughly about the group prior to crystallizing his ideas in identifying the relative importance of various characters and their distribution in different component species. Unless these concepts are absorbed with the required perfection, we cannot add taxonomic authenticity to our 'treatments'. It also indicates how cautious one should be in the identification of a new species, as it demands both maturity and criticality.

Infra-specific taxa

Many regard infra-specific categories only as positional terms. Some others believe that they may be incipient

species in various stages of development[8]. If a species is broadly circumscribed, the typical element is to be contrasted with successively described variants and treated in a category subordinate to the species with respect to nomenclature. All included elements of the infra-specific rank are to be coordinated. When a single infra-specific rank is present, a trinomial form of nomenclature will be applied[9]. The term subspecies came into general use during the 19th century and was meant to designate taxonomic units just below the species level. Mayr[10] defines a subspecies as an aggregate of phenotypically similar populations of a species differing taxonomically from other populations of the species. The emphasis here is usually on the allopatric nature of the populations (two or more populations of a species which have widely separate and non-overlapping distributions). In other words, a subspecies is a segment of a species with a distinct area and more or less distinct morphology[11]. A near-equivalent term used in ecology is ecotype. The ecotype is also the basic unit in biosystematics. It is accepted as a phyletic unit adapted to a particular environment but capable of producing fully fertile hybrids with other ecotypes of the same species. The ecotypes of one species are not isolated by genetic barriers and remain distinct only because they thrive in ecologically different environments. Many ecotypes are the equivalents of geographic subspecies. Variety was the only infra-specific category recognized by Linnaeus. Over the years it has been used in different senses, sometimes just below species level to mean subspecies or as a second infra-specific taxon, below the subspecies level. Variety may be regarded as (1) a morphological variant of the species without regard for distribution, (2) a morphological variant having its own geographical distribution, (3) a morphological variant sharing an area in common with one or more other varieties of the same species and (4) a variant representing only a colour or habit phase[9]. Crowson[12] explained that a variety is a phenotypically distinguishable, genetically determined variant and the varietal characters behave as if they are determined by only one or few hereditary factors. Infra-specific classification of plants continues to be practised by taxonomists. With many overlapping definitions and perceptions, there is greater subjectivity seen in their usage. Despite some attempts, no universal standards could bring in their differentiation and these are sometimes equivalent in practice. European taxonomists tend to favour subspecies, whereas their counterparts in the United States usually employ variety[13]. Given the general inconsistency of practice found, some authors state briefly their philosophy of infra-specific taxonomy with a purpose that their classifications are interpreted correctly and in their viewpoint. Taxonomist should collectively promote greater standardization of infra-specific classification. What is more important, irrespective of the rank named is that a taxonomist should ensure himself that he is accounting only definable and consistent variations and not the freaks.

Taxonomic research

Fundamental botanical research revolves around floristic (listing of all plants of a given area) and monographic (study of a plant group for its entire range of distribution) works. A flora enumerates plants of a particular geographical area with a purpose to identify them. A monograph deals with a taxonomic group over the whole range of its distribution. The two approaches in the botanical research are complementary; the former forms a basis for the latter and the latter supports, supplements and refines the former. Also, the former furnishes the material and literature in local perspective, while the latter reviews it in the perspective of the entire range of distribution and with reference to allied taxa to bring in universal acceptance to the concerned taxon and its elements in their placement and nomenclature. Satisfactory delimitation of a taxon is the crux of monographic work. Splitting and lumping are two ways in delimiting a taxon. In flora the keys to distinguish different taxa are usually artificial (effective with reference to species mentioned in the flora), while the keys given in the monograph are supposed to be natural (reflecting gaps and fill-ups) as the study of plant groups involves in their entire range of distribution. Monographers review all the material available, understand diversity from the entire area of distribution and follow it up by review of the literature and improvement based on their own assessment. Their judgements are supposed to be unbiased and generally respected, if not necessarily concurred with[9]. It is such a monographic base that is desired to write the new 'Flora of India', and without such a basis it will be a compilation only carrying errors of the past literature and many *paper taxa*[14].

Why should we write flora again?

The Flora of British India[15] by Hooker and his associates is the only standard reference work on which botanists in India rely to identify and study the flora of the country. Since then several under-explored areas have been intensively surveyed and a large number of specimens were collected. Many new taxa have been described and some genera were split or merged, changing the circumscription of many taxa. The names of many have changed by the application of International Code of Botanical Nomenclature. Above all, the area covered under Hooker's work had undergone political transformation. Though Hooker's work is considered as one of the well-documented ones after Bentham's *Flora Australiensis*[16], it has outlived its utility as we could not

give so far any flora that could serve better. There is a genuine need to update the knowledge about various plant groups and correct the errors committed due to various limitations such as lack of access to study the plants in the field and lack of good and adequate collections at hand. Further, the specimens were sometimes inadequately described for the said reasons, making it difficult to recognize the plants. Redescriptions, thus become essential for many species. Also, characters not verifiable in the herbarium sheet are included in the keys of certain groups in some floras which make them inoperative for the purpose of identification. A good species will have sufficiently good number of specific marks and these are to be brought out to augment our floras. We have the opportunity, access and time to be more faithful to our plants. Hooker was more inclined in lumping the species to determine how few, and not how many, species are comprised. This is one extreme viewpoint and a more judicious approach is necessary to list all good species and develop a good flora. Now, the floras of many adjacent countries are under publication, assimilating the revisionary works carried on different taxa. The new national flora envisaged by the Botanical Survey of India (BSI) intends to incorporate the above mentioned changes[17].

Problems in morphology

Hooker described 14,900 species (angiosperms) in his *Flora of British India*. The present-day estimates of total species of independent India stand at 17,500. The limits of many of these species were drawn on a morphological basis and sometimes these limitations have been wrongly drawn, either narrowly or widely. Some naturalists consider every minute character, if tolerably constant or prevalent, as of specific value. They consider two or more doubtful species to be distinct till they are proved as the one and the same. *Vernonia shevaroyensis* Gamble which is allied to *V. arborea* Buch.-Ham. (=*V. monosis* Benth. ex C.B. Clarke) was erected based on Perrotteet's collection and delimited by leaf shape, tomentum, ribs of achene and the absence of glands between them. However, Matthew[18] felt that *V. shevaroyensis* is not distinct from *V. arborea* as there exist many individuals with intergrading characters from plains to hills. The absence of distinct discontinuity and inconsistency in variation in different habitat situations made the differences insignificant and hence reduced *V. shevaroyensis* to a synonym of *V. arborea*. The absence of type from Central National Herbarium (CAL) and its elimination from type locality placed taxonomists in a difficult situation to verify these contentions. Hooker and Thomson[19] stated that differences of habit, colour, hairiness and other organs than those of reproduction, are generally fallacious as specific marks, being attributable to external causes, and easily obliterated under cultivation. In practice, therefore, a species is usually what the taxonomist considers on the incomplete evidence available. As a result, along with many species awaiting description and naming, there are many others that have been described and named more than once. A good number of 'replacement taxa' were cited which refer to pairs of species of a genus with continuous range of distribution from plains to hills of which one occurs in the plains or extends up to lower elevations while the other takes off to higher elevations, where the former ceases to exit[18]. Examples include *Flacourtia indica, F. ramontchi*; *Urena lobata* ssp. *lobata, U. lobata* ssp. *sinuata*; *Atlantia monophylla, A. racemosa*; *Toddalia asiatica* var. *gracillis*, *T. asiatica* var. *floribunda*; *Canthium dicoccum* var. *dicoccum*, *C. dicoccum* var. *umbellatum*; *Maba buxifolia*, *Maba neilgherrensis*; *Wrightia tinctoria*, *W. arborea*, and *Hemidesmus indicus* var. *indicus, H. indicus* var. *pubescens*. Here the limits between pairs of species are clear and distinct and each taxon in the pair deserves its own identity and a name of its own. Though theoretically species are precisely definable, this is achieved only when the right kind of specific marks are diagnosed. It was stated that the species of genus *Polycarpaea* are difficult for discrimination, if attempts are made to distinguish them by the habit or shape of the foliage[20,21]. Majumdar[22] has used inflorescence and stipules as key characters, which were found inadequate. A recent revision of this genus has used more discernible characters such as presence or absence of radical leaves, the nature of indumentum, and colour and size of sepals and petals to delimit various species[23]. A good percentage of named species cannot be recognized on the basis of existing literature and hence need redescription. The endemic and rare *Leucas wightiana*, which is restricted to Tamil Nadu in southern India, is often confused with the more common and widespread *L. aspera*, *L. indica* and *L. zeylanica*. Recently, the taxonomy of these species was discussed at length and keyed out with their diagnostic characters and illustrated[24]. The aim of such redescriptions is to know the less-known more. Water plants are taxonomically difficult as they lack adequate herbarium material; a paucity of critical developmental details of various groups; a high degree of adaptability in form, structure and function and an apparent simplicity resulting from reduction and prevalence of convergence and parallelism[25]. Families like Podostemaceae and Hydrocharitaceae exhibit extreme reduction in the morphology and plants of the former are reduced to thallus.

The peculiarities of reproduction give rise to considerable problems in the delimitation of species. Earlier concepts emphasized that species are entities unable to cross or produce fertile hybrids and stressed the rigidity of species. It is now discovered that many

hybrids between species are partially fertile. The differences between a series of species become obscured by the development of these hybrids. Such situations are to be appropriately investigated. The existence of a series of related species with different multiples of the same basic chromosome number is known as polyploidy. Hybridization combined with polyploidy is thus a common cause of taxonomic confusion. Cook[26] remarked that the nomenclature of *Nymphaea* in India has been very confused and some names were often used in the wrong sense. Systematists should place considerable value on the importance of cytological findings in solving such problems.

It should also be our endeavour to look for characters missed, underestimated or misinterpreted by earlier workers. Recently an attempt was made to present the overlooked variations in *Phyllanthus polyphyllus*, a species confined to peninsular India and northern Sri Lanka. The description of this species in the earlier floras is varied and sometimes contradictory. Critical studies undertaken on material in Madras Herbarium (MH), CAL and Kew (K) revealed that ignoring the wide range of variability in its totality earlier, appeared to have led to variance in the description. Finally, few characters mentioned in the earlier floras were negated, two types of male flowers identified and an intergrading variation in the stylar portion of female flowers was observed[27]. Some taxonomists while working on local floras match the specimens with those in the herbarium to determine identity. It is an easy way to identify species more mechanically, but one is prone to lose the habit of looking at them scientifically and would often miss hidden characters and variability. In the specimens of *Justicia glauca* inflorescence portion with broader orbicular bracts look prominent. On careful studies, the author isolated some specimens in MH – the usual ones having larger leaves and longer internodes with one type of capsules enclosed by the bracts, while the isolated specimens have few smaller leaves and only one or two internodes and two types of capsules beyond the bracts. This is a report of heterocarpy in Acanthaceae, where the inflorescence is pedunculate. Though there are numerous such other reports where issues related to morphology were resolved after critical studies by taxonomists, the author presented cases drawn from his own experience, as he found it easy to explain.

Problems of fewer collections

Some species are known to science only from one or few collections which are insufficient to give a full picture of their variation, population structure and distribution. A recent scrutiny of duplicates of some rare species listed through Red Data Books revealed that many of them were not collected after their type collections. Thus the existence of such species seems to be either restricted to tiny pockets of type localities or they appeared as freaks or had vanished because of inviable population strengths. An effort to relocate such plants in Andhra Pradesh proved unsuccessful. The species include *Albizia thompsonii* (Andhra Pradesh, Orissa), *Phlebophyllum jeyporense* (Madhya Pradesh, Orissa, Andhra Pradesh) and *Taxocarpus roxburghii* (East Godavari and Visakhapatnam in Andhra Pradesh). *Pimpinella tirupatiensis* (Tirupati hills of Chittore district) and *Decaschistia rufa* (Ballepalle of Cuddapah) are also known for their limited collections in the Eastern Ghats. This is also the case with some species from the Western Ghats. They are known by type collections and include *Sageraea grandiflora* (Konni forest in Quilon district), *Impatiens munnarensis* (high ranges near Munnar Kanniamalai in Idukki), *I. anaimudica* (Anaimudi slopes in Idukki district), *I. johnii* (Kallar valley in Idukki), *Vernonia recurva* (Anamalai hills), *Actinodaphne lanata* (Nilgiris), *Buchanania barberi* (Nadari in Travancore), *Ilex gardneriana* (Nilgiris), *Memecylon sisparense* (Sispara in Nilgiri hills) and *Pavetta travancorica* (Courtallam hills). Some others are known only by one or two type collections and are equally less known for their ecology. They include *Vateria macrocarpa,* (Muthukulam in Boluampatty of Palghat divison) and *Melicope indica* (Avalanche, Bangitappal, Kunndha, Sispara, etc.). *Acer sikkimensis* var. *serrulatum* (Mishmee hills), *Acronema pseudotenera* (N. Sikkim), *Coelogyne treutleri* (Sikkim), *Pimpinella evoluta* (Naga hills) and *P. flaccida* (Nagaland) are also known by type collections or few collections from Eastern India. *Arenaria curvifolia* (Garhwal Himalayas, Uttar Pradesh) and *Microschoenus duthie* (Tehri Garhwal, Uttar Pradesh) are known for their limited collections from Northern India. Similarly, as many as 60 species are known by type collections only from Andaman and Nicobar islands and are not recollected so far[28–31].

Problems in nomenclature

The codification of nomenclature incorporated in the International Code of Botanical Nomenclature is mandatory in effect and resulted in the revision of many names to conform to these rules, particularly the rule of priority. The principle of priority (Article 11–12) rules that the first valid published name for an organism is the one to be retained and used. This principle sounds well in theory, but its practical application was complicated by the fact that many names published in obscure books and journals were not rediscovered until several years afterwards, when well-known names had to be rejected in their favour. Some taxonomists and bibliographers find great satisfaction in spending their time

digging out literature for publication dates and in finding out that a name was published two months or two weeks or two days earlier than another. For people familiar with bibliographic work, these diggings are endless and will result in endless name changes. Such activities should be definitely discouraged[32]. Principle of priority has thus become a serious cause of instability in plant nomenclature. Synonyms have been a source of trouble and confusion ever since plant names were given. There are at least 600–800 species in Indian floras, each one having close to 10 synonyms. Taxonomic inflation is also owing to botanists working over restricted areas, who exaggerate the relative importance of characters, or who institute new taxa out of inexperience. Deciding synonymy is now the greatest hindrance to the progress of systematic botany and it has been on the increase burdening taxonomic research. Species names are ascertained and recognized by means of typological procedure. Typological procedure, type specimens and associated protologues provide pragmatic starting points for all follow-up work on species and in standardizing or improving the communication of information about the names. It is known that many of our species need redescribing which have no representative specimens in India. The protologues of many species are sketchy and the types, scattered in international herbaria, are far from accessibility. In such a situation, the verification of type as a basis for every name has its practical limitations. Their accessibility is paramount to take decisions with respect to every name.

Role of herbaria

Herbarium is a dried and pressed collection of plants and arranged in pigeon holes in an accepted sequence of classification[9]. Specimens so preserved, once soaked and dissected, present all the characters in observable condition. Accompanied by full field notes (information that cannot be had after leaving the field) such as those on place of collection, habit, size and shape of canopy, habitat and characters that disappear on drying like scent, colour of flower and latex, it is valued as good as the original living plant. Although this argument sounds well, fresh specimens stand unmatched when they come for study. Many characters which come under field notes in general, prominently project and contribute to overall identity of the species in the field. This limits the herbarium taxonomist from visualizing habit of a species in its original habitat. Besides, improper pressing may sometimes lead to disfiguring of the specimen and certain characters. In spite of these limitations, herbaria with all the specimens and associated data assume great importance. There are about 60 herbaria in this country, including that of BSI[17]. Taxonomic botany is historically connected and the many present-day herbaria possess the rich legacies of old collections. These specimens work as basis in resolving taxonomic intricacies. The herbarium of Shillong (Assam) has the collections of N. E. Perry from Lushai and Garo hills and N. L. Bor from Aka and Naga hills. Also it has the sheets transferred by the forest department[33]; the herbarium of Pune (BSI) inherited the collections of T. Cooke and W. A. Talbot. Notable among other collectors are Kanitkar, Ranade, R. K. Bhide and Ryan. About 1,38,000 specimens are housed in this herbarium which includes 475 types[34]. The collections from MH include those of Peter Rottler of Tranquebar mission. Other collections include those of C. A. Barber, R. H. Beddome, G. Bidie, T. F. Bourdillon, A. G. Bourne, H. F. Cleghorn, Drew, W. Elliot, C. E. C. Fischer, J. S. Gamble, J. D. Hooker, M. A. Lawson, V. Narayanaswami, T. Thomson, R. Wight, etc. There are about 2000 type specimens and many authentic materials. At present, nearly 2,00,000 specimens are housed in this herbarium. The author's experience in MH indicates that critical studies of all collections may result in tracing a number of sheets with their annotations, which can be connected to specimens cited and/or descriptions discussed in the floras produced during that time. Hence, old collections are important and deserve to be used with care and caution. The important collections of other BSI herbaria were reviewed earlier[35–38]. Among the non-BSI herbaria, the Dehra Dun herbarium (DD) located in Forest Research Institute and College was started by J. S. Gamble in 1890. The erstwhile Saharanpur herbarium was merged with it in 1908. The DD now contains more than 3,00,000 specimens. It includes the collections of J. E. T. Aitchison, N. L. Bor, D. Brandis, J. F. Duthie, J. S. Gamble, G. Govan, B. H. Haines, U. N. Kanjilal, P. C. Kanjilal, G. Mann, H. F. Mooney, A. E. Osmaston, R. N. Parker and C. E. Parkinson. The Blatter herbarium located in St. Xavier's College, Mumbai houses more than 1 lakh specimens. The collections of Sedgewick, about 7000, were acquired by this herbarium. Other collections present are those of Acland, Lisboa, Banerjee, Mundkar and H. Santapau[34]. There are still smaller herbaria with holdings restricted from known local floristic activity. The general collections may be stopped now and future explorations may be by monographers for specific taxa as fresh specimens serve better in certain situations. Specialized collections may also include those of rare and endangered species when monitoring missions are taken up for such species. Herbaria attain significance based on number of specimens, their exposure to outside workers and finally their good maintenance. Their maintenance is important for other reasons too. Taxonomists in practice leave vouchers behind for further scrutiny and verification. Also, in every taxonomic work, it is customary to cite the specimens studied and it becomes a scientific compulsion to safeguard such specimens and make them

available to the researchers when necessary. There were arguments with regard to profitability of maintenance of huge collections in herbaria in view of high maintenance costs and the space occupied. There was a proposition that all duplicates should be pulped out after entering all the field data into the computer, as these specimens are rarely used and their maintenance is not worthwhile[39]. Such a proposal is impertinent in the Indian context as we are far behind in completion of our basic research on morphology of various groups. Massive collections in the herbaria are indispensable to document location-specific variations, the correctness and authenticity of the names given and in the verification of distribution data. These specimens may be needed any time; once pulped in haste, we never see them again. Most estimates, on global biodiversity were based on information available in the herbaria. Threatened status of different species was also assessed through scrutiny of herbarium specimens. All the publications generated in the form of Red Data Books from BSI were based on information mostly drawn from the herbaria. Rao[40] outlined the paramount role of herbaria in all-round development of biology.

Some suggestions

In Indian plant taxonomy, what is needed more is elaborate description encompassing a complete range of variations with illustrations of all species. The vegetative characters, neglected in the past, and others if any, should be studied to check whether any of them constitute more striking characters to enhance our understanding on flora. Some *Impatiens* spp. are delimited by the number of lobes in the upper lip of the flower which is recognizable only in fresh specimens, but not in the dried state. So far, no other character was reported to work out the identity of dried specimens. Likewise, some *Strobilanthes* spp. flower rarely and their identity is needed through study of vegetative characters. Critical studies of literature and specimens will essentially lead to problem identification in different groups. This should be an important taxonomic activity that helps us to know where we stand with respect to different groups and also for further improvement. Unfortunately, we set different (unwritten) standards of seriousness for flora and revision works. It is often felt that a person involved in flora will have no time to look critically at each specimen he collects and is condoned even if there are any omissions or wrong identifications. It is contended that someday these specimens will be subjected to a revisionary study and can be taken care of at that time. But it is often ignored that a person who collects the specimens is at a greater vantage in determining the identity than the one who later re-examines it. Our experience in the field and observations on fresh material using advanced instrumentation should improve the quality of our descriptions. We should persist in our efforts to recognize our species on a morphological basis. Nomenclature issues, phenetic analysis, phylogenetic analysis (cladistics), etc. in fact should stand secondary at this point of time, as descriptions and diagnostic keys of many groups require improvement. Proliferation of floras in the published form without criticality is a muddle that affected the taxonomic communities. The ways and means of such publications have become simple; prepare check-lists based on specimens available (take the names granted for correctness) at various herbaria and then append each one with description, citation, phenology and uses from the known provincial floras. Specimen numbers from the study area from different herbaria are noted to quote them under 'specimens studied' (which they little do!) to add authenticity. Such unscrupulous publications make taxonomic research unimpressive. More often, the author of such publications is the only one who profits, as publications and not their quality still work as a measure of one's performance in promotions. The result is, we have numerous floras around and none is of any help when it comes to resolve any intricacies you come across in various taxa. Earlier provincial floras, in contrast, supplemented each other in furnishing information. For example, Fl. Presidency Madras is known for elaborately written generic keys and generic descriptions[41]; on the other hand Fl. Presidency Bombay[42], present specific descriptions in greater detail. Such floras in combination to-date work so effectively and only very few floras can match them in their utility. When regional or state or district floras are to be planned for publication, the author should bear in mind the following points to justify publication: (1) All endemic elements of the area are to be exhaustively described and illustrated. (2) Keys provided should at least have two to three morphological characters to distinguish different species. (3) Spot characters if any are to be given along with illustrated sketches which considerably help one to identify the plants in the field. (4) Characters provided in the keys may be shown as far as possible in the illustration. Wherever possible, the name of herbarium where type is located may be mentioned under critical taxonomic notes.

One of the strengths of the national institutes like BSI compared to other institutions is their specimen. There are about sixty notable herbaria in the country harbouring 36 lakh specimens. A database of these specimens and its accessibility through a network (WAN) or by creating a website for basic accessibility of information on the availability of specimens in different herbaria would be of immense help. This organized database can avoid unnecessary handling of sheets, particularly old ones, if specimens are to be consulted for taking data from labels regarding use, local name, occurrence,

availability, etc. from different herbaria[43]. Besides, the assessment and update of this database help us to review areas of exploration periodically. One of the components of Capacity Building in Taxonomy, besides improving trained manpower, is to enhance the infrastructural facilities. A type is considered as a taxonomist's reference point to work on any name. The taxonomist's difficulty starts if the protologue is with scant description and type becomes inaccessible. Types in various herbaria run to a few thousands and there is no organized type database. Image database of the types was attempted few years ago in MH, but could not take off as software developed proved ineffective and pictures taken from the camera coupled to a computer could not cover the entire herbarium sheet. Such problems may now be surpassed with improved technology. A recent review by Heywood[44] emphasized how important the electronic databases and information systems are in taxonomic research. He mentioned how projects like Euro + Med PlantBase are proving to be effective in providing on-line database for the vascular plants of Europe and the Mediterranean. This is also the case with flora of China and flora of Mesoamericana, which are going simultaneously for web versions to cater to the social needs of people at large, besides facilitating easy information access to taxonomists. A photograph taken from a type can be scanned and the image can be stored for ready consultation. Such an image takes a memory of 4–5 MB and a CD can accommodate 130 type sheets. These can be easily transported when necessary for consultation and can serve better than microfiche (Figure 1). The competence of a taxonomist and the quality of work he produces increase with experience and also how successfully he uses all the available information on the concerned taxon. As the subject is historically connected, he should be aware of the explorations in Indian botany from the late 18th century onwards, the important events, the collections of noted botanists and their availability at various herbaria, the literature in the form of floras, monographs, checklists and the location of types. A great number of illustrations of Indian plants exists today in remotely published or unpublished condition. Majority of them are not available to taxonomists, particularly people working in non-BSI institutions. Indifference and insensitivity are not uncommon elements in the fellow scientists. When literature or specimens are required from the other herbaria, it takes its own time and depends on the will of the persons from the other end. In these days of information boom and fast communication, taxonomists still follow old methods and lose time. Notable illustrations from *Hortus Malabaricus* by Van Rheede (700), *Her-*

Figure 1. *Clematis gouriana* Roxb. (Barber's collection) Raika to dia, Ganjam District, 29 January 1900.

Figure 2. *Nymphaea rubra* Roxb. ex Andrews (From: *Illustrations of Indian Botany*, Wight, R., 1840).

barium Amboinense (696 plates) by Rumphius, *Plantae Asiaticae Rariores* by N. Wallich (in three folio volumes and 296 plates), *Plants of Coromandal Coast* (300) and *Icones* (2595) by Roxburgh, *Illustrations of Indian Botany* (in two volumes and 182 colour plates), *Icones Plantarum Indiae Orientalis* (2101 plates) and *Spicilegium nilgherrense* (with coloured copies of the portions of the plates of icones) by Robert Wight, *Illustrations of the Himalayan Mountains* (in two volumes and 100 plates) by Royle and *Flora of Javae and Rumphia* (several folio volumes with colour plates) by Blume have limited accessibility. All these illustrations can be digitized and may be made available in all research centres of taxonomy. As in the case with types, each digitized illustration can take a memory of 3–5 MB and a CD can accommodate 130–200 pictures (Figure 2). The woes of a taxonomist cannot be lessened by advanced instrumentation, extra funds and personnel but by such facilities, types and a well coordinated support from other allied sciences.

India boasts of the third largest scientific manpower in the world, but there are few taxonomists in the country. Khoshoo[45] has rightly pointed out that taxonomists are a vanishing tribe among the biologists and are greatly overshadowed by the biotechnologists and environmentalists. The failure to enthuse students in taxonomic research rests with universities as they stress more on modern branches of biology and under-rate taxonomy as a science of routine plant collection and follow-up identification through matching of specimens in the herbarium. One of the important functions of taxonomy is to identify an organism and assign it a correct name. Scientists of other branches of biology scarcely realize its importance. They give scant respect to properly reproduce the correct names of taxa on which they had worked. A recent publication in *Current Science*[46] indicates that out of 217 articles published during 1990–1999 in this journal, only in 60 articles were the names of plants correctly reproduced. Mistakes pertaining to spellings, punctuation marks, abbreviations and absence or misuse of parentheses were common. Thus modern biologists neither give attention nor importance when it comes to the correct names of the subjects they work on.

When the 'Flora of India' was envisaged, the work was thought to be of semi-monographic and semi-compilation nature, so that the survey could show some tangible results within reasonable time[47]. If revisions are to be seriously undertaken in the country, the vast collections now remaining under-used in the national and regional herbaria (now largely used in matching for routine naming of new collections) are required to be studied and/or loaned to specialists working on different groups. This is possible only by adopting technologies available, connecting the information base of all the herbaria and make it accessible to all the scientists working on different groups. In future we require to handle more plants and more new species with enhanced collection activity, growing herbaria and increasing the number of species. We should remember that the number of described species is only 1,26,188 out of the 4,00,000 estimated unknown[48]. The computer facilities in taxonomic laboratories are hence a must to execute the assigned jobs in the given time targets. This spade work is necessary to prepare a solid ground to make the 'Flora of India' a success.

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Tuberculosis research in India and China: From bibliometrics to research policy

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India and China lead the world in the incidence of tuberculosis (TB), accounting for 23% and 17% respectively, of the global burden of the disease and hold the 15th and the 18th positions in terms of incidence per 100,000 population. But India accounts for only about 5–6% of the world's research output in this area and China a paltry 1% as seen from papers indexed in three international databases, viz. PubMed, Science Citation Index and Biochemistry and Biophysics Citation Index over the ten-year period 1990–1999. Thus there is a tremendous mismatch between the share of the burden of the disease and share of research efforts. Is such mismatch acceptable? It raises the question 'should resource-poor countries invest in research or should they depend on research performed elsewhere and invest their meagre resources predominantly in health-care measures?' We argue that both India and China should invest much more in research than they do. We have also mapped TB research in the two countries and identified institutions and cities active in research, journals used to publish the findings, use of high impact journals, impact of their research as seen from citations received and extent of international collaboration. Although China performs much less research than India and its work is quoted much less often, it seems to have done far better than India in health-care delivery in TB. Perhaps the Chinese are better able to translate know-how into do-how than the Indians.

THE nature and extent of health research undertaken in developing countries is a matter of great global concern. Research in developing countries is characterized by a grossly inadequate research capacity and research productivity. In addition, too high a proportion of the research that is done is not sufficiently focused on the health problems of the countries concerned. Unfortunately, these issues have not attracted adequate research attention. This paper is based on the premise that collecting better and more comprehensive data is the first

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