Chapter

1

Plants, Taxonomy and Systematics

Taxonomy (or systematics) is basically concerned with the classification of organisms. Living organisms are placed in groups on the basis of similarities and differences at the organismic, cellular, and molecular levels. Described species of organisms on earth were estimated between 1.4 million and 1.8 million (Stork, 1988; Barnes, 1989; Hammond, 1992). Wilson (1992) estimated that roughly 1.5 million species of described species comprised 73.1% Animals, 17.6% Plants, 4.9% Fungi, 4.1% protists and only 0.4% Bacteria. Hammond (1992) proposed a working estimate of 12.5 million species of organisms on earth consisting of 9.6 m animals (1.2 m described), 300,000 plants (250,000 described), 990,000 Fungi (80,000 described), 400,000 protists (90,000 described) and nearly 400,000 bacteria (only 6000 described).

The United Nations Environment Programme's *Global Biodiversity Assessment* published by Convention on Biological Diversity (2001) estimates the number of described species of living organisms as approximately 1.75 million, slightly more than 10% of estimated 14 million species. Whereas nearly 90% of estimated plant species have already been described (270,000 of 300,000), only 12.5% of animals (1.3 m of 10.6 m), 4.7% of Fungi (70,000 of 1.5 m), 13% of Protoctists (80,000 of 600,00) and only 0.4% of Bacteria (4,000 of 1 m) have been described so far. The list grows every year. Subsequent publication by Chapman (2009) puts figures of described plant species as 310,129 (of 390,800 estimated) that includes 268,600 described angiosperms (estimated 352,000). The more recent estimates, however, put figures of flowering plants only as around 400,000 (Edwards, 2010 on Physorg.com). Best estimate by Census of Marine life, published by Mora et al (2011) in PLoS Biology puts total number of Eukaryotic species on earth as 8.7 million, with 6.5 million species on land and 2.2 million in oceans, as against the earlier rough estimates between 3 million and 100 million. These 8.7 m species comprised 7.77 m animals (954,434 described), 611,000 Fungi (43,271 described), 298,000 plants (215,644 described), 36,400 Protozoa or protists (8,118 described) and 10,358 bacteria (described, predicted 9680). Only 1.2 m species of 8.7 m estimated have been described and catalogued. Furthermore, the study says a staggering 86% of all species on land and 91% of those in the seas have yet to be discovered, described and catalogued.

Pappas (2016), concluded that there may be 100 million to even 1 trillion species on this planet, based on scaling rules that linked the number of individual organisms to the number of total species. The list grows longer every year.

Christenhusz and Byng (2016) who have compiled a list of estimated number of genera and species in families recognised mainly in APG IV (2016) and other recent classifications estimate described and accepted number of plant species as ca 374,000, of which approximately 308,312 are vascular plants, with 295,383 flowering plants (angiosperms, including 74,273 monocots). Global numbers of smaller plant groups are as follows: algae ca 44,000, liverworts ca 9,000, hornworts ca 225, mosses 12,700, lycopods 1,290, ferns 10,560 and gymnosperms 1,079.

Most recent study by Brenden et al (2017) estimates suggest that there are likely to be at least 1 to 6 billion species on Earth, and in contrast to previous estimates, rather than being dominated by insects, the new Pie of Life is dominated by bacteria (approximately 78 %), protists 7.3 %, plants 0.02 %, Fungi 7.4 %, and animals 7.3 % (Fig. 1.1). Classifying these organisms has been a major challenge, and the last few decades have seen a lot of realignments as additional ultrastructural and molecular information piles up. These realignments have primarily been the result of realization that the branches of the phylogenetic tree must be based on the concept of monophyly, and each taxonomic group, kingdoms included, should be monophyletic. Unfortunately only a fraction of these estimates, just 1.5 million species have been described.

Before attempting to classify the various organisms, it is necessary to identify and name them. A particular group of individuals, unique in several respects, is given a unique binomial, and is recognized as a species. These species are grouped into taxonomic groups, which are successively assigned the ranks of genera, families, orders, and the process continues till all the species have been arranged (classified) under a single largest, most inclusive group. Classifying organisms and diverse forms of life is challenging task before the biologists.

PLANTS AND KINGDOMS OF LIFE

Plants are man's prime companions in this universe, being the source of food and energy, shelter and clothing, drugs and beverages, oxygen and aesthetic environment, and as such they have been the dominant component of his taxonomic activity through the ages. Before attempting to explore the diversity of plant life it is essential to understand as to what is our understanding of the term **Plant**, and the position of plants in the web of life. Traditionally, the plants are delimited as organisms possessing cell wall, capable of photosynthesis, producing spores and having sedentary life. A lot of rethinking has resulted in several different interpretations of the term plant.

Two Kingdom System

The living organisms were originally grouped into **two kingdoms.** Aristotle divided all living things between plants, which generally do not move or have sensory organs, and animals. Linnaeus in his *Systema naturae* published in 1735 placed them under **Animalia** (Animals) and **Vegetabilia** (Plants) as two distinct kingdoms (Linnaeus placed minerals in the third kingdom Mineralia). Linnaeus divided each kingdom into classes, later grouped into phyla for animals and divisions for plants. When single-celled organisms were first discovered, they were split between the two kingdoms: Mobile forms in the animal phylum Protozoa, and colored algae and bacteria in the plant division Thallophyta or Protophyta. As a result, Ernst Haeckel (1866) suggested creating a third kingdom **Protista** for them, although this was not very popular until relatively recently (sometimes also known as **Protoctista**). Haeckel recognized **three kingdoms**: **Protista**, **Plantae** and **Animalia**.

Two Empires Three Kingdoms

The subsequent discovery that bacteria are radically different from other organisms in lacking a nucleus, led Chatton (1937) to propose a division of life into **two empires**: organisms with a nucleus in **Eukaryota** and organisms without in **Prokaryota. Prokaryotes** do not have a nucleus, mitochondria or any other membrane bound organelles. In other words neither their DNA nor any other of their metabolic functions are collected together in a discrete membrane enclosed area. Instead everything is openly accessible within the cell, though some bacteria have internal membranes as sites of metabolic activity these

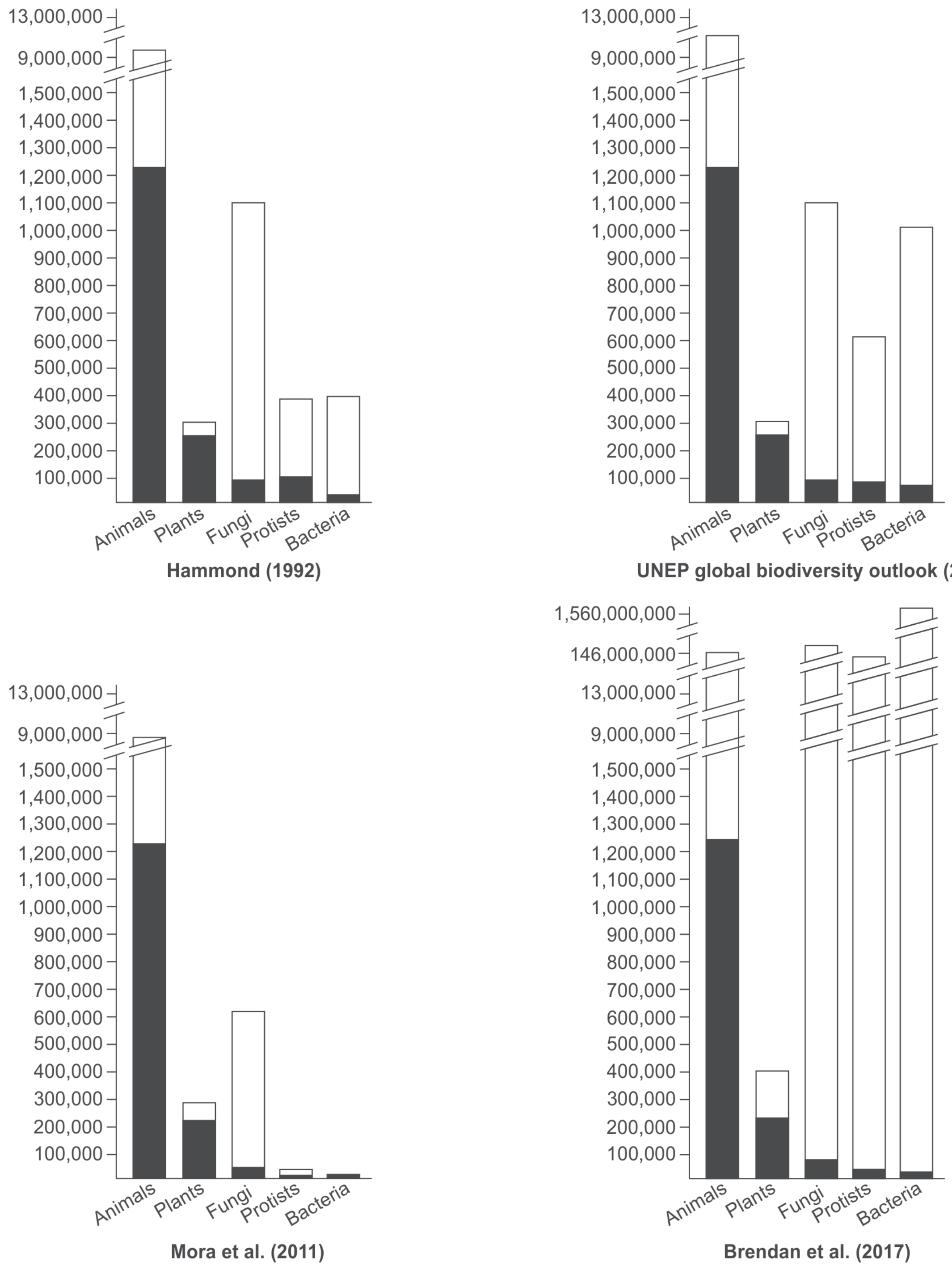

Fig. 1.1: Estimated number of species on earth and the described number of species (solid lower portion of bar) in major groups of organisms. The estimates in recent years have shifted from Animals to Bacteria, Fungi and Protists as dominant groups

membranes do not enclose a separate area of the cytoplasm. **Eukaryotes** have a separate membrane bound nucleus, numerous mitochondria and other organelles such as the Golgi Body within each of their cells. These areas are separated off from the main mass of the cell's cytoplasm by their own membrane in order to allow them to be more specialized. The nucleus contains all the Eukaryote cell DNA, which gets organized into distinct chromosomes during the process of mitosis and meiosis. The energy is generated in mitochondria. The exception to this rule are red blood cells which have no nucleus and do not live very long. Haeckel (1866) proposed a three kingdom classification recognising Protista, Plantae and Animalia, the additional kingdom Protista including all single-celled organisms that are intermediate between animals and plants. Herbert Copeland (1938), who gave the prokaryotes a separate kingdom, originally called Mycota but later referred to as **Monera** or **Bacteria**. Copeland later on (1956) proposed a **four-kingdom system** placing all eukaryotes other than animals and plants in the kingdom **Protoctista,** thus recognizing four kingdoms **Monera**, **Protoctista**, **Plantae** and **Animalia**. The importance of grouping these kingdoms in two empires, as suggested earlier by Chatton was popularized by Stanier and van Niel (1962), and soon became widely accepted.

Five Kingdom System

American biologist Robert H. Whittaker (1969) proposed the removal of fungi into a separate kingdom thus establishing a **five kingdom system** recognizing **Monera**, **Protista**, **Fungi**, **Plantae** and **Animalia** as distinct kingdoms. The fungi like plants have a distinct cell wall but like animals lack autotrophic mode of nutrition. They, however, unlike animals draw nutrition from decomposition of organic matter, have cell wall reinforced with chitin, cell membranes containing ergosterol instead of cholesterol and have a unique biosynthetic pathway for lysine. The classification was followed widely in textbooks.

Six or Seven Kingdoms

Subsequent research concerning the organisms previously known as archebacteria has led to the recognition that these creatures form an entirely distinct kingdom **Archaea.** These include anaerobic bacteria found in harsh oxygen-free conditions and are genetically and metabolically completely different from other, oxygen-breathing organisms. These bacteria, called **Archaebacteria**, or simply Archaea, are said to be 'living fossils' that have survived since the planet's very early ages, before the Earth's atmosphere even had free oxygen. This together with the emphasis on phylogeny requiring groups to be monophyletic resulted in a **six kingdom system** proposed by Carl Woese, et al. (1977). They grouped Archaebacteria and Eubacteria under Prokaryotes and rest of the four kingdoms Protista, Fungi, Plantae and Animalia under Eukaryotes. They subsequently (1990) grouped these kingdoms into three **domains Bacteria** (containing Eubacteria), **Archaea** (containing Archaebacteria) and **Eukarya** (containing Protista, Fungi, Plantae and Animalia).

Margulis and Schwartz (1998) proposed term **superkingdom** for domains and recognized two superkingdoms: **Prokarya** (Prokaryotae) and **Eukarya** (Eukaryotae). Former included single kingdom **Bacteria** (Monera) divided into two subkingdoms **Archaea** and **Eubacteria. Eukarya** was divided into four kingdoms**: Protoctista (Protista), Animalia, Plantae** and **Fungi.**

Several recent authors have attempted to recognize seventh kingdom of living organisms, but they differ in their treatment. Ross (2002, 2005) recognized Archaebacteria and Eubacteria as separate kingdoms, named as **Protomonera** and **Monera**, respectively again under separate superkingdoms (domains of earlier authors) **Archaebacteria** and **Eubacteria**. He added seventh kingdom **Myxomycophyta** of slime molds under superkingdom Eukaryotes. Two additional superkingdoms of extinct organisms Progenotes (first cells) and Urokaryotes (prokaryotic cells that became eukaryotes):

Superkingdom Progenotes*....
....first cells now extinct

Superkingdom Archaebacteriae
Kingdom Protomonera
.....archaic bacteria

Superkingdom Eubacteria
Kingdom Monera ....bacteria

Superkingdom Urkaryotes*.....
prokaryotic cells that became eukaryotes

Superkingdom Eukaryotes.....
... cells with nuclei

Kingdom Protista..........protozoans

Kingdom Myxomycophyta
..... slime molds

Kingdom Plantae............plants

Kingdom Fungi.............fungi

Kingdom Animalia...........animals

Patterson and Sogin (1992; Fig. 1.2) recognized seven kingdoms, but include slime molds under Protozoa (Protista) and instead establish **Chromista** (diatoms) as seventh kingdom. Interestingly the traditional algae now find themselves distributed in three different kingdoms: eubacterial prokaryotes (the blue-green cyanobacteria), chromistans (diatoms, kelps), and protozoans (green algae, red algae, dinoflagellates, euglenids).

Cavalier-Smith (1981) suggested that Eukaryotes can be classified into nine kingdoms each defined in terms of a unique constellation of cell structures. Five kingdoms have plate-like mitochondrial cristae: (1) **Eufungi** (the non-ciliated fungi, which unlike the other eight kingdoms have unstacked Golgi cisternae), (2) **Ciliofungi** (the posteriorly ciliated fungi), (3) **Animalia** (Animals, sponges, mesozoa, and choanociliates; phagotrophs with basically posterior ciliation), (4) **Biliphyta** (Nonphagotrophic, phycobilisome-containing, algae, i.e. the Glaucophyceae and Rhodophyceae), (5) **Viridiplantae** (Nonphagotrophic green plants, with starch-containing plastids). Kingdom

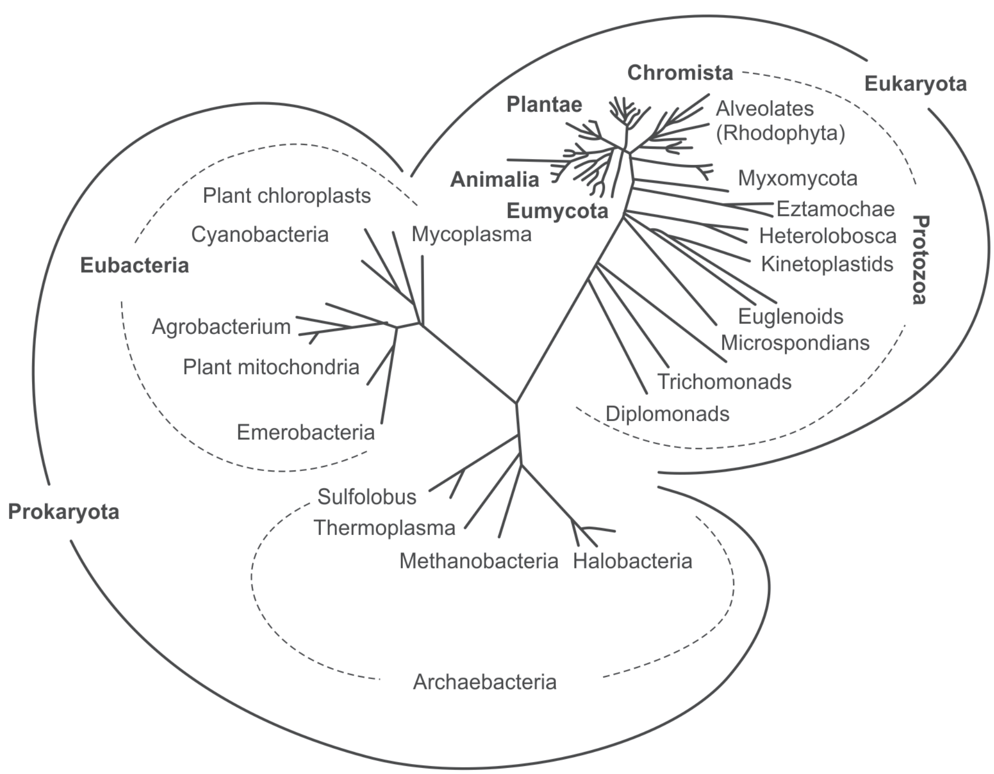

Fig. 1.2: Seven kingdoms of life and their possible phylogeny (after Patterson and Sogin 1992)

(6), the **Euglenozoa**, has disc-shaped cristae and an intraciliary dense rod and may be phagotrophic and/or phototrophic with plastids with three-membraned envelopes. Kingdom (7), the **Cryptophyta**, has flattened tubular cristae, tubular mastigonemes on both cilia, and starch in the compartment between the plastid endoplasmic reticulum and the plastid envelope; their plastids, if present, have phycobilins inside the paired thylakoids and chlorophyll c2. Kingdom (8), the **Chromophyta**, has tubular cristae, together with tubular mastigonemes on one anterior cilium and/or a plastid endoplasmic reticulum and chlorophyll c1 + c2. Members of the ninth kingdom, the **Protozoa**, are mainly phagotrophic, and have tubular or vesicular cristae (or lack mitochondria altogether), and lack tubular mastigonemes on their (primitively anterior) cilia; plastids if present have three-envelope membranes, chlorophyll c2, and no internal starch, and a plastid endoplasmic reticulum is absent. Kingdoms 4–9 are primitively anteriorly biciliate. A simpler system of five kingdoms suitable for very elementary teaching is possible by grouping the photosynthetic and fungal kingdoms in pairs. It was suggested that various compromises are possible between the nine and five kingdoms systems; it is suggested that the best one for general scientific use is a system of seven kingdoms in which the Eufungi and Ciliofungi become subkingdoms of the Kingdom Fungi, and the Cryptophyta and Chromophyta subkingdoms of the Kingdom Chromista; the Fungi, Viridiplantae, Biliphyta, and Chromista can be subject to the Botanical Code of Nomenclature, while the Zoological Code can govern the Kingdoms Animalia, Protozoa and Euglenozoa.

These 9 kingdoms together with two or one kingdom of prokaryotes total eleven or ten kingdoms of life. Subsequently, however, Cavalier-Smith (1998, 2000, 2004) reverted back to six kingdom classification recognizing Bacteria, Protozoa, Animalia, Fungi, **Plantae and Chromista** under two empires Prokaryota and Eukaryota. Prokaryotes constitute a single kingdom, Bacteria, here divided into two new subkingdoms: Negibacteria, with a cell envelope of two distinct genetic membranes, and Unibacteria, comprising the phyla Archaebacteria and Posibacteria. Outline of the classification is as under:

Empire Prokaryota

- Kingdom **Bacteria**
  - Subkingdom **Negibacteria** (phyla Eubacteria, Sphingobacteria, Spirochaetae, Proteobacteria, Planctobacteria, Cyanobacteria)
- Subkingdom **Unibacteria** (phyla Posibacteria, Archaebacteria)

Empire Eukaryota

- Kingdom **Protozoa**
  - Subkingdom **Sarcomastigota** (phyla Amoebozoa, Choanozoa)
  - Subkingdom **Biciliata**
- Kingdom **Animalia** (Myxozoa and 21 other phyla)
- Kingdom **Fungi** (phyla Archemycota, Microsporidia, Ascomycota, Basidiomycota)
- Kingdom **Plantae**
  - Subkingdom **Biliphyta** (phyla Glaucophyta, Rhodophyta)
  - Subkingdom **Viridaeplantae** (phyla Chlorophyta, Bryophyta, Tracheophyta)
- Kingdom **Chromista**
  - Subkingdom **Cryptista** (phylum Cryptista: cryptophytes, goniomonads, katablepharids)
- Subkingdom **Chromobiota**

The name **archaebacteria** seems to be confusing. They were so named because they were thought to be the most ancient (Greek '*archaio*' meaning ancient) and sometimes labelled as living fossils, since they can survive in anaerobic conditions (methanogens-which use hydrogen gas to reduce carbon dioxide to methane gas), high temperatures (thermophiles, which can survive in temperatures of up to 80°C), or salty places (halophiles). They differ from bacteria in having methionine as amino acid that initiates protein synthesis as against formyl-methionine in bacteria, presence of introns in some genes, having several different RNA polymerases as against one in bacteria, absence of peptidoglycan in cell wall, and growth not inhibited by antibiotics like streptomycin and chloramphenicol. In several of these respects archaebacteria are more similar to eukaryotes. Bacteria are thought to have diverged early from the evolutionary line (the clade neomura, with many common characters, notably obligately co-translational secretion of N-linked glycoproteins, signal recognition particle with 7S RNA and translation-arrest domain, protein-spliced tRNA introns, eight-subunit chaperonin, prefoldin, core histones, small nucleolar ribonucleoproteins (snoRNPs), exosomes and similar replication, repair, transcription and translation machinery) that gave rise to archaebacteria and eukaryotes. It is, as such more appropriate to call archaebacteria as **metabacteria**.

The eukaryotic host cell (Fig. 1.3) evolved from something intermediate between posibacteria and metabacteria ("archaebacteria"), which had evolved many metabacterial features but not yet switched to ether-linked lipid membranes in a major way. They would no doubt cladistically fall out as primitive

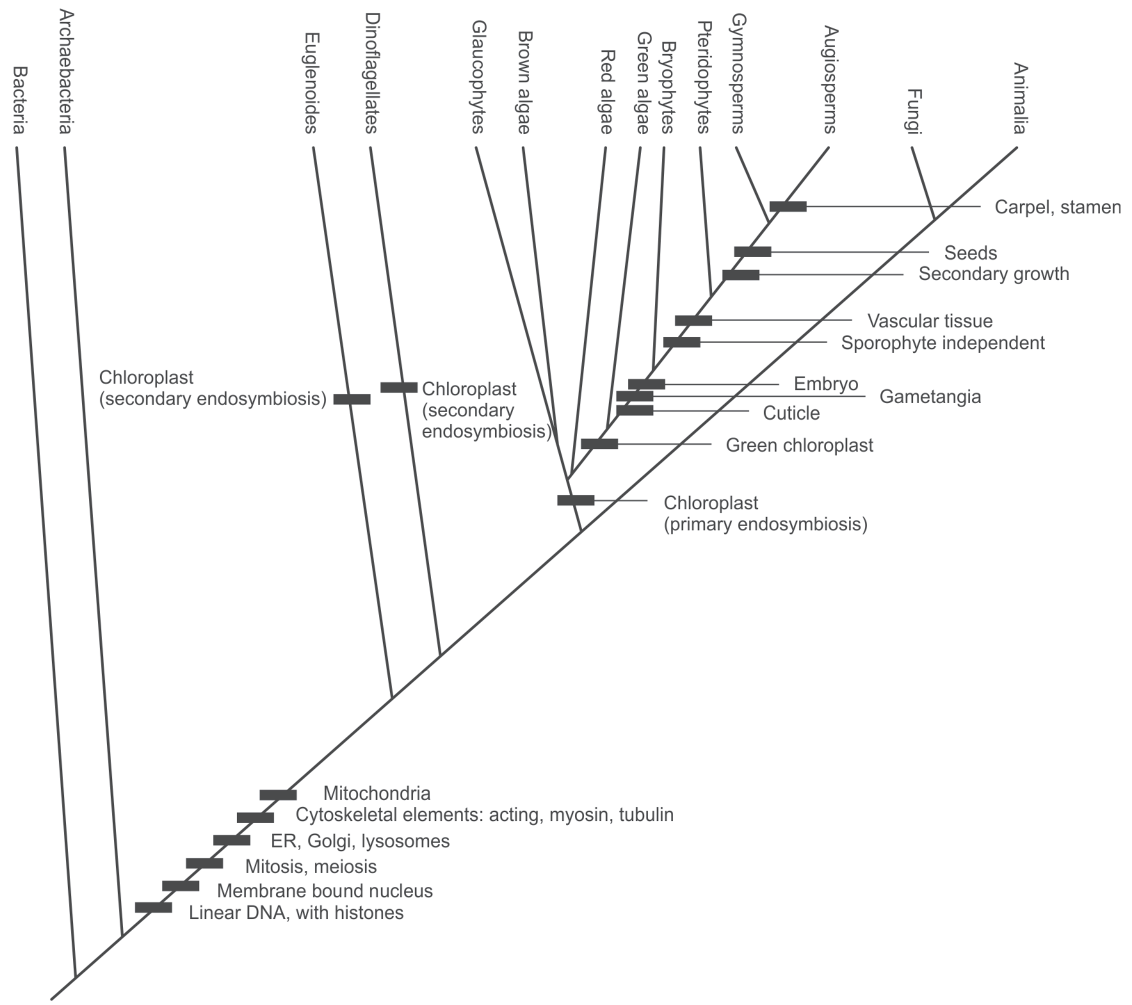

Fig. 1.3: Cladogram showing the evolution of major groups of organisms and the associated apomorphies. Chloroplast evolution has occurred twice, once (primary endosymbiosis) eukaryote cell engulfing a photosynthetic bacterial cell, and elsewhere (secondary endosymbiosis) eukaryotic cell engulfing an eukaryotic cell containing chloroplast

metabacteria, but whether such forms are still extant is uncertain. There are lots of metabacteria out there which are uncultured (only known from environmental sequences) or just undiscovered, so who knows.

The further shift from archaebacteria to Eukaryotes involved the transformation of circular DNA into a **linear DNA** bound with histones, formation of **membrane bound nucleus** enclosing chromosomes, development of **mitosis**, occurrence of **meiosis** in sexually reproducing organisms, appearance of membrane bound organelles such as **endoplasmic reticulum**, **Golgi bodies** and **lysosomes**, appearance of **cytoskeletal elements** like actin, myosin and tubulin, and the formation of **mitochondria** through endosymbiosis.

A major shift in this eukaryotic line which excluded animal and fungi, involved the development of **chloroplast** by an eukaryotic cell engulfing a photosynthetic bacterial cell (probably a cyanobacterium). The bacterial cell continued to live and multiply inside the eukaryotic cell, provided high energy products, and in turn received a suitable environment to live in. The two thus shared **endosymbiosis**. Over a period of time the bacterial cell lost ability to live independently, some of the bacterial genes getting transferred to eukaryotic host cell, making the two biochemically interdependent. Chloroplast evolution in Euglenoids and Dinoflagellates occurred through **secondary endosymbiosis**, wherein eukaryotic cell engulfed an eukaryotic cell containing a chloroplast. This common evolutionary sequence is shared by green plants (including green algae; green chloroplast), red algae (red chloroplast) and brown algae and their relatives (commonly known as stramenopiles; brown chloroplast), in which diversification of chloroplast pigments occurred, along with the thylakoid structure and a variety of storage products.

The Plant Kingdom

It is now universally agreed that members of the plant kingdom include, without doubt the green algae, liverworts and mosses, pteridophytes, gymnosperms and finally the angiosperms, the largest group of plants. All these plants share a green chloroplast. Red algae, Brown algae and Glaucophytes, latter two together known as stramenophiles, also belong to this kingdom. All these groups share the presence of a chloroplast. All green plants share a green chloroplast with chlorophyll b, chlorophyll a, thylakoids and grana, and starch as storage food. Evolution of cuticle combined with gametangia and embryo characterizes embryophytes, including bryophytes, pteridophytes and seed plants. The development of vascular tissue of phloem and xylem, and independent sporophyte characterize tracheophytes including pteridophytes and seed plants. Secondary growth resulting in the formation of wood and seed habit differentiates seed plants. The final evolution of a distinct flower, carpels and stamens, together with vessels and sieve tubes set apart the angiosperms, the most highly evolved group of plants.

Out of nearly 3,90,000 species of plants known nearly 22,500 species belong to usually overlooked mosses and liverworts, 15,000 ferns and their allies, 1,050 to gymnosperms and 352,000 to angiosperms (belonging to about 485 families and 13,372 genera), considered to be the most recent and vigorous group of plants that have occupied earth. Angiosperms occupy the majority of the terrestrial space on earth, and are the major components of the world's vegetation.

Brazil and Colombia, both located in the tropics, are considered to be countries with the most diverse angiosperms floras and which rank first and second. China, even though the main part of her land is not located in the tropics, the number of her angiosperms still occupies the third place in the world, and has approximately 300 families 3,100 genera and 30,000 species.

TAXONOMY AND SYSTEMATICS

There are slightly more than one-third of a million species of plants known to man today, the information having been accumulated through efforts of several millenniums. Although man has been classifying plants since the advent of civilization, **taxonomy** was recognized as a formal subject only in 1813 by A. P. de Candolle as a combination of Greek words **taxis** (arrangement) and **nomos** (rules or laws) in his famous work *Theorie elementaire de la botanique*. For a long-time plant taxonomy was considered as 'the science of identifying, naming, and classifying plants' (Lawrence, 1951). Since identification and nomenclature are important prerequisites for any classification, taxonomy is often defined as the '***science dealing with the study of classification, including its bases, principles, rules and procedures***' (Davis and Heywood, 1963).

Although **Systematics** was recognized as a formal major field of study only during the latter half of twentieth century, the term had been in use for a considerable period. Derived from the Latin word *systema* (organized whole), forming the title of the famous work of Linnaeus *Systema naturae* (1735), the term Systematics first appeared in his *Genera Plantarum* (1737), though Huxley (1888) is often credited to have made the first use of the term in his article in *Nature* on the systematics of birds. Simpson (1961) defined **systematics** as a '***scientific study of the kinds and diversity of organisms, and of any and all relationships between them***'. It was recognized as a more inclusive field of study concerned with the study of diversity of plants and their naming, classification and evolution. The scope of taxonomy has, however, been enlarged in recent years to make taxonomy and systematics synonymous. A broader definition (Stace, 1980) of **taxonomy,** to coincide with **systematics** recognized it as '***the study and description of variation in organisms, the investigation of causes and consequences of this variation, and the manipulation of the data obtained to produce a system of classification***'.

Realization of the fact that a good number of authors still consider taxonomy to be a more restricted term and systematics a more inclusive one has led recent authors to prefer the term **systematics** to include discussion about all recent developments in their works. Modern approach to systematics aims at reconstructing the entire chronicle of evolutionary events, including the formation of separate lineages and evolutionary modifications in characteristics of the organisms. It ultimately aims at discovering all the branches of the evolutionary tree of life; and to document all the changes and to describe all the species which form the tips of these branches. This would not be possible unless information is consolidated in the form of an unambiguous system of classification. This, however, is again impossible without a clear understanding of the basic identification and nomenclatural methods. Equally important is the understanding of the recent tools of data handling, newer concepts of phylogenetics, expertise in the judicious utilization of fast accumulating molecular data in understanding of affinities between taxa.

Prior to the evolutionary theory of Darwin, relationships were expressed as **natural affinities** on the basis of an overall similarity in morphological features. Darwin ushered in an era of assessing **phylogenetic relationships** based on the course of evolutionary descent. With the introduction of computers and refined statistical procedures, overall similarity is represented as **phenetic relationship**, which takes into account every available feature, derived from such diverse fields as anatomy, embryology, morphology, palynology, cytology, phytochemistry, physiology, ecology, phytogeography and ultrastructure.

With the advancement of biological fields, new information flows continuously and the taxonomists are faced with the challenge of integrating and providing a synthesis of all the available data. Systematics now is, thus, an **unending synthesis,** a dynamic science with never-ending duties. The continuous flow of data necessitates rendering descriptive information, revising schemes of identification, revaluating and improving systems of classification and perceiving new relationships for a better understanding of the plants. The discipline as such includes all activities that are a part of the effort to organize and record the diversity of plants and appreciate the fascinating differences among the species of plants. Systematic activities are basic to all other biological sciences, but also depend, in turn, on other disciplines for data and information useful in constructing classification. Certain disciplines of biology such as cytology, genetics, ecology, palynology, paleobotany and phytogeography are so closely tied up with systematics that they can not be practiced without basic systematic information. Experiments cannot be carried out unless the organisms are correctly identified and some information regarding their relationship is available. The understanding of relationships is particularly useful in the applied fields of plant breeding, horticulture, forestry and pharmacology for exploring the usefulness of related species. Knowledge of systematics often guides the search for plants of potential commercial importance.

Basic Components (Principles) of Systematics

Various systematic activities are directed towards the singular goal of constructing an ideal system of classification that necessitates the procedures of identification, description, nomenclature and constructing affinities. This enables a better management of information to be utilized by different workers, investigating different aspects structure and functioning of different species of plants.

Identification

Identification or determination is recognizing an unknown specimen with an already known taxon, and assigning a correct rank and position in an extant classification. In practice, it involves finding a name for an unknown specimen. This may be achieved by visiting a herbarium and comparing unknown specimen with duly identified specimens stored in the herbarium. Alternately, the specimen may also be sent to an expert in the field who can help in the identification.

Identification can also be achieved using various types of literature such as Floras, Monographs or Manuals and making use of identification keys provided in these sources of literature. After the unknown specimen has been provisionally identified with the help of a key, the identification can be further confirmed by comparison with the detailed description of the taxon provided in the literature source.

A method that is becoming popular over the recent years involves taking a photograph of the plant and its parts, uploading this picture on the website and informing the members of appropriate electronic Lists or Newsgroups, who can see the photograph at the website and send their comments to the enquirer. Members of the fraternity could thus help each other in identification in a much efficient manner.

Description

The description of a taxon involves listing its features by recording the appropriate character states. A shortened description consisting of only those taxonomic characters which help in separating a taxon from other closely related taxa, forms the **diagnosis**, and the characters are termed **diagnostic characters.** The diagnostic characters for a taxon determine its **circumscription**. The description is recorded in a set pattern (habit, stem, leaves, flower, sepals, petals, stamens, carpels, fruit, etc.). For each **character,** an appropriate **character-state** is listed. Flower colour (character) may thus be red, yellow, white, etc. (states). The description is recorded in semi-technical language using specific terms for each character-state to enable a proper documentation of data.

Whereas the fresh specimens can be described conveniently, the dry specimens need to be softened in boiling water or in a **wetting agent** before these could be described. Softening is often essential for dissection of flowers in order to study their details.

Nomenclature

Nomenclature deals with the determination of a **correct name** for a taxon. There are different sets of rules for different groups of living organisms. Nomenclature of plants (including fungi) is governed by the **International Code of Nomenclature for Algae, Fungi and Plants (ICN)** since 2011 (earlier known as International Code of

Botanical Nomenclature, (ICBN)) through its rules and recommendations. Latest Shenzhen Code adopted in 2017 has been published in June, 2018, containing several changes in rules and recommendations for these groups. Updated every six years or so, the **Code** helps in picking up a single correct name out of numerous scientific names available for a taxon, with a particular circumscription, position and rank. To avoid inconvenient name changes for certain taxa, a list of conserved names is provided in the Code. Cultivated plants are governed by the International Code of Nomenclature for Cultivated Plants (**ICNCP)**, slightly modified from and largely based on the Botanical Code.

Names of animals are governed by the International Code of Zoological Nomenclature (**ICZN**); those of bacteria by International Code for the Nomenclature of Bacteria (**ICNB**), now called Bacteriological Code (**BC**). A separate Code exists for viruses, named the International Code of Virus Classification and Nomenclature (**ICVCN**).

With the onset of electronic revolution and the need to have a common database for living organisms for global communication a common uniform code is being attempted. The **Draft BioCode** is the first public expression of these objectives. The first draft was prepared in 1995. After successive reviews the fourth draft, named **Draft BioCode (1997)** prepared by the International Committee for Bionomenclature was published by Greuter, et al. (1998), latest version **Draft BioCode 2011** (Hawksworth, et al. 2011) is available on the web. The last decade of twentieth century also saw the development of rankless **PhyloCode** based on the concepts of phylogenetic systematics. It omits all ranks except species and 'clades' based on the concept of recognition of monophyletic groups. The latest version of PhyloCode (PhyloCode5, 2014) is also available on the web.

Phylogeny

Phylogeny is the study of the genealogy and evolutionary history of a taxonomic group. Genealogy is the study of ancestral relationships and lineages. Relationships are depicted through a diagram better known as a **phylogram** (Stace, 1989), since the commonly used term **cladogram** is more appropriately used for a diagram constructed through cladistic methodology. A phylogram is a branching diagram based on the degree of advancement (**apomorphy**) in the descendants, the longest branch representing the most advanced group. This is distinct from **a phylogenetic tree** in which the vertical scale represents a geological time-scale and all living groups reach the top, with primitive ones near the centre and advanced ones near the periphery. Monophyletic groups, including all the descendants of a common ancestor, are recognized and form entities in a classification system. Paraphyletic groups, wherein some descendants of a common ancestor are left out, are reunited. Polyphyletic groups, with more than one common ancestor, are split to form monophyletic groups. Phenetic information may often help in determining a phylogenetic relationship.

Classification

Classification is an arrangement of organisms into groups on the basis of similarities. The groups are, in turn, assembled into more inclusive groups, until all the organisms have been assembled into a single most inclusive group. In sequence of increasing inclusiveness, the groups are assigned to a fixed hierarchy of categories such as species, genus, family, order, class and division, the final arrangement constituting a system of classification. The process of classification includes assigning appropriate **position** and **rank** to a new **taxon** (a taxonomic group assigned to any rank; pl. **taxa**), **dividing** a taxon into smaller units, **uniting** two or more taxa into one, **transferring** its position from one group to another and **altering** its rank. Once established, a classification provides an important mechanism of information storage, retrieval and usage. This ranked system of classification is popularly known as the **Linnaean system**. Taxonomic entities are classified in different fashions:

1. **Artificial classification** is utilitarian, based on arbitrary, easily observable characters

such as habit, colour, number, form or similar features. The **sexual system** of Linnaeus, which fits in this category, utilized the number of stamens for primary classification of the flowering plants.

2. **Natural classification** uses overall similarity in grouping taxa, a concept initiated by M. Adanson and culminating in the extensively used classification of Bentham and Hooker. Natural systems of the eighteenth and nineteenth centuries used morphology in delimiting the overall similarity. The concept of overall similarity has undergone considerable refinement in recent years. As against the sole morphological features as indicators of similarity in natural systems, overall similarity is now judged on the basis of features derived from all the available fields of taxonomic information (phenetic relationship).
3. **Phenetic classification** makes the use of overall similarity in terms of a phenetic relationship based on data from all available sources such as morphology, anatomy, embryology, phytochemistry, ultrastructure and, in fact, all other fields of study. Phenetic classifications were strongly advocated by Sneath and Sokal (1973) but did not find much favour with major systems of classification of higher plants. Phenetic relationship has, however, been very prominently used in modern phylogenetic systems to decide the realignments within the system of classification.
4. **Phylogenetic classification** is based on the evolutionary descent of a group of organisms, the relationship depicted either through a **phylogram, phylogenetic tree** or a **cladogram**. Classification is constructed with this premise in mind, that all the descendants of a common ancestor should be placed in the same group (i.e. group should be **monophyletic**). If some descendants have been left out, rendering the group **paraphyletic**, these are brought back into the group to make it monophyletic (merger of Asclepiadaceae with Apocynaceae, and the merger of Capparaceae with Brassicaceae in recent classifications). Similarly, if the group is polyphyletic (with members from more than one phyletic lines it is split to create monophyletic taxa (Genus *Arenaria* split into *Arenaria* and *Minuartia*). This approach, known as **cladistics,** is practiced by cladists.
5. **Evolutionary taxonomic classification** differs from a phylogenetic classification in that the gaps in the variation pattern of phylogenetically adjacent groups are regarded as more important in recognizing groups. It accepts leaving out certain descendants of a common ancestor (i.e. recognizing **paraphyletic** groups) if the gaps are not significant, thus failing to provide a true picture of the genealogical history. The characters considered to be of significance in the evolution (and the classification based on these) are dependent on expertise, authority and intuition of systematists. Such classifications have been advocated by Simpson (1961), Ashlock (1979), Mayr and Ashlock (1991) and Stuessy (1990). The approach, known as **eclecticism,** is practiced by **eclecticists**.

The contemporary phylogenetic systems of classification, including those of Takhtajan, Cronquist, Thorne and Dahlgren, are largely based on decisions in which **phenetic information** is liberally used in deciding the phylogenetic relationship between groups, differing largely on the weightage given to the cladistic or phenetic relationship.

There have been suggestions to abandon the hierarchical contemporary classifications based on the **Linnaean system,** which employs various fixed ranks in an established conventional sequence with a **'phylogenetic taxonomy'** in which monophyletic groups would be unranked names, defined in terms of a common ancestry, and diagnosed by reference to synapomorphies (de Queiroz and Gauthier, 1990; Hibbett and Donoghue, 1998). Angiosperm Phylogeny Group is continuously evolving APG system of classification, latest APG IV (2016) and its variant APWeb Version 14 developed in 2017 are also available on the web.

Classification not only helps in the placement of an entity in a logically organized scheme of relationships, it also has a great predictive value. The presence of a valuable chemical component in one species of a particular genus may prompt its search in other related species. The more a classification reflects phylogenetic relationships, the more predictive it is supposed to be. The meaning of a natural classification is gradually losing its traditional sense. A 'natural classification' today is one visualized as truly phylogenetic, establishing monophyletic groups making fair use of the phenetic information so that such groups also reflect a phenetic relationship (overall similarity) and the classification represents a reconstruction of the evolutionary descent.

Aims of Systematics

The activities of plant systematics are basic to all other biological sciences and, in turn, depend on the same for any additional information that might prove useful in constructing a classification. These activities are directed towards achieving the undermentioned aims:

1. To provide a convenient method of identification and communication. A workable classification having the taxa arranged in hierarchy, detailed and diagnostic descriptions are essential for identification. Properly identified and arranged herbarium specimens, dichotomous keys, polyclaves and computeraided identification are important aids for identification. The **Code** (ICN), written and documented through the efforts of IAPT (International Association of Plant Taxonomy), helps in deciding the single correct name acceptable to the whole botanical community.
2. To provide an inventory of the world's flora. Although a single world Flora is difficult to come by, floristic records of continents (**Continental Floras; *cf.*** *Flora Europaea* by Tutin, et al.), regions or countries (**Regional Floras; *cf.*** *Flora of British India* by J. D. Hooker) and states or even counties (**Local Floras; *cf.*** *Flora of Delhi* by J. K. Maheshwari) are well documented. In addition, **World Monographs** for selected genera (e.g. The genus *Crepis* by Babcock) and families (e.g. *Das pflanzenreich* ed. by A. Engler) are also available.
3. To detect evolution at work; to reconstruct the evolutionary history of the plant kingdom, determining the sequence of evolutionary change and character modification.
4. To provide a system of classification which depicts the evolution within the group. The phylogenetic relationship between the groups is commonly depicted with the help of a phylogram, wherein the longest branches represent more advanced groups and the shorter, nearer the base, primitive ones. In addition, the groups are represented by balloons of different sizes that are proportional to the number of species in the respective groups. Such a phylogram is popularly known as a **bubble diagram**. The phylogenetic relationship could also be presented in the form of a phylogenetic tree (with vertical axis representing the geological time scale), where existing species reach the top and the bubble diagram may be a cross-section of the top with primitive groups towards the centre and the advanced ones towards the periphery.
5. To provide an integration of all available information. To gather information from all the fields of study, analysing this information using statistical procedures with the help of computers, providing a synthesis of this information and developing a classification based on overall similarity. This synthesis is unending, however, since scientific progress will continue and new information will continue to pour and pose new challenges for taxonomists.
6. To provide an information reference, supplying the methodology for information storage, retrieval, exchange and utilization. To provide significantly valuable information concerning endangered species, unique elements, genetic and ecological diversity.
7. To provide new concepts, reinterpret the old, and develop new procedures for correct determination of taxonomic affinities, in terms of phylogeny and phenetics.

8. To provide integrated databases including all species of plants (and possibly all organisms) across the globe. Several big organizations have come together to establish online searchable databases of taxon names, images, descriptions, synonyms and molecular information.

Advancement Levels in Systematics

Plant systematics has made considerable strides from herbarium records to databanks, recording information on every possible attribute of a plant. Because of extreme climatic diversity, floristic variability, inaccessibility of certain regions and economic disparity of different regions, the present-day systematics finds itself in different stages of advancement in different parts of the world. Tropical Asia and tropical Africa are amongst the richest areas of the world in terms of floristic diversity but amongst the poorest as far as the economic resources to pursue complete documentation of systematic information. The whole of Europe, with more than 30 m square kilometres of landscape and numerous rich nations with their vast economic resources, have to account for slightly more than 12000 species of vascular plants. India, on the other hand, with meager resources, less than one tenth of landscape, has to account for the study of twice the number vascular plants. A small country like Colombia, similarly, has estimated 4,500 different species, with only a few botanists to study the flora. Great Britain, on the other hand, has approximately 1370 taxa (Woodland, 1991), with thousands of professional and amateur botanists available to document the information. It is not strange, as such, that there is lot of disparity in the level of advancement concerning knowledge about respective floras. Taxonomic advancement today can be conveniently divided into four distinct **phases** encountered in different parts of the world:

Exploratory or Pioneer Phase

This phase marks the beginning of plant taxonomy, collecting specimens and building herbarium records. The few specimens of a species in the herbarium are the only record of its variation. These specimens are, however, useful in a preliminary inventory of flora through discovery, description, naming and identification of plants. Here, morphology and distribution provide the data on which the systematists must rely. Taxonomic experience and judgement are particularly important in this phase. Most areas of tropical Africa and tropical Asia are passing through this phase.

Consolidation or Systematic Phase

During this phase, herbarium records are ample and enough information is available concerning variation from field studies. This development is helpful in the preparation of Floras and Monographs. It also aids in better understanding of the degree of variation within a species. Two or more herbarium specimens may appear to be sufficiently different and regarded as belonging to different species on the basis of a few available herbarium records, but only a field study of populations involving thousands of specimens can help in reaching at a better understanding of their status. If there are enough field specimens to fill in the gaps in variation pattern, there is no justification in regarding them as separate species. On the other hand, if there are distinct gaps in the variation pattern, it strengthens their separate identity. In fact, many plants, described as species on the basis of limited material in the pioneer phase, are found to be variants of other species in the consolidation phase. Most parts of central Europe, North America and Japan are experiencing this phase.

Experimental or Biosystematic Phase

During this phase, the herbarium records and variation studies are complete. In addition, information on **biosystematics** (studies on transplant experiments, breeding behaviour and chromosomes) is also available. Transplant experiments involving collecting seeds, saplings or other propagules from morphologically distinct populations from different habitats and growing them under common environmental conditions. If the differences between the original populations were purely ecological, the differences would disappear under a common environment, and there is no justification in regarding them as distinct taxonomic entities. On the other hand, if the differences still persist, these are evidently genetically fixed. If these populations are allowed to grow together for several years, their breeding behaviours would further establish their status. If there are complete reproductive barriers between the populations, they will fail to interbreed, and maintain their separate identity. These evidently belong to different species. On the other hand, if there is no reproductive isolation between them, over the years, they would interbreed, form intermediate hybrids, which will soon fill the gaps in their variation. Such populations evidently belong to the same species and better distinguished as ecotypes, subspecies or varieties. Further chromosomal studies can throw more light on their affinities and status. Central Europe has reached this phase of plant systematics.

Encyclopaedic or Holotaxonomic Phase

Here, not only the previous three phases are attained, but information on all the botanical fields is also available. This information is assembled, analyzed, and a meaningful synthesis of analysis is provided for understanding phylogeny. Collection of data, analysis and synthesis are the jobs of an independent discipline of systematics, referred to as **numerical taxonomy**.

The first two phases of systematics are often considered under **alpha-taxonomy** and the last phase under **omega-taxonomy**. At present, only a few persons are involved in encyclopaedic work and that too, in a few isolated taxa. It may thus be safe to conclude that though in a few groups omegataxonomy is within reach, for the great majority of plants, mainly in the tropics, even the ‘alpha’ stage has not been crossed. The total integration of available information for the plant kingdom is, thus, only a distant dream at present. Concerted efforts are essential to focus on unexplored regions and little-known taxa.