SYSTEMATIC BOTANY

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Summary

Plant systematics is an ancient science based firmly in the empirical tradition. It has its roots in the study of medicinal plants and agriculture. The formulation of modern classifications involves the accumulation of taxonomic data via observation and experimentation. From these data generalities on evolutionary relationships are induced and a classification or classificatory hypothesis formulated. Classifications change when new data falsify the existing ones. Classifications may change but names, for the most part, remain constant. Within any given classification each taxon can bear only one scientifically valid name. DNA sequence data have challenged most of our major classificatory concepts. Groups such as algae, bryophytes, pteridophytes, and gymnosperms have all proved to be paraphyletic, and even sometimes polyphyletic. As a result, they have had to largely be abandoned. In the last two decades of the twentieth century, cladistic philosophy has initiated a major paradigm shift, with classifications being replaced by cladifications and the naming of groups abandoned in favor of naming clades. Although empirically sensible and desirable, cladifications are not yet in a form that can serve the needs of most users of classifications, including conservationists.

1. Introduction

Few sciences can be as intimately connected as taxonomy and biodiversity. In fact, the utilization and conservation of plant resources would be impossible without the science of systematic botany. Plant species need to be scientifically named not just for the sake of naming them but because this name acts as a key to information associated with that species. In turn, it is this information that we use to either exploit or care for the plant concerned, or for the habitat in which it lives. With more than 240 000 extant species of flowering plant, the process of naming needs to be done in a careful and systematic manner.

The hierarchical framework dictated by the International Code of Botanical Nomenclature is used to express the pattern of relationship between taxa and makes for easier retrieval of information associated with plant names. It is this pattern of relationship that also enables us to identify plants. The identification of plant species is one of the most important tasks in the conservation process. It is this pattern of kinship that also gives classifications a certain amount of predictive capacity. For example it enables researchers to deduce that if a species has anti-malarial properties, then so may some of its relatives.

Patterns of relationships among plants have been recognized for thousands of years. However, it is only recently that the reason for this has become known; that is the realization that plant species are genetic and evolutionary entities, that they are phylogenetic phenomena. Plants that seem related in most cases do so because they evolved from a common ancestor. The fact that species are phylogenetic entities requires plant systematists to have a profound comprehension of evolutionary processes and their end products, and to understand how the genesis of species, known as speciation, occurs.

Before a species can be named and classified, taxonomists have to collect data on it. The collection of these data is an empirical and therefore experimental pursuit. However, the placement of species within the taxonomic hierarchy adds a subjective element to the process. Thanks mainly to the advent of microcomputers, attempts have been made to remove this subjectivity via statistical or computational methods.

Because of scientific necessity, all classifications are based on specimens housed within herbaria. It is these voucher specimens that anchor the theoretical taxonomic framework to the physical world of real entities. Among other things, these specimens enable taxonomists to either verify or falsify existing classificatory hypotheses and to extend their research. Herbaria also represent arks of plant diversity and floristic models of the earth's phytosphere.

Herbaria, many of which house millions of specimens, have benefited substantially from the information revolution brought about by advances in computer technology. Computers with their ability to store and retrieve large quantities of data, and also to transmit and present such data via the Internet, make them ideal for use in taxonomy. Such data include information of importance to the non-taxonomic community. Conservationists, for instance, now have easy access to distribution patterns and ecological data obtained from herbarium specimens. Computerized data are not just restricted to written information but can include maps and plant images of various sorts. The creation of interactive, multiple entry keys for plant identification has taken the forefront, and the employment of artificial intelligence has begun to minimize the chances of mistaken identifications. Botanical information technology has changed the way taxonomists work more than any other technology since the invention of the printing press in Europe.

Because of a wide range of new data (in particular nucleic acid sequence data) and newly employed analytical methods (in particular cladistics), the higher-level classification of photosynthetic organisms has undergone a revolution. Nowhere is this more clearly seen than with algae. Once seen and taught as a coherent group, these organisms are now considered to span several different kingdoms, and some algae (blue-green algae) are actually bacteria. The range of different characteristics and lifecycles exhibited by these so-called algae is almost unrivaled anywhere else among the photosynthetic biota. In the end these organisms are linked by only three characteristics: their ability to photosynthesize (albeit using quite different chemicals), their less complex overall level of organization, and their aquatic habitat.

Despite their diversity, the photosynthetic organisms seem to have made the transition to land only once, via an evolutionary line of plants called the green algae. This group, more aptly called the Chlorophyta, is now known to be on the same evolutionary branch as the terrestrial plants and are placed with them in the Kingdom Plantae. The events surrounding their transition to land are still poorly known and available data are sparse and conflicting. Certainly, the most primitive of the presently extant terrestrial plants, the so-called bryophytes, are now thought to be polyphyletic, and two of these, the liverworts and mosses, may even have come into existence much later via secondary reduction to a simpler form. The mosses, however, show some strong connections with the Rhyniophyta, a group of extinct pteridophytes represented by some of the earliest known fossilized land plants.

The pteridophytes, also known as the ferns and fern allies, are now thought to represent a level of organization rather than a monophyletic group. Members are typified by a similar lifecycle, and characterized by the production of spores and a separate gametophyte generation. Extant groups of pteridophytes exhibit a wide and disjunct range of morphology and anatomy, each representing a progressively more advanced condition. Unrelated groups with a similar level of organization and life history are referred to as belonging to the same evolutionary grade. This contrasts with an evolutionary clade in which plant groups of different or the same levels of organization and life histories are connected by common ancestry, that is they form a monophyletic lineage. The extinct Progymnosperms more or less span the gap between the pteridophyte condition and the spermatophyte (or seed-bearing) condition, and the Pteridosperms (early gymnosperms) still possess many pteridophyte characteristics.

The gymnosperms or plants with naked seeds may be polyphyletic or monophyletic; the evidence for both is equally strong. Once again, the gymnosperms represent a level of organization rather than a coherent phylogenetic group. The evolution of seed and pollen enabled their adaptation to drier conditions than most pteridophytes can handle and members of *Welwitschia* are desert dwellers. This movement away from the land-water interface into drier habitats has characterized the evolutionary adaptation of land plants.

The angiosperms, distinguished by among other characteristics the production of flowers and fruit, had their origins from within the gymnosperms but from precisely which ancestral stock is still a source of contentious debate. This controversy is firmly tied to differing interpretations concerning the origin of the flower. In particular, two theories, the euanthial (the flower is a modified branch) and the pseudanthial (the flower is a modified set of branches), are diametrically opposed and have equally strong supporting evidence. Arguments for both monophyly and polyphyly have been muted but nucleic acid sequences support a monophyletic origin. Co-evolution with dinosaurs (for 40 million years) as herbivores and insects (for the past 120 million years) as pollinators probably played a part in the appearance, subsequent divergence, and eventual rise to dominance of the angiosperms. Early habitat preference, and place and time of appearance are still not satisfactorily resolved. Whatever their origins, modern data supports a Hallier-Bessey type classification in which the Magnoliales and allies (the Magnoliidae) are basal within the angiosperms. However, the cladistic analysis of molecular data has led to a restructuring in higher-level angiosperm classification (family and above) and will, in the twenty-first century, probably see classifications (and their nomenclature) replaced by cladifications. Although cladifications are seen as being advantageous by many biologists, they will probably be less useful to the average end user of taxonomy who is primarily interested in getting to know a local flora by identification and access to the literature associated with the identified plant via its name.

2. Aims and Philosophy of Plant Systematics

The main aim of plant taxonomy is to produce a congruent workable system of classification for all known fossil and extant plant species. However, with between 323000 and 522733 types of photosynthetic organisms recognized, this is not a simple or easy task (see Table 1).

Group	**Number of species**	Alternative Estimate
Cyanobacteria	500	—
Euglenophyta	1,000	800
Dinophyta	2,000	1,200 / 4,000
Haplophyta	500	—
Chlorarachniophyta	6	—
Rhodophyta	5,000	10,000
Chrysophyta	1,000	500
Bacillariophyceae	5,000	5,600
Phaeophyceae	2,000	1,500
Chlorophyta	7,000	6,000 / 16,000
Marchantiophyta	7,000	—
Anthocerotophyta	100	—
Bryophyta	15,900	—
Pteridophytes	12,000	—
Spermatophytes	422,127	250,000
Lichens/Mycophycophyta	25,000	16,500
Total: 506,133		
Highest estimate: 522,733		
Lowest estimate: 322,506		

Table 1. Numbers of known photosynthetic species

The following list represents the endeavors and goals of plant taxonomy.

1) To understand:

- the spatial and temporal genecological dynamics of plant populations and their gene pools,
- the nature and biology of plant species,
- how species evolve, and the forces that promote and control this process, and
- the spatial and temporal patterns of phenotypic variation exhibited by populations and species

2) To use this understanding to render:

- descriptions of all plant taxa from the intraspecific to domain level,
- hierarchical classifications that best express the diversity and evolutionary relationships of extant and fossil plant species,
- a system of scientific names which is unambiguous and which interfaces with

both the classification and the immense body of information already in existence,
- analytical keys as an aid to the identification of plant diversity, and
- an understanding of how and why the decision making was undertaken so that readers and other workers will appreciate, even if not accept, the findings

The eventual outcome of this process would be to name and describe the world's flora and to carry this information within a coherent and universally applicable system of classification. The task of classifying the world's biodiversity is far from complete. Estimates vary from authority to authority, but it has been suggested that only 1.5 million organisms out of a total of between 5 million and 10 million have been described and named. It is believed that there are some 50000 unnamed higher plant species, 15000 of these in South America alone.

2.1. The Role of Plant Classifications in Life Support Systems

Classifications contribute substantially to the understanding and management of earth's life support systems. Not only do they supply us with unambiguous names that we can use for communication, but they also help us to comprehend the extent of plant diversity and supply information about the role these species play within the biosphere. Sadly, if present extinction rates continue to accelerate, as much as 50% of the worlds' present biodiversity will have become extinct by the end of the twenty-first century. In fact, it has been estimated that some 1 million species will become extinct before the year 2030. Presently 10% of the world's flora (some 30000 species) is classified as threatened. Some groups are more affected than others, for instance 29% of all palms are currently endangered. Many species will disappear forever without us knowing anything about them or their potential to enrich or sustain our world. The formulation of sustainable conservation strategies for this diversity begins with knowing what exists. That is it must have a name and a description. Information on plant ecology, life-history, chemistry, geography, and so on is also required. Plant systematics has a role to play in every phase from plant discovery to data collection to published management policies.

In addition to their ecological role, plant resources also have an important economic role. The exploration of the seas and new lands by Europeans, during the Middle Ages, was partly driven by the search for cheaper supplies of spices. By the 1800s, Economic Botany was an important pursuit in many European countries. England, for example, maintained a string of tropical gardens that were used to explore the agricultural and economic potential of tropical plants, such as sugarcane and rubber. Germany sent out special expeditions to search for economically important plant species. However, this emphasis began to change and for most of the twentieth century economic botany was largely ignored. In the 1990s, due partly to the Aids crisis and pharmaceutical drugs being beyond the financial resources of most of the world's population, the interest in ethnobotany, in particular alternative medicines, was revived. Ethnobotany not only deals with indigenous botanical knowledge but also with the ethics behind bioprospecting and intellectual property rights. The resurgence of interest in ethnobotany has been coupled with a growing global awareness of environmental issues and problems.

2.2. Philosophical Basis of Plant Classification

It is often said that taxonomy is not an empirical science—however, this is not the case. In fact, unlike many other disciplines it utilizes data collected through experimental, analytical, descriptive, and developmental research. These data are then used to induce generalities about relationships and phylogeny. In turn these generalities are used to deduce a classification. This classification is the resulting hypothesis. It is not unusual to have several different classifications, or hypotheses, which explain the data equally well. These classifications can then be verified (i.e. do new data confirm the hypothesis?) or falsified (i.e. do new data refute the hypothesis?). Because a hypothesis can be wrong and still have new data support it, falsification (the hypothetico-deductive method of Popper) is now the more acceptable route taken. Phenetics, by using multivariate analysis, adds a statistical dimension of certainty to the results.

Cladistics works in a similar manner. Data are used to induce generalities about the evolution of characteristics, known as character evolution (the diagnostic features, structures or characteristics of plants are referred to in the botanical literature as characters). Computer programs are then used to deduce a cladogram based on parsimony. The end cladogram is the resulting hypothesis, which can then be either verified or falsified.

Cladistics claims to be more empirical than traditional phylogenetic classifications, and in the deduction of a hypothesis this is certainly the case. However, during the inductive phase of both processes, the inference of generalities (whether about patterns of relationship or polarity of structures) is largely, although not exclusively, subjective. Both methods follow sets of rules based on their underlying philosophy; but those of cladistics are unquestionably more rigid. The goals of cladistics differs from that of classification in that it aims to understand the evolutionary pathways of plant groups and to present this in the form of a cladogram, which may or may not be rendered into a cladification. Cladograms are more the end product than a means to a name. Both phenetics and cladistics differ from the more traditional classificatory approach in that their results are deduced mathematically, whereas in the traditional method the resulting hierarchical classifications are obtained more subjectively.

In the traditional phylogenetic procedure, a taxonomic revision is usually undertaken when problems are encountered in trying to identify herbarium or field specimens using an older classificatory system. In other words new data no longer fits with past observation. The new revision aims to resolve these problems by proposing an adjusted classification, which takes into account the new evidence. Although the initial collection of data may involve a reductionist approach, the synthesis of evidence is holistic in nature. In dealing only with nucleic acid sequence data, molecular systematics is more heavily reductionist in its approach and, to some extent, leans toward scientific determinism in its philosophy. In the end the aim of plant taxonomy, molecular systematics, and cladistics is, despite their differing philosophies, the same. That is they all attempt to understand the patterns of diversity exhibited by plant species and to establish the evolutionary events that led to it. Plant systematics not only provides the rest of botany with names but also depends on other disciplines for data that may be useful in making classifications. As a consequence of the process of classification, plant systematists add information to the literature about the plants they have studied. In fact, classifications are both information storage and information retrieval systems. This makes them ideal for computer-based information technology. End products of plant systematics include: research papers, plant descriptions, analytical keys, checklists, illustrations, catalogues, manuals, floras, field guides, cladograms, and monographs. Plant systematics will doubtfully be finite in its goals.

3. History and Development of Plant Systematics

Within recorded history, all early peoples had systems of named plant types. These usually localized knowledge systems are generally referred to as folk taxonomies or ethnotaxonomies. In such systems names are commonly allocated on the basis of plant use. That is plants would have received names based on whether they were edible or poisonous, whether they had perceived medicinal or magical properties, and whether they were used for craft work or as building material. In folk taxonomies plant relationships are rarely taken into account and so they can scarcely be considered scientific in the empirical sense, although they are still invaluably useful and of important survival value. Although essentially simple in format, these systems nevertheless enable users to make distinctions between closely related plant types as accurately as any modern classification can. It is this inherent usefulness, combined with their simplicity and accuracy that has kept folk taxonomies in use. It is thus not surprising that the first written botanical works were based on such folklore systems.

In particular, ancient authors concentrated on plants of medicinal or ethnobotanical value; such works are referred to as herbals. The oldest surviving botanical work, the *Pen Ts'ao*, falls into this category. Written 4800 years ago by the Chinese Emperor Chi'en (Shen) Nung, it detailed some 365 medicinally and agriculturally used plants. The Ebers Medical papyrus from Egypt (3500 BP), an Assyrian herbal (1700 BP), Sumerian clay tablets with plant prescriptions, and the Celtic Ogham alphabet—which is based on the names of 20 sacred trees—show widespread interest in plants and probably only represent the tip of a much larger body of ancient information. Because these classificatory arrangements are not based on relationship (i.e. they make no attempt to place together plant species that look similar), they are said to be artificial.

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Biographical Sketch

Dr. Ashley Nicholas was born August 15, 1954, in Zambia, and is now a South African citizen. Ashley obtained his B.Sc. from the University of Natal, Pietermaritzburg, in 1976, majoring in Botany and Zoology. His B.Sc. (Honors) was obtained in 1979. His research for this degree involved a taxonomic treatment of *Drosera* in the summer rainfall regions of southern Africa. For his M.Sc. degree he undertook a taxonomic revision of the broad-leaved species of *Asclepias* in southern Africa, obtaining this qualification in 1983. Since 1980 he has continued to work on members of the family Asclepiadaceae and enrolled for a Ph.D. at the University of Durban~Westville in 1994. His doctoral thesis involved a taxonomic revision of the subtribe Asclepiadinae in southern Africa, and covered 23 genera and 182 species. He was awarded the degree in 1999 and also received the South African Association of Botanists

Bronze medal for the best botany Ph.D. produced in the country for that year.

Between 1981 and 1985 Ashley curated the Donald Killick Herbarium for the Department of Forestry in Pietermaritzburg, leaving to join the staff of the National Herbarium of the Botanical Research Institute in Pretoria. In 1988 he was selected as the South African Liaison Botanist and sent to Kew Gardens, England. He occupied this position for three years and took the opportunity to visit and consult with herbaria in England, Ireland, and the US. In 1994 he accepted a teaching position at the Botany Department of the University of Durban~Westville, where he still lectures. His teaching duties include modules on plant diversity, taxonomy, conservation, and research methodology. He also curates the Ward Herbarium, which is attached to the university. His postgraduate students pursue research topics in taxonomy, with a focus on the order Gentianales in southern Africa. He also has postgraduate students looking at aspects of gene conservation in endangered plant species.

Ashley has published 43 papers, mostly on the Asclepiadaceae, which continues to be his main research focus. However, he has also published on the taxonomy of families as diverse as the Brassicaceae and Droseraceae. He has also published on aspects of herbarium management, in particular on herbarium pests, and on nomenclatural issues. Ashley's expertise is often sought by other authors on the Asclepiadaceae as it manifests itself in Africa. He collaborates with scientists in England, Germany, and elsewhere in South Africa. He is also a member of the South African committee of SABONET and is involved with the Zulu Plant Names Project, which aims to document and preserve indigenous knowledge.