SYSTEMATICS OF ANGIOSPERMS AND PLANT ECOLOGY

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Unit – 1

Lesson – 1

VEGETATION TYPES

1.0 Objective

This chapter attempts to provide a conspectus of the vegetation types of the world in general and that of India in particular.

1.1 INTRODUCTION

Vegetation is the plant cover. Natural vegetation is the most valuable, non-renewable resource in any geographic location. It regulates the environment of the area and thus defines the environmental conditions too. Conservation and planned utilization of this resource of a region calls for reliable and latest information on the nature, quantum and distribution of its vegetation. Accurate information on and estimation of area under vegetation is important for various applications and planning. Satellite data have now emerged as the important source for inventorying and monitoring of vegetation.

Vegetation is structurally dynamic. It varies from habitat to habitat, as well as altitude, latitude and longitude-wise. Several environmental factors such as climate, soil and biotic organisms establish the vegetation type. Vegetation is influenced by the prime parameters like the amount of rainfall, extent of its distribution and course of the year besides the regime of rains (i.e. seasonal occurrence of rainfall and the mean temperature during the coldest month). All these factors interact and transform the climate of the habitat into a specific bioclimate. The study of climate in relation to life, particularly of plant life (as most of the animals are migratory and live in specialized niches) is called *bioclimatology*. So, from time to time, plants and vegetation remain the prime (bio) indicators of climatic conditions (Meher-Homji & Gupta 1999).

Flora is the plant wealth of a region. In the Flora, the species are enlisted and envisaged in a descriptive and taxonomic manner. Vegetation, on the other hand, is the pattern in which the species are grouped to constitute landscapes like forest, savannah, grassland, desert, etc. While flora is the result of phylogenetic evolution, vegetation is the outcome of the interaction between biota and climate. The dynamics of vegetation are initiated by natural disturbance that, in plant communities, is defined in terms of major catastrophic events originating in the physical environment. Examples include fires, landslides, windstorms and floods. These are the external agents of change in vegetation. Animals (biotic disturbance) exert a continuous influence on vegetation, causing periodic vegetation change. However, both endogenous and exogenous facators cause the changes in vegetation.

The climax in the vegetation development is a paradigm in plant ecology. The climax concept has stages like *climatic climax, monoclimax, polyclimax*, etc. The climax is to be seen as the community integration and species evolution. The climax species are to be looked at as the best competitors in a regional flora, and it is assumed that they cause the local extinction of successional species (White 1979). According to Whittaker (1974), "there is no distinction between climax and succession, except relative instability and relative significance of directional change….". Vegetation can be non-forest and due to plantations. Then, it is not natural but renewable. Besides, it will be under the human selection, with inputs, and usually more productive. Such vegetation is the product of human activity taken up under afforestation programmes, or one of agricultural practices. This vegetation is secondary and can never be considered .as original forest, or construed as natural ecosystem.

The early classifications of vegetation were descriptive. The later systems are holistic and better founded, with increased knowledge of environmental factors operating, interaction of biotic factors, impact of disturbance regimes, and advanced and more sensitive techniques available for the study such as remote sensing to perceive the vegetation at a larger scale.

1.2 VEGETATION TYPES OF WORLD

Murai *et al.* (1990) proposed vegetation classification at global level using satellite remote sensing. It is related to Koppen's classification of major climates and consists of *eight* major vegetation categories, namely, Tropical forest, Evergreen forest, Deciduous forest, Grassland, Semi-desert, Desert, Alpine desert and Tundra. There are several classifications of the world vegetation now available. The following is one such general classification of vegetation to follow:

1.2.1 Major Types of World Vegetation

- Tropical and subtropical forests
- Lowland evergreen rain forest and semi-evergreen rain forest
- Tropical montane forest

- Tropical cloud forest
- Monsoon forest and tradewind forest
- Tropical and subtropical deciduous forest, thorn forest, and thorn scrub
- Tropical hammock and subtropical hammock
- Savanna (tropical grasslands)
- Savanna grassland
- Savanna woodland and parkland
- Temperate grasslands
- Prairie
- Desert grassland
- Steppe
- Heathland
- Mediterranean-type scrub
- Sclerophyll woodland
- Open- and closed-scrub heathland
- Cold and high elevation heathland
- Wet and dry sclerophyll forest
- Desert and desert-like scrub
- Shrub steppe
- Warm desert scrub
- Fog desert scrub
- Cool desert scrub
- Salt desert and inland alkali-sink scrub
- Temperate forest
- Temperate summer green deciduous and mixed evergreen-deciduous forest
- Temperate rain forest
- Temperate and montane coniferous forest
- Cool temperate rain forest
- Taiga
- Arctic and temperate alpine tundra
- Tropical alpine
- Strand
- Marine and estuarine wetlands
- Mangal (mangrove)
- Coastal salt marsh
- Marine meadow and surfweed
- Freshwater wetlands
- Shallow lacustrine and upland meadow habitats
- Freshwater marsh and herbaceous swamp
- Vernal pool ephemeral
- Sphagnum bog and related mire communities
- Forested wetlands

1.3 VEGETATION TYPES OF INDIA

The original classification of Champion (1936) which was based on Schimper, Köppen and Thornthwaite, and its revised version (Champion & Seth 1968) provide a detailed account of the forest types of India. It is still the most commonly used classification of plant cover in India. But, it has certain drawbacks. It was based on relatively few samples from selected stands with consequent gross generalizations of vegetation types. Besides, there was excessive reliance on environmental terminologies. Puri *et al.* (1960, 1989) dealt at length the shortcomings of the existing classifications of current vegetation of India, more in the light of Champion & Seth 1968), and proposed their own system. It is a holistic classification of vegetation, which starts with the driest series of *Calligonum polygonoides* occurring in the Indian arid zone and gradually proceeds to the wetter types. Each vegetation type includes information content on its distribution, ecological amplitude (range of elevation, climatic and edaphic factors), physiognomic and floristic composition, and the corresponding types in the classification of Champion & Seth. The vegetation of peninsular India was classified into four types, viz. Thorny, Deciduous, Semi-evergreen and Evergreen. Each type was further divided into series: Thorny (3), Deciduous (17), Semi-evergreen (1) and Evergreen (10). These series were further grouped into Teak, Sal, Miscellaneous, Montane and Transitional categories. Savannahs and grasslands are discussed under each category as stages of degradation, affected by biotic and abiotic pressures. It is beyond the scope of the present lesson to incorporate, even briefly, the available information in this regard. Therefore, a simplified version of the vegetation types by Meher-Homji (1984) is presented here, which begins with the wet vegetation and ends with the driest kind, i.e. of *Calligonum polygonoides*, in reverse to the presentation by Puri *et al.* The vegetation cover of India was divided into 29 types, grouped under 11 phytogeographic zones (Fig. 1.1). It is incomplete without the mangroves and grasslands. Moreover, it covers only peninsular India, leaving the vegetation types of Himalayas. So, the gap is filled by adding Mangroves, Montane temperate forest, Alpine vegetation, and grasslands. Beside, there are certain modifications incorporated wherever necessary.

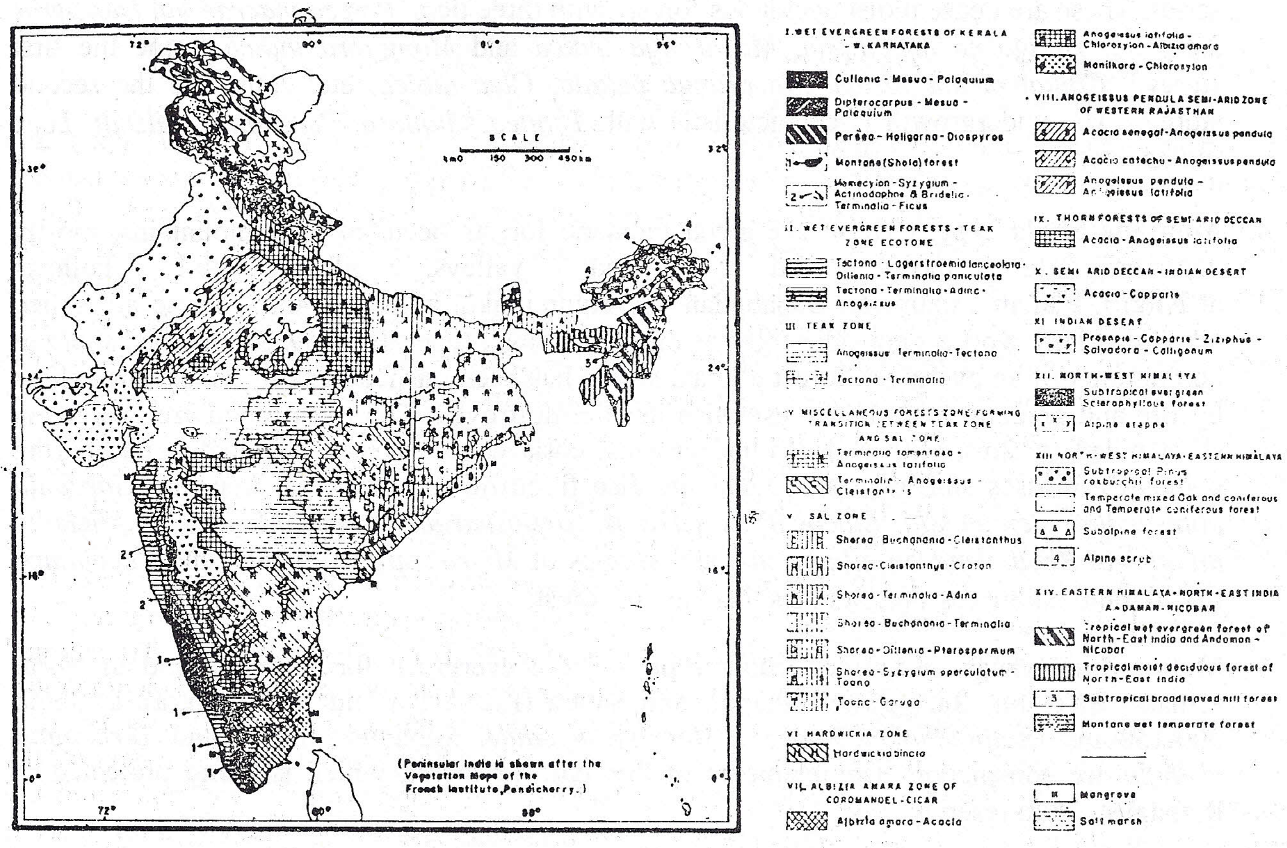

Fig. 1.1 Vegetational types of India (after Meher-Homji 1984).

1.3.1 West Evergreen Forests of West Coast and Western Ghats

1. **Cullenia-Mesua-Palaquium type**: These are potentially evergreen occurring in western side of Western Ghats (Kerala and parts of Tamil Nadu), below 1000m. These are dense, moist, multi-storeyed forests with evergreen species. First storey: *Artocarpus hirsutus, Cullenia exarillata, Mesua ferrea, Palaquium ellipticum.* Second storey: *Cinnamomum verum, Hydnocarpus laurifolia, Diospyros ebenum,* etc. Third storey: *Allophyllus serratus, Aporusa lindleyana, Xanthophyllum flavescens,* etc. Undergorwth: *Calamus rotang, Leprotea crenulata, Ochlandra trvancorica, Pandanus tectorius,* etc. The ground vegetation of these forest patches are often cleared and used for cardamom plantations. However, these forests are protected in nature reserves like Kalakad, Neyyer, Periyar and Silent Valley.

2. **Dipterocarpus-Mesua-Palaquium type**: These potentially evergreen forests are confined to 12^0N to 14^0 40', up to 1500m. *Dipterocarpus indicus, Kingiodendron pinnatum, Melia dubia, Mesua ferrea* and *Palaquium ellipticum* dominate the forests and form the top canopy. Sommeshwara nature reserve cares for this kind of forest.

3. **Persea-Holigarna-Diospyros typ**. These potentially evergreen forests occur north of the preceding type, up to 1500m. Pu ri *et al.* named the same as Persea-Diospyros-Holigarna

series. These are dense moist deciduous forests with three tiers. *Persea macrantha, Diospyros buxifolia, Holigarna arnottiana, Macaranga indica* and *Mangifera indica* frame the first storey. *Cinnamomum verum, Macaranga peltata, Olea dioica,* etc. constitute the second storey. The undergrowth is characteristic with *Thottea siliquosa, Psychotria dalzelli, Leea indica*, etc.

4. **Montane Shola type**: These evergreen montane forests occur at high mountains, mostly confined to moist and sheltered valleys, glens and hollows at Nilgiri, Plalani, Anamalai, Bababudan and Kudremukh, above 1500m. These are called 'sholas'. Many workers consider them as climatic climax type. Bor (1938) regarded *shola* to be the relict of an evergreen forest climax, which has been pushed back to its last stronghold by fire and grazing. It cannot re-establish itself if destroyed. The trees found are evergreen, short boled (<12m), with dense round crowns, coriaceous leaves and branches harbouring epiphytes, mosses and lichens. Lianas are also frequent. The principal trees are *Gordonia obtusa, Illex denticulata, Elaeocarpus serratus, Meliosma arnottiana, M. wightii, Michelia nilagirica, Rhododendron nilagiricum* and species of *Microtropis, Syzygium* and *Vaccinium.* Eravikulum nature reserve includes this kind of forest.

5. **Memecylon-Syzygium-Actinodaphne type**: These evergreen forests are found in North Kanara, Belgaum, Ratnagiri, Kolhapur, and Satara (Karnataka and Maharashtra), at about 900-1500m. *Actinodaphne hookeri, Memecylon edule, Syzygium cumini* and *Terminalia chebula* are conspicuous tree elements in this type of forest, which is being protected in Ratnagiri nature reserve.

6. **Bridelia-Syzygium-Terminalia-Ficus type**: These potentially evergreen forests are encountered on the upper slopes of Western Ghats in Maharashtra, Mt. Abu, Girnar and summit of Ranathambor, from 600-1700m. *Bridelia retusa, Ficus racemosa, Heterophragma* spp., *Syzygium cumini* and *Terminalia* spp. lead the vegetation type. Karnala and Mt. Abu are the areas where these forests are protected.

1.3.2 Wet Evergreen Forest- Teak Forest Ecotone (transitional zone)

7. **Tectona-Lagerstroemia-Dillenia-Terminalia paniculata type**: These are moist deciduous forests occurring on the eastern side of Western Ghats in Maharashtra, Karnataka and Kerala, up to 1000m. Many species are common to the dry deciduous teak type mentioned below. *Lagerstoremia microcarpa* and *Terminalia paniculata* are confined to the western half of southern India. *Tectona grandis, Dillenia pentagyna* and *Xylia xylocapra* are exclusive species of the top canopy. Dandeli is the nature reserves, which includes this type of vegetation.

8. **Tectona-Terminalia-Anogeissus type**: This is a vegetation type that is transitional between the moist and dry deciduous forests. These occur in Thane, Nasik, Dangs and Bulsar districts in Maharashtra and Nagar-Haveli, up to 1000m. The top canopy is structured by *Tectona grandis, Terminalia alata, Anogeissus latifolia, Haldinia cordifolia* and *Dendrocalamus* (bamboo). Borivli, near Bombay, is the nature reserve.

1.3.3 Teak Zone

9. **Anogeissus-Terminalia-Tectona type**: These dry deciduous forests are spread from Jansi and Guna to Kanyakumari, up to 1000m. *Anogeissus latifolia, Terminalia alata, Tectona grandis, Dalbergia latifolia, Santalum album, Pterocarpus marsupium* and *Boswellia serrata* outline the top canopy. Major wildlife from India inhabits these forests, which are being protected under Bandipur, Madumalai, Nagarhole, Pakhal and Gir wildlife sanctuaries.
10. **Tectona-Terminalia type**: These dry deciduous forests are more or less the same as the above in the vegetation but for want of *Anogeissus*. These forests occur in Nallamalais, North Telangana, Raipur, Sagar, Panna, Kalahandi and Bhandara, up to 1000m. Tadoba, Bori, and Kutru are the reserves of it.

1.3.4 Teak-Sal transition zone

11. **Terminalia-Anogeissus type**: These dry deciduous forests occur in Tikamgarh, Satna, Rewa, Sidhi and Panna districts of Madhya Pradesh, Jansi of Uttar Pradesh and parts of Gujarat and Rajasthan, below 1000m. *Terminalia alata* and *Anogeissus latifolia* combine dominate the vegetation type. Sivapuri nature reserve conserves this kind of forest.

12. **Terminalia-Anogeissus-Cleistanthus type**: The teak and sal forests as a rule do not overlap and are generally separated by this dry deciduous miscellaneous type of forest. These forests are characteristic of the vegetation found north of Godavari in Andhra Pradesh, and Waiaganga-Chattisgarh-Mahanandi basin, below 1000m. This vegetation type is same as the above in the floristic composition bur for the appearance of *Cleistanthus collinus* in the understorey as the dominant species. *Terminalia alata, Anogeissus latifolia, Xylia xylocarpa*, etc. form the top storey while *Cassia fistula, Phyllanthus emblica*, etc. constitute the intermediate storey. The soils are sandy or loamy red ferruginous. Nagjhira and Nawegaon nature reserves care for this kind.

1.3.5 Sal zone

13. **Shorea-Buchanania-Cleistanthus type**: These are transitional between dry deciduous and moist peninsular sal forests. These occur in Bastar, Raipur, Kanker, Bilaspur, Raigarh, Sundargarh, Sambalpur and Kalhandi districts, below 1000m. *Shorea robusta, Buchanania lanzan, Cleistatnthus collinus* and *Madhuca indica* dominate the vegetation.

14. **Shorea-Cleistanthus-Croton type**: This vegetation type is same as the above but for the appearance of *Croton oblongifolius*. Birbhum, Chaibasa, Dhanbad, Bankura, Medinipur, Balsore, etc. are the areas where this vegetation is found; Dalma is the nature reserve protecting this kind of vegetation.
15. **Shorea-Buchananaia-Terminalia type**: These dry deciduous peninsular forests are found in Pachimarhi hills and Chhindwara district, at 1076m. *Terminalia* is the entrant here. Pachimarhi is the region where this kind of vegetation is protected.

16. **Shorea-Terminalia-Haldinia type**: This is a moist peninsular forest found in central India, Orissa, Bihar and sub-Himalayan tracts, about 1030m. *Shorea rubusta, Terminalia alata, Haldinia cordifolia, Xylia xylocarpa*, etc. form the top canopy while *Diospyros montana, Carea arborea, Kydia calycina, Mallotus philippensis*, etc. form the intermediate storey. The undergrowth is of *Grewia hirsuta, Helicteres isora, Clerodendrum viscosum*, etc. This vegetation is conserved in Kahnha, Palamau, Dudhwa and Cobrett national park.
17. **Shorea-Dillenia-Pterospermum type**: These coastal semi-evergreen forests occur in Puri and Cuttack districts of Orissa. *Shorea robusta, Dillenia pentagyna, Pterespermum heyneanum, etc.* form the dominant storey. Two species of *Cycas* (*C. orixense* and *C. sphaerica*, ined.), other than *C. circinalis* (which is characteristic of Western Ghats), mark this vegetation on the eastern slopes.
18. **Shorea-Syzygium-Toona-Symplocos type**: These moist peninsular sal forests are encountered in hills and plateaus of Orissa, Chotanagpur, Raigarh, etc. at about 900m. Along with sal, *Syzygium operculatum, Toona ciliata, Symplocos cochinchinensis* and *Dillenia pentagyna* constitute the major vegetation. These forest support good wildlife and the kind the forest is protected at Simlipal.
19. **Toona-Garuga type**: These are semi-evergreen forests without sal, above 900m in Koraput, Bailadilla, Papikonda and Vishakapatnam hills. Where these are found dense, there they are three-storeyed with the semi-deciduous *Toona ciliata, Garuga pinnata, Bombax ceiba, Persea macrantha*, etc. forming the first-storey, in view of the disappearance of sal due to over exploitation. *Fagaria budrunga, Cordia macleodii, Callicarpa arborea*, etc. form the second storey. The undergrowth is formed of *Colebrookea, Flemingia, Phoenix*, etc.

1.3.6 Hardwickia zone

20. **Hardwickia binata type**: These dry deciduous forests cover the dry plateaus of Tamil Nadu (Salem), Karnataka and Andhra Pradesh, Jalagaon and Dhulia districts, Satamala, Satpura, Mahadeo hills and Vindhyas, below 800m. *Hardwickia binata, Anogeissus latifolia* and *Pterocarpus santalinus* are the conspicuous elements of the vegetation.

1.3.7 Albizia amara zone

21. **Albizia amara-Acacia type**: These are shrubby woodlands which cover Tamil Nadu, Coastal Andhra plains, Rayalaseema, Bellary, Bijapur, Chitradurga, Dharwar, Kolar and Bangalore in Karnataka, below 600m. *Albizia amara, Pterospermum suberifolium Petrolobium hexapetala* and *Sapindus emarginatus* are the dominant elements.
22. **Anogeissus-Chloroxylon-Albizia type**: This scrub jungle is found in interior Karnataka, about 900m. The prominent tree elements are *Albizia amara, Choloxylon swietenia* and *Anogeissus latifolia*. Rani-bennur nature reserve intends to preserve this category of vegetation.
23. **Manilkara-Chloroxylon type**: These scrubby woods inhabit the coastal plains of Coromandel. *Manilkara hexandra, Chloroxylon swietenia, Memecylon umbellatum, Drypetes sepiaria, Dispyros ferrea* and *Albizia amara* make this forest. Point Calimere is the reserve for this kind of vegetation.

1.3.8 Anogeissus pendula semi-arid zone (Rajasthan)

24. **Acacia senegal-Anogeissus pendula type**: These are dry deciduous low forests occupying the areas in Sirohi, Pali, Ajmer, Jaipur, Barmer, Jodhpur districts, etc., below 600m. *Anogeissus pendula* is the dominant species. Its associates are *Acacia senegal* and *Commiphora mukul*. The type is associated mainly with brown soils.
25. **Acacia catechu-Anogeissus pendula type:** This vegetation is like the above but for the presence of *Acacia catechu*. This type occurs in Alwar, Sawi-Madhopur, Bharatpur, Gwalior, Bhilwara, Chitorgarh and Shajapur districts and Aravalli range, below 600m. Sariska and Ranthambor preserve this vegetation. The soils are of brown and black type.

26. **Anogeissus pendula-Anogeissus latifolia type:** These dry deciduous forests are found in Udaipur, Ajmer, Kota, and Shivapuri districts, Orcha and Bundelkhan plateau, below 600m. The soils are eutrophic brown. It approaches Anogeissus latifolia-Terminalia type though *Terminalia* is absent. In comparison to the above, *Anogeissus latifolia* replaces *Acacia catechu* in this vegetation type. This kind of vegetation is being preserved in Darrah.

1.3.9 Deccan Thorn Forest

27. **Acacia-Anogeissus latifolia type**: These thorny thickets occupy the Tapti-Purna valley and Deccan, below 600m. *Acaia nilotica* and *Anogeissus latifolia* are prominent among the woods.

1.3.10 Deccan-India Desert

28. **Acacia-Capparis type**: The thorny thickets of this kind are found in Deccan (from Bijapur to Julwania), Noth Gujarat and west of Aravali, below 800m. Species of *Acacia* and *Capparis* dominate these jungles. Fleshy euphorbes abound. At places, *Phoenix sylvestris* is seen. This type corresponds to *northern thorn scrub* and to the *northern Euphorbia semi-desert scrub* of Champion.

1.3.11 Indian Desert

29. **Prosopis-Capparis-Ziziphus-Salvadora type:** These are scattered shrubs encountered in Kutch (Gujarat) and western Rajasthan, below 400m. *Prosopis cineraria, Capparis dicidua, Salvadora oleoides* and *Ziziphus nummularia* form the major vegetation. *Calligonum polygonoides* is confined to the dune slopes whereas *Haloxylon* is more common in the interdunal areas. Desert National Park intends to preserve this kind of jungle.

1.3.12 Coastal Estuarine zone

30. **Mangroves**: According to Aubreville (1970), mangroves or *mangals* are the coastal tropical formations along the border of the sea near river mouths or estuaries. These are sometimes called 'Littoral *and tidal swamp forests'* (Champion & Seth 1968). Based on polyhaline data, the mangrove vegetation is classified into *Euestuarine* and *proestuarine*; the latter are further divided three subtypes Rao & Banerjee 1982), viz. **Tidal mangroves** (muddy soils

2)

under tidal influence: vegetation is luxuriantly growing scrubs and trees like *Aegiceras, Avicennia, Ceriops* and *Rhizophora*), **Euhaline** (highly salt-tolerant species growing in apparent dry or wet conditions: the vegetation is of *Acanthus ilicifolius* and *Clerodendrum inerme*, and herbs *Cressa cretica, Suaeda maritima*, etc.) and **Prohaline** (where the sea waters mix with freshwaters: the vegetation is of *Barringtonia, Bruguiera, Cerbera, Excoecaria, Scyphiphora* and *Sonneratia*). Although included by some, the non-halophilous vegetation and plantations (beach forests) do not constitute the mangroves. Fifty-eight principal salt-tolerant halophilous species are known from India, which belong to 41 genera and 29 families.

Fosberg (1975) recognized two categories of mangroves, viz. (i) *Core mangroves* with taxa like *Avicennia, Bruguiera, Ceriops, Kandelia, Lumnitzera, Rhizophora, Nypha* and *Sonneratia* forming the principal components, and (ii) *peripheral mangrove* species with a large ecological tolerance which would extend to areas beyond the influence of tides and salinity as in the case of *Acrostichum aureum, Hibiscus tiliaceous, etc.*

These mangroves occur in the mouth of Ganga (West Bengal), Mahanandi (Orissa), Godavari and Krishna (Andhra Pradesh), Cauvery (Tamil Nadu) in the east coast, west coast (Maharashtra and Gujarat), and Andaman and Nicobar Islands (Bay of Bengal), occupying more than 6.8 lakh hectares. The mangroves in Andhra Pradesh occupy 582 sq km which is 0.9% of geographic area. They occur in the estuaries of Vamsadhara, Godavari, Krishna and Pennar. Ramasubramanian *et al.* (2003) enlisted 35 species of mangroves belonging to 27 genera and 20 families of *Magnoliophyta* in Godavari and Krishna confluences. Mangroves are important as they help in the production of detritus, organic matter and recycling nutrients thereby enrich the coastal waters and support benthic population of sea. They prevent soil erosion, act as buffer for mainland from storms, and thus protect the coast from erosion. Besides, they provide feeding, spawning and nursery grounds to many organisms aside from providing a number of direct and indirect products, benefits and services to the humans. *Mangals* are now very much threatened habitats due to water pollution, aquaculture, fuel wood collection, etc.

1.3.13 Montane Temperate Forest. These are further classified under climatic, edaphic and biotic factors. These occur on Himalayas, the youngest mountain system of the world. The vegetation can be considered under western and eastern Himalayas (Fig. 1.2), the two biogegraphic zones, based on annual precipitation, topography, temperature, humidity and snowfall. It extends from 1500-3630m. The vegetation above it and the snowline is called Alpine zone. The vegetation of the Eastern Himalayas broadly differs from that of the Western Himalayas by having fewer conifers (*Abies, Pinus, Taxus* and *Tsuga*) and much more broad-leaved forests (Behera *et al.* 2002). There are more than 20 oaks as against the five in the Western Himalayas. The *Rhododendrons* have greater abundance and variety. There are tree ferns and orchids which greatly out number those in the Eastern Himalayas. The temperate zone in Eastern Himalayas is divisible into lower and upper. While the vegetation of the lower zone is dominated by broad-leaved oaks such as *Quercus lamellose, Q. lineate, Michelia excelsa*, species of *Pyrus, Symplocos, Meliosma*, etc., conifers such as *Abies webbiana, Picea spinulosa, Larix griffithiana* and *Tsuga brunoniana* along with willows, *Juniperus,* etc. dominate form the vegetation of the upper zone. The common bamboo is *Arundinaria racemoma*. In the Western Himalayas, with increasing altitude, the broad-leaved forests are gradually replaced by *Pinus roxburghii, Cedrus deodara, Pinus excelsa* and *P. gerardiana, Picea morinda* and *Abies pindrow* (Fig.1.2).

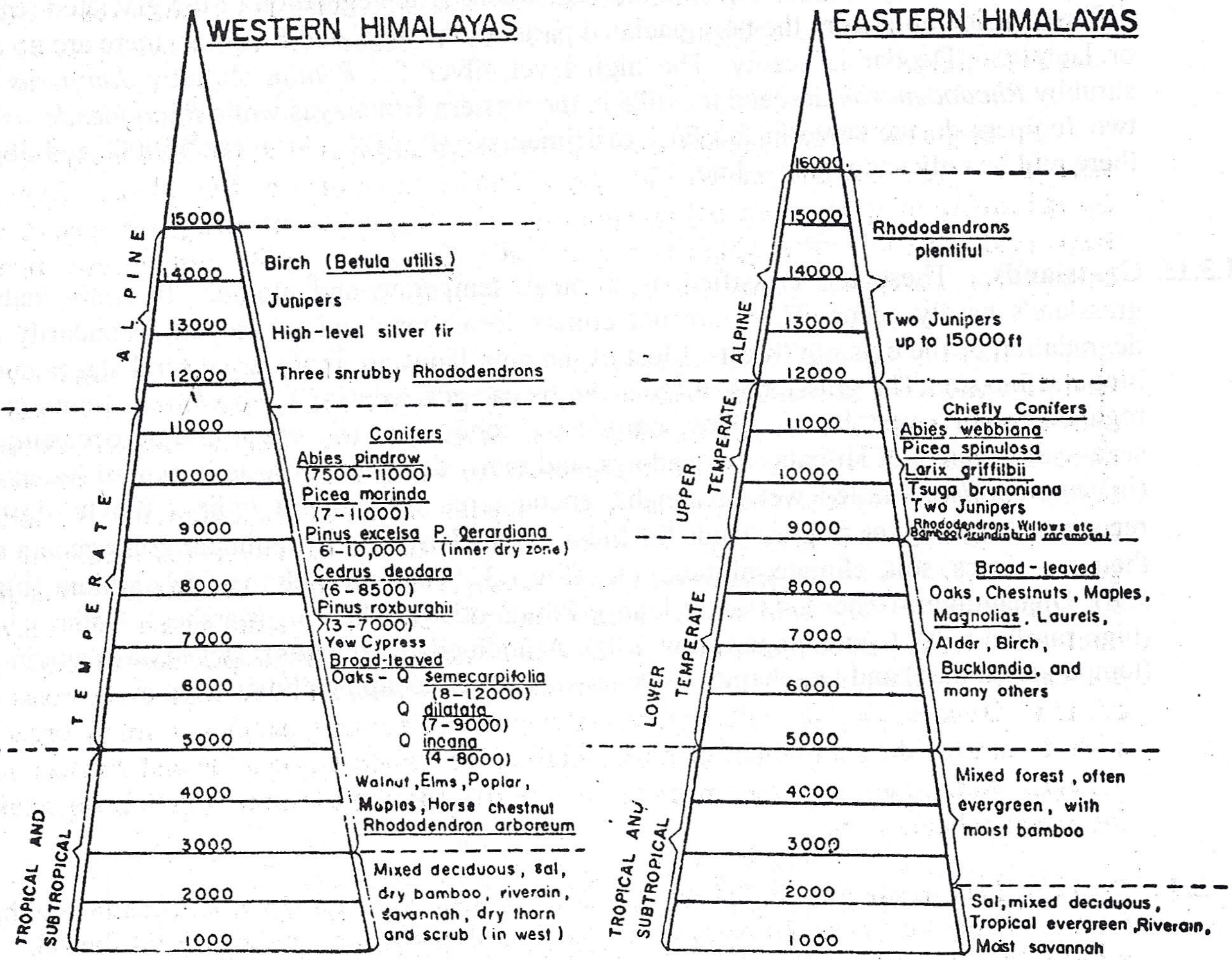

Fig.1.2 Vegetation zones in Eastern and Western Himalayas (After Puri *et al.* 1983).

1.3.14 Alpine zone

1.3.14.1 Alpine Forest. It is extensive throughout the (eastern and western) Himalayas, above 12000'. It is the limit for tree growth. This vegetation is divided into sub-alpine forests, and alpine, moist alpine and dry alpine scrubs. The tree height gets reduced with increased altitude. The smaller plants and sparse growth with *Potentilla*, *Primula, Saxifraga, Sedum*, etc. and lichens characterize the ultimate vegetation. The vegetation of the glaciated regions differs considerably from the non-glaciated parts. In the glaciated Kashmir, there are no oaks or laurels. Deodar is scanty. The high level silver fir, *Betula*, shrubby *Juniperus* and shrubby *Rhododendron* descend the hills in the western Himalayas while *Rhododendrons* and two Junipers do the same in the Eastern Himalayas (Fig.1.2). At about 15000' and above, there will be only snow (snow-line).

1.3.15 Grasslands. These are classified as tropical, temperate and alpine. In India, natural grasslands hardly occur. These are not climax formations and developed secondarily due degradation of the existing forests. Most of the grasslands are in different seral stages due to biotic influence. The grasslands in India can be categorized as: (i) *xerophilous*, found in the regions of northwest India, under semi-desert conditions, (ii) *mesophilous*, occurring as savannahs, typical of Himalayan meadows, and moist deciduous forests in central India, and (iii) *hygrophilous*, called wet savannahs, encountered in southern India. Whyte (1957) recognized *eight* types of grasslands for India, on the basis of the dominant grass genera and their associates, soil, climate, altitude, etc. (Fig.1.3). They are Sehima-Dichanthium (black soil), Dichanthium-Cenchrus (sandy loam), Phragmitis-Saccharum (Marshes), Bothriochloa (high rainfall belt), Cymbopogon (low hills), Arundinella (Moutains), Deyeuxia-Arundinella (temperate climate) and Deschampsia-Deyeuxia temperate alpine climate) types.

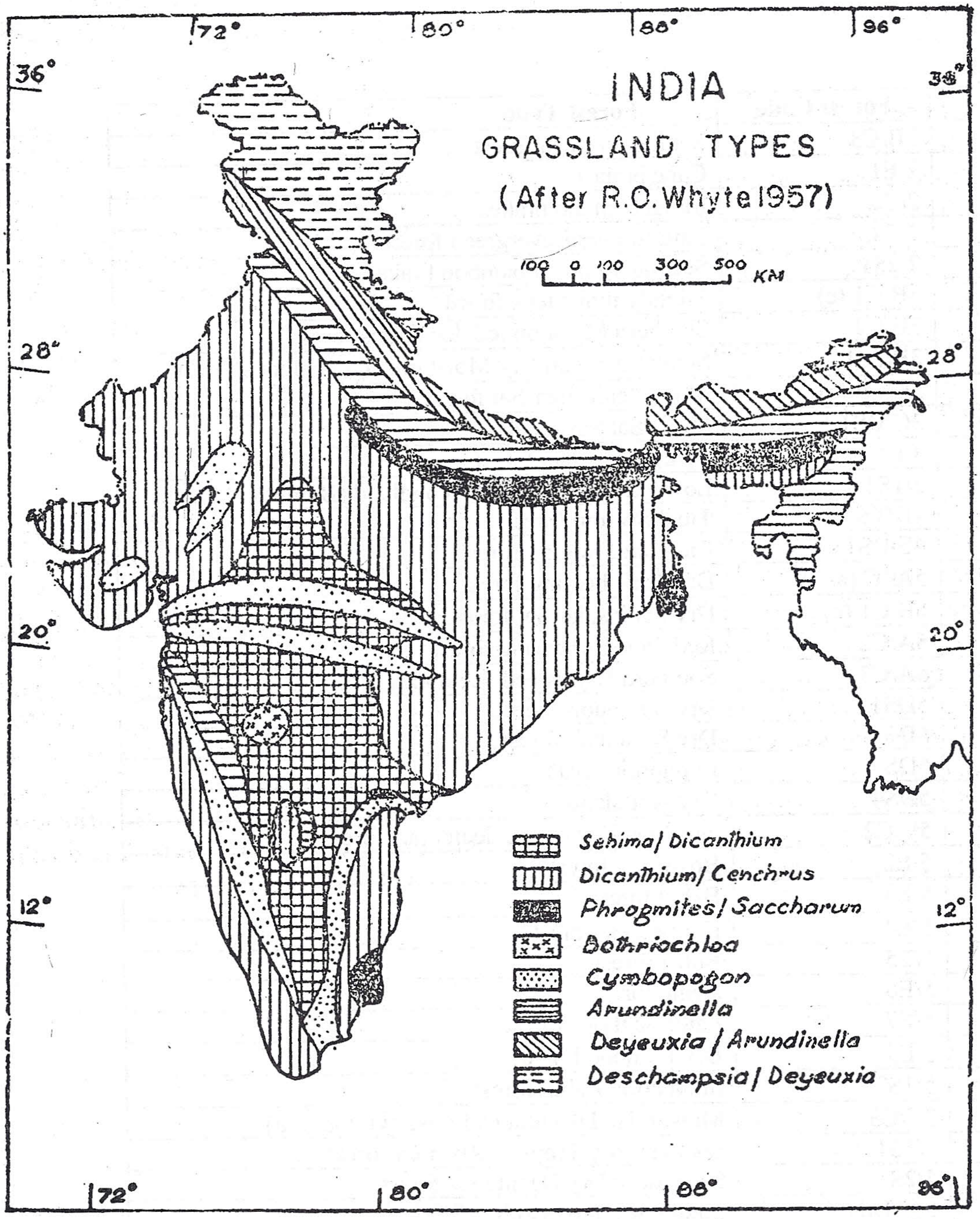

Fig.1.3 Grassland types of India (After Whyte 1957).

.4 FOREST TYPES OF ANDHRA PRADESH

The types of forests met within Andhra Pradesh, as per the revised classification of Champion & Seth (1968) are:

	Forest Code	Forest Type
1	2B/C3	Semi-evergreen forest
2	2/E1	Cane brakes
3	2/E3	Moist bamboo brakes
4	2/E4	Lateritic semi-evergreen forest
5	2/2S1	Secondary moist bamboo brakes
6	3B/C1 (c)	Slightly moist teak forest
7	3B/C2	Southern Moist mixed deciduous forest
8	3B/2S1	Southern Secondary Moist mixed deciduous forest
9	3C/C2 (e)	Moist Peninsular Sal forest
10	3C/DS1	Moist Sal Savannah
11	3/E1	Terminalia alata forest
12	3/1S1	Low alluvial Savannah Woodland (Bombax-Albizia)
13	4B/TS	Tidal Swamp forest
14	4E/RS1	Riparian Fringing forest
15	5A/ C (a, b)	Dry Teak bearing forest
16	5B/C1 (c)	Dry Peninsular Sal forest
17	5A/C2	Red Sanders bearing forest
18	5A/C3	Southern Dry mixed deciduous forest
19	5DS1	Dry Deciduous Scrub
20	5DS2	Dry Savannah forest
21	5DS3	Euphorbia scrub
22	5DS4	Dry Grassland
23	5B/C2	Northern Dry mixed deciduous forest
24	5/E2	Boswellia forest
25	5/E3	Babul forest
26	5/E4	Hardwickia forest
27	5/E5	Butea forest
28	5/E6	Aegle forest
29	5/E7	Lateritic thorn forest
30	5/E9	Dry Bamboo brake
31	5/1S3	Inundation Babul forest
32	3C/C3	Moist mixed deciduous forest (without Sal)
33	5/1S1	Southern dry Tropical Riverain forest
34	5/2S1	Secondary Dry Deciduous forest
35	6A/ DS1	Southern Thorn scrub
36	6A/DS2	Southern Euphorbia scrub
37	6/E4	Salvadora scrub
38	6/DS1	Cassia auriculata scrub
39	6B/Ds1	Ziziphus scrub
40	6A/C1	Southern Thorn forest
41	6B/C2	Ravine Thorn forest
42	7C1	Dry Evergreen forest

Besides, there are subsidiary and seral types spread over limited areas in the State.

Model Questions

a) Essay type:

1. Describe the vegetation types of India.
2. How is the plant cover classified at global and regional levels?

b) Short type:

Wet evergreen forest. Sholas. Dry deciduous forest. Teak zone. Sal zone. Hardwickia zone. Deccan thorn forest. Mangroves. Alpine zone. Temperate Montane forest. Grassland.

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Dr. VATSAVAYA S. RAJU

Unit- I

Lesson – 2

PLANT DISTRIBUTIONS: PAST AND PRESENT

2.0 Objective

This chapter intends to explain how plants, particularly the angiosperms, are distributed over the terrestrial land during the earth's episodes. It is important to know the distributions of the dominant taxa that formed the vegetation, or the productive world, in the past and the present since nothing of life is constant over a very long term, i.e. over millions of years. This explains how the floras evolve due to adaptations to changes, and how the environment is *holocoenotic* and its control is *primary* on the distributions of plants at any point of time.

2.1 INTRODUCTION

The first appearance of the terrestrial vascular plants took place approximately at about 430 million years (Ma) ago, during the Silurian. These were the early land plants. The plant fossils record (Fig. 2.1) clearly demonstrates the increasing trend of species-level diversity through geological time (Niklas *et al.* 1983). These were of four major groups evolved, namely, early land plants (*Bryophyta*), spore-producing plants (*Pteridophyta*), seed plants or gymnosperms (*Cycadophyta*) and flowering plants or angiosperms (*Magnoliophyta*). The spore-producing plants (lycopsids, filicopsids, shenopsids and progymnospersms) superseded the early land plants in the Devonian, at about 390 Ma. They were followed by gymnosperms (cordaites, pteridiosperms, conifers, cycads, bennettites, Gnetales and ginkgos) in the Lower Carboniferous, around 340 Ma. The last major reproductive innovation and radiation was that of the

Angiosperms in the Cretaceous, about 120 Ma. But, what is interesting is that there is no evidence for mass-scale reductions in the species-level diversity in the plant fossil record in comparison to the faunal record. Furthermore, with the radiation of each new group, the speciation rates were very high initially though decreased later to a low baseline. The only exception to this is the group of angiosperms; their overall numbers is still increasing and have yet to plateau. On the whole, the plant evolution appears to be concentrated in distinct intervals in geological time rather than evenly spread. Besides, an increase in morphological complexity and total plant species diversity took place in relatively short intervals of geological time, interspersed by longer periods of stasis. It is curious to note that the peaks of plant extinctions do not coincide with at least four of the 'big five' mass extinctions events.

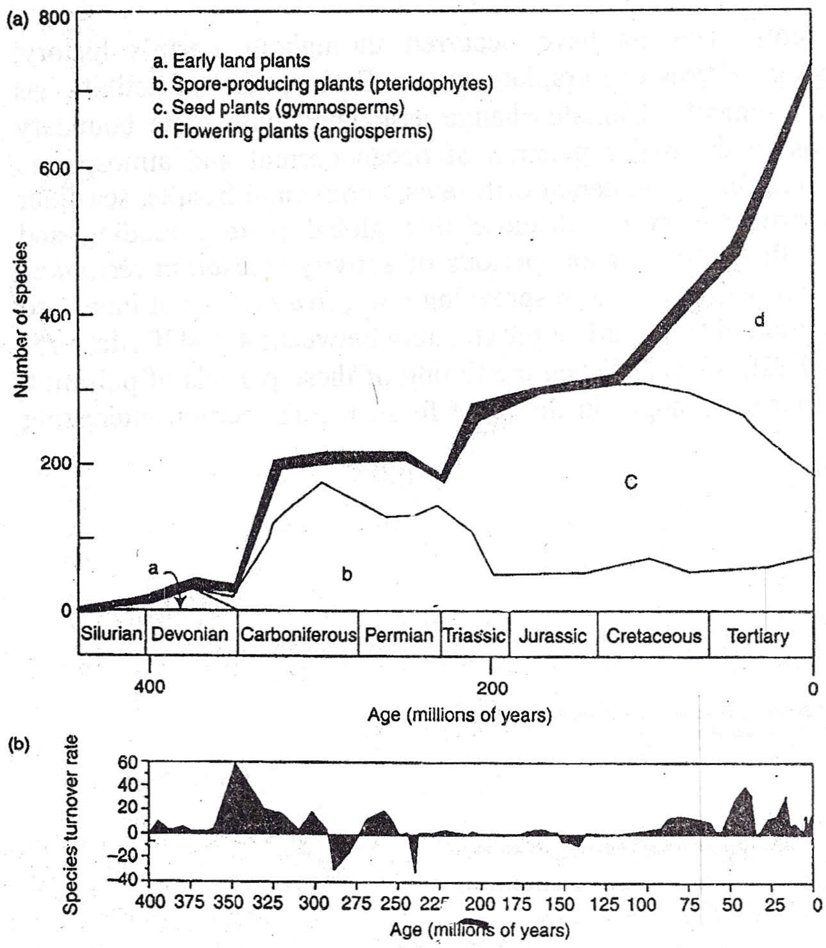

Fig. 2.1 Species-level diversity curves for vascular plants over geological time (Niklas *et al.* 1983).

2.2 PLANT DISTRIBUTIONS IN THE PAST

The background of distribution of the existing and extinct floras is crucial for Plant Systematics though the subject of Plant Geography is a broad field of study in itself. The distribution of the plants in the past can be called *palaeogeography.* It is based on plant fossil evidence. The evidence from plant fossil record reveals a broadening spectrum of diversity and morphological complexity through geological time. Biological interactions such as adaptations, competition and coevolution must have played a key role in terrestrial diversification (Niklas 1977). These are believed to be responsible for the decline in species diversity of incumbent clades of plants as the new ones evolved. Chronologically, there is a close relationship between major evolutionary change in the plant fossil record and the pulses of global plate spreading and increased tectonic activity (Sheridan 1997). Various physical/climatic parameters associated with these tectonic pulses probably may provide the answer to what is driving the plant evolution. According to Willis & McElwain (2002), the pulses of increased atmospheric CO_2 might well have been crucial to plant evolution, by furnishing a global extrinsic abiotic stress from which plants could not escape.

Plate Tectonics. Plate boundary reorganizations have occurred throughout Earth's history, involving collisions, rifting and changing patterns of intraplate stress. Each 'pulse' of activity has influenced every aspect of global environment. Climate change associated with plate boundary reorganizations results from alterations to the major patterns of ocean current and atmospheric circulation. Geological evidence gathered form continental drift rates, continental basalts, sea-floor spreading and subduction rates and orogenic events disclose that global plate spreading and subduction may have been episodic, with relatively short periods of activity (*pulsation tectonics*) separated by long periods of inactivity. Based on sea floor spreading rates, *five periods* of increased tectonic activity was recognized in the geological record, approximately between: 460-430 Ma, 375-350 Ma, 300-260 Ma, 170-160 Ma, and 120-80 Ma. When the timing of these periods of pulsation tectonics (Sheridan 1987) is superposed with changes in the plant fossil record, certain interesting patterns emerge (Fig. 2.2).

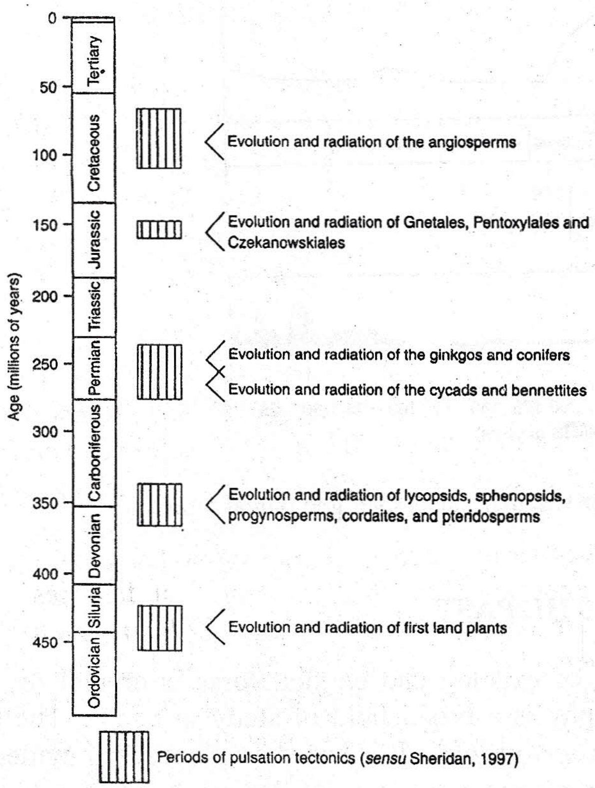

Fig. 2.2 Periods of pulsation tectonics and evolution/radiation of major plant groups.

(i) **460-430 Ma** (*Mid-Ordovician - Silurian*): During this period, the first identified rapid plate spreading took place. It resulted in the closing of the Iapetus Ocean that separated Laurentia (North America) from Baltica (Europe) and Gondwana (South America, Africa, Antarctica and Australia). During this period, there was first evidence for the terrestrialization of land by non-vascular plants. Fossil spores and cuticles without stomata indicate the presence of bryophyte-type plants (Graham *et al.* 2000) from 460 Ma on one hand, and true vascular plants like *Cooksonia* by the late Silurian (430 Ma), on the other.

(ii) **375-350 Ma** (*Mid-Devonian - early Carboniferous*): It was the episode when Baltica collided with Laurentia, and the Avalon volcanic arc terrain with Canada. It resulted in the rapid spreading of the new oceanic crust between Baltica and Gondwana. It was also the geological time period when rapid evolution and radiation of the lycopsids, shenopsids, progymnosperms, and the two earliest seed plant taxa (cordaites and peteridosperms) took place.

(iii) **300-260 Ma** (*late Carboniferous – early Permean*): It was the period of plate coalescence, resulting in the formation of Pangea, as a consequence of collision between Gondwana and Kazakhastan, and Siberia and Kazakhstan (Briggs 1995). The fossil record indicates the evolution and major radiation of the gymnosperms, beginning with the first appearance of cycads and bennettites around 280 Ma, ginkgos at 270 Ma, and the conifers from 260 Ma.

(iv) **170-160 Ma** (*middle Jurassic*): It was during this period the initial break-up of Pangea took place. As a consequence, there was rapid spreading of proto-Atlantic oceanic crust, with the parting North America from Africa/South America (Gondwana). In the plant fossil record, there was no new reproductive grade appears to have evolved but for the notable addition to the gymnosperms of *Pentoxylales* and *Czekanowskiales* (Stewart & Rothwell 1993) besides the *Gnetales*. These taxa are suggested as possible precursors to the angiosperms (Hughes 1994). The *Taxales*, among the conifers, also make their maiden appearance.

(v) **120-80 Ma** (*Cretaceous: Aptian-Campanian*): Major break-up of Pangea and rapid sea-floor spreading episodes in the Atlantic and Pacific were the major events of the latest pulse. During this period, South Atlantic, North Atlantic and Indian Ocean set up their margins. The first unequivocal evidence for the appearance and initiation of massive radiation of the angiosperms occurred.

Angiosperms increased both in the number of species and morphological diversity during the late Cretaceous (Fig. 2.3). The fossil evidence suggests that a number of families of northern and southern hemispheres have appeared for the first time. These include *Betulaceae, Fagaceae, Gunneraceae, Juglandaceae* and *Ulmaceae.* These constitute trees and shrubs. The remarkable numbers of angiosperm fossils with close affinities to extant families from late Cretaceous suggest that, during this period, all the angiosperm families might have probably originated.

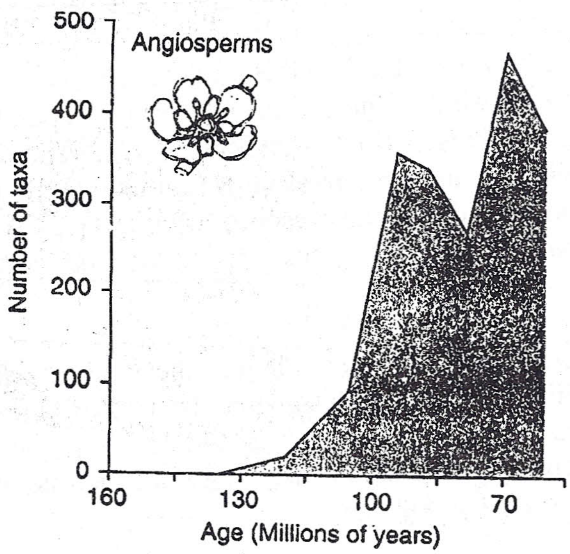

Fig. 2.3 Expansion of the *Magnoliophyta.*

2.2.1 Biogeographic Distribution of Global Vegetation in the past 65 million years

2.2.1.1 Late Cretaceous (~84-65 Ma):

Most of the present day angiosperm families are basically tropical in their requirements. The majority of the trees, which appeared in the late Cretaceous (100-65 Ma), have the present-day distribution that is largely tropical or subtropical. Therefore, it is probable that many taxa now classified as northern/southern temperate species by their distribution still possess the traits that would enable them to survive in early environmental conditions that prevailed during their origin. Horrell (1991) and Upchurch *et al.* (1999) carried out a detailed 'biome level-analysis' of global phytogeography and palaeoclimate for the late Cretaceous (Maastrichtian. ~71-65 Ma). They recognized *six* global biomes (Fig. 2.4).

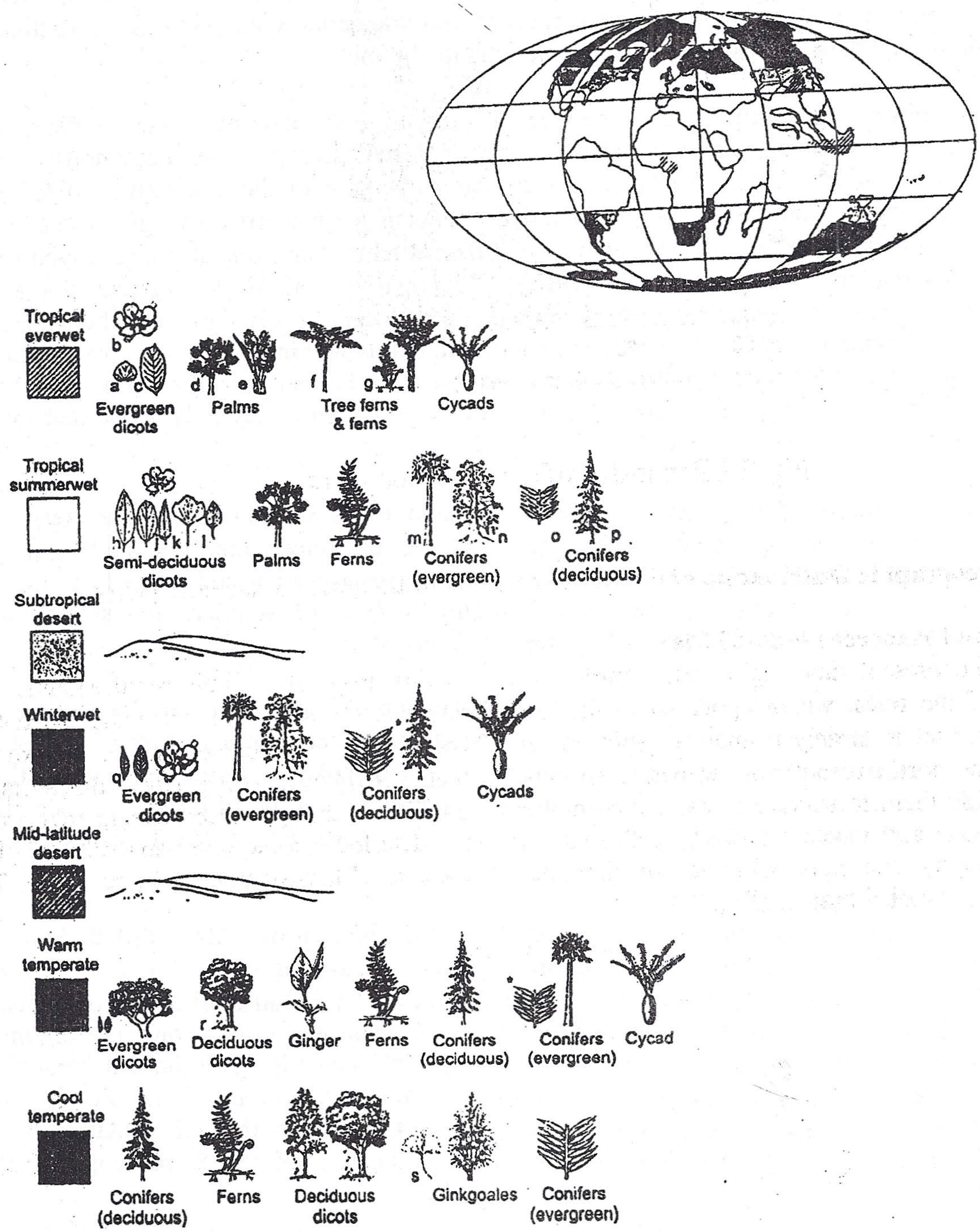

Fig. 2.4 Biomes of the late Cretaceous (84-65 Ma).

i. **Cool temperate biome.** It coincides roughly with the present-day Arctic circle, consisting of Canada, Greenland and Siberia in the northern hemisphere and Antarctica in the southern hemisphere

(Horrell 1991). The vegetation was a polar forest, dominated by deciduous and evergreen conifers (*Pinaceae* and *Taxodiaceae*, less significantly *Araucariaceae* and *Cupressaceae*), ferns and ginkgos. Angiosperms formed the understorey with members from *Betulaceae* and *Juglandaceae*. In the southern hemisphere, the dominant podocarpacean and araucarian conifers, and the southern beech (*Nothofagus*, the magnoliopsid genus) characterized the biome.

ii. Warm temperate biome. It existed between 45^0 and 65^0 palaeolatitude, covering the present-day northern North America, southern Greenland, parts of western Europe, Russia and northern China in the northern hemisphere and Australia and coastal Antarctica in the southern hemisphere. The characteristic vegetation of this biome included abundant angiosperms, evergreen and deciduous conifers, ferns and cycads. This vegetation was described as 'subtropical broad-leaved evergreen forest and woodland' (Upchurch *et al.* 1999). The members of *Magnoliophyta* abundant were *Fagaceae, Betulaceae, Juglandaceae, Ulmaceae, Proteaceae* (only southern hemisphere) and *Winteraceae* among the *Magnoliopsida*, and coryphoid palms within *Liliopsida*. *Araucariaceae* and *Taxodiaceae* were the apparent conifers. A detailed fossil floral analysis (Wing *et al.* 1993) revealed that though the angiosperm dicots constitute 61% of total diversity, they only accounted for 12% of cover when compared to 49% by ferns.

iii. Winterwet biome. The vegetation between palaeolatitudes 30^0 and 45^0 is characterized by the incident evergreen dicots together with evergreen and deciduous conifers, and some cycads. Monocots were relatively of lower abundance. Yet, angiosperms formed part of the understorey rather than the upper canopy (Upchurch & Wolfe 1987). In the southern hemisphere, the floras contain abundant ferns and angiosperm families like *Lauraceae*.

iv. Subtropical desert biome. The extensive evaporite deposits during the late Cretaceous indicate high rates of evaporation over precipitation. These deposits occur in a northern hemisphere belt which includes the present-day north America, China and Yukatan peninsula, and southwestern Africa and southern South America in the southern hemisphere. No fossil floras have been found in these biomes probably because of the low preservation potential of fossil plants in the arid environments.

v. Tropical summerwet biome. It incorporates most of the present-day Africa, South America and India from the palaeolatitudes 0^0 to 25^0 (Horrell 1991). According to Upchurch *et al.* 1999), it conforms to 'tropical semi-deciduous forest' type vegetation. It includes all of angiosperms, ferns, conifers and cycads. Both pollen and wood fossils suggest that the common conifers were members of *Araucariaceae*, *Cheirlepidaceae* and *Podocarpaceae*. Of interest is that India had floral elements typical of both the northern hemisphere (*Fagaceae* [*Nothofagus*], *Proteaceae* and *Podocarpaceae*) and southern hemisphere. This suggests that, by the late Cretaceous, the Indian plate was already part of the equatorial biogeographical region in spite of the position 30^0 S, palaeogeographically (Briggs 1995).

vi. Tropical everwet biome. It was much smaller and restricted to subequatorial West Africa, Malaysia, and possibly Somalia and Colombia (Horrell 1991) when compared to the present-day tropical rain forest. The equatorial region was predominated by palms (*Arecaceae*), including the extant mangrove palm genus *Nypa*, as suggested by pollen evidence. Other angiosperms, ferns and tree-ferns were abundant while evergreen or deciduous conifers were almost absent, except *Araucariaceae* in Malaysia.

2.2.1.1 Late Palaeocene to early Eocene (~60-50 Ma):

The overall fossil evidence for this interval indicates that the vegetation of the period was adapted to a warm and moist global climate. Woodlands of angiosperms, conifers and ferns extended from pole to pole. It was markedly diverse and there were more of tropical elements than the warm or slightly cooler proceeding early Palaeocene (Wing *et al.* 1992). *Six* biomes (Fig. 2.5) have been recognized for this period after biogeographic analysis (Wolfe 1985; Meyen 1987; Janis 1993) and with the evidence from climatically sensitive sediments (Boucot *et al.* 2001). Seasonality and daylength are believed to be the prime factors motivating the distribution of vegetation types.

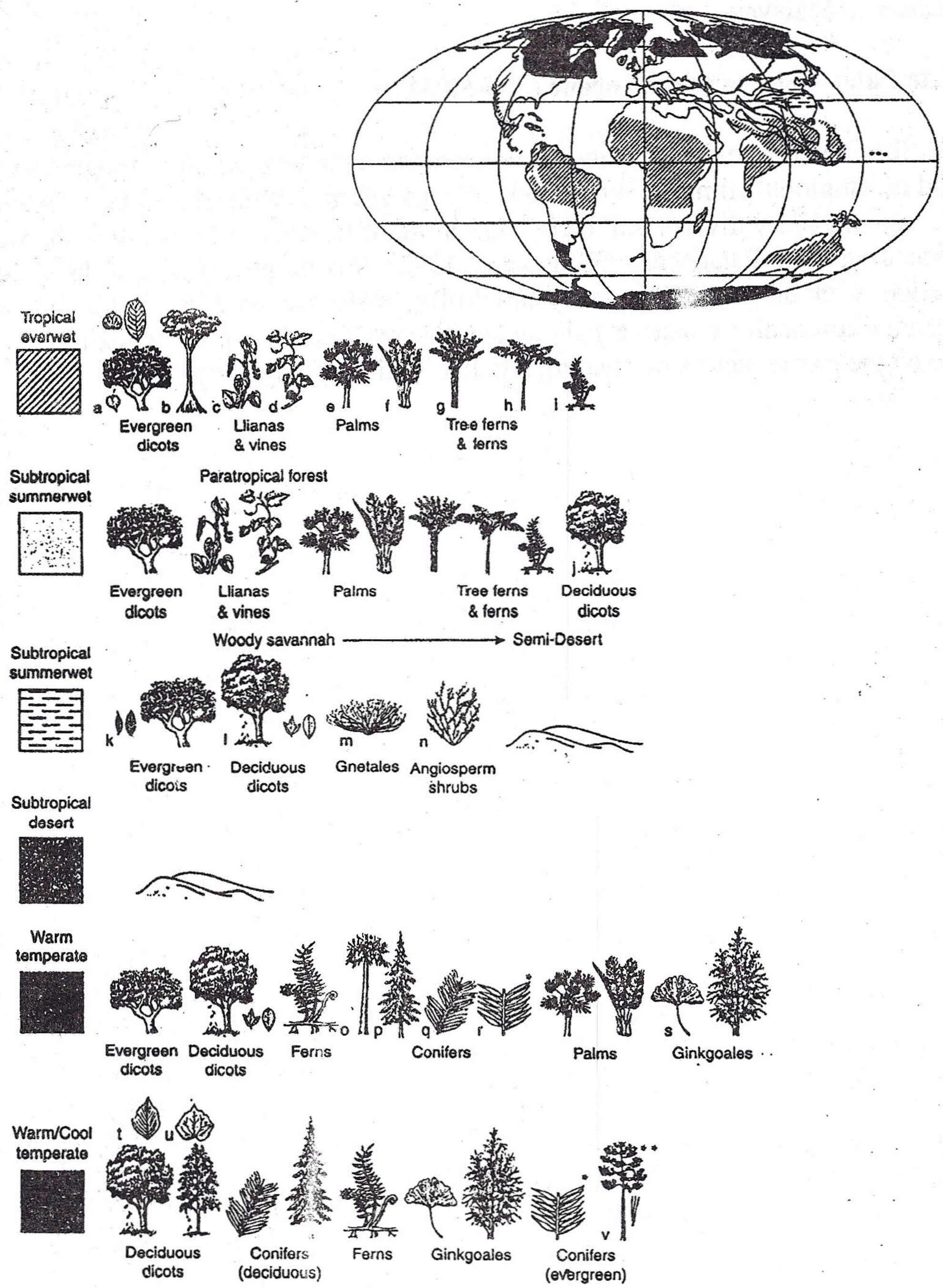

Fig. 2.5 Suggested biomes for the late Palaeocene and early Eocene.

i. Tropical everwet biome. The prevailing extensive humid tropical conditions lead to the spread of this biome in vast area, spanning the majority of the present-day South America, Africa, Southeast Asia, and southern and northern America. They developed into multistratal rain forests. The angiosperms have undergone quick diversification and modernization from which majority of the features so characteristic of the present-day tropical rainforest vegetation emerged. Evergreen trees with megaphyllous leaves (12 cm length) and drip-tips were present indicating humid and warm climatic conditions, without cold or dry seasons. The present-day dominant families such as *Araliaceae, Dipterocarpaceae, Elaeocarpaceae, Sapindaceae, Simaroubaceae, Tiliaceae*, etc. were first recorded in these biomes. Palms were diverse and abundant while the conifers like *Araucariacceae* and *Podocarpaceae* and ginkgos though present were rare.

ii-iii. Subtropical summerwet biome. It has two components: (i) *Paratropical forest*: It was the vegetation which covered northern Europe, North America and Russia in the northern and eastern Australia and parts of Argentina in the southern hemisphere during 60-50 Ma. It was really special as regards the composition and extent. Wolfe (1985) calls it 'paratropical rainforest'. The angiosperm families of this biome include *Anacardiaceae, Annonacee, Burseraceae, Lauraceae, Sapindaceae*, etc. almost all which are presently tropical to subtropical in distribution (Collinson 2000). Palms, lianas and climbers (*Icacinaceae, Menispermaceae* and *Vitaceae*) were the common elements in the fossil flora of this biome. Mangrove swamps fringed these forests. (ii) *Subtropical woodlands and wood savannah*: Aridity marked by the presence of evaporates and decrease in the leaf-size sketch the vegetation. These woodlands flourished in northern Tibet, southern Australia and parts of Argentina.

iv. Summerwet/Semi-desert biome. The presence of evaporates and calcretes and absence of coal in the present-day North Africa, central Asia and parts of South America mark the most arid regions. These regions were possibly transitional between summerwet and semi-desert conditions during the early Eocene. The fossil floras from China are 80% xerophytic shrubs (*Nitraria* and *Ephedra*) reflecting the semi-desert conditions. Probably, these shrubs were intermixed with *Alnus, Betula, Juglans, Liquidamber*, etc. (Li *et al.* 1984) indicating that full subtropical desert conditions was yet to develop.

v. Warm temperate biome. It encompassed the areas in the present-day Canada, southern Greenland and much of northeastern Asia in the northern hemisphere and Argentina and coastal Antarctica in the southern hemisphere. The dominant vegetation of this biome was evergreen with entire margined leaves bearing no drip-tips. These are called '*notophyllous broad-leaved evergreen forest*' (Wolfe 1985). The prevailing conditions were humid climate with monthly mean temperature from 13^0 to 20^0 C. Fossil evidence suggests that the floras forming this biome can be called 'oak-laurel' group because of the dominant *Fagaceae, Lauraceae, Theaceae* and *Magnoliaceae*.

vi. Warm/Cool temperate biome. It is constituted by unique vegetation, referred to as '*polar broad-leaved deciduous forest*' (Wolfe 1985). It was stretched poleward of about 70^0 in both the hemispheres, an area of the globe that is presently either treeless or under ice. It includes the northernmost Canada, Greenland, Siberia and, in the southern hemisphere, Antarctica. These polar forests have no modern analogue. The angiosperm remains indicate that the leaf was large but

3)

deciduous (e.g. *Acer, Alnus, Betula, Juglans, Populus* and *Quercus*). The conifers present in the high latitudes were also mostly deciduous (e.g. *Ginkgo, Larix, Metasequoia, Pseudolarix* and *Taxodium*). In the southern hemisphere, these forests were different with deciduous angiosperms and needle-leaved gymnosperms though the predominant tree elements were evergreen. The trees consisted of *Araucaria, Podocarpus* and *Nothofagus*. This difference was probably due to a climate characterized by lower seasonal ranges of temperature and higher levels of precipitation (Axelrod 1966).

Grasses. The appearance of grasses, which belong to the family Poaceae during the Palaeocene and early Eocene in the fossil record, marks the most outstanding evolutionary event for the humankind. Presently, there are more than 10000 species of grasses, spread in tropical and subtropical savannahs, temperate grasslands and steppes, covering 30% of planet's terrestrial land. These provide 52% of carbohydrates in human diet.

2.2.1.2 Oligocene (~34-25 Ma):

It was the period of significant global climatic cooling, increased aridity, major ocean circulation changes, and the initiation of ice on Antarctica. So, there were major reorganizations and redistributions of global vegetation took place during this period. While the poleward extent of tropical and paratropical vegetation severely restricted, the equatorial extent of the temperate vegetation expanded. *Six* biomes (Fig. 2.6) were recognized for the Oligocene (Wolfe 1985; Collinson 1992; Boucot *et al.* 2001).

i. Tropical everwet biome. Exact composition or location of it cannot be indicated for want of enough fossil evidence. However, it can be envisaged that these were more or less identical to those of the late Palaeocene and early Eocene though greatly reduced in latitudinal extent (Fig. 2.6). The predominant tropical trees species belonged to *Bursearaceae, Elaeocarpaceae, Euphorbiaceae, Fabaceae* and *Sapindaceae*. The mangroves inhabited the coasts but restricted to tropical and subtropical latitudes unlike in the earlier period.

ii-iii. Subtropical summerwet biome. It covered the area of North and South America, Africa, Asia and Australia between 10^0-30^0 palaeolatitudes in both the hemispheres. The concerned evidence indicates climatic aridity and equatorial limit of the biome. The fossil pollen and macrofloral evidence suggest that there existed two distinct plant formations in the biome: (i) *Paratropical forest*: Broad-leaved evergreen vegetation which occupied the less arid areas of the biome. These are placed immediately below the tropical everwet biome. The fossil flora from Africa included the angiosperms *Fabaceae, Annonaceae, Ebenaceae* and *Sterculiaceae*. The dominant microphyllous fossil leaves are indicative of seasonal aridity, typical of monsoon climates of summerwet biomes. *Cephalotaxus* and *Calocedrus* are the two gymnospermous taxa present amongst the dominant angiosperms. (ii) *Summerwet/ semi-desert biome*: The vegetation is to be classified as *woody savannah* in view of the abundant evaporite deposits. It covered the lands in Mongolia, Kazakhstan, northwest China and central North America in the northern hemisphere and parts of South America in the southern hemisphere. In China, arid-adapted shrubs like *Ephedra* and *Nitraria* together with members of *Chenopodiaceae* (saltbush family) became established.

iv. Warm/Cool temperate biome. By Oligocene, a wide band of both evergreen and deciduous broad-leaved woodlands established throughout central *Eurasia and North America and in* northernmost Africa. The warm temperate biome vegetation was consisted of cold temperate hardwoods like *Alnus, Betula, Corylus, Nyssa, Quercus* and *Ulnus*, warm temperate trees such as *Carya, Cercidiphyllum* and *Sequoia.* The percentage of taxa bearing entire-margined leaves decreased considerably. The climatic cooling during Oligocene was reflected in the changes in floristics and leaf physiognomy.

v. Cool/Cold temperate biome. This biome covered Canada, Greenland and most of Russia and Siberia in the north and southern tip of South America in the south, by the early Oligocene. The vegetation is referred to as '*mixed coniferous and deciduous woodland*'. The dominant elements of the vegetation include *Metasequoia* and *Alnus* (Wolfe 1992) in the northern hemisphere and *Nothofagus* and *Podocarpus* in the southern hemisphere (Truswell 1990). The abundance of *Pinaceae* in high-latitude fossil floras has increased from mid-Eocene which trend continued during the Oligocene.

vi. Cold temperate/Arctic biome? As yet, there is little evidence to confirm the formation of tundra in the Oligocene. Angiosperm shrubs, herbs and C_3 grasses existed or formed the vegetation.

Evolution of C_4 Plants. According to the method by which CO_2 is fixed, all higher plants are classified as C_3, C_4 and CAM. There are biochemical and physiological differences among these plants which were due to differential response to drought, temperature and CO_2 concentrations. Majority of *Pteridophyta, Cycadophyta* and *Magnoliophyta* possess C_3 photosynthetic pathway. The other two pathways are more recent. The C_4 plants are exclusive to *Magnoliophyta* though common among the *Poaceae (Liliopsida).* The pathway is also found in the members of *Amaranthaceae, Chenopodiaceae, Cyperaceae, Euphorbiaceae* and *Portulacaceae.* On the other hand, CAM plants are the cacti or members of *Asclepiadaceae, Bromeliaceae* and *Crassulaceae.* Several of polypodiaceous members and *Welwitschia mirabilis* also exhibit this pathway. C_3 pathway is believed to have evolved not later to late Silurian (~420 Ma), and the antiquity of CAM could be late Cretaceous (130 Ma) whereas the C_4 pathway evolved by the middle Miocene (~ 7-5 Ma)

2.2.1.3 Late Miocene (11.2-5.3 Ma):

By this time, steep pole to equator gradients had formed while ice-sheets formed at the South Pole and its build-up started in the northern hemisphere. Continental ice caps formed at the poles caused sea levels to drop; there was decreased global moisture availability. Consequently, continental interiors became increasingly arid while the shorelines were exposed due to falling of sea level. *Eight* major biomes were recognized during this period (Fig. 2.6); these are still realized today. The vegetation of this period is described as 'age of herbs' (Briggs 1995).

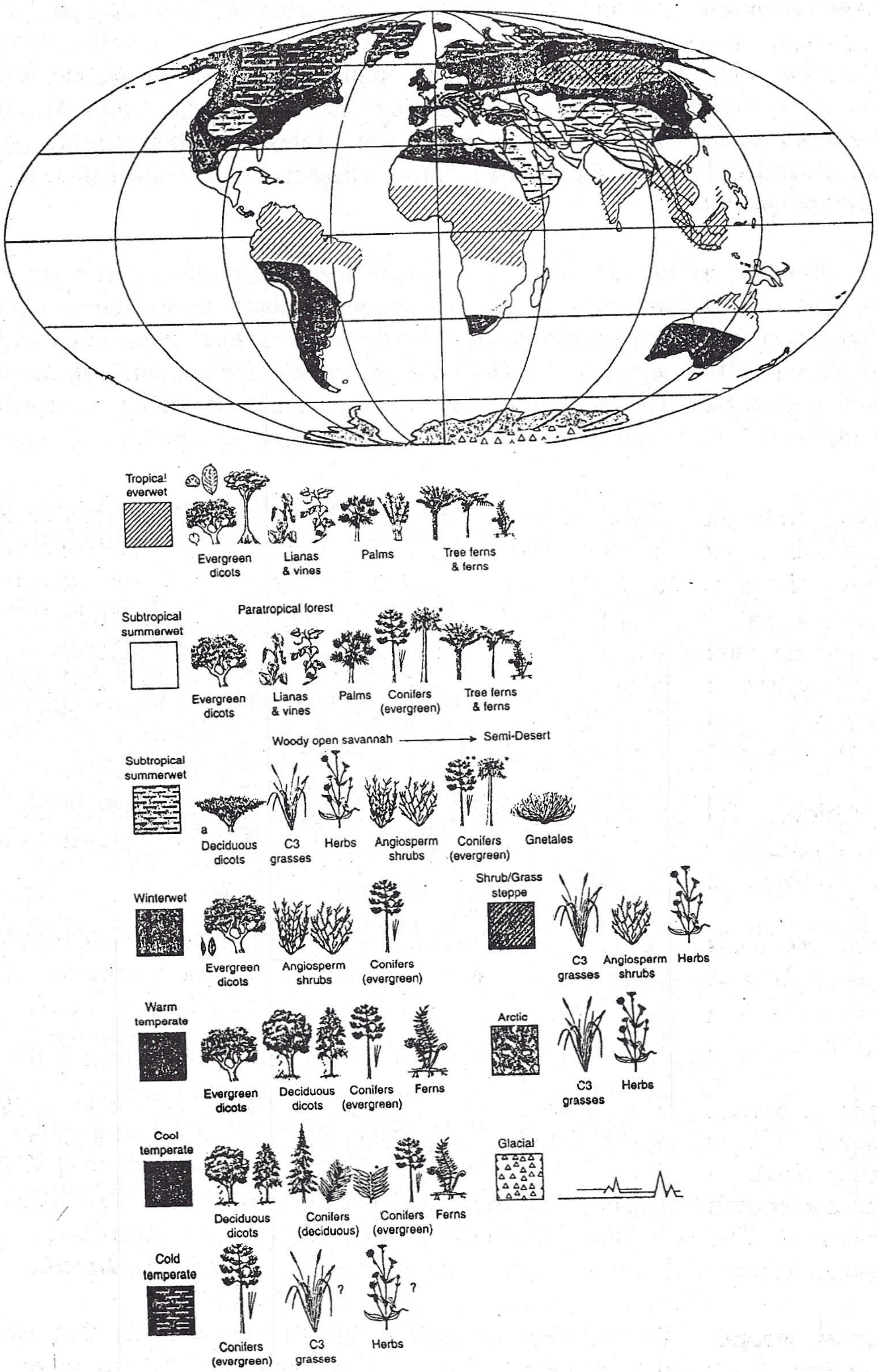

Fig. 2.6 Suggested biomes for the late Miocene.

i. Tropical everwet biome. A band of tropical rain forest extended over central Africa, northern South America, southern Asia and northern edge of Australia (Fig. 2.6). These forests remained more or less the same after 10 Ma though much reduced in area due to anthropogenic influence. The vegetation was highly diverse with plentiful evergreen trees, palms, lianas, vines, and a few conifers (incl. *Araucariaceae* and *Podocarpaceae*). The *Dipterocarpaceae*, one of the most important families of the Old World tropics today, appeared for the first time in the Miocene, in the fossil record of India (Meyen 1987).

ii. Subtropical summerwet biome. It is the paratropical forest poleward of approximately of 25^0 in both the hemispheres. Such forest was abundant in China, dominated by evergreen angiosperm trees with microphyllous entire-margined leaves, mixed with conifers like species of *Pinus, Picea* and *Glyptostrobus* (Guo 1993). The dominant *Magnoliophyta* were *Fagaceae* and *Lauraceae*. These are the forests generated by the continental uplift of Himalayas and Tibetan plateau, growing the under monsoon climate.

iii. Summerwet/subtropical desert biome. The above paratropical forest graded into more impoverished deciduous forest predominated by *Fagaceae* as in northwest India, or into open woody savannah in areas of high evaporite occurrence as in Arabia. There was an increase in the proportion of grasses in this period. The vegetation of these regions had angiosperm shrubs and bushes with spinose-margined xerophyllous leaves. Along with *Chenopodiaceae*, the gymnoperms, *Pinus* and *Juniperus*, increased their abundance. As regards the *desert vegetation*, the fossil pollen data from Kazakhstan and Gobi desert of China show high percentages of grasses and herbs, indicating a grassy savannah or a transitional biome which has no modern analogue today.

iv. Winterwet biome. This biome that existed during the late Cretaceous is discernible again in the Miocene, after a long absence. This vegetation principally composed of pine-oak woodlands with microphyllous shrubs and trees such as *Arbutus, Rhus* and *Ceanothus*.

v. Warm temperate biome. It consisted of lowland *Taxodium* swamps and deciduous forest formed of *Acer, Papulus, Salix* and *Quercus*. The whole biome is now much restricted in extent with lowered broad-leaved evergreen components compared to the late Palaeocene and early Eocene. It incorporated parts of western North and South America, cape of Africa, southwestern Australia, etc.

vi. Cool temperate biome. The equatorial limits of this biome extended from 45^0 in the Oligocene to 35^0 (highlands) – 25^0 (lowlands) by late Miocene. The poleward extent of the biome, on the other hand, has come down to below 70^0 from 80^0 in both the hemispheres, following increased seasonality and cooler global temperatures. Besides, Antarctica had become deforested with *tundra* vegetation developed. The vegetation was a mosaic of different communities (*Alnus, Acer, Betula, Platanus*, *Quercus*, *Ulmus,* and evergreen/deciduous *Pinaceae*) along with the *Taxodium* swamps.

vii. Shrub/Grass steppe. The interiors of Eurasia and North America that were arid and increasingly cooler, developed vegetation types which can be approximated to the present-day grasslands, prairies and steppes. New non-woody groups such as *Asteraceae* made their consistent appearance in the sediments of China, indicating the environmental preference for herbs. **A cold**

temperate biome? *Taiga-like* vegetation appeared in the late Miocene that indicates further cooling in the northern hemisphere. Present-day taiga is located in high latitudes of the northern hemisphere, but does not extend all the way to the poles. It is obvious that the Miocene polar climate was, though cooler, was still warmer than today.

viii. Arctic biome. It is construed that the entire Antarctic continent, which remained free of ice in the late Miocene, was covered by tundra vegetation (Singh 1988). However, unequivocal fossil evidence for tundra was not available until 3 Ma.

The re-arrangement of the biomes has been particularly pronounced over the past 1.8 Ma (Quaternary) in response to the environmental changes associated with the glacial and interglacial cycles.

2.3 PLANT DISTRIBUTIONS IN THE PRESENT

Life communities fit into the major climatic zones of the earth. Vegetational formations represent the basic framework of life-communities (Grisebach 1866). These are understood as tropical rain forest, montane forest, savannah, etc. Every vegetational formation has a specific structure. The study of the current distribution patterns of the vegetation is called *phytogeography*, which is being dealt separately in Unit IV. Presently, it is considered here from a different perspective, and in compatibility with the study of the distribution of the plants in the past, described above.

The world terrestrial vegetation types are called biomes. The vegetational formations together with the animals adapted to them are known as *biomes*. It is the plant matrix with the total number of animals included. How many biomes are there? There is no unanimity; no two ecologists agree on this count. The ecosystems, which are allied, are grouped under biomes. These constitute the macro-ecosystems. While biomes are the genera, ecosystems are the species. Although biomes provide convenient shorthand for describing the world's biota (i.e. flora and fauna), they have been mainly defined in terms of their dominant vegetation. Whittaker (1975) classified the world's terrestrial biomes. These are not dealt here not from ecosystem standpoint but from vegetation viewpoint:

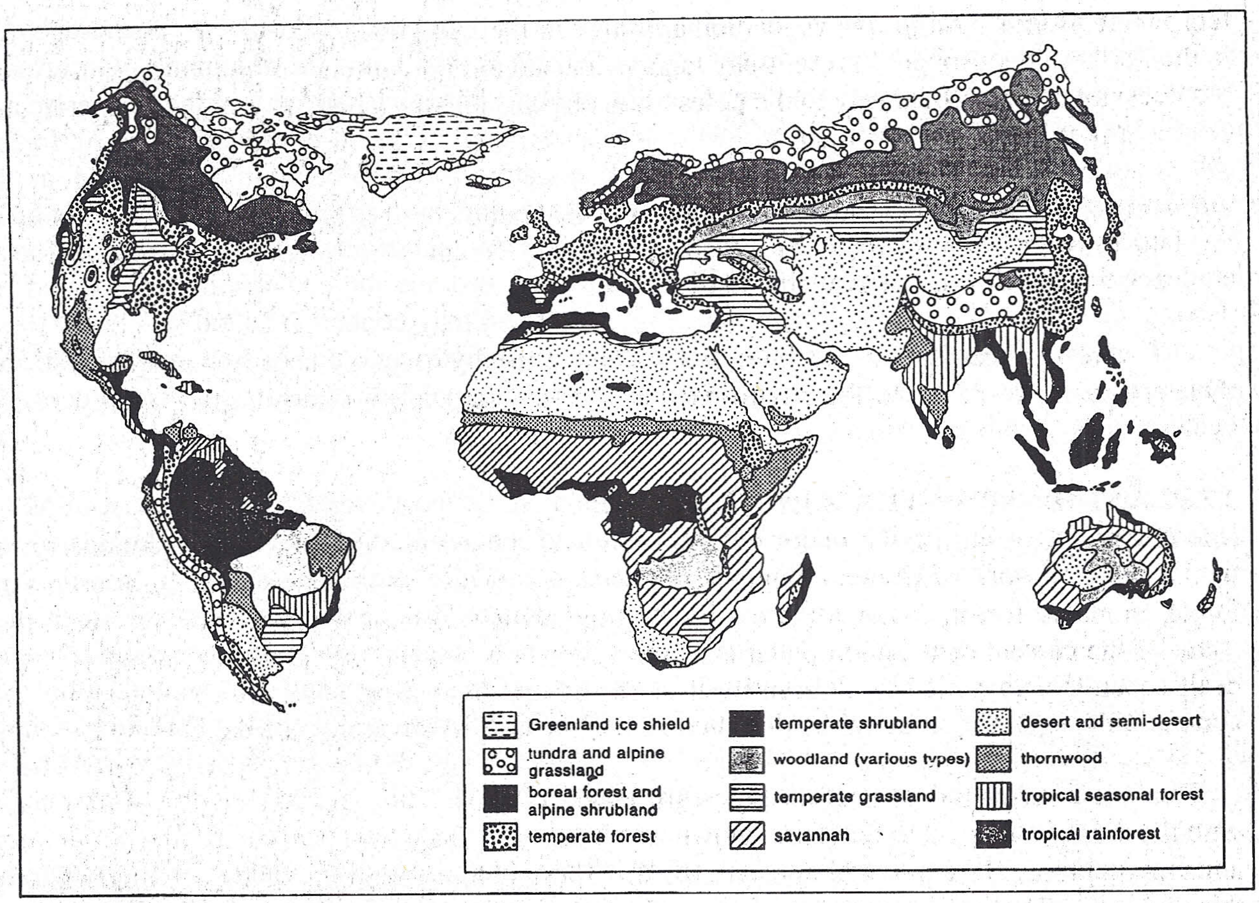

Fig. 2.7. Current terrestrial biomes of the world.

2.3.1.1 Tundra. The name is derived from the Finnish word *tunturi*, meaning an unforested hill. Vast areas of northern Asia and Canada are covered with low treeless expanses known as tundra. Mosses, lichens (with characteristic *Cladonia rangifera*, the reindeer moss, which is in fact lichen) and heaths rich in low scrub predominate. The growing season is too short, the winter is too cold, and the soil is shallow and unsuitable for tree growth. Only annuals, sedges (*Carex* spp.), and dwarf willows (*Salix* spp.) are found. The land fauna are critically dependent on the productivity of sea around.

2.3.1.2 Taiga. These are the north boreal forests, extending from northeastern Europe across Russia to the Pacific Ocean, right across America and Alaska. It contains the largest uninterrupted regions of the forest in the world. It is the only biome which stretches right round the earth interrupted only by the oceans. It forms a zone on average 1500 km wide. Towards the north, it grades into tundra and in the south it merges into deciduous forest or grassland. It is very cold in the taiga. Coniferous trees dominate the vegetation. In fact, these biomes are monotonous-looking conifer forest with relatively few other type trees (*Abies, Alnus, Betula, Larix, Picea, Pinus* and *Populus*). The ground flora includes delicate flowering plants like *Linnaea borealis, Moneses uniflora* and *Goodyera repens*.

2.3.1.3 Forest. Forests are the plant communities with dominance of trees or phanerophytes. Forests are classified on the basis of climate, physiognomy, floristics and the dominants. Occurrence of forest indicates optimal growth conditions in the region. Forests occur both in the temperate and tropical zones and occupy about 0.4% of the terrestrial land. Present-day distribution of forests shows continuous evergreen vegetation along the equator (the tropical rain forest) and in the temperate region from 45-60^0 latitudes (Taiga forest). Owing to seasonality (alternating cold and rainy periods), there occur deciduous forest in the tropics and subtropics. The tropical rain forest, with its favourable climatic conditions and diverse niches, provide the ecological back ground for rich faunal diversity. A square kilometer area in a rain forest may contain 200-300 species of trees, unparallel in any other biome. Trees with buttresses, epiphytes and lianas are characteristic of tropical rain forests. At present, the rain forest biome all over the world is in the process of destruction at the hands of people no different from us.

The temperate rain forests are found in some parts of India, northwestern Pacific coast of North America, southern Chile, west coast of New Zealand and Australia. These are dominated by gymnosperms (*Picea, Podocarpus, Pseudotsuga, Sequoia, Thuja,* etc.). The standing crop is large while the recycling of the nutrients is slow due to cool climate. The deciduous forests of the tropics are also known as monsoon forests. The temperature is usually high (c. 24^0) with the precipitation of 75-200 cm during the growth period. These habitats have warm summers and cold winters. The trees of these forests drop leaves during the hot or dry season. The canopy is not close, nor is the diversity high when compared to the tropical rain forests. In India, these forests are filled with species of *Tectona, Shorea, Terminalis, Dalbergia, Pterocarpus, Acacia*, etc.

2.3.1.4 Savannah. These are tropical grasslands, with scattered trees (Whittaker 1975) though the Spanish word *sabana* means grassland. Controlled by climate and soil, form three types of savannahs: Humid with 3-4.5, Arid with 6-7 and Thorn-bush with 8-9.5 arid months per year. In the humid savannah, the annual precipitation is still 1200 mm or more. In the rainy season, the ground is covered cent percent with plants while the proportion of fire-proof trees and pyrophytes is large. The trees reach a height of 6-12 m with large leaves and thick bark. These are largely untouched by forest fires. In the arid savannah, the annual precipitation is about 5000 to 1100 mm. There will be interrupted tree cover while the grass grows up to 1-2 m height and consists of hard-leaved tufts. Trees may be absent or when present grow up to 5-10 m. They are deciduous with the absence of lianas. In the thorn-bush savannah, the annual precipitation is only 200-700 mm. The grass cover is only 30-60 cm high while the thorn-bushes like Acacias and Mimosas dominate the landscape along with baobab tree (*Adansonia digitata*), etc. These formations are most extensive in Africa, but also found in Australia, South America and southern Asia. These support abundant wildlife, particularly larger mammals. Savannahs are subjected to fires, which resulted from lightening, or anthropogenic. So, the trees species must be fire resisting. The grazing by herbivores on one hand and the population control of herbivores by carnivores on the other profoundly influences the climax vegetation of the habitat. The role of the keystone species in this vegetation is very crucial both for fauna and flora. Accordingly, the savannahs may transform into woodlands or grasslands.

2.3.1.5 Grassland. These cover 20% of the earth's land surface. These are classified into tropical, temperate and alpine grasslands. The precipitation to evaporation ratio is less than one in grasslands. The soils are chernozems and chestnut soils. The vegetation is dominated by grasses, legumes ad members of *Asteraceae*. The climate is moderate, with summers dry and winters cool. The tropical grasslands are situated 200 away from the equator where the rainfall varies from 40-100 cm. Tropical grasslands of Africa abound in ungulates, deer, antelopes, giraffes, lions, etc. Most of the temperate grasslands are found across large areas of Eastern Europe and Asia (called **Steppe**), central North America (**Prairie**) and Argentina (**Pampas**), Hungary (**Puszta**) and South Africa (**Veldt**). The rainfall is about 25-75 cm per year. The European steppes lie between the forests to the north and the deserts to the south. Most of these steppes are now diverted to wheat production. There are not many species of birds there for want of trees. Nor is the steppe ideal for reptiles or amphibians. Tall grass prairies are dominated by species of *Andropogon* and *Buchloe*. The alpine grasslands are found high up mountains which tend to change towards the poles. These regions receive more rain and snowfall than the poles. The soil is thin and the rocks are loose. The alpine plants other than grasses grow slowly and bear beautifully coloured flowers (e.g. *Crocus, Fritillaria, Gentiana, Primula* and *Saxifraga*).

2.3.1.6 Desert. Edaphic and climatic factors control the desert conditions. Based on the substrata, the deserts can be distinguished into Rocky, Stony, Salt-clay, Sand and Salt deserts. Besides, they are classified as cold (temperate) and hot (warm) deserts. The deserts are the Sahara in the northern Africa, Kalahari in southern Africa, Thar in India, the deserts of Mexico, Atacama in South America, and the Australian deserts are hot deserts. The deserts of Iran and Turkey, the Gobi desert of Mongolia and some deserts of Argentina are classified as cold deserts. The flora and fauna (inc. people) are adapted to the desert conditions. While the primary productivity is very low in deserts, the consumer animals are locusts, rodents, camels, etc. On the whole, the number of species in a desert, relatively, is far less. For example, in the South American Rocky desert, there are only 250 plant species in 100 000 km^2.

The plants tolerant to extreme conditions in a desert can be classified as: (i) *Rain plants*: These spring to life and break into flower after rain, e.g. *Mesembryanthemum* and *Mollugo*. (ii) *Poikilohydrous plants*. These are plants whose leaves appear to wither during drought and immediately return to normal condition when wetted. Examples are *Selaginella* and *Chelianthes*. (iii) *Xerophytic plants*: These are adapted to sand desert as *Aristida pungens*. (iv) *Perennial plants*: These are plants with well-developed root system, e.g. *Tamarix* species which send roots up to 30m deep. (v) *Succulent plants*: These possess water-storing tissues or ability, e.g. the cacti in the American deserts and the euphorbes of the African deserts. (vi) *Sclerophilous plants*: These are with hard leaves or none and cover with thorns, and (vii) *Salt plants*: These occur in dry basins, like *Chenopodiaceae*.

Model Questions

a) Essay type:

1. Write an essay on the distribution of the extinct global vegetation.
2. Depict the distribution of the current/extant global vegetation.

b) Short type:

Pulsation tectonics and patterns of plant group emergence. Vegetation of late Palaeocene to early Eocene. Vegetation of Oligocene. Vegetation of late Miocene. Appearance of Grasses. Evolution of C_4 plants. Tropical everwet biome. Paratropical forest. Summerwet or Semi-desert biome. Warm temperate biome. Winter biome. Cool temperate biome.

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Dr. VATSAVAYA S. RAJU

Unit –1

Lesson – 3

SYSTEMS OF CLASSIFICATION: PRE-DARWINIAN SYSTEMS

"The urge to classify is a fundamental human instinct;............it accompanies us into the world at birth and stays with us to the end."

(*Tindell Hopwood* 1959)

3.0 **Objective**

This chapter attempts to present the systems of plant classifications and the conceptual advancements till Darwin revealed his theory of evolution.

3.1 INTRODUCTION

The term *classification* is applied for both the *process* of classification as well as for the *product* of this practice, i.e. the system of classification. Biological classification is the process of grouping together the like organisms and the subsequent placing together of these groups into bigger ones. Therefore, the system of classification contains taxonomic categories like species, genus, family, order, class and division) into which the units or groups of units are placed. The system of classification thus requires a hierarchy of categories for these placements. Therefore, classification, in a biological sense, is the *ordering of the plants into groups that are arranged in a hierarchy.*

The taxonomist has learnt by experience, as principles of classification, two aspects: (i) in process of classification in which the taxonomist should assess the totality of similarities and differences of the organisms studied, and (ii) the characters are to be weighted with respect to their value in circumscribing the groups recognized and differentiating them. Different systems of classifications, such as practical, artificial, natural, evolutionary and phylogenetic systems have been proposed with the needs, levels of understanding the relationships of the groups, data means, and changing perspectives. This developmental process can be stated as the evolution of the current systems of classification. The refinement of the existing classification will go on; it is a continuous process. However, as means, the taxonomists have in mind, the *ideal* classification. It is a kind of *master* *classification*, in the structure of which all known facts are incorporated and in the design of which the doctrine of evolution places a fundamental part.

3.1.1 Developmental Phases

The development of plant classification can be considered as four successive phases (Davis & Heywood 1963):

1. *Pioneer or Exploratory Phase*: The primary concern was identification. The flora was known largely from the limited herbarium material, with meager field data. Morphology and plant distribution provide the data on which the taxonomist must rely. Much of the European flora during the time of Linnaeus falls under this category.

2. *The Consolidation Phase*: The species were studied both in the herbarium and for a considerable period in the field. Local variations in species were better known. Floras and basic Monographs were produced. Much of the floras of the southern Europe and near East are of this category.

3. *The Biosystematic Phase*: Not only the geographical distribution was well known, cytological and biosystematic data on the groups were available. The emphasis was on microevolution and variation. The floras of UK, USA and Japan could attain this phase.

4. *The Enclopaedic Phase*: It is the consolidation of the above three phases. All the available evidence was considered in order to express the taxonomic and evolutionary relationships of plants at all levels of the hierarchy.

The first two phases correspond to the 'alpha' classification of Turrill (1938), the preliminary classification that was based almost entirely on the external morphology. The classifications of de Candolle and Bentham & Hooker are of this category. The other two phases come up to the 'omega' classification, the natural system based on all available and relevant data. To day, the systems of plant classifications of the world crossed the 'alpha-stage' and progressing nearer to the goal of 'omega' classification (Davis & Heywood 1963).

3.2 SYSTEMS OF CLASSIFICATION

Basically, we realize three kinds of classifications, viz.: Artificial, Natural and Phylogenetic or Phyletic (Fig. 3.1).

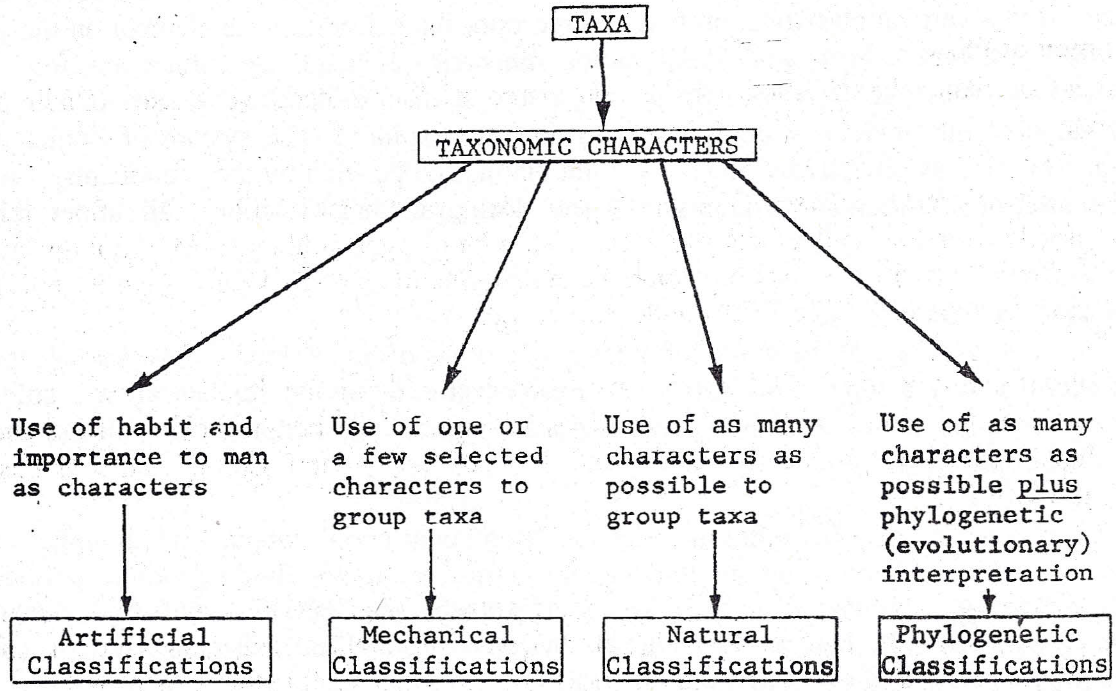

Fig. 3.1 From taxa-to-system in the development of various general biological classifications.

(a) ***Artificial Classification***. Most of the early systems of classification to a great extent were artificial, i.e. they were based on a few convenient characters for the purpose of identification. The system of Linnaeus is a good example of artificial classification. Linnaeus used a few sexual characters like the number of stamens, their fusion, number of styles, etc. Consequently, *Canna* (*Cannaceae*, *Liliopsida*), *Euphorbia* (*Euphorbiaceae, Magnoliopsida*) of *Magnoliophyta* and *Pinus* (*Pinaceae*) of *Cycadophyta* were included under one class, the *Monandria*. We know pretty well that these taxa are no way related. However, the artificial systems are special purpose classifications. They are practical classification, good for the purpose for which they are meant.

(b) ***Natural Classification***. Darwin (1859) revealed his theory of evolution and revolutionized the approach to biological classification. This landmark helped to group the classifications proposed into pre- and post-Darwinian systems based on the philosophical (evolutionary) content employed in the system. It is presumed that larger the number of characters shared by different taxa, more closely are they related to each other. Natural classification has a predictive value and is two-dimensional. And, it is a horizontal classification. The system of Bentham & Hooker (1862-1883) was the culmination of natural systems. Although post-Darwinian *in publication,* it was pre-Darwinian *in concept*.

(c) ***Phylogenetic classification***. Post-Darwinian systems are mostly claimed to be phylogenetic in principle. They are based on phylogenetic inference and usually presented in the form a evolutionary shrub, or phyletic tree depicting the presumed divergence of the groups. A phylogenetic classification is usually based on a natural system and modified in the light of the evolutionary or fossil evidence. It is a vertical classification that is three-dimensional, with time element on the y-axis. It is. Unless we have a horizontal classification (phenetic) at hand, we cannot construct a vertical (phyletic) classification. The phenetic and phyletic systems are like the two sides of a coin. The practical value of the phyletic systems is yet to be fully explored. The system of Engler & Prantle, though classified as phyletic by others, was not claimed to be such by the proponents. The systems of Hutchinson, Takhtajan, Cronquist, Thorne, Dahlgren and Goldberg fall under this category.

3.3 PRE-DARWINIAN SYSTEMS

The quest for knowledge is one of the more noble insatiable urges of humankind. Their knowledge of plants has accrued over a long period of time. Besides, the history of science always holds fascination for general public as well as the professionals alike. The insights from history are necessary for a better progress.

The current systems of classifications are the results of continuous labour and thoughts of generations of taxonomic workers. Although there are no sharp lines drawn dividing various periods of progress, the following stages can be realized: Period of Ancients (ca. 300 BC – 1500 AD), Period of Herbalists (1500-1580), Period of Mechanical Systems (1580-1760), Sexual System (of Linnaeus), and the Period of Natural Systems (1760-1880).

3.3.1 Period of Ancients. It can be considered in two heads, the Pre-literate Humankind and Ancient Literate Civilization.

(a) ***The Pre-literate Humankind***: We can only infer about the practical knowledge of plants of pre-literate societies who were gathering food from the landscape. Through experience they learnt the elements of botany that are edible or not. It is interesting to note that the present-day 'primitive societies' have their own linguistic mechanisms to identify and distinguish the plants parallel to the professional taxonomists of today.

(b) ***Ancient Literate Civilization***: With the dawn of civilization, the ancient man has come learn how to read and write before the advent of printing which allowed one to recall the data. Earlier to it, the dissemination of knowledge was an oral affair. The first individuals among the ancients whose contribution can be recalled are Theophrastus, Dioscorides, Pliny and Magnus. They tried to transmit what was generally known about plants. The classifications were based on habit and a few groups were recognized.

Theophrastus (c.370-287 BC), a pupil of Aristotle, called *Father of Botany*, classified 480 kinds of plants into trees, shrubs, under-shrubs and herbs, and then into cultivated and wild kinds. He distinguished between or among the annuals/biennials/
perennials, seed/stem/leaf, determinate/indeterminate inflorescence, hypogyny/ perigyny/ epigyny, monocot/ dicot, etc. The groupings were artificial and recognized no categories comparable to those, which we know them today. The philosophy was that of Plato and Aristotle, with the rule of 'excluded middle' (i.e. a given object is either A, or not A). Several the generic names (e.g. *Daucus,*

Crataegus, Narcissus, to name a few) employed by Theophrastus in his *De Historia Plantarum* are in use even today.

Parasara (250- 120 BC), the Indian scholar, has compiled *Vrikshayurveda*, one of the earliest works dealing with science of life. It has chapters on morphology, internal structure of plants, types of soils, and forests in India. **Charaka** (1st century AD) wrote his *Charaka Samhita* in which he recognized trees (with and without flowers), herbs that wither after fruiting, and herbs with spreading stems.

About 60 AD, **P. Dioscorides,** the Greek Physician, wrote his *De Materia Medica*, carrying accounts of 600 medicinal species. The manuscript is better known as *Codex Juliana*. This work held an important historical position in botany for one and half millennia. Dioscorides grouped the plants under oils, spices, cereals, condiments, etc. and attempted to recognize some natural groups like *labiates* and *umbels*. The genus, *Dioscorea* (family *Dioscoreaceae*), immortalize his name.

Islamic botany. The Muslim empire between 610-1100 AD saw the revival of literacy, with the translation of manuscripts from Greek. The emphasis was on agriculture and medicine. **Ibn-Sina** (Avicenna) authored the scientific classic *Canon of Medicine*, comparable to *Meteria medica*. **Ibu-al-Awwan** of 12th century described 600 plants.

Albert Magnus (1193-1280), called the *Doctor Universalis* and *Aristotle of the Middle Ages* by historians, accepted Theophrastus' classification for the most part and recognized differences in stem structure between mono- and dicots. The criteria employed for major categories are: leafy vs. non-leafy; the leafy were divided into *Corticatae* (monocots) and *Tunicatae* (dicots); the latter in turn were divided into herbaceous and woody. He named and described the garden vegetables in his *de Vegetabilis*, which was read for the next two centuries.

3.3.2 Period of Herbalists (ca. 300 BC–1500 AD). The need for mediaeval medicine has lead to the compilation of numerous herbals. The authors of these works are called herbalists. The earlier replicas of plants were crude woodcuts. Then came the illustrations, mostly from the Dioscorides, which were copied and recopied till they lost originality. The helpless later generations (the herbalists of the 16th and 17th centuries) have to take-up brush, or seek the help of an artist, and go to the living plant. Therefore, we find fairly accurate figures in the herbals of Brunfels, Bock, Fuchs, Mattioli, l'Obel, etc. Brunfels (1530) recognized the *Perfect* (flowers visible at arm's length) and *Imperfect* (flowers not visible). Bock (1539) described, though concisely, 567 species. Fuchs (1542) provided fine engravings of the New World plants. Mattioli (1544) created excellent illustrations of plants whereas Cordus (1561) gave emphasis to its odour and taste besides describing the plant morphologically. l'Obel's (1581) classification was based upon general form, growth habit, economic uses and width of leaf. He supposed the grass-like plants with narrow leaves as simpler forms and trees as the most perfect derived via dicot herbs and shrubs. Bankes, Turner and Gerard are the other names worth mentioning here. During the Period of Herbalists, the quality of descriptions and illustrations has improved noticeably. There was an increase in the number of plants known as well. And, there was an attempt to group the closely related together, e.g. composites, umbels, grasses, rushes, etc.

Renaissance. The 15th century saw the renaissance in Europe with the technical advances, in particular the invention of printing machine. The scientific navigation skills have led to explore the botanical wealth in the distant lands.

3.3.3 Period of Mechanical Systems (1580-1760). The classification were mainly based on form, though taken into cognizance a number of other criteria. The primary concern was information retrieval. The system itself was more important. More and more natural groups were recognized with the improvement in the hierarchy of categories. The early taxonomists Caesalpino, Jean/Gaspard Bauhins, Rivinus, Ray, Magnol, and Tournefort contributed to the development of these systems. The efforts were culminated in the sexual system of Linnaeus.

Andrea Caesalpino (1590-1613), the first plant taxonomist to provide a methodical classification. He was the earliest Italian botanist to do so. Using *a priori* weighting (Aristotelian Approach), he sought a classification of plants upon reasoning rather than utilitarian considerations. Organs of fructification were considered more important than the habit. Fruits were classified on the basis of position, locule number and seed number. He recognized: stem woody/herbaceous, ovary inferior/superior, sap milky/watery, bulbs present/absent, etc. He had good conception of genus and described 1520 plants in his *De Plantis* (1583).

Jean Bauhin (1541-1613) attempted his classification with good diagnoses of 5000 plants in his *Historia Plantarum Universalis* (which was in print posthumously in 1650). Earlier, his brother Gaspard [Casper] Bauhin (1560-1624) published his *Pinax* (1623) with 6000 species, a work dominated for a century. He placed together the composites, crucifers, cucurbits, poppies and solanads though kept the duckweeds among the cryptogams and water ferns with mosses. He was the first to use the binomial nomenclature, followed by Augustus Rivinus (1690), who emphasized the importance of corolla in his system. The Bauhin-brothers were immortalized befittingly by the generic name *Bauhinia*, bearing bi-lobed leaves.

John Ray (1628-1705), the English Philosopher and naturalist, proposed his system from the best of Magnus, Caesalpino, Malphigi and Grew. He formulated his own rule that 'all parts of the plants should be considered for classification', a principle now considered the cornerstone for the natural system. He grouped the plants on the basis of form, gave clear keys to genera, and described 18000 species. His concept of the species was much more superior than that of Linnaeus to come later. In *Methodus Plantarum* (1703), he divided the plant kingdom into *Herbae* and *Arborae,* both consisted of Monocots and Dicots under *Perfectae* (seed plants) though the *Imperfectae* (the non-flowering Algae, Fungi, etc.) formed the initial group in *Herbae*. His *Bacciferae*, however, included many unrelated genera having fruits with fleshy pericarp.

Pierre Magnol (1689) used conspicuous characters of roots, stems, flowers, seeds, etc. He was the first to form the concept of the modern family, and enlisted 76 of them.

J.P. de Tournefort (1656-1708) developed an interest in the collection of medicinal plants from his school days. While working as Professor of Botany at Paris, he extensively toured Europe to collect plants. His *Institutiones Rei Herbariae* (1700) contained descriptions of 698 genera, many of which were later validated by Linnaeus (e.g. *Abutilon, Betula, Castanes, Fagus* and *Ulmus*). He is called the 'Father of genus concept'. His system was much inferior to that of Ray.

Rudolf Camerarius (1694) demonstrated the sexuality in plants by simple experiments. He confirmed that the stamens are male and style/ovary form the female organ of a flower, while pollen was necessary for seed set. This profoundly influenced the young mind of Carl Linné leading to his proposal of a sexual system, the climax for mechanical or artificial systems of plant classification.

3.3.4 Sexual System. More and more plants were discovered and described by 18th century. The problems of identification have become acute, as has been confronted by Linnaeus who believed that it was his mission to recognize and record the works of the Creator. Being impressed by the work of Camerarius (1694), Linnaeus paid good attention to the stamens and pistils in flower. The relative constancy in the numbers of the sex organs enabled him to build his basically arithmetical, so-called "Sexual System" of classification. Linnaeus described all the genera known till then and accepted by him in his *Genera Plantarum* (1737). Being a Professor of Botany and Medicine at Uppsala, he published his *Species Plantarum* (1753) in which he keyed out 6000 species of 1000 genera in 24 classes, on the number and arrangement of stamens. The classes were divided into *orders* (subclasses) on the number of their pistils (*Monogynia, Digynia, Trigynia*).

Carl Linné or Carolus Linnaeus (in Latin) was born in Sweden on 23 May 1707. He entered University of Lund in 1727, and shifted to University of Uppsala in 1729. He worked under the guidance of Professor Rudbeck. His first work was *Hortus upplandicus*, an enumeration of plants in Uppsal Botanical Garden following the system of Tournefort. He was appointed Professor of Botany and Medicine in University of Uppsala, a position that he held until his death in 1778.

The work of Linnaeus has clear deficiencies: his sexual system was largely unnatural above the genus level, his species concept was inferior to that of Ray, plant descriptions attained all time low though reflected the philosophical viewpoint of the day (not recovered till the time of de Candolle), and there was neglect of vegetative characters at genus level and above (this delayed the process of development of a natural system of classification in the Adansonian sense). However, his achievements outweighed the shortcomings. He: (i) put the nomenclature of the past in order, (ii) provided a practical way to identify the plants known then, (iii) created the technical terminology required by taxonomy, (iv) supplied accurate descriptions of floral characters, (v) accepted mostly natural species and genera, and (vi) established the binomial system of nomenclature. Linnaeus' system was of great utility in identification though deliberately and admittedly artificial. It remained widely used for a generation until it was superseded by the system of de Jussieu.

3.3.5 Period of Natural Systems (1760-1880). Later than never, it was realized that unrelated plants often came together in the groupings of Linnaeus, signaling the need for a more objective classification. It was the time when France was under turmoil and undergoing intellectual ferment. The French took the lead through de Jussieu whose system brought in a turning point in the history of plant classification. It was an attempt to put the seemingly related plants (plants that look alike) together, using as many characters as possible. The efforts have come from the French, German and British workers: Adanson, Lamarck, families of de Jussieu and de Candolle, Brown, Lindley, Endlicher, Brongniart, Braun, and ultimately by Bentham & Hooker combine.

Michel Adanson (1727-1806), a French botanist, devised a classification using as many features as possible giving equal weighting of characters. He found the systems of Tournefort and Linnaeus as hopelessly inadequate to deal with the rich tropical flora of Senegal. He rejected the artificial systems for a natural one believing that all organs should be taken into account while classifying them. This was the basis for Numerical taxonomy, which is otherwise called Adansonian technique. In the two-volume work, *Familles des plantes* (1763), he realized 58 orders on their natural affinities. **de Lamarck** (1744-1879) another French botanist, known for his *Flore Françoise* (1778) and Lamarckism took up the inheritance of traits, and prepared framework for the future natural systems.

de Jussieu family. Antoine (1686-1758), Bernard (1699-1776) and Joseph (1704-1779) were the three brothers of a French family. The eldest studied at the University of Montpellier under Pierre Magnol. He succeeded Tournefort as *Director de Jardin des Plantes*, Paris. For good, he added Bernard as the staff. The youngest of the brothers spent many years in South America collecting plants and became insane when he lost the collections. Bernard started arranging the plants in the garden as per the system of Linnaeus. Having dissatisfied, he started re-arranging them again and again in the garden. He has not published the system and left it to his nephew, **Antoine Laurent de Jussieu** (1748-1836). Largely based on his uncle's system, A.L. de Jussieu published *Genera plantarum* (1789) in which he classified the plants into three groups: *Acotyledones* (Algae, Fungi, Hepaticae), *Monocotyledones* (Stamina hypogyna [Aroideae], Perigyna [Palmae] and epigyna [Musae, Orchides] and *Dicotyledones* (Apetalae, Monopetalae, Polypetalae and Diclines irregularis). On corolla characters and ovary position, he erected 15 classes and 100 ordines naturalis, which are now understood as orders and families, respectively. *Acotyledones* (Cryptogams) included some hydrophytes whereas Diclines irregularis contained Amentiferae, Euphorbes and Coniferae. de Jussieu is better known for his 'concept of the family'.

de Candolle family. The works of three generations of de Candolle family dominated botany from the time of de Jussieu until Darwin's discoveries (Davis & Heywood 1963). The de Candolles were of the Swiss family. **Augustin Pyrame de Candolle** (1778-1841) was born in Geneva but had his education in Paris. He became Professor of Botany at Montpellier. He was the first to introduce the term taxonomy (*taxonomie*) in his *Théorie élémentaire de la botaniquei,* published in 1813. He expounded the principles that should underlie a natural classification, following de Jussieu, Lamarck and Cuvier. He emphasized the importance of morphological and anatomical characters, and used *a priori* weighting. Placing *Ranunculaceae* at the base, he arranged the groups on reduction and fusion of floral parts and delimited 161 natural orders. To provide an outline of his classification: The vascular plants with cotyledons (*Vasculares*) included the Class I Dicotyledonae (incl. Conifers) with four subclasses (Thalamiflorae, Calyciflorae, Corolliflorae and Monochlamydeae) and Class II Monocotyledonae (incl. Cycads) with two subclasses (Phanerogamae and Cryptogamae). The plants without cotyledons were called *Cellulares* (Group A: Mosses and Liverworts and Group B: Lichens, Fungi and Algae). As per Cain (1959), his system is transitional between the nearly Aristotelian systems of Caesalpino and Linnaeus, and a purely empirical one. Being at Geneva, he undertook the monumental task of describing all the known species of vascular plants.under the title, *Prodromus systematis naturalis regni vegetabilis*, the first volume of which appeared in 1824. A.P. de Candolle could publish only seven of the 17 volumes, and the work was continued by his son **Alphonse de Candolle** and grandson **Casimir de Candolle** till 1873.

Robert Brown (1773-1858), the English botanist, though has not proposed any system, contributed much to the understanding of the nature of gymnosperms (naked seeds) as a group distinct and discrete from angiosperms (later Hofmeister designated the two groups in 1851), floral morphology of *Asclepiadaceae* and *Orchidaceae*, cyathium in *Euphorbiaceae* and spikelet in *Poaceae* which helped the subsequent taxonomists to classify these groups better.

John Lindley (1830), in his *Introduction to the Natural System of Botany*, recognized the distinction between gymnosperms and angiosperms. His treatment of monocots was precursor to Hutchinson's system on account of perianth. **Stephan Endlicher** (1840), on the other hand, clearly separated the Cryptogams from seed plants. The Lower Dicots were apetalous, a line picked up then by the Englerian School. **Alexander Braun** (1853), following Endlicher and Brongniart, influenced Eichler, Engler, Wettestein, *et al.* with his concepts. He treated monocots and dicots together and separately from gymnosperms. The monocots were arranged from simple to complex nature: *Lemnaceae* to *Orchidaceae* while the dicot spread out progressed from Apetalae to Polypetalae.

George Bentham (1800-1884) & **Sir Joseph Dalton Hooker** (1817-1911). For the first time two outstanding British botanists have joined hands to present the most elaborate ever-natural system of classification of seed plants. It was published between 1862 and 1883 as three-volume work in Latin entitled, *Genera plantarum*. Hooker was the son of Sir William Hooker, the Director of Royal Botanic Gardens at Kew whom he succeeded. He was more a plant explorer and phytogeographer. He published the *Flora of British India* in 7 volumes (1872-1997). Bentham, on the other, was the senior and more serious taxonomist. To his credit, authored seven volumes of the Flora of Australia and dealt with families like *Labiatae, Polygonaceae, Scrophulariaceae*, etc. at global level for de Candolle's *Prodromus*.

Bentham & Hooker's *Genera plantarum* included names, descriptions and the classification of all the seed plants then known. Bentham who spared 27 long years to complete his share contributed the greater part of it. The taxa were arranged according to their own classification though it was structured directly on the system devised by de Candolle, a close friend of Bentham. In all, 202 natural orders (= families) were realized which were grouped into 25 cohorts (= orders) and 21 series largely based on original descriptions. These were set in 3 subclasses and classes of each category. The following is the skeleton of the scheme presented up to the series mentioning the first and last of the cohorts/orders:

Bentham & Hooker divided the Phanerogams (Seed Plants) into three classes with Gymnosperms sandwiched between the dicots and monocots. On the presence or absence of petal- and their fusion, the Dicotyledons were split into three subclasses,

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Class I: Dicotyledons:

Subclass A. Polypetalae

Series 1. Thalamiflorae (Cohort 1. Ranales – 6. Malvales)
2. Disciflorae (Cohort 7. Geraniales – 10. Sapindales)

3. Calyciflorae (Cohort 11. Rosales – 15. Umbellales)

Subclass B. Gamopetalae

Series 4. Inferae (Cohort 16. Rubiales – 18. Campanulales)
5. Heteromerae (Cohort 19. Ericales – 21. Ebenales)
6. Bicarpellatae (Cohort 22. Gentianales – 25. Lamiales)

Subclass C. Monochlamydeae (no cohorts realized; so orders are mentioned)

Series 7. Curvembryeae (Orders 128. Nyctagineae- 134. Polygonaceae)
8. Multiovulatae aquaticae (Order 135. Podostemaceae)
9. Multiovulatae terrestris (Order 136. Nepenthaceae - 138. Aristolochiaceae)
10. Microembryeae (Order 139. Piperaceae – 142. Monimiaceae)
11. Daphnales (Order 143. Laurineae – 147. Elaeagnaceae)
12. Achlamydosporeae (Order 148. Loranthaceae –150. Balanophoreae)
13. Unisexuales (Order 151. Euphorbiaceae – 159. Cupuliferae)
14. Ordines anomali (Order 160. Salicineae – 163. Ceratophyllaceae)

Class II. Gymnospermae: (Order 164. Gnetaceae, 165. Coniferae, 166. Cycadaceae)

Class III. Monocotyledons:

Series 15. Microspermae (Order 167. Hydrocharitaceae – 169. Orchidaceae)
16. Epigynae (Ordeer 170. Scitamineae – 176. Dioscoreaceae)
17. Coronarieae (Order 177. Roxburghiaceae – 184. Raptaceae)
18. Calycineae (Order 185. Flagellariaceae – 187. Palmae)
19. Nudiflorae (Order 188. Pandanaceae – 192. Lemnaceae)
20. Apocarpae (Order 193. Triuridaceae – 195. Najadaceae)
21. Glumaceae (Order 196. Eriocauleae – 200. Gramineae)*

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* Two more orders addedin the Appendix

viz. Polypetaiae, Gamopetalae and Monochlamydeae. These were further divided into series, cohorts (modern orders) and natural orders (modern families). However, no cohorts were realized for Monochlamydeae or Monocotyledons. Instead, the series were directly divided into natural orders. The classification is a refinement over the systems of de Candolle, Lindley and de Jussieu. The system was accepted throughout the British Empire, USA, India and certain other Asiatic countries.

Merits: 1. The system is simple and easy to follow; therefore, it is of much practical value. It is widely followed for the arrangement of specimens in British and Indian herbaria, museums and botanical gardens. 2. The descriptions of families and genera are precise and largely based on first hand observations. These were never surpassed in quality by any later system. 3. Unlike de Candolle, the Gymnosperms were treated in a single and separate group though placed amongst the Angiosperms. 4. The Dicotyledons were placed before the Monocotyledons, a position accepted by many proponents of the present-day classifications. 5. The arrangement of taxa was based on overall natural affinities and morphological features that can be examined with naked eye, or with a hand lens. 6. Although a few important characters were chosen to diagnose some groups, the groupings themselves were based on a combination of characters rather than a single one. Examples are the placement of *Delphinium* with fused petals in *Ranunculaceae* and the retention of gamopetalous members of *Cucurbitaceae* in Polypetalae. 7. The Heteromerae were rightly placed prior to Bicarpelllatae. 8. Although the system was not phyletic, the *Ranales* (which includes the primitive woody *Magnoliales*) were placed at the beginning of Dicotyledons, 9. The recognition of the natural group Disciflorae, for the first time, as a series within Polypetalae, is appreciated.

Demerits. The system being pre-Darwinian in concept attracted the following criticism though often unjustified. 1. Although published after Darwin's theory, does not incorporate the content of phylogeny. Of course, the system was evolutionary at times though was not admitted by the proponents. 2. Even though Brown clearly established Gymnosperms as a discrete group, it was recognized and placed on par and between Dicots and Monocots. 3. There was no consistency in the treatment of groups (subclasses and series) throughout. In subclass Polypetalae, the series progressed from superior over. In the very next subclass Gamopetalae, the series commenced with inferior ovary (Inferae) to the surprise of all. 4. Monochlamydeae is an unnatural assemblage, with strong relatives in Polypetalae on one hand and Gamopetalae on the other. Examples are: *Caryophyllaceae* were placed in Polypetalae while its closer allies *Illecebraceae* and *Chenopodiaceae* were kept in Monochlamydeae. All these were treated later under Centrospermae. Similarly, from Monochlamydeae, the *Podostemaceae* (Multiovulatae aquaticae) better belong to *Rosales* while *Chloranthaceae* (Microembryeae) and Laurineae (Daphnales) are related to *Magnoliales*. 5. The Unisexuales are a heterogeneous assemblage of families, which have in common the unisexual flowers. Takhtajan (1987) placed these families under Hamamelididae and Dilleniidae whereas Cronquist (1988) preferred to keep them in Hamamelidae and Rosidae. 6. Some of the families like *Saxifragaceae, Euphorbiaceae* and *Urticaceae* are unnatural and polyphyletic, or treated in a conservative way. The later workers segregated them into a number of smaller but more natural (monophyletic) families. 7. The classification of the Monocotyledons is most unsatisfactory. The treatment was not parallel to Dicotyledons. It starts wrongly with the highly specialized *Orchidaceae* (Microspermae) though rightly ends with the climax group *Poaceae* (Glumaceae), and 8. Within Monocots, *Amaryllidaceae* and *Liliaceae* that are generally closely held (Cronquist even merged the both under one family, *Amaryllidaceae*) were placed in Epigynae and Coronarieae, respectively.

Charles Darwin was a close friend of Hooker. Both Bentham & Hooker had the knowledge of the theory of organic evolution. Yet, they published the system as it was conceived originally. Therefore, it remained a post-Darwinian publication with the pre-Darwinian concept prevailing.

Summary. The development of taxonomy was largely confined to Europe prior to the acceptance of theory of evolution. The first attempts at classification were largely based on Aristotelian principles involving Logical Division and the weighting of characters according to *a priori* reasoning (Davis & Heywood 1963). Typological thinking, associated with the belief in Special Creation, and neglect of variation for taxonomic purposes mark the pre-Darwinian period. Systems based on habit were gradually replaced by the Sexual system of Linnaeus in which floral features far outweighed the others. Later, even Linnaeus realized that a natural system would be preferable to an artificial one.

By the middle of 19th century, knowledge of variation has become impossible to ignore. And, increased attention was paid to geographical distribution. The consolidation of Linnaean period was followed by habit alignment in the field under de Jussieus, the preparation of monographic revisions under the de Candolles took place. De Candolle's system was extended and improved by Bentham & Hooker. The sequence of families in their system even reflected the evolutionary trends. Following the natural system has become a standard practice while the taxonomic principles were firmly based on plant morphology, anatomy and floral structure.

Model Questions:

a) Essay type:

1. Describe the pre-Darwinian systems of classification.
2. Write a succinct account of the early systems of plant classification emphasizing how they progressed philosophically to be realistic?
3. How the system of Bentham & Hooker was post-Darwinian in publication but Pre- Darwinian in concept? Justify.
4. How we attained the natural system of classification for plants?

b) Short type:

Developmental phases of classification. Alpha classification. Omega classification. Artificial classification. Sexual system of Linnaeus. Natural classification. Period of Ancients. Herbalists. Contributions of de Jussieu family. Contributions of de Candolle family.

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Unit - 1

Lesson - 4

POST-DARWINIAN SYSTEMS OF CLASSIFICATION

4.0 **Objective**

This chapter attempts to present the progress in the development of current systems of classification consequent upon the revolutionary thinking among the biologists, understanding of natural processes like evolution, and designing and development of sophisticated sensitive gadgets, screening techniques, computers, etc. to collect and collate data of much concern to improve the existing systems of classification.

4.1 INTRODUCTION

The kinds of classifications considered so far are empirical, i.e. based on lesser or greater number of characters which can be observed and assessed. The groupings were made, following certain logical principles, almost mechanically by placing together those organisms that share the largest number of features (Heywood 1967). Besides, the characters employed were those of the present-day organisms and no evolutionary principles were involved. *The Origin of Species* published by Charles Darwin in 1859 revolutionized the thinking by biologists. The species were looked upon as populations, which are dynamic and changed with time giving rise to lineages of closely allied organisms. Once the evolutionary processes were acknowledged, the systems of de Candolle and Bentham & Hooker were found unsatisfactory. So, there were immediate attempts to restructure the plant classifications accordingly. Many systems were produced in great vigour and without loss of much time, with the requirement that they should not be alike. As expected, the initial systems proposed were only transitional. Progressively better contributions were made in this regard by Eichler, Baillon, Engler & Prantl, Bessey, Hallier, Wettstein, Rendle, Hutchinson, and Melchior. The most striking feature of post-Darwinian systems is that they not only attempt to be evolutionary but also to be phylogenetic.

4.2 PHYLOGENETIC SYSTEMS

The similarities shown by the phenetic groups are probably the result of common evolutionary ancestry. This was usually assumed to be so by the post-Darwinian taxonomists. This allows the phenetic groups to be treated as phyletic ones though this may not be true in all cases. The reason for this is that not all evolution is divergent. In fact, there are several interrelated evolutionary processes that are to be known for a phylogenetic interpretation. Here one to be considered *Patristics, Cladistics* and *Chronistics* though briefly.

The phenetic similarity among the groups may due to common ancestry and then it is called *patristic*. The similarity may be simple or derived. In the latter, the characters of the descendants are not the same as in the common ancestor (which they have independently modified in some way). The phenetic similarity may also be due to convergence, when it is termed *homoplastic*. The resemblance in phenetic groups is not due to inheritance from common ancestry and includes convergence and parallelism. *Parallelism* may be defined as the development of similar features separately in two or more groups which are genetically similar and fairly closely related lineages. *Convergence* is the development of similar features separately in two or more genetically diverse and not closely related lineages and not due to common ancestry. The aquatic habit and well-dissected leaves in related species of buttercups (*Ranunculus*) is the example for parallelism. The superficial resemblance in fleshy cacti, senecios and euphorbias or the presence of pollinia in Ascepiads and Orchids, are the examples for convergence. *Cladistics* is that part of phylogenetic relationship that refers to the pathways of evolution. When represented in the form a tree, it is the study of how many branches are there and which branch arose from which and in what sequence. Apart from these, the time element is an important component in phylogenetic classifications, which is called *chronistics*. It may be defined as the study of time scale during which the evolutionary events occur. In phylogenetic diagrams, the time element is indicated by the vertical axis though often implied or even ignored. So, a truly phylogenetic classification must express not only the phenetic relationships but also include and distinguish between patristic, cladistic and chronistic dimensions.

4.2.1 Transitional Systems : The early systems though intended to be were not phylogenetic. Neither there was enough effort nor there available required data to deem the systems to be phyletic. So, these systems remained largely natural, with some flavour of phylogeny. Such systems can be called *transitional*. Under this category can be treated the systems of Eichler and Engler & Prantl.

August W. Eichler (1773-1858), a German botanist, proposed a system on genetic relationships of plants, which cannot be called phylogenetic in the modern sense. His system (1883) gradually replaced that of the system of de Candolle. Eichler divided the plant kingdom into two groups: Cryptogamae and Phanerogamae. The former had three divisions, namely Thallophyta, Bryophyta and Pteridophyta. The latter group included Gymnospermae and Angiospermae. Angiospermae were divided into two classes, the Monocotyledonae and Dicotyledonae. Choripetalae and Sympetalae formed the Dicotyledonae, with Monochlamydeae being abolished and dispersed between the two groups. Of course, the Monocotyledonae preceded the Dicotyledonae.

Adolph Engler (1844-1930) & **Karl Prantl** (1849-1893). As part of a guide to the plants of the Breslau botanic garden, Engler (1886) published a classification based on Eichler's system. It differed only in the matters of detail, nomenclature of major categories, etc. Engler's deviations of Eichler's system were due to the influence of earlier proposals by Braun, Brongniart and Sachs. Engler called the seed plants as *Embryophyta Siphonogama* that incorporated the Gymnospermae and Angiospermae in the sequence. The Angiospermae were divided into Monocotyledonae and Dicotyledonae, the latter comprising the subclass Archichlamydeae (Choripetalae with petals and Apetalae without) and Metachlamydeae. The system was expanded in 1892 in his *Syllabus* and yet further in his other two monumental systematic works, *Die natrlichen Pflanzenfamilen* (1887–1915, in collaboration with Karl Prantl) and *Das Plfanzenreich* (1900 onwards).

Engler's *Syllabus* and *Pflanzenfamilien* covered the whole of plant kingdom – a range that gave the system, for pure practical reasons, an international prestige greater than its intrinsic value as a satisfactory system of classification (Davis & Heywood 1963). The system was followed to arrange the specimens in most American and Continental herbaria. For the first time, anatomical data decorated the text rather than influencing the actual system. In fact, the Englerian system was not meant to be phylogenetic in a simple linear sense. Engler was highly conscious of the dominance of parallel evolution and therefore refrained from depicting a phylogenetic tree. The predisposal of Gymnosperms before the Angiosperms and Monocots before Dicots was the major deviation maintained.

Merits. 1. The system had significant improvements over Bentham & Hooker. The Gymnosperms were treated as a separate group and positioned before Angiosperms. 2. In comparison to Bentham & Hooker, the Monochlamydeae were abolished and the Archichlamydeae and Metachlamydeae constituted more natural groups. 3. Many large heterogeneous families of Bentham & Hooker were split into smaller natural families, e.g. the family *Urticaceae* was segregated into *Urticaceae, Ulmaceae* and *Moraceae*. 4. The disposal of Monochlamydeae has brought together the elements that were related and closely placed but separated due its creation by Bentham & Hooker. 5. The *Compositae* in Dicots and *Orchidaceae* in Monocots, with inferior ovary, zygomorphic and complex floral structure, were treated as advanced families and placed towards the ends of the groups. 6. The terms *cohort* and *natural order* were replaced by better terms, *order* and *family*, respectively. 7. The system was followed globally to arrange the herbaria, museums, etc. since it dealt with the whole of plant kingdom.

Demerits. Many drawbacks with the system of Engler & Prantl have come to the fore with better understanding of the phylogeny of flowering plants. They are largely due to the conceptual thinking of primitive flower (simplicity represents primitiveness). To mention some of the major setbacks are: 1. The system is not phylogenetic in the modern sense. 2. The polyphyletic origin of Angiosperms is now disregarded for monophyly. 3. The *Ranales* (sensu lato) are now conceived more primitive than to their Amentiferae. The Ranalian School of thought now prevails over the Englerian. 4. Monocots preceding Dicots is objected to and not accepted by the contemporary phylogenists. 5. The dichlamydeous flowers derived from monochlamydeous forms is untenable. In Monocots, the Helobieae though a primitive group, was placed after Pandanales, a relatively advanced taxon. 6. The derivation of free central placentation from parietal that in turn from axile is contrary to the floral anatomical evidence, and 7. The system was published in German language, which is not known to many.

4.2.2 Intentional Phylogenetic Systems

Rearranged natural systems in the light of phylogenetic information lead the way to the dawn of new generation of classifications that reflected evolutionary development.
Charles Bessey, the American botanist, paved the way in this direction. It was consolidated by Hallier, Wettstein, Rendle, Hutchinson and Benson.

Charles Bessey (1845-1915), a student of Asha Gray, was the first American to make a major contribution to plant classification through his paper 'Phylogenetic taxonomy of flowering plants' published in Annals of Missouri Botanic Garden in 1915. He considered Angiosperms to have evolved from *Cycadophyta* through a *bennettitalean ancestry*. He modified the system of Bentham

& Hooker in the light of his 28 phyletic dicta. His phyletic diagram (Fig. 4.1) resembles a cactus plant (better known as Besseyan cactus). He believed in the *strobiloid theory* of origin of flower. From such flower, he formed two evolutionary lines: **Strobiloideae** (Ranalian line) with connation of like parts and **Cotyloideae** (Rosalian line) with connation of unlike parts. The *Ranales* (sensu lato) in Dicots and *Alismatales* in Monocots were considered most primitive in each group. He abolished Polypetalae, Gamopetalae and Monochlamydeae as natural groups, putting less emphasis on the fusion of petals. Instead, he stressed more on hypogyny vs. epigyny. The major criticism against his system is that he tried to derive the groups directly form one another.

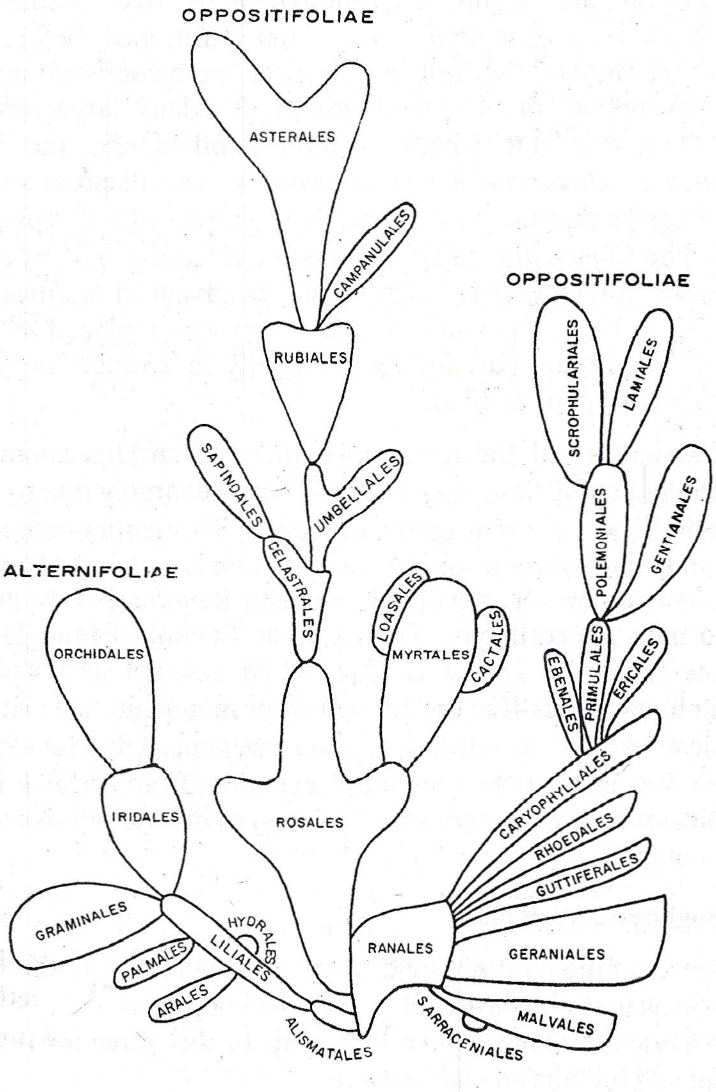


Fig. 4.1 Bessey's cactus or phylogentic shrub.

Hans Hllier (1868-1932), a German botanist, proposed a classification of Angiosperms like that of Bessey, starting with *Ranales*. *Magnoliaceae* were separated from *Ranales* as *Annonales*. The Dicots were placed before Monocots.

Richard von Wettstein (1862-1931), an Australian botanist, erected a system on Englerian line but it was superior to that of Engler's. The contemporary phylogenists approve the relative positions of many dicot families in the system.

Alfred Rendle (1865-1938), an English botanist and Keeper of Department of Botany, British Museum of Natural History, published his *Classification of Flowering Plants* (1904,1925) under the Englerian line of thought (the unisexual inconspicuous anemophilous flowers are more primitive over the bisexual, brightly coloured insect pollinated flowers: accordingly, the monocots and Amentiferae are primitive). He graded the Dicots into three groups, Palmae were separated as distinct order, Lemnaceae were considered advanced over Araceae and placed grasses subordinate to lilies.

John Hutchinson (184-1972) was a British botanist associated with the Royal Botanic Gardens, Kew. He published his classification in *The Families of Flowering Plants,* with Dicots in 1926 and Monocots in 1934 (combined 3rd ed. in 1973 posthumously). He was a field botanist and excellent artist, spent good time botanizing Africa. He was the writer of several works and treatises. He was the first to provide a working key to the families of Angiosperms at the global level. His classification has closer affinities with Bentham & Hooker and Bessey. He borrowed many of ideas of Bessey and superimposed upon them a primary division which is almost Aristotelian, i.e. the vertical division of Dicotyledons into fundamentally and predominantly woody **Lignosae** and fundamentally and predominantly herbaceous **Herbaceae**. He traces their descent from mainly woody *Magnoliales* and herbaceous *Ranales* (sensu lato). He believes angiosperms to be monophyletic from an ancestral group of Gymnosperms that may have been parallel to *Cycadeoideae* which he called *Proangiosperms.*

Hutchinson has dealt the classification of flowering plants included under the Phylum Angiospermae. His classification was based on 24 principles, known as phyletic dicta. Within Angiosperms, the Dicots and Monocots were given the ranks of subphyla, with Dicots as forerunner. *Magnoliaceae* were regarded as the most primitive family within the living Angiosperms. The Dicots were divided into Lignosae and Herbaceae, with the former starting with *Magnoliaceae* and ending with *Verbenaceae*. On the other hand, Herbaceae commenced with *Paeoniaceae* and terminated with *Lamiaceae*. The treatment of Monocotyledons is more satisfactory than any of the earlier systems. The group had three evolutionary line or divisions: **Calyciferae** (calyx-bearers), **Corolliferae** (corolla-bearers) and **Glumiflorae** (glume-bearers). Altogether 411 families were recognized, 342 in Dicots and 69 in Monocots. Hutchinson system has not proceeded beyond family level for majority of taxa and therefore could not be used to arrange floras, herbaria, etc.

4.2.3 Contemporary Phylogenetic Systems

A number of contemporary taxonomic workers have contributed to the improvement of the classifications with new information from different sources like ultrastructure, phytochemistry, biochemistry, etc. Advances in electronics and computers helped to further the efforts. In this regard, Takhtajan, Cronquist, Thorne and Dahlgren made outstanding and lifetime contributions. An outline of their systems is presented below. For greater details, one can refer to the references cited at the end of this lesson.

Armen Takhtajan (1910 -) is a Russian botanist associated with V.L. Komorov Botanic Institute at St. Petersburg (Leningrad) and a living legend who presented a detailed classification of Angiosperms which started with the study of placentation types. The first version (1954) of his classification was published in Russian. He revised his system from time to time (1966, 1980, 1987 and 1997). He placed Angiosperms in the division *Magnoliophyta* that was divided into two classes *Magnoliopsida* and *Liliopsida*, for the traditional dicots and monocots. All the groups were namec based on type method. His classification belongs to Ranalian School being strongly influences by th works of Bessey, Hutchinson and Hallier and also of some progressive German workers. Th classification approaches closer to that of Cronquist in the treatment of higher categories. Takhtaja believed in the monophyletic origin of *Magnoliophyta* and derived them from seed ferns *Lyginopteridophyta*. An outline of the system of classification (1997) is given below:

Division **Magnoliophyta** (2 classes, 17 subclasses, 72 superorders, 233 orders and 593 families)

Class 1. **Magnoliopsida**: 11 subclasses, 56 superorders, 175 orders, 459 familes.
Subclasses: 1. Magnoliidae, 2. Nymphaeidae, 3. Nelumbonidae, 4. Ranunculidae, 5. Caryophyllidae, 6. Hamamelididae, 7. Dilleniidae, 8. Rosidae, 9. Cornidae, 10. Asteridae, and 11. Lamiidae.

Class 2. **Liliopsida**: 6 subclasses, 16 superorders, 58 orders, 133 familis.

Subclasses: 1. Liliidae, 2. Commelinidae, 3. Arecidae, 4. Alimatidae, 5. Triurididae, and 6. Aridae.

Like other phylogenetic systems, Takhtajan presented the presumed relationships of various subclasses and superorders in a bubble diagram (Fig. 4.2). His system is more phyletic than that of Hutchinson and is now widely accepted. Clifford (1977) who studied the monocots at length, supports the recognition of subclasses. The splitting of Asteridae into two subclasses Lamiidae and Asteridae is a more rational distribution of sympetalous families. Takhtajan is more a splitter, created more number of unigeneric families. The system is of little practical value.

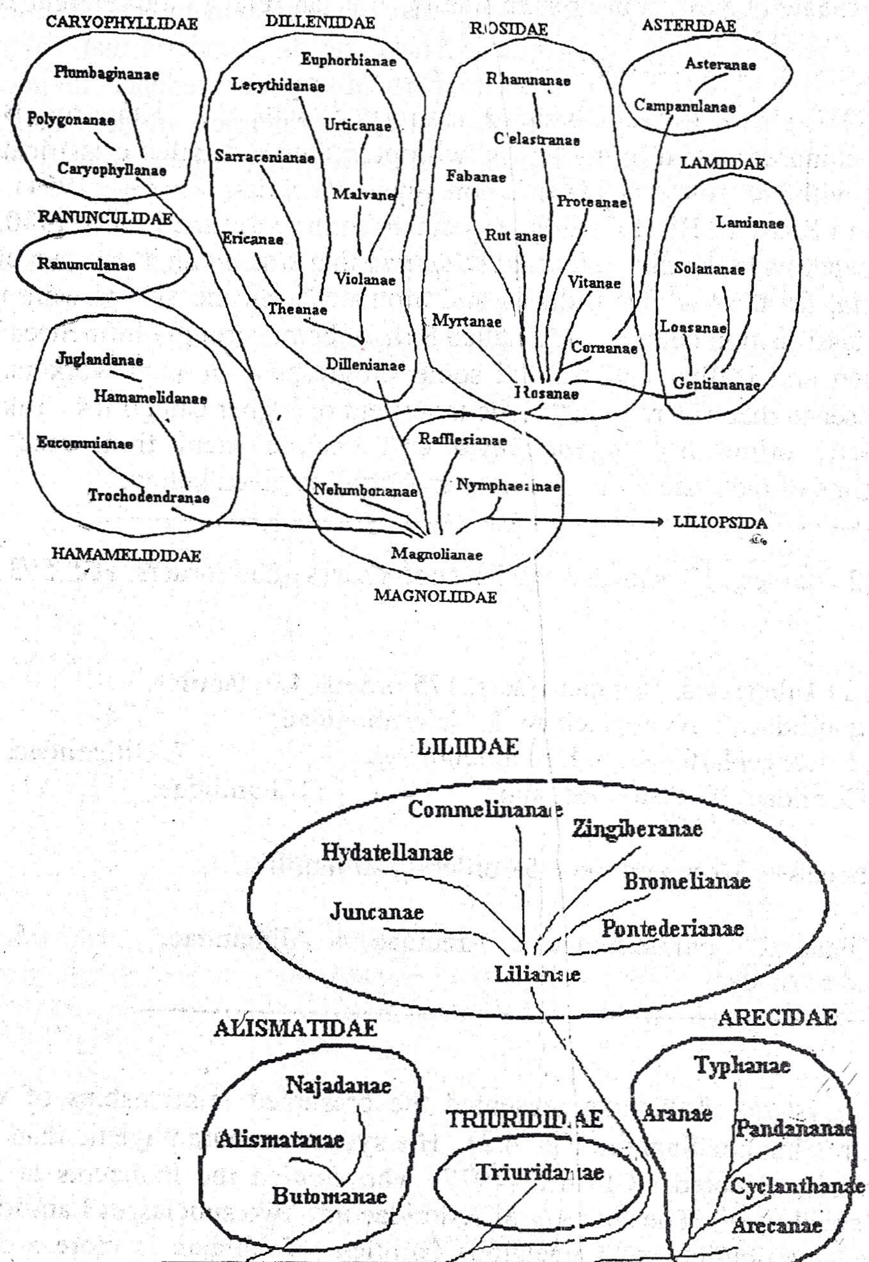


Fig. 4.2 Putative relationships of subclasses and superorders of *Magnoliophyta* as per Takhtajan.

Arthur Cronquist *(1919-1992) worked at New York Botanical Garden till his death.* He published different versions of his system from 1957 till 1988. He was a contemporary and good friend of Takhtajan and discussed their systems closely though differed with regard to certain basic tenets of their classifications. His classification resembles that of Takhtajan in the treatment of higher categories. He has not recognized the superorders. The basic difference is that Takhtajan attached more importance to cladistic relationships while Cronquist gave credence to phenetic evidence. The merit of the classification lies on the phylogenetic principles, modern data, and treatment of individual groups than on the general or overall classification. The system is widely used in USA. To present an outline of his 1988 system:

Division: **Magnoliophyta:** 2 classes, 11 subclasses, 89 orders, and 386 families.

Class 1. Magnoliopsida: 6 subclasses, 64 orders, 320 families.
Subclass 1. Magnoliidae
2. Hamamelidae
3. Caryophyllidae
4. Dilleniidae
5. Rosidae
6. Asteridae

Class 2. Liliopsida: 5 subclasses, 19 orders, 66 families.
Subclass 1. Alismatidae
2. Arecidae
3. Commelinidae
4. Zingiberidae
5. Lilidae

Nomenclature of the groups was in accordance with ICBN. The relationships of the subclassed were depicted for the two classes (Figs. 4.3 & 4.4). Superorder as a rank above the order is not recognized,a significant deviation from the contemporary systems of Takhtaian, Thorne and Dahlgren.

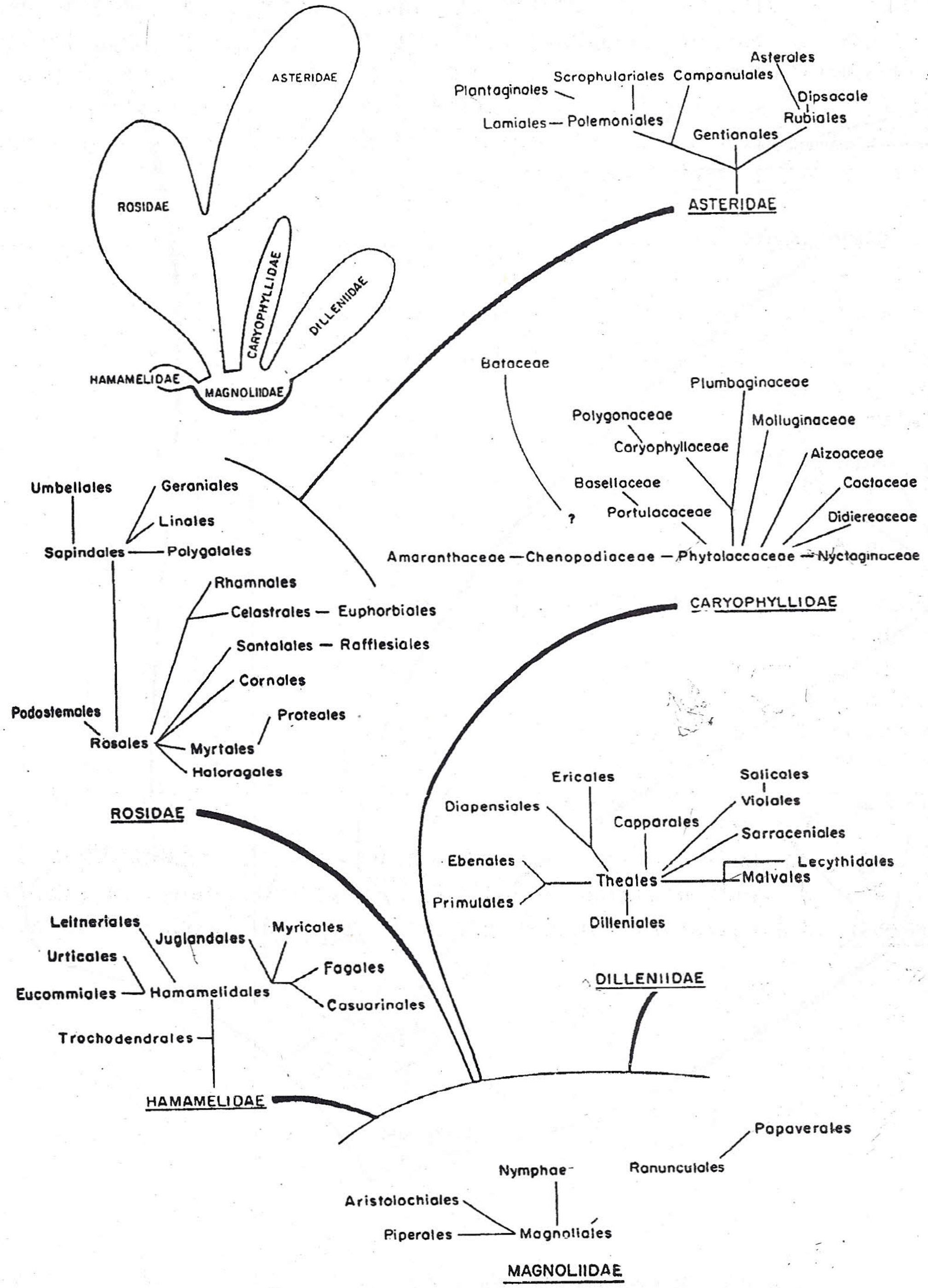


Fig. 4.3 Relationships in *Magnoliopsida.*

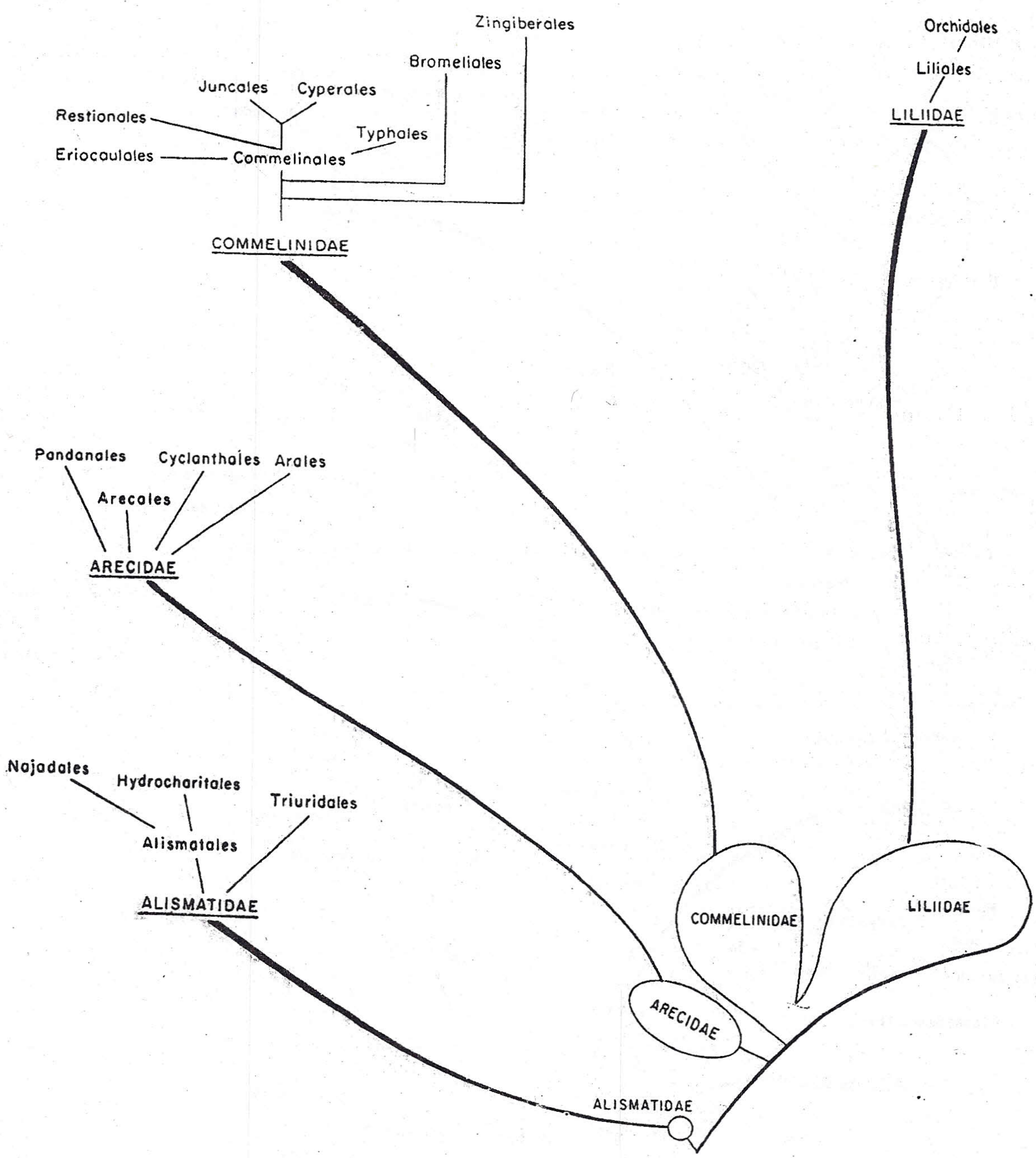
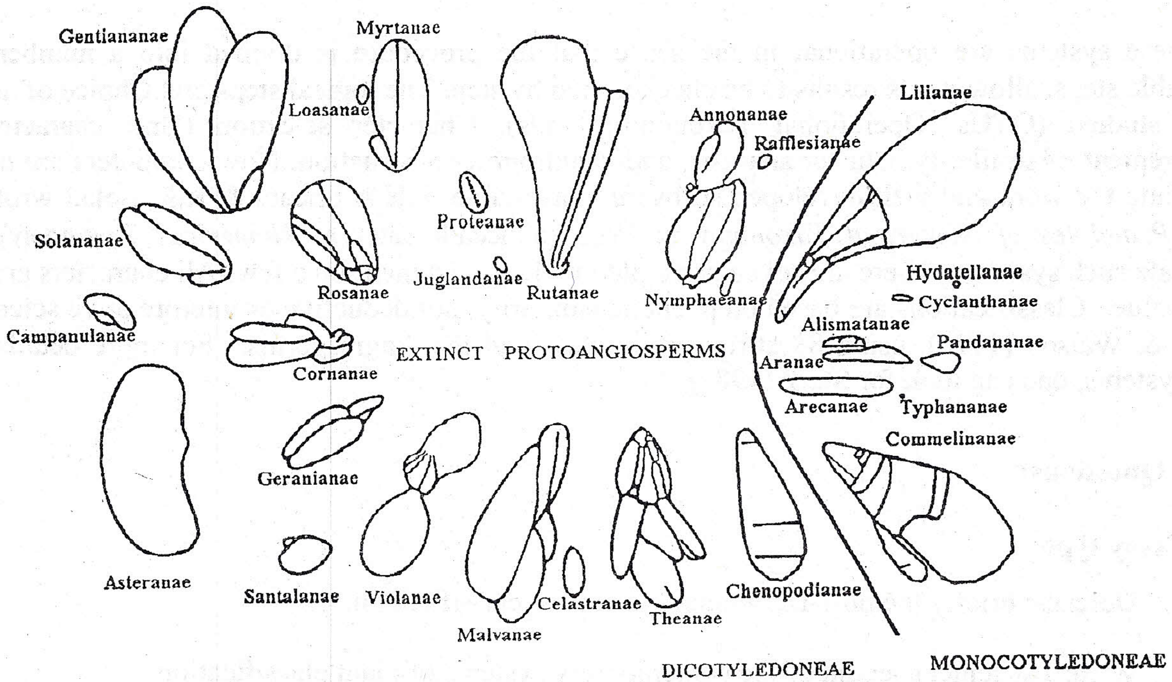


Fig. 4.4 Relationships in *Liliopsida*.

Robert F. Thorne (1920-) is an American taxonomist, a contemporary of Cronquist but from the west, i.e. Rancho Santa Botanic Garden at Claremont, California. His system has additional dimensions in phytochemistry and phytogeography. He periodically revised the system which has more in common with the above two systems. The semblance is because they worked with more or less the same data, an obvious disadvantage with contemporary workers. Thorne presented a synopsis of his classification in 1968. According to him, the divergences of his system are '*startling realignments that are new or at least different from standard treatments*'. His system differs from others as he attempted to stress on similarities more than on differences. His system, like others of his time, is based on phyletic principles and provided a phylogenetic shrub, placing the primitive groups in the center with the diverging groups radiating (Fig. 4.5). The relative strength (numbers of taxa) of each group is indicated by size. He recognized 19 superorders for Dicots and nine for Monocots.

Fig. 4.5 Thorne's phylogentic shrub in cross section.



Rolf Dahlgren (1932-1987), a Danish botanist who first proposed his classification in 1975, with revisions in 1980, 1981 and 1983. His system resembles the other current systems in the larger groups. His wife Gertrud Dahlgren published an updated version of his classification in 1989. The realignments were made in the light of evidence from embryology, ultrastructure and phytochemistry. The system included 25 superorders in *Magnoliopsida* and eight in *Liliopsida*.

Dahlgren's phylogenetic tree in cross section is something special and provides a convenient means to test the distribution of various traits. One can have a visual perspective based on its distribution to decide the relatedness of various groups as regards that trait. Of great interest is that the separation of Monocots and Dicots is not allowed if one followed a rigid Cladistic approach.

4.2.4 Modern Phenetic Systems

The term phenetic is applied to the classifications that are based on phenetic evidence. The term is used in contrast to the phyletic one. Now vast information is available about the plants from macro- to microscopic features and from macro- to micromolecules. These data are overwhelming and simply cannot be left unused. Besides, there are problems with the evolutionary and phylogenetic classifications in view of the prevailing cases of convergence, parallelism, gaps in fossil data, and problems of identification and interpretation of these data. Therefore, there is a need for parallel system of classification. In fact, this has worked out with the microorganisms and lower plants. Now, there are attempts to try the same with the higher plants. One such system approach is numerical classification, which is not only empirical but also operational. It is the numerical evaluation of the similarity between groups of organisms and the ordering of these groups into higher-ranking taxa.

These systems are operational in the sense that the procedure is divided into a number of repeatable steps, allowing its results to be checked step by step. The logical steps are: Choice of units to be studied (OTUs: Operational Taxonomic Units), Character selection (Unit characters), Measurement of similarity, Cluster analysis, and Dendrogrm construction. Now computers are used to execute the work and well-developed software is available. P.H.A Sneath & R.R. Sokal wrote a book, *Principles of Numerical Taxonomy* in 1963 (a decade later as *Numerical Taxonomy*) to formulate such systems. There are seven principle involved. To mention a few: All characters are of equal value. Classifications are based on phenetic similarity, not deductive or interpretative science. Young & Watson (1970), using 83 attributes, re-classified the Angiosperms. For more details of these systems, one can look for Stace (1980).

Model Questions:

a) Essay type:

1. Describe briefly the post-Darwinian systems of classification.
2. Write a succinct account of the contemporary systems of plant classification.
3. How the system of Engler & Prantl differs from that of Bentham & Hooker?
4. How the phyletic system of classification improved the recognition of higher taxonomic groups better?

b) Short type:

Intentional phylogenetic systems. Modern phenetic systems. Bessy's cactus. Hutichinson's system. Takhtajan's system. Cronquist's system. Thorne's system. Dahlgren's system.

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Dr. VATSAVAYA S. RAJU

Unit - II

Lesson – 5

PRINCIPLES OF TAXONOMY

Plant taxonomy has not outlived its usefulness: it is just getting under way as an attractively infinite task.

(L. Constance 1957: 92)

5.0 Objective

In this chapter, the student is introduced to the principles and concepts involved in dealing with plant diversity and taxonomic structure. It is the recognition of various levels in the taxonomic hierarchy as groups and categories, the objective and subjective groupings. Most importantly, it will be attempted to present a cross section of the concepts advanced to explain the dynamic nature of the species.

5.1 TAXONOMIC PRICIPLES

Faced with vast array of diversity in the natural world, man instinctively classifies. He divided this diversity into smaller, more manageable groups (Heywood 1967). Classification is the basic method by which the humans come to grips with and organize the external world. The ordering of the organisms into groups based on similarities and differences is called *classification*. The use of the term dates back to the times of Theophrastus (300 BC). The Swiss botanist, A.P. de Candolle (1813) coined the term 'taxonomie' (*taxis*: arrangement; *nomos*: rules or law) refers to the theory of classification. Gradually, the term was used generally for the methods and principles of classification of any group of organisms. Biologists active in the study of classification at that time were called taxonomists or systematists. The terms taxonomy and systematics were used interchangeably till Charles Darwin (1859) revealed his *theory of evolution* by natural selection. So, we arrive at three popular terms, viz. *classification*, *taxonomy* and *systematics*.

Are Systematics and Taxonomy distinct? In various text books on the subject or in the concerned general literature, there existed confusion as regards the usage, especially of the terms taxonomy and systematics. Therefore, Ross (1974) made a comprehensive survey of the usage of these terms, and made the following observations:

1. The terms classification and taxonomy are used as *synonyms*. However, persons like Heslop-Harrison (1953) considered classification as a broad term that includes taxonomy. On the contrary, Mason (1952) felt that taxonomy is to include systematics.
2. The terms taxonomy and systematics are used interchangeably (Lawence 1950; Radford *et al.* 1986; Jones & Luchshinger 1986).
3. There is an opinion, particularly in the light of theory of evolution, the term systematics is to be used in a broad sense to include taxonomy. To avoid any confusion, Griffiths (1974) suggested using the term '*metasystematics*'. However, the term is not popular.

In the opinion of the writer of this chapter, there is a need for all the three terms and they are indispensable. For an appreciation, one can dwell into the definitions set by Heywood (1967) to these terms.

Classification, in the biological sense, is the ordering of the plants into groups, which are arranged in a hierarchy.

Taxonomy is that part of systematics which deals with the bases, principles, procedures and rules.

Systematics is the scientific study of diversity and differentiation of the organisms and the relationships that exist between them.

Camp & Gilly (1943) proposed the field *biosystematy*. It seeks to delimit the natural biotic units and to apply to these units a system of nomenclature adequate to the task of conveying precise information regarding their defined limits, relationships, variability, and dynamic structure. The term biosystematy was later altered to biosystematics. However, Vickery (1984) pointed out that 'biotaxonomy' is preferable over the term biosystematics in view of the stated nomenclatural goal. We have another term in this context, i.e. *experimental taxonomy*. Small (1989) says that the term biosystematics is vague, pretentious and, superfluous but useful. So, we are caught between classical vs. experimental taxonomy; the Old Systematics vs. the New Systematics (of Huxley 1940). Davis & Heywood (1963) and Blackwelder (1967) have criticized the use of such contrasts.

Although taxonomy was the earliest of the biological sciences, it has not yet completed its basic tasks of surveying and classifying the organic diversity. Yet, we do not have a perfect understanding of its structure and evolution in detail. So, it is a moot question whether we will be able to discover and describe all the plant species in the tropics before they are destroyed by the advancing civilization. Another major taxonomic need today is the cataloguing of the world's genetic resources so that they can be conserved and utilized in the breeding programmes of the future generations.

Taxonomy is a functional science. It is one of the older botanical sciences. The principles of taxonomy are concerned primarily with the criteria employed. A discussion of these criteria presupposes an understanding of the units of classification, which will be considered under section 5.3 of this chapter. However, certain basic principles were formulated (Cronquist 1968). They are:

1. Taxa are properly established on the basis of multiple correlations of characters.
2. Taxonomic importance of a character is determined by how well it correlates with other characters which means that the taxonomic significance of a character is determined *a posteriori* rather than *a priori*; and
3. An important feature of taxonomy is its predictive value.

The most important of taxonomic principles is probably the value of correlation of characters. Obviously, no character of a taxon should be considered singly for the establishment of its relationship with other taxa. Second, the characters chosen shall exhibit maximum correlation with other characters. The importance of a character depends upon the level of its correlation. Actinomorhic corolla in *Scrophulariaceae*, zygomorphic corolla in *Ranunculaceae*, five stamens in *Tiliaceae*, etc. are not correlated and are considered uncharacteristic. Such characters are not of systematic significance. While they are of diagnostic value, the relationships must be considered on overall semblance. Third, the unusual characters often aid in predicting the probable relationship of taxa with other groups where the same characters are normal.

5.1.1 Fundamentals of Taxonomy

Taxonomy is basic to other sciences and at the same time dependent on them. It has no data of its own. It has to depend for its improvement, and indeed, for its existence entirely on information from other fields like morphology, anatomy, embryology, palynology, cytology, physiology, phytochemistry, genetics, ecology, phytogeography, paleobotany, evolution, etc. It is called the *taxogram* (Fig. 5.1). So, taxonomy is a pedestal upon which biology is built. And, the duties of a taxonomist are ever ending. There are three aspects of taxonomic procedure, namely, identification, nomenclature and classification. Of these, identification is the recovery side of taxonomy. Besides, identification and classification are interrelated and related to name; they are fundamental to taxonomy (Fig. 5.2).

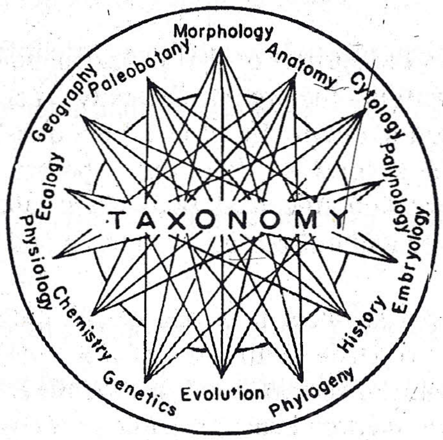

Fig. 5.1 Taxogram showing the relationships of various disciplines with taxonomy.

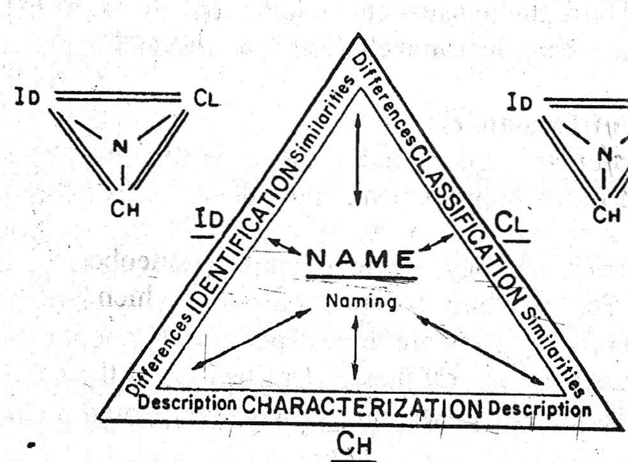

Fig. 5.2 Fundamentals of taxonomy.

5.1.2 Objectives of Plant Systematics

There are *five* major objectives of studying plant systematics:

1. To provide a convenient method of describing, identifying and classifying the plant taxa.
2. To provide a scheme of classification that attempts to express phenetic and phyletic relationships.
3. To provide an inventory of plant taxa, i.e. the preparation of the flora of a region, nation and continent.
4. To provide an understanding of the evolutionary processes and relationships; and
5. To provide an integrating and unifying role or focal point in the training of biology students.

5.2 CRITERIA FOR CLASSIFICATION

Based on criteria, the systems of classifications constructed are bound to differ. There are traditional and modern criteria used in plant classifications. The classificatory systems proposed initially were based on form relationships, artificial/practical, sexual or natural depending upon the number and nature of criteria employed. Then, there was evolutionary content incorporated followed by phylogeny. Lesson-1 of Unit-1 discussed at length the examples of all these categories.

The following *criteria* are used in obtaining a useful or better classification of plants:

1. Only genetically fixed variations should be used.
2. Natural classification should be firmly based on correlation of characters and discontinuity of variation.
3. All available material should be used when classifying a group.
4. When any taxon is revised, it should be studied throughout its entire geographical range, and
5. Consistency of treatment.

For a more detailed account of this, one can refer to Davis & Heywood (1963).

5.3 EVALUVATION OF TAXONOMIC CATEGORIES

5.3.1Taxonomic Hierarchy: Groups and Categories

Classification of biological organisms is based upon populations of species and their higher-ranking taxa. Before any discussion on the taxonomic hierarchy is attempted, there is need to define two terms, namely, *category* and *taxon*. *Category* refers to a particular level in the taxonomic hierarchy (such as class or genus); all the available categories represent every one of the levels in the classification system. So, categories are levels or ranks in the hierarchy and are purely artificial. All the categories need not always be used, but are available if desired. These are called *units of* *classification*. *Taxon* refers to a cluster of individuals grouped together based on the sharing of the features in common. Taxa are real objects in nature, which are recognized, delimited and described, but never defined (Bock 1977). Categories are meant to reflect degrees of differences in characters and character states of taxa. The differences at the higher levels of ranking are great while those at the lower levels are small.

Species are groups of individuals, which closely resemble each other in most characters. Those species which share most characters in common are placed together into larger (more inclusive groups) called *genera*; these genera in turn are assembled into yet more inclusive groups called *families*; these families into *orders*, and so on. Such a taxonomic structure is called *Linnaean hierarchy*. It was developed long before evolution was discussed as a possibility. Griffiths (1976) suggested that the biologists abandon the Linnaean hierarchy for 'unclassified hierarchy', following Hennig (1969). Since such a system would use only *synapomorphies* to construct unnamed classes, it is not acceptable as a general approach to biological classification. This system of building up a series of increasingly inclusive groups on the basis of overall similarities is referred to as the 'box-within-box' method or 'nested classes' (Fig. 5.3). However, the relative size of the boxes varies from group to group. The important categories in the taxonomic hierarchy are called species, genera, families, orders, classes and division. These are like a set of empty boxes arranged one within the other. Over the past 200 years, it has been decided arbitrarily about how many levels or categories are necessary to accommodate the variation within the whole plant kingdom. The scheme of basic categories of units which is in use and modified since Linnaeus is as follows:

- Division
  - Class
    - Order
      - Family
        - Genus
          - Species
            - Section
              - Tribe
                - Variety
                  - Form

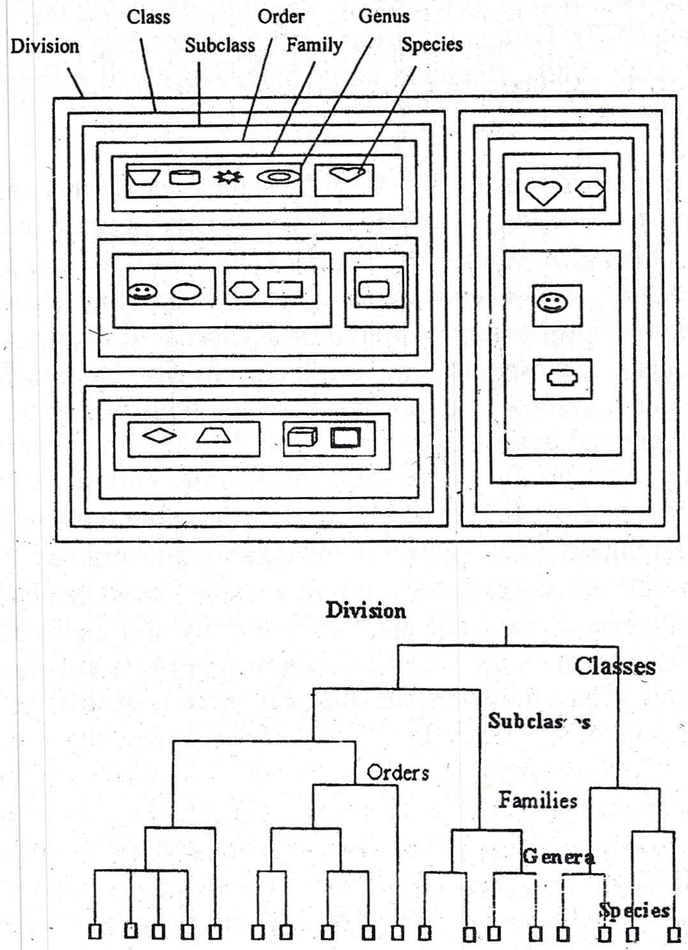

Fig. 5.3 Taxonomic groups according to hierarchical system.

Some additional and intermediate categories are recognized as per the need using the prefix, sub. Examples are suborder. subfamily, subtribe, subgenus, etc. The prefix super is used at least at one level, i.e. superorder. For various reasons, the Linnaean hierarchy has a definite structure and the relationships among its parts, the individual object (taxon) and the category, can be analyzed logically (Gregg 1954). Two basic types of relationships exist here: (i) subordinate, and (ii) coordinate. In the former, there are two types: (a) the relationships between an individual and its taxon and between a taxon and its respective category, and (b) those between a higher taxon and lower taxon. For example, in the first type of subordinate relationship, a paddy plant is a member of various taxa ranging from the higher taxon *Magnoliophyta* to the low taxon, *Oryza sativa*. So, it is a member at all these levels of taxonomic hierarchy – division to species. In the second type of subordinate relationship, that of inclusion, applies only to the connection between a higher and lower taxon. For instance, *Phyllanthus amarus* is included within the genus *Phyllanthus* which is likely included within the family *Euphorbiaceae*, and so on. And, coordinate relationships exist between individuals and categories. For the purpose of hierarchy, all the categories are equal and similarly all individuals are equal. Now, it is to be noted that categories are defined, taxa are circumscribed, and the names of taxa are simply assigned arbitrarily (Stuessy 1990).

5.3.2 Major Categories

The categories of higher level such as division, class, order and family are referred to as major taxonomic categories. A major category is considered as one whose name is not part of the name of the plants belonging to them. The major categories of vascular plants have been reasonably well established and their circumscriptions are the special studies of the phylogenist rather than of the ordinary taxonomic worker. Groups such as *Magnoliophyta*, *Liliopsida* or *Fabales* are of considerable magnitude. They are respectively represented division, class and order. The names applied to all these categories are Latin.

5.3.2.1 Division. The term 'divisio' (division) has been prescribed by the botanical code to represent the category of the highest maganitude within the plant kingdom. The more or less equivalent term 'phylum' is prescribed by the zoological code. However, some taxonomic workers like Hutchinson and Tippo have used the latter term to plant groups as well. The number of divisions realized within the plant kingdom is rather variable. For example, while Eichler (1883) recognized five divisions, Engler & Pratle (99187-1915) have realized 14. Sometime back, all the seed plants were generally grouped under one division, Spermatophyta, that is characterized by the dominant sporophytic generation and presence of ovules that develop into seeds. The closely related divisions may have originated either from a common ancestor or from different ones and therefore the boundaries between them may not always be sharp. The characters employed to circumscribe a division are often reproductive, morphological, or internal anatomical structures. Exceptions to do exist and may be observed for almost every divisional character. So, a division is characterized by an aggregate of characters rather than by any single infallible one.

A division may be further divided into subdivisions. The division Spermatophyta was often separated into two divisions, Gymnospemae and Angiospermae. But in view of the rules of the nomenclature and in the light of the modern evidence, the current systems of classification like that of Takhtajan (1997) realized the seed plants differently. Accordingly, we have two divisions: *Cycadophyta* (Gymnospermae) and *Magnoliophyta* (Angiospermae). The ending for the name of a division is thus, *-phyta*. Where the subdivisions are used, the denoting term ends with *phytina*.

5.3.2.2 Class. The next category subordinate in rank to division is class. The names applied to classes have the ending *–opsida*. The *Magnoliophyta* are divided directly into two classes, *Magnoliopsida* (Dicotyledonae) and *Liliopsida* (Monocotyledonae). The class may be further divided into subclasses. Takhtajan (1997) realized 11 subclasses like *Magnoliidae* to *Lamiidae* for his *Magnoliopsida* and six (*Liliidae* to *Aridae*) for *Liliopsida*. Conversely, the Latin names denoting the subclasses have the ending *–idea*. Although some authors (Takhtajan, Treub and Dahlgren) have used categories like *super class* and *infra class*, they are not popular or have gained acceptance.

6.3.2.3 Order. Each class or subclass may be subdivided into one or more orders. This category is next in line and subordinate to that of class. Bentham & Hooker (1862-1883) have used this term in lieu of the term family. It is not acceptable because, as per the Code, the orders shall end with *-ales*, not *-aceae*. The names of the orders are based on its constituent family or families, e.g. *Fabales, Fabaceae; Euphorbiales, Euphorbiaceae; Malvales, Malavaceae.* Accordingly, the traditional orders like *Parietales*, *Centrospermae*, *Unisexuales* cannot be and no longer be used. Now, all such ordinal names are rightly replaced in the current systems of classification.

An order is considered to be more homogeneous or possessing a degree of phyletic unity than the higher category so far discussed. An order may be divided into suborders, which have the ending –*ineae*, e.g. *Malvineae*. Sometimes, the subclasses were directly organized into *superorders*, as has been done by Takhtajan (1997). He realized 56 superorders (37 in 1987 system) for *Magnoliopsida* and 16 superorders for Liliopsida, e.g. *Asteranae.* The ending for the superorder *–anae* that was earlier rejected in favour of *–florae* has now been accepted by Dahlgren (1980) and Thorne (1992) in view of the fact that the latter restricts the usage to flowering plants, and is not universal in application.

5.3.2.4 Family. It is considered as the smallest of the major categories. It is the most commonly used category in taxonomic references. The name of the family is based on any of its constituent genera with the suffix *–aceae*, e.g. *Euphorbiaceae*, *Nymphaeaceae*. However, there are certain (8 family) names with irregular endings. These names are descriptive and in long usage (traditional) before the current rules of nomenclature were applied. For those who wish to follow the Code strictly, there are alternative names provided to each one of these:

Traditional Name	Alternative Name	Type
Cruciferae	*Brassicaceae*	*Brassica* L.
Guttiferae	*Clusiaceae*	*Clusia* L.
Leguminosae	*Fabaceae*	*Faba* Mill.
Umbelliferae	*Apiaceae*	*Apium* L.
Compositae	*Asteraceae*	*Aster* L.
Labiatae	*Lamiaceae*	*Lamium* L.
Palamae	*Arecaceae*	*Areca* L.
Gramineae	*Poaceae*	*Poa* L.

Article 18.5 provides that these names of long usage are validly published. It is better to use the alternative names for the above families though one is entitled to use either. It prevents the scope for confusion. The experience with use of *Fabaceae* vs. *Papilionaceae* (V.S. Raju 2004) and the wrong interpretation of the Code without much exception in the Indian taxonomy textbooks, research articles, Floras, etc. is sufficient experience to offer the above opinion. To elaborate, *Fabaceae* is the alternative name for *Leguminosae*, as a conservative and traditional family. When *Caesalpiniaceae* and *Mimosaceae* are recognized as independent families out of it, we have to use

the name *Papilionaceae* on par (Article 18.5), not *Fabaceae* as has done by several. Probably, there is a need to dispense with this system of alternative names altogether, as they are exception to two of the six principles of the ICBN (see Chapter 6 for more details).

If the family is large, it is divided into subfamilies. Again the names of the subfamilies are based on the constituent genera and have the ending, *–oideae*. For example, the *Euphorbiaceae* are divided into five subfamilies, namely, *Phyllanthoideae, Oldfieldioideae, Acalyphoideae, Crotonoideae* and *Euphorbioideae*. If the *Fabaceae* (Leguminosae) are to be divided into subfamilies, three of them are realized, viz. *Faboideae* (*Papilionoideae*), *Caesalpinoideae* and *Mimosoideae*. A secondary rank between family and genus may be a tribe. Latin names of the tribes have the ending, *–eae*, e.g. *Magnolieae, Roseae*. The tribes may further be divided into subtribes, e.g. *Rosinae* (with the suffix, -*inae*). The subfamilies may be divided into tribes. Or, at times, the family may be divided directly into tribes as has been done by Hutchinson for *Euphorbiaceae*.

Not all families recognized by botanists may be natural. Accordingly, the families may be 'definable' or 'indefinable'. Families such as *Acanthaceae, Apiaceae* and *Poaceae* are clearly delimited or defined. On the other hand, families like *Saxifragaceae*, *Ranunculaceae* and *Verbenaceae* are not. These families are obviously heterogeneous and sometimes called 'dumping grounds' for seemingly related taxa. Such families need to be studied further to delimit them better, make them more natural.

5.3.3 Minor Categories

A minor category of classification is considered here to be the one whose name becomes a part of the name of that plant. It may be a genus, a species, or any of the several categories subordinate in rank to that of the species. For convenience in classification and phyletic clarity, the larger genera are sometimes divided into subgenera, sections, subsections and series. The Latinized names of these phyletic groups do not enter into the names of these plants concerned. Since more workers deal with the minor categories than the major, more information is available about them. Consequently, more diversity of opinion and concepts exists concerning their delimitations.

5.3.3.1 Genus. The genus is the next principal category in the taxonomic hierarchy above the species. The genus is more difficult to define than the species. According to Mayr (1957), the genus is a 'taxonomic category which contains either one or a monophyletic group of species, and is separable from other genera by a decided discontinuity gap'. Every taxonomist knows how hopelessly opinions differ concerning the delimitation of genera and other units of higher ranks (Du Rietz 1930). The concept of the genus is probably the oldest among all taxonomic categories and perhaps the oldest one recognized by humans. Examples are willows, oaks, roses, etc. Each family includes one or more genera. It is generally conceived that various genera within a family are closely allied, and very often have a common ancestral stock. The genera are more precisely delimited by a set of well-defined characters. Besides, the generic name of a plant is the first of the two words which comprise the binomial. For instance, *Oryza sativa* is a binomial in which *Oryza* is the generic name. The Latin names of the genera are substantives (adjectives), always capitalized, singular and may be taken from any source or character. There is no uniform ending for the genera.

It is held that the genus is more than a mere taxonomic category and the species of the genus indicate phyletic relationships among themselves as well as those of the other genera of the same family. Therefore, genus is considered as a biological category. Accordingly, the taxonomic account of the genus must include the similarities of the origins, migrations, genetic, cytological, physiological and ecological behaviours and geologic history of its components. *Form genera* or *organ genera* are recognized in paleobotanical studies. There are the genera with only one species (monotypic, more precisely unispecific).

A genus may be divided into *subgenera* and then into *sections, subsections* and *series*. But, these are not fundamental to the hierarchy and are not always used in classification within a particular group. However, they are very helpful to provide the infrageneric structure within large genera like *Senecio* and *Euphorbia,* with more than 1000 species.

5.3.3.2 Species. The species is a fundamental category of the taxonomic hierarchy. The species are 'building blocks' in the biological classification. It is the lowest category of the hierarchy that is consistently used and recognized by all biologists of the world. Mayr (1942) remarked that 'whether he realizes or not, every biologist – even he who works on the molecular level – works with the species or parts of species'. Because of this importance, much attention has been paid to the study of species and so much of information has accrued. Therefore, to realize the species in nature, several definitions were offered and scores of species concepts were put forward.

5.3.4 Species Concept.

The principles of logical division used by Aristotle, based in part upon the ideas of Plato, were to be the basis of taxonomy for many years to come. It served as a scheme upon which his species concept was framed. Plato inadvertently laid the foundations for the *typological concept* of the species to come. Linnaeus' species concept was based upon the idea that originally all species had been created by God and each one possessed an 'essence' in the Aristotelian and religious senses (Stafleu 1971). Cuvier (1835) used '*morphological species concept*' based more on morphological plans or archetypes. Then, the theory of evolution was revealed by Darwin (1859). Darwin believed that species are extremely plastic and mutable; he also seemed to believe that species are real entities and not simply mental constructs. Conversely, he stressed on the evolutionary integrity of the species through descent from a common ancestor. It was the beginning of the *evolutionary concept* of the species. Of the recent workers, Ernst Mayr (1963) made a profound impact on the development of species concept. According to him, species are 'groups of actually or potentially interbreeding populations which are reproductively isolated from other such groups'. It is called the *biological species concept*, which is one of the widely held today. The current concepts of species are briefly mentioned below:

5.3.4.1 Morphological Species Concept. The one most frequently employed, especially by reversionary works in taxonomy, is the morphological species concept. It is otherwise called the *classical phenetic concept* (Sokal 1973) or *Linnaean classical species concept.* In practice, we usually do not have sufficient information on reproductive behaviour to allow the biological species concept to be applied successfully. Consequently, workers stressed the importance of recognizing species on morphological basis alone. Du Rietz (1930) has emphasized that species are smallest natural populations permanently separated from each by a distinct discontinuity in the series of biotypes. The Linnaean species concept of morphologically defined species has served as a practical and efficient system for information retrieval in most *Magnoliophyta*. Even in the cases where intermediates and hybridization are known, the classical concepts have often found useful and meaningful (Heywood 1975).

5.3.4.2 Biological Species Concept. It is the one held conceptually by most current systematists. It has two aspects (Mayr 1969): (i) a group of interbreeding populations, (ii) which are reproductively isolated from other such groups. Rarely, does any practicing plant taxonomist have such data on the group with which he or she is working. Although many taxonomists adhere to the broader conceptual base of the biological species concept, they practice morphological species concept by default. However, the utility of the biological species concept is that it deals with reproductive isolation that is important in evolutionary theory. Realizing the difficulties in determining the reproductive barrier, Ehrlich has remarked that, the biological species concept has outlived its usefulness. He went on to comment further that, 'no species has ever really been defined biologically, and it is unlikely that one ever will be'.

5.3.4.3 Genetic Species Concept. Another idea that is closely allied to the biological species concept is the genetic species concept. This assumes that the biological factors of gene flow and reproductive isolation are operative, but that the way to define species is by measure of generic differences or distance among the populations or groups of populations (Stuessy 1990). It uses quantitative measure of genetic distance rather than morphological or other, as the yardstick. Naturally, it has difficulties in practice due the simple fact that we do not really know anything about the generic differences between populations. Newer techniques of measuring similarity at least part of the genome through allozyme electrophoresis are helpful here. A modified approach to this concept involves direct measure of genetic distance from DNA sequences. It is now gaining momentum in plants, particularly through chloroplast DNA studies (Palmer & Zamir 1982). This technique is extremely helpful to taxonomic and phyletic studies.

5.3.4.4 Evolutionary Species Concept. The biological and genetic species concepts are useful but they do not refer to evolution directly though there is recognition of evolutionary significance. So, Meglitsch (1954), Simpson (1961) and Wiley (1978) developed a newer concept called *evolutionary species concept*. Accordingly, an evolutionary species is a lineage evolving separately from others and with its own unitary evolutionary role and tendencies (Simpson 19961). The concept has the time outlook to neontologist and a phyletic perspective of paleontologist. And it avoids the difficulties with determining actual or potential levels of interbreeding, gene flow and allows some degree of interspecific hybridization, provided that it does not interface with the fundamental evolutionary role of each species.

5.3.4.5 Cladistic Species Concept. The evolutionary species concept, as defined by Wiley (1978) is more appealing to the cladists who would search for a concept related to dichotomous branches on a cladogram. He defined the evolutionary species as a "single lineage of ancestral-descendant populations which maintains its identity from other such lineages and which has its own unitary evolutionary tendencies and historical fate". The word 'single lineage' refers to a single branch on a cladogram, changes in the definition such as 'maintains its identity from other such lineages' rather than 'evolves separately from others', 'historical fate' instead of 'evolutionary role' are significant shifts from ecological standpoint to a historical context, resulting from the apomorhic changes within single branches of a cladogram. Although embodies minor changes from those of Simpson's (1961) and Wiley's (1978) definition, it is substantially different and can be called *cladistic species concept*. Bremer & Wanntorp (1979) support it though Wiley (1981) regarded this as a special case of evolutionary species concept.

5.3.4.6 Ecological Species Concept. Van Valen (1976) holds that 'a species is a lineage (or closely related set of lineages) which occupies an adaptive zone minimally different from that of any the lineage in its range and which evolves separately from all lineages outside its range.' Here, the term adaptive zone is used in the sense of ecological niche. The concept assumes that differences in character distributions among species are mainly due to adaptation. In this concept, the reproductive element is downplayed, with the assertion that species are maintained for the most part ecologically, not reproductively. But, Grant (1977) held the view that 'ecological isolation is a universal feature of species and not a distinguishing feature of species'. Besides, ecological differentiation is not an exclusive or diagnostic feature of species (Grant 1992). The ecological species concept is not an alternative to biological species concept, but is an essential part of the latter.

Anderson (1990) compared and reviewed the four concepts of species, the phenetic (morphological, more strictly taxonomic), biological, evolutionary and ecological. He finds no explanatory value with the phenetic and evolutionary concepts and do not explain why different lineages develop with different phenetic characters while the biological species concept cannot deal with uniparental organisms and it too fails to identify the driving force of speciation. So, it is only the ecological species concept that has the potential to explain speciation on a basis common to all organisms.

5.3.5 Infraspecific Categories

A species is adequate to account for the patterns of morphological, ecological and other variations. In complex situations, such as species complexes, there is a need to recognize the categories below the level of species. Any category below the rank of a species is called an *infraspecific* category. It is a variant of a species. The current Code (Greuter *et al.* 2000: Article 4)) prescribes five infraspecific categories, namely, subspecies, variety (varietas), subvariety (subvarietas), form (forma) and subform (subforma). The usage of the terms subspecies, variety and form has changed over the years. Now, there is much confusion surrounding the usage of these terms. Some workers consider the infraspecific categories as abnormalities or appendage to species. With the advent of biosystematics, the species is considered to be the initial binomial to which the subsequently described variants are ascribed.

In the view of Ehrhart & Link, the subspecies are variations hereditarily developed as opposed to the environmental modifications, or plasticities, which are more indicative of varieties. The subspecies is a category to which should be referred those elements which possess geographic, ecological and morphological characters, and suspected to be an ecotype. The subspecies of the Englerian School is such that it was a category of morphological distinction with or without disjunctive distribution. Often, the terms subspecies and variety are used interchangeably. On other hand, the term variety was the choice for infraspecific categories of Asa Gray and the school. Fernald (1936) firmly believed that variety is to be used to recognize the geographic variations within the ordinary species. So, subspecies can be used for subdivisions of an aggregate species, or what might be called a species complex (Fosberg 1942). There are two schools of thought in USA: The *Eastern School* advocating that species are the first to be delimited into varieties and then the varieties with more similarities from the rest can be grouped into subspecies. The *Californian School*, on the contrary, views that subspecies are to be delimited first and the varieties are to be recognized next. There are instances where either subspecies or variety is preferred. Overall, the term *variety* is used indiscriminately.

The term *forma* is used to apply to the unusual morphological variants. It is commonly the smallest category employed in ordinary taxonomic works. These result due to trivial variations occurring among the individuals of any population, e.g. corolla colour, fruit colour, and habitat response. Some taxonomists never use this term in their formal classifications on the ground that such minor morphological variations are expected in sexual organisms. A further variant of the forma is *subforma*. Hardly is this term employed as it not of any practical utility.

Model Questions

a) Essay type:

1. Write an essay on the principles of taxonomy.
2. Describe the criteria for classification.
3. What is species? How is it conceptualized using different dimensions of it?
4. Write an essay on the evolution of species concept.
5. How to evaluate the taxonomic categories?

b) Short type:

Taxonomic structure, Taxonomic hierarchy, Units of classification, Taxonomic Groups and categories, Major categories, Minor categories, Division, Class, Order, Family, Alternative names, Genus, Species, Species concept, Morphological species concept, Biological species concept, Genetic species concept, Evolutionary species concept, Cladistic species concept, Ecological species concept, Infraspecific categories, Subspecies, Variety.

6)

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Lesson - 6

PLANT NOMENCLATURE

6.0 Objective

In this chapter, the naming of plants, use of Latin names, evolution of the binomial nomenclature, and the salient features of the current Code are presented.

6.1 INTRODUCTION

Botanical Nomenclature is the naming of the organisms called plants. *Is it the same as the naming of humans*? We cannot name the plants as we please! It is done through an internationally acceptable and practicable system of naming. Obviously, it is based on certain guiding principles at global level. First, *why we name the plants*? The sole reason is that any knowledge of the plant taxon is tagged to its name. Conversely, every taxon must have a clear, concise and precise name. Then, *why not common names*?

6.2 COMMON NAMES

Although vernacular/local/common names of plants can be used to advantage, there are several practical problems. Even vernacular names are available only for some plants of a region. Besides, plants have multiple names, even locally; these are not known outside the region or known to all who speak that language. To cite, the Convolvulaceous plant with edible tubers is known as *kanda gadda* and *thiyya kanda* in Telangana region, *genusu gadda* and *ratnapuri gadda* in Rayalaseema and *chilgada dumpa* in coastal Andhra in Telugu language itself. It is but the so-called 'sweet potato' in English, which is scientifically known as *Ipomoea batatas*. Besides, the vernaculars are employed to unrelated plants and the same name is used for different plant taxa. For example, *Agathis*, *Araucaria*, *Callitris*, *Casuarina* and *Pinus* are all collectively called 'pines'. Similarly, the oak (*Quercus*), Jerusalem oak (*Chenopodium*), poison oak (*Rhus*), silver oak (*Grevillea*) and tanbark oak (*Lithocarpus*) though unrelated are yet called 'oaks'. The biggest 'banyan tree' on planet earth is in Ananthapur district of Andhra Pradesh. It is *Ficus benghalensis*. It is called *marri* in Telugu, *ala* in Tamil and Malayalam, *alada* in Kannada, *bar* in Bengali, Hindi and Panjabi, *vadi* in Marathi, and with so many other names in India. The mango (*Mangifera indica*) is known by over 50 different names, all in Sanskrit itself.

Apparently, these local names are used neither consistently nor specific to a country though humans and plants are globally distributed. Therefore, the purpose of specificity, i.e. one name for one species, is not the rule. Moreover, no human can afford to learn all the names given or ascribed to a taxon by fellow humans in order to make use of the available information effectively. Any use of the plant is for human welfare; it must profit all humans alike. Therefore, there is need for a name that is used by all, from scientists to layman. So, there must be a uniform and universal system of naming the plants.

Our forefathers amongst the botanists evolved a system of nomenclature, which is now more or less full proof and catering to the need of all categories of users. It was achieved through the relentless efforts of generations of professional taxonomists and nomenclaturists through International Botanical Congress (IBC), which meets once in five years.

6.3 NOMENCLATURE AND CLASSIFICATION

Although plant classification and identification are the two different activities of a taxonomist, they are interrelated and related to name (Nomenclature). In fact, these three aspects form the "Fundamentals of Taxonomy". Classification deals with the taxonomic categories (division to variety) which are filled with groups of plants on the basis of their similarities and differences. The scientific names are applied to these groups to accommodate the corresponding levels of diversity in the taxonomic hierarchy.

6.4 EVOLUTION OF THE CURRENT SYSTEM OF NOMENCLATURE

6.4.1 Polynomials

The scientific names first ever employed were polynomials. They were, in fact, brief descriptions in Latin. For example, Plukenet (1692) called the present-day *Sida cordifolia* L. (1753) as "*Althaea maderaspatana subrotundo folia molli et hirsuto multiplis*" which means that it is a member of *Malvaceae* that grows near Madras (= Chennai) with soft hirsute branches bearing somewhat round leaves. The Greeks, such as Theophrastos (300 BC) and Pliny (70 AD) were perhaps the first to use the system of *polynomials*. But, this was replaced by binomial system of nomenclature in view of the practical difficulties in recalling and remembering these long names, preparing the indices, etc.

6.4.2 Binomials

Although Gaspard Bauhin (1560-1624) in 1623 and Rivinus in 1690 attempted the use of binomials for plants they dealt with, they were not consistent throughout their works. Therefore, the credit for introducing the binomial system has gone later to none other than Carl Linné (1707-1778) who used two names/epithets invariably for the species described in his *Species Plantarum* (published on 1 May 1753). So, Linnaeus deserves to be called the '*Father of Binomial Nomenclature*'.

In a binomial system, the name of every species comprises two (binary) epithets: one is the generic name and the other is the specific epithet. For example, the rice plant is called *Oryza sativa*. In this binomial, the first word *Oryza* designates the genus to which the plant belongs and the second name, *sativa,* a particular species of that genus. The second word of plant's name is a specific epithet and the two words in combination make the species name and form the binomial, which is a binary epithet. The generic name starts with an uppercase (capital) letter whereas the species name begins with a lowercase letter. Both are separated by a space; they are not to be joined while underscored. They are to be underlined when handwritten, typed, or printed in italics indicating that they are Latin words, not integral to the language we normally use. Besides, the scientific names are to be pronounced like Latin, though generally we do not. We cannot write the species name alone without being preceded by the generic name or its abbreviated initial. For instance, if we write directly the species name *sativa* (= cultivated), nobody is certain whether it is *Medicago sativa, Oryza sativa* or *Lactuca sativa.* Furthermore, whenever two or more words are used while erecting the genus or species, they are to be combined by a hyphen. Examples are *Coix lachryma-jobi* (Job's tears), *Hibiscus rosa-sinensis* (China rose), *Nycanthus arbor-tristis*, etc.

6.4.3 Latin Names

The earliest names given to plants were vernaculars in the respective regional languages (Greek, Latin, Sanskrit, Chinese, etc.). Since there was more scientific activity in Europe, slowly and steadily, the Greek and Latin names have come to be used or gained prominence. Later, the International Code of Botanical Nomenclature has accepted Latin as the language for naming the plants. These are called scientific names. *Why Latin*? Latin words are both precise and concise. But, Latin is no longer in use. However, Botanical Latin can be easily followed and understood than any of the modern languages. The problems with using Latin are common to all. Moreover, Latin is dynamic. It accommodates easily the words form all languages. On the other hand, attempts to bring naming in English (e.g. Standardization of Plant Names by Calpi and Daiton in 1942) were a failure. So, Latin stays as the medium for naming plants and one of the Principles [V] of the *Code* says that "Scientific names of taxonomic groups are treated as Latin regardless of their derivation". Hence, the Telugu names *Soymida* and *Suregada* are Latin names.

6.5 ORGANIZED NOMENCLATURE

In 1737, Linneaeus laid the foundations for an organized system of plant nomenclature in his *Critica Botanica*. To mention a few, he felt that: (i) No two genera should bear the same name, (ii) No two species in a genus can bear identical names, and (iii) Priority is to be given to the earlier names. Those days, the communications were not good and slow. Moreover, there was no established system of naming that was in vogue. Consequently, more names were given to one and the same taxon. Examples: *Setaria italica* was attributed 73, *Echinochloa crus-galli* 46 and *Cynodon dactylon* 23 scientific names. After Linnaeus, it was Augustine de Candolle (1813) who discussed at length the nomenclature of plants in his *Théorie élémentaire de la Botanique*. After five decades, again it was the forerunner for *Lois de la Nomenclature Botanique* of his son, Alphonse de Candolle. E.G. Steudel published his *Nomenclator Botanicus* in 1821 which was the list of Latin names of flowering plants known till then.

6.5.1 First International Botanical Congress

The first ever meet of taxonomists was held in Paris during August 1867 under the stewardship of Alphonse de Candolle to devise a code of conduct for the plant taxonomist in matters of nomenclature. It was attended by 150 botanists, mostly European, to discuss the *Laws of Botanical Nomenclature*, the draft of which was written and circulated by de Candolle to the invitees. The contents were discussed; with some modifications they were approved and declared as the "Guide" to botanical nomenclature. It draft consisted of three chapters and 68 articles, forming the Paris Code (1868). These are better known as the "de Candollean Rules. After 1867, so far, 16 International Congresses were held all over the world, bringing out a new Code every time. The *Preamble* of these Codes says, "This edition of the *Code* supersedes all previous editions".

6.6 ST. LOUIS CODE

It is the latest of the Botanical Codes, which is currently in operation. It is the embodiment of the deliberations made, accepted and adopted at the 16th International Botanical Congress, which was held at St. Louis, Missouri, USA, during July-August 1999. It was edited by Greuter *et al.* (2000) and published as *Regnum Vegetabile* 131. It is also made available through a website. The *St. Louis Code* does not differ substantially in the overall presentation and arrangement from the *Tokyo Code* (1994). The numbering of Articles and Appendices remains the same though there have been a few changes in the numbering of the paragraphs, Recommendations and Examples. The following are the excerpts from it.

International Code of Botanical Nomenclature
(St. Louis Code 2000)
Contents

6.6.1 Preamble

There are eleven points that make clear the need for, and the nature of the botanical nomenclature. To state them briefly: Botany requires a precise and simple system of nomenclature used by botanists in all countries, dealing with the terms which denote the ranks of taxonomic groups on one hand and the scientific names which are to be applied to the individual taxonomic groups on the other. The purpose of giving a name to a taxonomic group is not to indicate its characters or history, but to supply a means of referring to it and to indicate its taxonomic rank. There must be a stable method of naming the taxonomic groups. The useless creation of names is to be avoided. The *Principles* form the basis of the system of botanical nomenclature. The detailed *Provisions* are divided into *Rules*, set out in the *Articles* and *Recommendations*. *Examples* are added to rules and recommendations to illustrate them. The Provisions regulating the governance of this *Code* form its last Division. The *Code* is applicable to all organisms traditionally treated as plants, extant or extinct. Provisions for the names of hybrids appear in Appendix I. There is a separate *Code* for the cultivated plants. This edition of the *Code* supersedes all previous editions.

6.6.2 Priciples

I. Botanical nomenclature is independent of zoological nomenclature.

II. The application of names of taxonomic groups is determined by means of nomenclatural types.

III. The nomenclature of a taxonomic group is based upon priority of publication.

IV. Each taxonomic group with a particular circumscription, position, and rank can bear only one correct name, the earliest that is in accordance with the Rules, except in specified cases.

V. Scientific names of taxonomic groups are treated as Latin regardless of their derivation.

VI. The Rules of nomenclature are retroactive unless expressly limited.

6.6.3 Ranks of Taxa

The taxonomic group of any rank is referred to as taxa (singular: taxon). The fossil taxa are called morphotaxa. The system of nomenclature provides a hierarchical arrangement of the ranks of taxa (Articles 1-5). Every individual plant is considered as belonging to a number of taxa of consecutively subordinate principal ranks: kingdom (regnum), division or phylum (divisio, phylum), class (classis), order (ordo), family (familia), genus (genus), and species (species). Therefore, each species is assignable to a genus, family, and so on. For example, the species *Oryza sativa* would belong to the genus *Oryza*, family *Poaceae*, order *Poales*, class *Liliopsida* and division *Maganoliophyta*. By using the prefix sub-, secondary ranks can be created where required. Examples are subclass, suborder, subfamily, subgenus, etc.

The ending on the name of the taxon indicates its rank, for instance, we have the suffix -phyta (*Maganoliophyta*) for division, -opsida (*Magnoliopsida*) for class, -ales (*Magnoliales*) for order, -aceae (*Magnoliaceae*) for family, -oideae (*Mangnolioideae*) for subfamily, -eae (*Magnolieae*) for the tribe, etc. The principal ranks of hybrid taxa are nothogenus and nothospecies. The relative order of the ranks specified (Articles 3 & 4) cannot be altered.

6.6.4 The Type Method or Typification

It is a very important aspect of plant nomenclature, set out in Articles 7-10. The application of names of taxa of the rank of family or below is determined by means of nomenclatural types. A nomenclatural type is that element to which the name of a taxon is permanently attached, whether as a correct name or as a synonym (Article 7). The type of a species or infraspecific taxon is either a single specimen preserved in one herbarium, or other collection or an illustration. The type of a vascular plant is usually a herbarium specimen. Some material does not lend itself well to preservation of characters in dried form (such as succulents), in which case, the specimen may be preserved (in a fluid) in a jar and with diagnostic drawings and photographs supplemented. Even the live specimen in a garden can serve as the type. So, a type can be a herbarium specimen, specimen in a jar, illustration, photograph and a live plant. Usually, great care is given to type specimens. They are preserved separately, not mixed with common collections. Many institutions have a policy not to loan the types.

The type method was evolved over a period of time. It was followed with the purpose that a twig or whole plant (in case of herbs) can serve as a sample or representative of that species. It was believed that the characters are immutable. Conversely, the typological concept is in contradiction to the modern convictions or theory of evolution. However, it is being adopted at Stockholm Congress (1950) and retained in the current *Code* in the absence of any other effective alternative. Various kinds of types were officially designated in the *Code*:

A *holotype* is one specimen or other element used by the author of the name or designated by him, as the nomenclatural type. As long as it is extant, it fixes the application of the name concerned.

A *syntype* is one of two or more specimens or elements used by the author when no holotype was designated, or in lieu of a holotype, or when one or more specimens were designated simultaneously as type.

A *lectotype* is a specimen or illustration selected from the original material to serve as the nomenclatural type, when the holotype is not designated at the time publication, or if it is found to belong to more than one taxon.

A *neotype* is a specimen selected to serve as the nomenclatural type of a taxon in a situation when all the material on which the taxon was based is missing or destroyed.

A *paratype* is a specimen cited with the original description, other than the holotype.

An *isotype* is a specimen believed to be a duplicate of the holotype. It is always a specimen.

An *epitype* is a specimen or illustration selected to serve as an interpretative type when the holotype, lectotype, or previously designated neotype, or all original material associated with a validly published name, is demonstrably ambiguous and cannot be critically identified for purposes of the precise application of the name of a taxon.

Neotypification or Lectotypification is a necessary activity of a taxonomist when the plant taxa are found to have no extant types, a contradiction to the *Code*. Neotypification is the process of designating a neotype when the original material on which the taxon is based is missing or destroyed. On the other hand, lectotypification is the selection of material from the original material, which is a syntype, or an isotype if such exists. A lectotype always takes precedence over a neotype, except as provided by Art. 9.15.

6.6.5 Principle of Priority

The nomenclature of a taxonomic group is based on priority of publication. This is known as the Principle of Priority (Articles 11 & 12). When *Aesculus* L. (1753), *Pavia* Mill. (1754), *Macrothyrsus* Spach (1834) and *Calothyrsus* Spach (1834) are considered as a single genus, its correct name is *Aesculus* L. because of its priority in publication. Similarly, *Lawsonia inermis* L. (1753) has priority over *L. alba* Lam. (1789) and *Anemone* x *hybrida* Paxton (1848) antedates *A.* x *elegans* Decne (1852). The principle of priority is not mandatory for the names of taxa above the rank of family.

Limitation of the principle of priority (Articles 13-15) is an important and practical aspect of the *Code*. The valid publication of names for various plant groups is treated as beginning at the following dates:

Spermatophyta, Pteridophyta, Algae (with exceptions), Fungi, *Sphagnaceae* and Hepaticae: 1 May 1753 (Linnaeus, *Species Plantarum*, ed. 1) .

Musci (excl. *Sphagnaceae*): 1 Jan. 1801 (Hedwig, *Species Muscorum*).

Fossil Groups: 31 Dec. 1820 (Sternberg, *Flora der Vorwelt*, Versuch 1).

In order to avoid any disadvantageous nomenclatural changes entailed by the strict application of the rules, especially the principle of priority, the Code provides the lists of names of families, genera and species that are conserved (*Nomina Conservanda*) in Appendix II and III. These conserved names are legitimate though initially they may have been illegitimate. Examples: *Smithia* Aiton (1789) was conserved against *Damapana* Adans. (1763), and is automatically conserved against the earlier homonym *Smithia* Scop. (1777). *Hydrocera* Blume ex Wight & Arnott (1834) is proposed by V.S. Raju *et al.* (Taxon 51: 383-384. 2002) for conservation against the earlier *Tytonia* G. Don (1831).

6.6.6 Effective and Valid Publication

There are two basic conditions to be satisfied before a properly formulated name can have any standing in the botanical nomenclature. First, the name must be published in a medium appropriate to the requirements of the *Code*. Second, the name must be published in accordance with the provisions of the *Code*. If the first condition is fulfilled, the name is *effectively published* and in the latter case, the name is *validly published.*

6.6.6.1 Effective publication. It is the publication in accordance with the Articles 29-31. The publication is effected, under this *Code*, only by the distribution of printed matter (through sale, exchange or gift) to botanical institutions, libraries, etc. It is not affected by communication of names at a public gathering, by placing the names in collections or gardens open to public, by handwritten or typed manuscripts or the other unpublished material, by publication online, or distributable electronic media.

Publication by indelible autograph after 1 January 1953 is not effectively published. It is the case with names published in trade catalogues, non-scientific journals, seed exchange lists, etc. The date of effective publication is the date on which the printed matter became available.

6.6.6.2 Valid Publication. There are several requirements for an effectively published name to be validly published (Articles 32-45). In order to be validly published, a name of taxon (excluding autonyms) must: (a) be effectively published (Articles 29-31); (b) have a form which complies with the provisions of Articles 16-27; (c) be accompanied by a description or diagnosis or by reference to a previously and effectively published description or diagnosis; and (d) comply with the special provisions of Articles 33-45.

A name is not validly published when it is not accepted by the author in the original publication or when it is merely proposed in anticipation of the future acceptance, when it is merely cited as a synonym and by mere mention of the subordinate taxa included in the taxon concerned. A new name or combination published on or after 1 January 1953 without a clear indication of the rank of the taxon concerned is not validly published (Article 35). Publication on or after 1 January 1953 of the name of a new taxon of the rank of genus or below is valid only when the type of the name is indicated (Article 37).

A name of a taxon below the rank of genus is not validly published unless the name of the genus or species to which it is assigned is validly published at the same time or was validly published previously (Article 43). Example is the genus *Hydrocera* Blume (Bijdr.: 241. 1825) of *Balsaminaceae*. As per Article 43, Blume has not validly published either the generic or the species name under *Hydrocere* (Raju *et al.* 2002)

It is to be noted that all validly published names need not be *legitimate* and all legitimate names be correct names. Legitimate names (Article 6.3 & 6.4) are those that are in strict accordance with the rules; the others being *illegitimate* (Articles 52 & 53). Superfluous names (1 type, 2 names) and later homonyms (2 types, 1 name) are illegitimate names. The *correct name* (Article 6.5) is the legitimate name that must be adopted for it under the rules.

6.6.7 Author Citations

For indicating the name (unitary, binary or tertiary) of a taxonomic group to be correct and in order that the date of publication may be readily verified, it is necessary to cite the author who first published the name in question. Articles 46-50 govern the author citations. The book "Author of Plant Names" edited by R.K. Brummitt & C.C. Powell (1992) provides the abbreviation for authors. There is a need for uniform application of author citations.

6.6.7.1 Original Author. Who first validly published the name concerned is called the original author. The author names after scientific names are abbreviated. Examples: *Rosaceae* Adans., *Rosa* L., *Rosa gallica* L., *Rosa gallica* var. *eriostyla* R. Keller, *Rosa gallica* var. *gallica*. (Adans. = Adanson; L. = Linnaeus). The last mentioned name is without author citation since it is an autonym (Articles 22 & 46).

6.6.7.2 Joint Authors. When a name has been published jointly by two authors, the names of both should be cited, linked by means of the word *et* or by an ampersand (&). When more than two authors have published the name, the citation should be restricted to that of the first one, followed by *et al.* Example: *Didymopanax gleasonii* Britton et Wilson (or Britton & Wilson) and *Arthraxon raizadae* Jain *et al.* The author citation for the latter is, in fact, Jain, Hemadri & Deshpande.

6.6.7.3 Name Proposal. When a name has been published but not validly by one author and is subsequently validly published and ascribed to him by another author, the name of the former author followed by "ex" may be inserted before the name of the publishing author. Example: *Hydrocera*

Blume ex Wight & Arn. In this case, Blume (1825) has not validly published the name *Hydrocera* but it was validated later (1834) by Wight & Arnott.

6.6.7.4 Taxon Transfer. When a taxon of a lower rank than genus is transferred to another taxon, with or without alteration of the rank, retains the epithet. The author who first published this legitimate epithet (the author of the basionym) must be cited in parentheses followed by the author/s whoever made the alteration (the author/s of the combination). Examples: *Chamaesyce pallens* (Dillwyn)V.S.Raju (*Euphorbia pallens* Dillwyn); *Chamaesyce senguptae* (N.P.Balakr. & Subr.)V.S.Raju & P.N.Rao (*Euphorbia senguptae* N.P.Balakr. & Subr.); *Erythropsis colorata* (Roxb.) Burkill (*Sterculia colorata* Roxb.); *Euphorbia deccanensis* V. S. Raju var. *nallamalayana* (J.L. Ellis) V. S. Raju (*Euphorbia linearifolia* Roth var. *nallamalayana* J.L.Ellis). The names mentioned in parentheses are all basionyms.

6.6. 8 Rejection of Names

Application of correct names involves the identification of illegitimate names. A legitimate name must not be rejected just because its epithet is inappropriate, disagreeable or another is preferable. In this regard, the users of the *Code* and the students of taxonomy must be familiar with certain terms often used in the text of the Code. They are later homonyms, nomen nuda, *nomen superfluum*, tautonyms, etc. These names are the rejected names in the *Code.*

6.6.8.1 Later Homonyms. The *Code* does not allow the use of the same (identical) name to two different taxa of the same rank (see Rule IV) sine each taxon should have only one correct name at that rank. Such names, if exist, constitute the homonyms. On publication, these are categorized as *earlier* and *later* homonyms. The latter category of names is illegitimate. For example, we have two names as *Ziziphus jujuba*: one of Lam. (1789) and the other of Miller (1768). The earlier name of Miller is to be applied to it while the Indian jujube (regu) described by Lamarck is to be correctly called *Z. mauratiana* Lam. Similarly, V.S. Raju has to reject a later homonym and give a new name (nomen novum) to the Indian sedge, in the absence of any available name. Examine the following citations:

Pycreus govindarajalui V.S. Raju in Taxon 40: 103.1991, nom. nov.

Cyperus decumbens Govind. in J. Indian Bot. Soc. 52: 72. 1973.

Pycreus decumbens (Govind.) P. Singh & V. Singh in J. Econon. Taxon. Bot. 5: 467. 1984, non Koyama 1976.

Govindarajalu (1973) published his new species in *Cyperus* L. (s.l.) of a specimen from Maharashtra in peninsular India. Since *Pycreus* is now accepted as a segregate genus, P.Singh & V.Singh transferred the name from *Cyperus* to *Pycreus* in 1986. They cited the basionym *Cyperus decumbens* Govindr. They did everything required by the *Code* to affect the transfer. But, they were unaware of the fact that there exists already one *Pycreus decumbens* described by Koyama in 1976 of a plant from Brazil. *Pycreus decumbens* (Govind.) P.Singh & V.Singh, therefore, forms a later homonym and hence illegitimate. Illegitimate names cannot be maintained and are to be replaced. Accordingly, V.S.Raju (1991) provided a new name *Pycreus govindarajalui* to the Indian taxon which is the correct name to be used under *Pycreus*.

6.6.8.2 Nomen nuda. The scientific names with no accompanied descriptions are naked and treated as nomen nuda (abbreviation: nom. nud.). Wallich, in his *Catalogue* (1832), published several names which are nomen nuda. Some of these were validated later by providing descriptions, e.g. *Cerasus cornuta* Wall. ex Royle. Similar is Moon's (1824) *Catalogue* of Sri Lankan plants. The new names in Roxburgh's *Hortus Bengalensis* (1814) were largely nomen nuda which were validated later by him or by others, e.g. *Echites paniculata* Roxb. [Hort. Beng. 20. 1814, nom. nud.] Fl. Ind. ed. Carey 2: 17. 1832.

6.6.8.3 Superfluous Names. A name, unless conserved or sanctioned, is illegitimate and is to be rejected if it were nomenclaturally superfluous when published. For example, *Entada pursaetha* DC. (Prodr 2: 425. Nov. 1825) and *Entada monstachya* DC. (Prodr. 2: 425. Nov. 1825) are superfluous and illegitimate because of *Entada rheedei* Spreng. (Syst. Veg. ed. 16, 2: 325. Jan.-May 1825). All these names pertain to Indian *gilla theega*, a liana from *Mimosaceae*.

6.6.8.4 Tautonyms. According to botanical Code, a name is to be rejected, if it is a tautonym. Tautonyms are those in which the specific epithet exactly repeats the generic name. Examples are *Linaria linaria*, *Malus malus* and *Strobus strobus*. So, the correct name for apple is *Pyrus malus*, not *Malus malus*. However, we do not reject the names like *Cajanus cajan* and *Sesbania sesban* as they are not true tautonyms, but paratutonyms. *Arum dracunculus* L. (1753), when transferred to *Dracunculus* Mill., is named as *D. vulgaris* Schott (1832). It is because the use of the Linnaean epithet in the transfer would result in a tautonym which is illegitimate.

6.7 NAMES OF HYBRIDS

The names of hybrids are covered in Appendix I of the *Code* (Articles H.1-H.10). The hybrids between two species of the genus are written by a formula consisting of a multiplication sign (x) or by addition of the prefix "notho". Example: *Musa* x *paradisiaca* L. A nothotaxon cannot be designated unless one parental taxon is known or can be postulated. Placing the multiplication sign between the names of the taxa may indicate a hybrid between named taxa; the whole expression is then called a hybrid formula. The nothogeneric name of a bigeneric hybrid is a condensed formula in which the names adopted for the parental genera are combined in a single word, using the first part or whole of one and the last part or the whole of the other. e.g. x Agropogon P. Fourn. (1934) (= *Agropstis* L. x *Polypogon* Desf.). Boivin (1967) published x *Mattia* for what he considered to be an intergeneric hybrid *Phippsia* (Trin.)R.Br. x *Pucciniellia* Parl. This name cannot be used for that hybrid since it is not a condensed formula. The correct name is x *Pucciphippsia* Tzvelev (1971).

6.8 DRAFT BIOCODE

An attempt was made towards achieving a unified code thereby merging all the existing codes dealing with the names of all biological organisms. Accordingly, a draft biocide was prepared and discussed at length during the last congress hled at St. Louis in 1999. However, after a through discussion, it was differed for future consideration. Those interested can have further details about it from the website:
http: www.rom.on.ca/biodiversity/biocode/biocode.htm.

Model Questions

a) Essay type:

1. What is plant nomenclature? What basic objectives does it serve? Brief state the principles and rules which govern the naming of seed plants?
2. Provide a brief account ICBN.

b) Short type:

Author citations, Biocode, Basionyms, Correct name, De Candollean Rules, Effective publication, Holotype, Illegitimate names, Legitimate names, Later homonyms, Limitation of Principle of priority, Names of hybrids, Nomen nuda, Principle of Priority, St. Louis Code, Tautonyms, Typification, and Valid publication.

REFERENCES

Greuter, W. *et al.* 2000. International Code of Botanical Nomenclature (St. Louis Code.) *Regnum Vegetabile* 131. Koeltz Scientific Books, Koenigstein.

Raju, V.S., Nair, V.J., Narayana, L.L. & Dutt, B.S.M. 2002. (1532) Proposal to conserve the name *Hydrocera* against *Tytonia* (*Balsaminaceae*). *Taxon* 51(2): 383-384.

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Lesson-7

CURRENT CONCEPTS IN PLANT TAXONOMY: SYSTEMATIC ANATOMY AND CYTOTAXONOMY

7.0 Objective

In this chapter, an attempt will be made to introduce to the student how the traditional aspects of botany like anatomy and cytology help to resolve the problems in classification that could not be sorted out based on gross morphology alone. The study also brings to light the fact that how the rapid strides in the instrumentation (technology) could improve the ability of a taxonomist to perceive better the relationships among the taxa.

7.1 SYSTEMATIC ANATOMY

Plant anatomy, the internal form and structure of plant organs, is one of the classical sources of data employed in plant taxonomy. The English worker Nehemiah Grew (1682) laid the foundation for this in his *The Anatomy of Plants* while Solereder (1908) set the stage in his *Systematic Anatomy of Dicotyledonae*. Engler & Prantle (1887-1915) used the anatomical information in their classification though it only decorated the text. Metcalfe & Chalk (1950, 1979 & 1983) consolidated the comparative anatomical data on *Magnoliophyta*. Now more monographs are available for specific orders and families of plants (e.g. *Juncales* – Cutler 1969; *Dioscoreales* – Ayensu 1972; *Palmae* – Tomlinson 1969; *Cyperaceae* – Metcalfe 1971).

Types of Anatomical data: These are of two types, one is endomorphic (in contrast to exomorphic or morphological) and the other is ultrastructural. The former data are observed largely by light microscope and latter by use of transmission electron microscope (TEM). Scores of applications of anatomical data in systematics are available and it is not possible to chronicle all of them here. A few examples are cited under the following heads.

7.1.1 Foliar Anatomy

Data can be obtained form the petiole, blade or cotyledons. Most foliar features of taxonomic significance are derived from the blade.

Petiolar anatomy offers very valuable clues to segregate the closely related families within the natural order *Scitamineae* (Engler & Prantle 1889), which was considered as a singly family by Bentham & Hooker (1883). Tomlinson (1962) ably demonstrated how the *Scitamineae* can be divided into eight families (*Costaceae*, *Heliconiaceae*, *Sterlitziaceae* and *Zingiberaceae* of Nakai and *Cannaceae*, *Lowiaceae* and *Marantaceae* of Engler, and *Musaceae* of Hutchinson) and justified it on anatomical grounds, which includes petiolar anatomy.(Fig. 7.1)

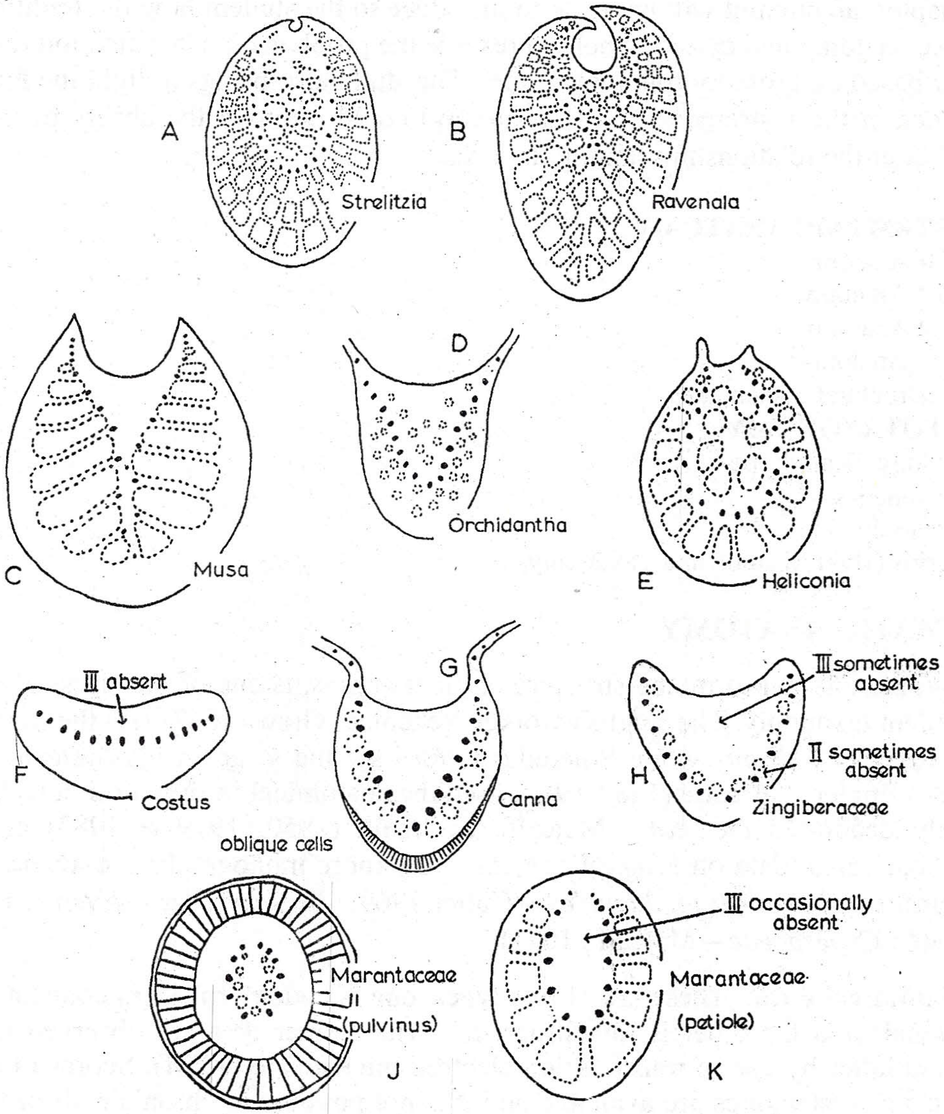

Fig. 7.1 Petiolar anatomy in *Scitamineae*.

The foliar epidermis (hypodermis, when present) offers many useful characters as shown by Stace (1966). The cuticle, epidermis, stomata, trichomes and idioblasts, with variation in their distribution provide comparative data of much importance. These are studied through paradermal sections (peelings) or by obtaining the impression using nail polish, glue, etc. P.N. Rao & V.S. Raju (1988) established the significance of cuticular striations in the order *Euphorbiales*. The variation in stomata and its importance in the classification of *Euphorbiaceae* were documented by Raju & Rao (1977). Furthermore, Raju & Rao (1987) introduced the *basic stomatal type* as a reliable taxonomic tool to distinguish the segregate genus *Chamaesyce* from the traditional and conservative Linnean *Euphorbia*. The leaves can be described as epi-, hypo- or amphistomatic on the incidence of stomata in the adaxial, abaxial or both, respectively. The stomata can be orientated parallel or at right angles to midrib and margins or arranged diffusely (Raju & Rao 1977). There are several types of stomatal complexes occurring in *Magnoliophyta*. Metcalf & Chalk (1950) have realized only four types for *Magnoliopsida*, viz. aniso-, anomo-, dia- and paracytic types. Now, the number has increased manifold (Stace 1965; Payne 1970; Dilcher 1974; Raju & Rao 1977). Recently, Prabhakar (2004) proposed a new classification of stomata.

The basic stomatal type is anisocytic in *Chamaesyce* whereas it is paracytic or anomocytic in *Euphorbia* s.s. Within *Combretaceae*, the stomata are paracytic in the subfamily *Strephonematoideae* and anomocytic in *Combretoideae* (excluding the tribe *Laguncularieae*, where they are cyclocytic). In *Acanthaceae*, the stomata are diacytic while they are anomocytic in the closely allied *Scrophulariaceae*. The stomatal frequency, stomatal indices and absolute stomatal number are all used to distinguish the taxa at specific and infraspecific levels.

Trichomes, *paillae* and *emergences* are of much significance wherever they occur. The Himalayan species *Hedera nepalensis* with its scales can be identified from that of its European counterpart, *H. helix*, with its stellate trichomes. The three varieties recognized under *Morinda pubescens* on anatomical ground (Kumari *et al*. 2002) can be distinguished on the distribution and trichome type on plant body. Accordingly, the foliar trichomes are absent (var. *pubescens*) or present (either curved as in var. *stenophylla* or straight as in var. *tomentosa*). Based on trichomes, Ramayya (1969) provided a key to the genera of *Asteraceae* from India. Rao & Raju (1985) and Raju (1981) discussed at length the bearing of foliar trichomes at subfamily level and below in the *Euphorbiaceae* and at ordinal level in the *Euphorbiales* of Cronquist, respectively.

In *Poaceae*, the leaf offers more features of diagnostic value. Prat (1960) demonstrated that leaves with **Festucoid type** bear simple silica cells and no bicellular trichomes and **Panicoid type** hold complicated silica cells and bicellular trichomes. The ultrastructural studies of guard cells in *Poaceae* (Brown & Johnson 1962), phytoglyphs in *Eucalyptus* (Carr *et al*. 1971) and crystals in nuclei of epidermal cells (Septa 1977) brought to light the taxonomic significance of these features. The mesophyll also offers features for classification. For example, on the basis of palisade distribution, the leaves are isobilateral (on both sides), dorsiventral (adaxial) or centric (all around). The presence of crystals, druses, sclereids, and other idioblasts make the leaves distinct. T.A. Rao & Das (1979) provided the distribution of sclereids in *Magnoliophyta*, following the system of classification of Dahlgren. The structure of the bundle sheath, especially in *Euphorbia*,

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Centrospermae and *Poaceae* with C_4 photosynthesis (Kranz anatomy) is diagnostic. These bundle sheath cells have centrifugally localized chloroplasts, wanting grana (Brown 1977).

Some plants take up soluble *monsilicic acid* from the soil and subsequently deposit it in their tissues as silica bodies. Such bodies have distinctive shapes and distribution patterns as systematic markers. The diversity and distribution of silica bodies in *Liliosida* (Prychid *et al.* 2003) revealed that they are restricted to a few genera of orchids and the large commelinid clad (*Arecacee, Cyperaceae, Juncaceae* and *Poaceae*); they are absent from some lilioid and basal monocots. The most common type is more or less spherical; the other types include a conical form (grasses and orchids) and amorphous fragmentary type (silica sand).

7.1.2 Nodal Anatomy

Node is that part of the stem to which the leaves are attached. Nodal anatomy describes the nature of vascular continuity between two organs, the stem and the leaf. Based on the number of leaf gaps in the cauline stele left by the departing leaf traces, the nodes are described as unilacunar, trilacunar and multilacunar. The nodal patterns are often articulated in terms of number of traces and gaps. To illustrate, the unilacunar node with single departing trace is expressed as 1:1, with two traces as 1:2, and a trilacunar with three tracaes as 3:3 (Fig. 7.2), etc. In nodal anatomy, the genus *Trimenia* of *Monimiaceae* closely resembles *Austrobaileya* in bearing two discrete stands that are related to a single gap whereas in *Piptocalyx*, another related genus of the family, there are two traces at subnodal level which bifurcate forming four strands.

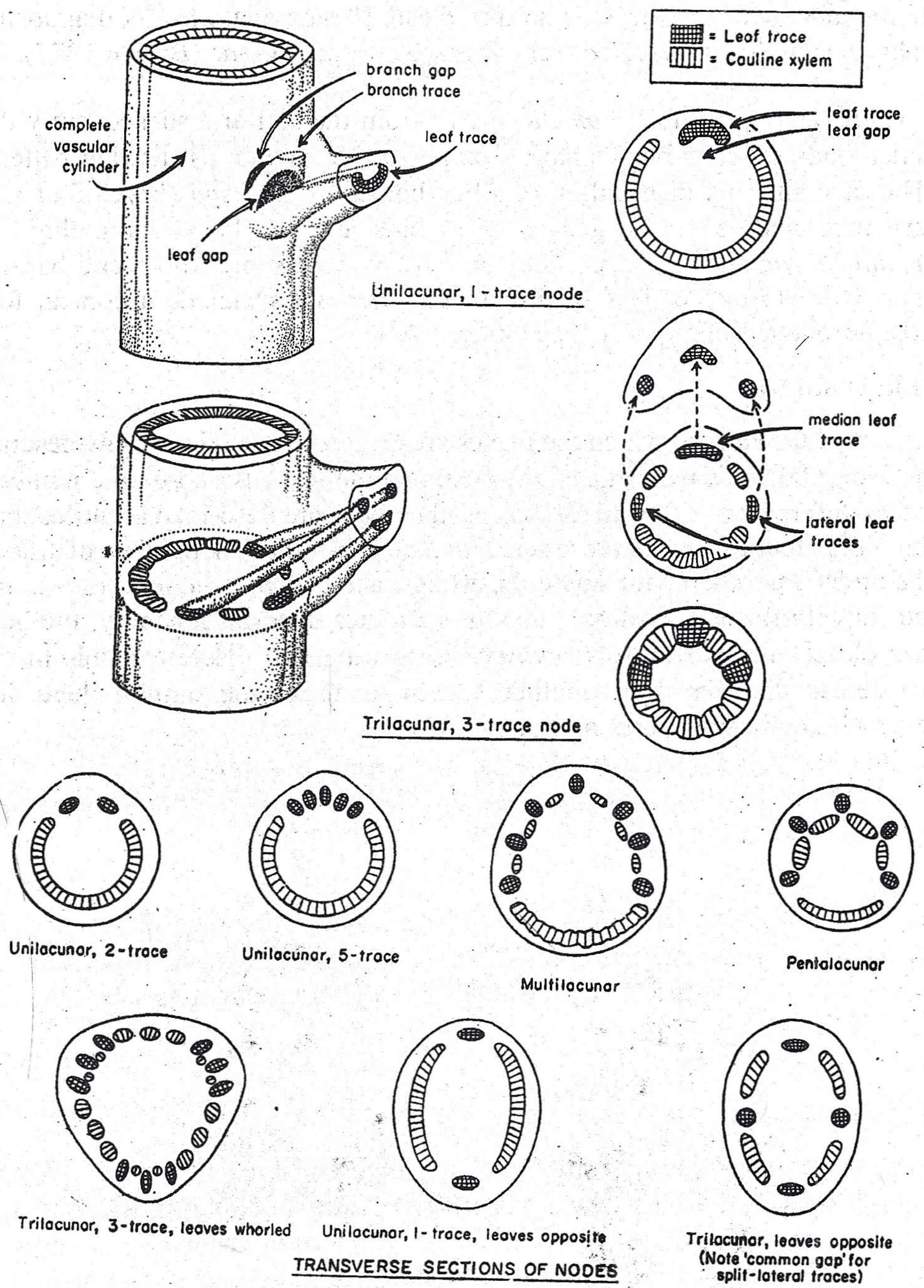

Fig. 7.2 Nodal vasulature.

7.1.3 Floral Anatomy

The angiosperm flower contains many patterns of vascularization that are helpful in establishing the relationships in several instances, e.g. *Hamamelidaceae* (Bogle 1970). For general information on floral anatomy, one can refer to Eames, *Morphology of Angiosperms* and Esau, *Plant Anatomy*. The Indian workers, namely, V. Puri from *Meerut*, V.S. Rao from *Bombay*, L.L. Narayana, M. Radhakrishnaiah and Digamber Rao from *Warangal*, P.S. Prakasa Rao from *Nagarjunanagar* and K.S. Manilal from *Calicut*, contributed much to the understanding of floral anatomy of several taxa, of both academic and systematic interest.

For example, there is dispute regarding the affinities, status and systematic position of *Vivianiaceae.* While Dahlgren and Rouleau recognized *Vivianiaceae* Klotzsch as an independent family under *Geraniales*, Bentham, Cronquist, Goldberg Takhtajan, Thorne and Young retained it in *Geraniaceae.* Earlier, Hutchinson placed it in *Pittosporales*. L.L. Narayana & Ramadevi (1995) studied the floral anatomy of *Viviania* and concluded that *Vivianiaceae* are closely allied to *Geraniaceae* (in all essential floral features such as hermaphroditic, actinomorphic, pentamerous and hypogynous flowers, 3-traced sepals, contorted petals, 1-traced petals and stamens, obdiplostemony with adnation between petal midribs and antipetalous staminal traces, 3-5 traced carpels, anatomically parietal placentation, and antisepalous glands. The predominantly Australian *Pittosporaceae* differs from *Vivianiaceae* in the tetracyclic flowers, haplostemonous androecium and in the absence of nectariferous lobes associated with stamens (Radhakrishnaiah 1977). So, floral anatomical evidence, in conjunction with data from other disciplines, supports the treatment of *Vivianiaceae* as an independent family and its alliance with *Geraniaceae* rather than with Hutchinson's *Pittosporales*.

In *Apiaceae, Centella* and *Hydrocotyle* are distinguished from one another on floral features. The inflorescence is a cyme and the ovules receiving vascular supply from alternate bundles in *Centella* whereas the inflorescence is an umbel and the ovules get vasculature from the fused adjacent bundles in *Hydrocotyle*.

7.1.4 Wood Anatomy

The anatomy of stem, particularly xylotomy, is an important area of study. Vast information is available about the woods of all arborescent economic species. This information has been of great help to identify both extinct and extant woods. The structure of secondary conductive tissues like xylem and its three-dimensional nature (the axial and horizontal systems) can be best studied with a wood microtome. The wood is cut in transverse (TS), radial longitudinal (RLS} and tangential longitudinal sections (TLS). Maceration of wood elements is also of help to know the nature of end wall perforations, inter-vascular pitting, length of the elements, etc.

The wood can be described as ring porous or diffuse porous based on the distribution of vessels; the axial parenchyma may be paratracheal (aliform, confluent, scanty or vasicentric) and apotracheal (banded, diffuse, diffuse-in-aggregates or terminal); the rays may be homogeneous, heterogeneous or aggregate; the intervascular pitting may be alternate, opposite or scalariform, etc. The end walls (perforation plates) and ray-vessel pitting offer features of diagnostic and evolutionary nature. The presence or absence of oxalate crystals, tyloses in the wood are also diagnostic. For example, within the genus *Juglans*, the ray cells are elliptic in *J. cinerea* whereas round in *J. nigra*. Furthermore, the oxalate crystals are absent from the wood parenchyma of the former while present in the latter.

The woods of *Cycadophyta* (Gymnosperms) are classified as softwoods which are formed exclusively of tracheids whereas those of *Magnoliophyta* (Angiosperms) as hardwoods formed of vessels. Vessels are found in a few advanced *Cycadophyta* like *Ephedra* whilst they are absent from certain primitive *Magnoliophyta*. Bailey (1944) concluded that the vessels in *Magnoliophyta* arose from tracheids with scalariform pitting whereas, in *Gnetales*, they arose from tracheids with circular pittings. In other words, he suggested independent origin of vessels in these two groups. The presence of vesselless members amongst the primitive *Magnoliopsida* (*Amborellaceae*, *Tetracentraceae*, *Trochodendraceae* and *Winteraceae*) has lead to the surmise that primitive angiosperms were vesselless. The absence of vessels in other groups of *Magnoliopsida* (e.g. aquatic families like *Nymphaeaceae, Ceratophyllaceae* and *Podostemaceae* is due to secondary loss.

The separation of *Paeonia* from *Ranunculaceae* and *Austrobaileya* from *Monimiaceae* into independent families (*Paeoniaceae* and *Austrobaileyaceae*) was based on wood anatomy (Bailey & Swamy 1948).

7.1.5 Ultrastructural Systematics

The advent of scanning electron microscopy (SEM) and transmission electron microscopy (TEM) marked a new era in plant systematics. They helped to explore better the micromorphology of plant organs and tissues. Behnke & Barthlott (1983) made an extensive study of *Magnoliophyta* for new evidence using SEM and TEM. The study of sieve-element plastids in *Centrospermae* and other groups by Behnke and his school has proved worthwhile. All sieve-element plastids contain starch grains differing in number, size and shape. The protein accumulates in specific plastids in the form of crystalloids and filaments. Accordingly, two types of plastids are noticed: **P-type**, which accumulates proteins and **S-type**, which does not accumulate proteins. Starch may be present or absent in both the types. The P-type plastids are further divided into six subtypes:

1) **PI-subtype**: These plastids contain single crystalloids of varying sizes and shapes besides the irregularly arranged filaments. This subtype is considered as the most primitive within *Magnoliophyta*.
2) **PII-subtype**: In this subtype, the plastids bear several cuneate crystalloids pointed towards the centre. It is characteristic of all *Liliopsida*. Within *Magnoliopsida*, this subtype is found in *Asarum* and *Saruma* of *Aristolochiaceae*, a possible link between the two classes of the division *Magnoliophtyta*?

3) **PIII-subtype**: The plastids of this subtype contain a ring-shaped bundle of crystals. It is characteristic of the *Centrospermae*. The removal of *Bataceae* and *Gyrostemonaceae* from *Chenopodiales* is supported on the ground that this subtype of plastids are absent from these families. This subtype is further categorized into *three* forms based on the presence of crystalloids of globular (PIIIa) or hexagonal (PIIIb) nature, or their absence (PIIIc). Based on plastid structure, Behnke (1976) proposed the division of *Centrospermae* into *three* family groups, corresponding to the suborders *Caryophyllineae*, *Chenopodineae* and *Phytolaccineae* as proposed by Friedrich (1956). But, later, Takhtajan (1987) recognized only two suborders, merging *Phytolaccineae* with *Caryophyllineae*. Of the *three* orders of his superorder *Carypophyllideae*, only *Caryophyllales* bear PIII-subtype plastids. The other two orders, *Polygonales* and *Plumbaginales*, contain S-type. On this evidence, Behnke earlier (1977) suggested the removal of the latter two orders to the subclass *Rosidae* which characteristically bear S-type plastids. This was not given due credence by Cronquist (1988).
4) **PIV-subtype**: In this, the plastids contain a few polygonal crystalloids of different sizes. This subtype is restricted to *Fabales*.
5) **PV-subtype**: These plastids bear many crystalloids of varying sizes and shapes as in the *Ericales* and *Rhizophoraceae*, and
6) **PVI-subtype**: In this, the plastids bear a single circular crystalloid, found only in *Buxaceae*.

Behnke & Barthlott (1983) discussed at length the various forms of sieve-tube plastids and their possible evolutionary significance. A schematic representation of the same is presented in Fig. 7.3.

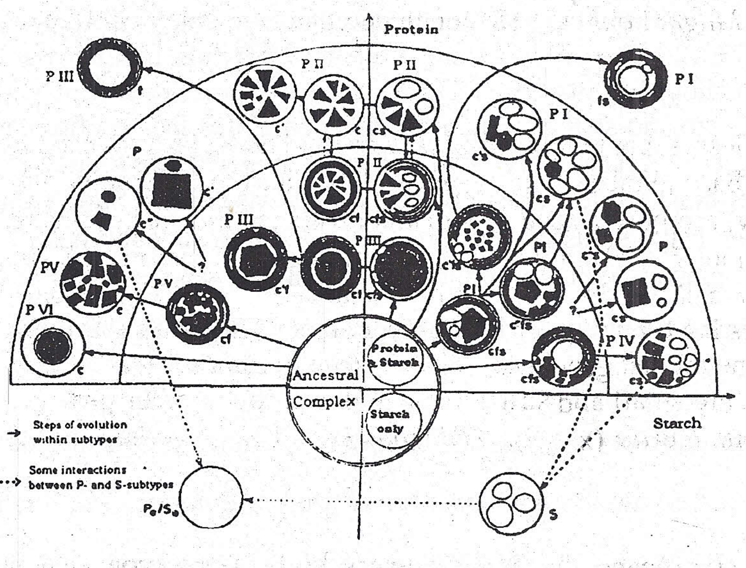

Fig. 7.3 Sieve-tube plastids and the trends of their possible evolution.

7.2 CYTOTAXONOMY

The use of cytological data in the elucidation of taxonomic problems is called *cytotaxonomy*. There are two nuclear aspects that are of importance to a taxonomist. They are: (i) the number, size, shape and structure of chromosomes, i.e. *karyotype*, and (ii) the behaviour of chromosomes during the meiosis and, to some extent, their behaviour during the mitosis.

7.2.1 Cytology: Karyotype

The appearance of somatic chromosomes at the mitotic metaphase is called *karyotype*. Karyotypes are calculated from the means of a substantial number of observations of chromosomes from the cells squashed, and are often presented diagrammatically as *idiograms* or *karyograms*. The karyograms are distinctive and form the chromosomal portraits of the species. Karyomorphology or Karyosystematics is a specialized branch of botany, which involves not only the number and size of chromosomes but also their morphology and internal anatomy. It has much potential information for the clarification of relationships. Examples are *Aristolochiaceae* (Morawetz 1985), *Brunelliaceae* and *Caryocaraceae* (Ehrendorfer *et al.* 1984), etc.

Chromosomes, the carriers of genetic information, can be observed either from the root tips (somatic or diploid [2*n*] number or by squashing the anthers (gametic or haploid [*n*] number) in a species. The most frequent number in a genus or other higher taxon is called *base number* (x). Federov (1969) made available the chromosome numbers in flowering plants, following Darlington & Janaki-Ammal (1945) and Darlington & Wylie (1955). Now, Missouri Botanical Garden has put up a web on the chromosome numbers available for various plant species. In *Magnoliophyta*, the chromosome number varies from the lowest (2n = 4) in *Haplopappus gracilis* (*Asteraceae*) to the highest (2n = 264) in *Poa littorosa* (*Poaceae*). Raven (1975) provided a review of the chromosome numbers at family level for *Magnoliophyta*. He concluded that x = 7 as the original base number for the taxon.

To provide some examples in this regard: *Family Level*: The *Ranunculaceae* are predominated by large chromosomes and base number. *Aquilegia* and Thalictrum, originally placed in two tribes or subfamilies of the family, are now placed in a distinct tribe, as they are characterized by smaller chromosomes and base number 7. *Subfamily Level*: Within Poaceae, the *Bambusoideae* have x = 12 whereas *Pooideae* are characterized by x = 7. In *Rosaceae*, x = 17 in *Pomoideae* while the remainder of the subfamilies have x = 7, 8 or 9. *Genus Level:* The genus *Jatropha* is uniform with 2n = 20, and distinct from the related genera of *Crotonoideae* in *Euphorbiaceae*. *Infrageneric Level.* Although the chromosomes are small and structurally uniform, the number provided support for the its cleavage into sections, *Audibertia* (x = 9), *Pulegium* (x = 10), *Mentha* (x = 12) and *Preslia* (x =18).

To illustrate further the significance in the differences in the Karyotype, one has to look at the breeding behaviour of morophologically closely allied species. The two species of *Gutierrezia*, namely, *G. sarothrae* (a shrub) and *G. texana* (a stout annual) occur in southern USA. Their ranges overlap in Texas and Mexico, with no hybrids formed despite the fact that both of these have the same haploid number (n = 4) with one metacentric and three acrocentric chromosomes. A detailed study of their karyotypes (Ruedenberg & Solbrig 1963) disclosed the structural differences in individual chromosomes which made the pairing impossible. In *G. sarothrae*, the short arm in one of the chromosomes is considerably longer than in the other two; and of these last two, one possesses a satellite. Of these, the SAT chromosome is the largest, followed by the subterminal, the submedian and the median in that order. On the other hand, *G. texana* has the metacentric chromosome as the largest one. Of the three acrocentric, two are subterminal and one is submedian. This study of chromosomal morphology clearly explains why there is no hybridization between these two species.

The information contained within the karyotypes can be enhanced by studying the banding patterns of the chromosomes. In this technique, different dyes (e.g. Giemsa) are used to stain the heterochromatin. More recently, '*in situ* hybridization of satellite DNA' from one taxon to another, using radioactively labeled DNA of one species and autoradiography (Fig. 7.4). It facilitates better comparisons of chromosome complements, e.g. *Scilla* complexes.

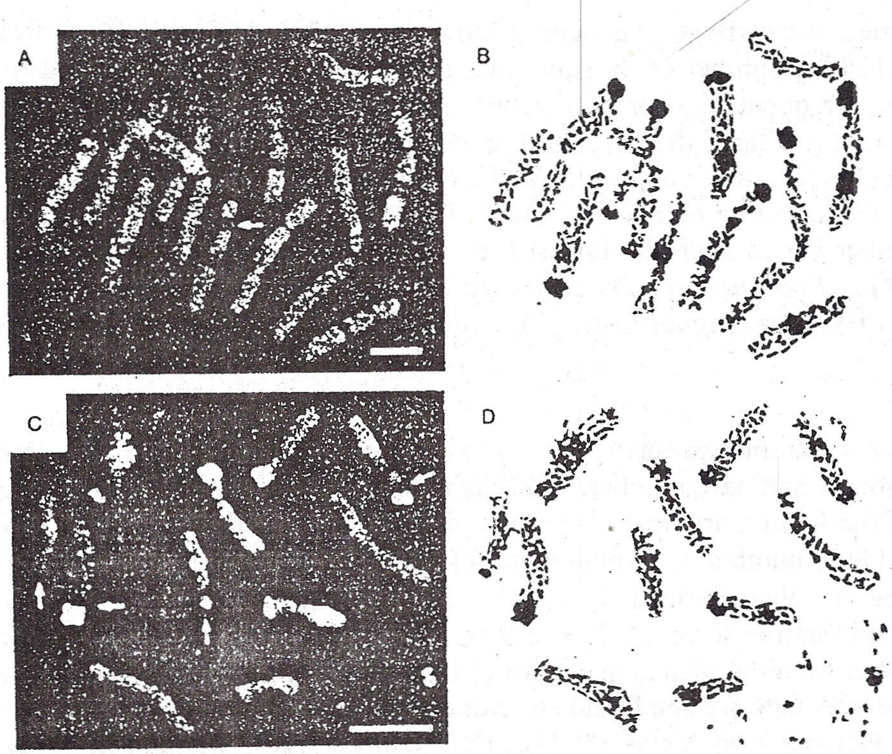

Fig. 7.4 *In situ* hybridization of satellite-DNA-cRNA on to chromosomes.
A,B: Scilla siberica, A - quinacrine staining; C,D: S. mischtschekoana,
C – DAPI sataining.

7.2.2 Cytogenetics

Cytology interwoven with genetics is called *cytogenetics*. Population genetics developed only after the rediscovery of Mendel's work. Cytogenetics *per se* began after the cytological basis of heredity was recognized in the beginning of the 20th century. The great works of Goodspeed (1934) on *Nicotiana*, Bobcock & Stebbins (1938) on *Crepis*, etc. provided the impetus to the concept of *New Systematics* by Huxley (1940). The attraction of the cytogenetic data for plant taxonomist is that they probe the real hereditary bases of evolutionary divergence and hence offer a more reliable yardstick for classification. The genetic similarities and differences among the taxa can be determined in two different ways: (i) crossing studies to determine the genetic basis of selected taxonomic characters, and (ii) isozyme analyses to yield an estimate of genetic distance between taxa.

Cytogenetic data are more valuable at the lower level of the taxonomic hierarchy. There is no record of successful interfamilial crosses in *Magnoliophyta*. The only way to overcome the barrier is to attempt for somatic cell hybridization (Levin 1975).

If genera are successfully crossed in someway, it raises the taxonomic question whether they should be merged into one genus (Anderson & Reveal 1966). Within the genus, artificial crossibility is usually achieved at specific, series, sectional and subgeneric levels. It is here most useful cytogenetic data are obtained and applied. e.g. *Antennaria* and *Cattleya*. Similarly, isozyme data are compared at higher levels in the hierarchy. However, one has to be cautious in the interpretation of this data in view of parallel mutations giving rise to identical isozymes.

Chromosome behaviour. Much of the information can be gained from the behaviour of the chromosomes during the meiosis. In *Cyperaceae* and *Juncaceae* with smaller chromosome and diffuse cetromeres, the equational division precedes the reductional division, instead of *vice versa*. Greater degrees of genomic non-homology result in non-pairing at meiosis (*asynapsis*), or loose pairing without the formation of chiasmata so that the bivalents fall apart before the metaphase (*desynapsis*). However, Solbrig (91968) listed 15 genes which are known to affect the regularity of meiosis, several of which are concerned with pairing itself.

7.2.3 Polyploidy

The closely related species within a genus often differ in the chromosome number. The most frequent variations are due the phenomenon known as *polyploidy*. Most of the variations in chromosome numbers known are due to the gain or loss of regular chromosomes either by duplication of complete sets (*euploidy*) or by changes of individual chromosomes (*aneuploidy*). So, we have two levels of ploidy. However, at times, there is *segmental allopolyploidy*, an intermediary. Some diploid hybrids between the species show high degree of pairing and fertility. The polyploids formed from them show mainly bivalents, some quadrivalents and trivalents showing that they have some segments which are homologous in the two genomes. Examples are *Primula kewensis*, which arose in cultivation and *Delphinium gypsophilum*, which was formed in nature. These species are called segmental allopolyploids, which are more common in nature than the strict autopolyploids or allopolyploids.

Polyploidy is widespread in plants and has been a major contributor to plant evolution. It is estimated that 20-50% (70% according to Goldblatt, 1980) of the *Magnoliophyta* are polyploids. Polypoidy is rather rare in animals.

In the grass genus *Festuca*, there are species with $2n$ = 14, 28, 42, 56 and 70; such species are to be called diploids, tetraploids, hexaploids, octaploids and decaploids, respectively. Obviously, these numbers are based upon 7, the gametophytic chromosome number of the diploid species. It is the base-number or basic chromosome number (x). It is the basic set of chromosomes of the *genome* carrying the genetic information. In a diploid species, $x = n$. But, in a polyploid species, n is a multiple of x. For example, in a tetraploid species, $2n = 4x = 28$ (since $x = 7$).

Cryptic or *semi-cryptic* polyploidy are employed to cover the cases where there is little or no external manifestation of differences in the ploidy level. Examples are *Mimmulus guttatus* and *Galium verum*.

7.2.4 Hybrids (Hybridization and Taxonomy)

Winge (1917) stressed the importance of hybridization in polyploidy. Speciation by hybridization occurs in a number of plants though rarely in animals. Two sympatric species A and B, interfertile in F_1, cross to produce A x B, allopolyploid individuals showing hybrid vigour. They happen to breed among themselves and not with the members of one of the parental species. With stronger fitness, these individuals develop at the expense of the parental species. To a taxonomist, hybridization normally implies the known or assumed crossing between plants belonging to different taxa, usually species, subspecies or, in rare cases, genera (Davis & Heywood 1963). According to Stebbins (1959), it is the crossing between the individuals belonging to separate populations, which have different adaptive norms. Hybridization plays a constructive role both in speciation and macroevolution. In the role of hybridization in speciation, there are three important aspects, viz.: (i) Stabilization of hybrid derivatives by means of amphidiploidy, (ii) Stabilization by introgression, and (iii) Stabilization of segregates from hybridization.

(i) ***Amphidiploidy***: It is the doubling of the chromosome. As Boecher (1962) says, 'it not the doubling up of a chromosome complement which is crucial but rather the success of the tetraploids'. *Senecio cambrensis* ($2n$ = 60) is an amphidiploid formed between *S. vulagris* ($2n$ = 40) and *S. squalidus* ($2n$ = 20). Several allopolyploids arose due to crosses between different genera, e.g. *Triticale* (n = 28) from *Triticum asetivum* (n = 21) and *Secale cereale* (n =7) and *Raphanobrassica* (n = 18) from *Raphanus sativum* (n =9) x *Brassica oleraceae* (n = 9).

(ii) *Introgression*: It involves gradual infiltration of the germplasm of one species into that of another, and usually occurs between species which show some measure of reproductive isolation. It is achieved in three phases: a) the initial formation of F_1 hybrids, b) their back-crossing to one or other of the parental species, and c) natural selection of certain favourable recombinant types.

Anderson (1949, 1953) was perhaps the first to do extensive work on introgression. Two types of introgression are noticed, namely, the sympatric and allopatric.

(iii) *Hybrid segregates*: Although the above-mentioned two phenomena are the usual ways by which the hybrid progeny are established, this result can arise without either of them (Stebbins 1959). For example, Southern Californian *Pentstemon spectabilis* with somewhat bilabiate, purplish blue corollas is derived by hybridization between *P. grinnellii* that has widely bilabiate, bright blue corolla and *P. centranthifolius* with narrowly tubular red corolla. The parents are kept apart because one is pollinated by carpenter bees and the other is by humming birds. The F_1 hybrid formed in nature was without a specific pollinator, though fertile when artificially pollinated. A new pollinating agent has adopted the F_1 hybrid and *P. spectabilis* is derived from it by segregation and selection.

Hybrid complexes: Grant (1953) recognized *five* types of hybrid complexes. (i) *Homogamic complex*, in which the hybrid derivatives are sexual and predominantly diploid, e.g. *Quercus*. (ii) *Clonal complex*, in which the hybrids reproduce mainly or entirely by vegetative means and remain more or less localized, e.g. *Mentha.* (iii) *Heterogamic complex*, in which the hybrid derivatives are permanent structural heterozygotes, e.g. *Oenothera*. (iv) *Polyploid complex*, in which the derivatives are sexual polyploids, e.g. *Valeriana officinalis*, and (v) *Agamic complex*, in which derivatives reproduce entirely or partially by unfertilized seed or bulbils, e.g. *Crepis*.

Model Questions

a) Essay type:

1. Write an essay on systemaic anatomy.
2. Present a brief account of cytotaxonomy.

b) Short type:

Foliar epidermis and taxonomy, Nodal anatomy and taxonomy, Floral anatomy and taxonomy, Wood anatomy and taxonomy, Ultrastructual Systematics, Cytotaxonomy, Karyotype, Idiogram, Polyploidy and taxonomy, Hybridization and taxonomy.

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Unit - II

Lesson - 8

CURRENT CONCEPTS IN PLANT TAXONOMY: PHYTOCHEMISTRY AND PHYTOGEOGRAPHY IN RELATION TO TAXONOMY

8.0 Objective

This chapter brings to fore the significance of plant natural product chemistry in relation to systematics – how the traditional use of chemical characters like oils, latex, mints, etc. in classification lead to the use of most modern molecular markers. Besides, there will a focus on the application of natural (geographic) distributions of various groups of plant taxa, endemism, etc. in taxonomy.

8.1 PHYTOCHEMISTRY

Chemosystematics, Chemotaxonomy, Biochemical Systematics, Macromolecular Systematics, Micromolecular Systematics, etc. refer to more or less the same area of study as 'phytochemistry in relation to taxonomy'. In it, the distribution of chemical molecules are examined to know their affinities and to classify the taxa. So, chemotaxonomy can be simply defined as the elucidation of the problems of classification using the chemical data. Strictly speaking, chemotaxonomy incorporates the principles and procedures involved in the use of chemical evidence to sort out the taxonomic problems.

Application of chemical information to identify the plant taxa is not something new. Our forefathers have categorized plants as mints, thymes, turpentines, etc. The very division of *Asteraceae* was done essentially based on the presence or absence of latex, which is a chemical character. Silica in sedges is another such marker. So, chemical characters can be used in a classification almost as readily as familiar features like phyllotaxis, indumentum, stomata, chromosome number, etc. The early information of chemical distribution was through the medicinal plants, when chemical extraction, separation, identification and structural determination were slow and difficult. Now, thanks to rapid screening techniques available like chromatography (paper, columnar, thin-layer and gas), electrophoresis (disc and immuno) etc., we are able to accrue vast chemical data about so many kinds of plants in a short period. The natural phytochemical constituents can be classified conveniently under:

1. **Micromolecules**: These are the compounds with low molecular weight, less than 1000.

   a) *Primary Metabolites*: These are the compounds involved in vital metabolic pathway: Examples are citric acid, protein amino acids, etc.

   b) Secondary *Metabolites*: These are the compounds formed as the by-products of metabolism and often perform non-vital functions. Examples are alkaloids, non-protein amino acids, phenolic compounds, saponins, terpenoids, etc.

2. **Macromolecules:** These are the compounds with high molecular weight, 1000 or more.

   a) *Non-semantides*: These are the molecules not involved in information transfer. Examples are starches, celluloses, etc.

   b) *Semantides*: These are the information carrying molecules. Examples are DNA, RNA and proteins. Zuckerkandl & Pauling (1965) defined information-carrying molecules as *semantides*. They further classified the DNA (primary source of information) as *primary semantide*, RNA (secondary source of information) as *secondary semantide*, and proteins (translation of the code into sequences of amino acids) as *tertiary semantides*.

Accordingly, there are two broad areas of chemosystematics, namely, Micromolecular Systematics and Macromolecular Systematics.

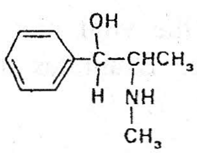
8.1.1. Micromolecular Systematics

Primary metabolites are the compounds involved in the vital metabolic pathways. These are ubiquitous and therefore of little taxonomic significance. Examples are Aconitic acid in *Aconitum* and citric acid in *Citrus*, which participate in Krebs cycle.

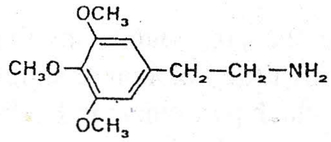
On the other hand, *secondary metabolites* perform non-vital functions and are less widespread. These are usually the byproducts of metabolism. These are of importance to the plant as they help in chemical defense against herbivores, pathogens, seed predators, etc. and help in pollination and dispersal. Examples are alkaloids, flavonoids, terpenes, non-protein amino acids, etc.

8.1.1.1 Amino acids. Amino acids are recognized as building units from which proteins are synthesized. Amino acids are known to occur in plant tissues since asparagine was isolated in 1806. Later, many amino acids were found when proteins were hydrolyzed. Examples are alanine, aspartic acid, cysteine, glutamine, glycine, methionine, etc. These are called *protein* amino acids. Ragan (1993) demonstrated the significance of amino acids in the numerical classification of *Cyperaceae.*

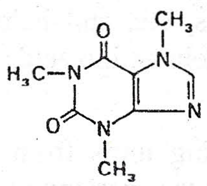
8.1.1.2 Alkaloids. No satisfactory definition of alkaloids exists even today since they do not constitute a natural group of materials in terms of source, structure or properties (Smith 1976). Alkaloids are organic, nitrogen containing bases, usually with a heterocyclic ring of some kind. While they are not essential to plant growth, they have effects on the central nervous system of animals. We have *true alkaloids* (related to amino acids and have heterocyclic ring), *protoalkaloids* (related to amino acids but without a heterocyclic ring) and *pseudoalkaloids* (biogenetically unrelated to amino acids). Examples are ephedrine (*Ephedra*), caffeine (*Coffea*), cocaine (*Erythroxylum*), nicotine (*Nicotiana*), quinine (*Cinchona*), etc. Furthermore, some alkaloids exhibit narrow distribution. Examples are morphine alkaloids found only in opium poppy (*Papaver somniferum*, *Papaveraceae*), coniine in a few *Apiaceae*, strychnine group in *Strychnos* (*Loganiaceae*), cocaine in *Erythroxylum* (*Erythroxylaceae*), etc. These alkaloids have been used since long as medicines, stimulants and drugs of abuse. Algae do not produce alkaloids. And the aquatic plants producing alkaloids bear aerial/floating leaves. So, alkaloids are important but specific to plant groups (Fig. 8.1).



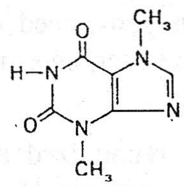
I Ephedrine



II Mescaline

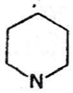


III Caffeine

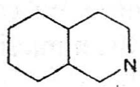


IV Theobromine

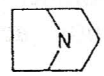
V Pyridine



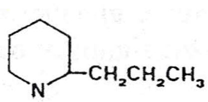
VI Piperidine



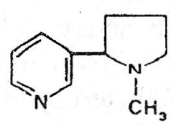
VII Isoquinoline



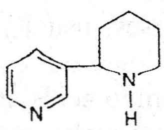
VIII Tropane



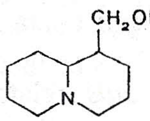
IX Coniine



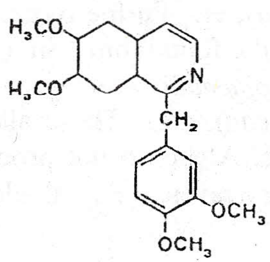
X Nicotine



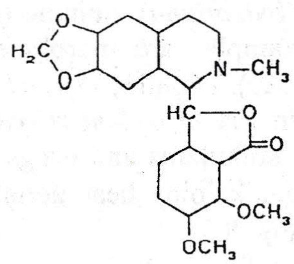
XI Anabasine



XII Lupinine



XIII Papaverine



XIV Hydrastine

Fig. 8.1 Structure of select alkaloids.

8.1.1.3 Flavonoids. Flavonoids comprise a set of biosynthetically related compounds that occupy an important position amongst the plant constituents as taxonomic markers. Examples are chalcones, cyanidin, delphinidin, luteolin, myricetin, tricin, etc. They are widely distributed, show much structural variation, and stable enough to be detected even in herbarium specimens besides they are easily and quickly identifiable (Harborne 1967). Gornall *et al.* (1979) made a survey of the distribution of flavonoids in the *Magnoliophyta*, in the light of its classification by Dahlgren. They made several general observations. To mention some of them here: (i) Many flavonoids types are highly scattered. (ii) Many *Liliopsida* show flavonoids patterns different from those of *Magnoliopsida*, and (iii) *Caryophylliflorae* is distinct among polypetalous group in often wanting myricetin and also proanthocyanidins, which are otherwise common. This *superorder* is unique in possessing betalains.

8.1.1.4 Betalains. A most striking example concerns the red and yellow pigments called *betacyanins* and *betaxanthins*. These are structurally related and occur only in certain *Magnoliopsida*. The synthetic pathway of betalains is very different from that of the anthocyanidins, and other flavonoids It is interesting to note that betalian-bearing families lack anthocyanins. Betalains are known from about 10 families that are traditionally included in a single order *Centrospermae*. Of these, *Cactaceae* have a critical taxonomic history, and are often being placed in a separate order, *Opuntiales* or *Cactales*.

Table 8.1 Chemical classification of Centrospermae.

Classification		
Structural	**Chemical**	**Compromise**
		Caryophyllidae
Centrospermae	**Chenopodiales**	**Chenopodiales**
Chenopodiaceae	Aizoaceae	Aizoaceae
Amaranthaceae	Amaranthaceae	Amaranthaceae
Nyctaginaceae	Basellaceae	Basellaceae
Phytolaccaceae	Cactaceae	Cactaceae
Gyrostemonaceae	Chenopodiaceae	Chenopodiaceae
Aizoaceae	Didiereaceae	Didiereaceae
Portulacaceae	Nyctaginaceae	Nyctaginaceae
Basellaceae	Phytolaccaceae	Phytolaccaceae
Caryophyllaceae*	Portulacaceae	Portulacaceae
Molluginaceae*		
Cactales		
Cactaceae		

		----------Sapindales
Caryophyllales	**Caryophyllales**	
Didiereaceae	Caryophyllaceae* Molluginaceae*	Caryophyllaceae* Molluginaceae*

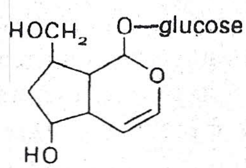
*Anthocyanin-bearing families.

The above case clearly demonstrates the use of chemical characters for a better and more natural classification of the traditional *Centrospermae*. Pollen morphology (Nowicke 1975) and sieve-element plastids (Behnke 1976) support the above chemically revised compromise classification.

8.1.1.5 Terpenoids and Steroids. Natural terpenoids and steroids resemble the alkaloids in being diverse and for want of obvious demarcation from the other kinds of compounds. Terpenoids, in general, are regarded as the components of essential oils. They are categorized as hemi-, mono-, di-, tri-, tetra-, poly- and sesquiterpenoids. True steroids are mostly alcohols or esters. Chemical races, with underlying genetic differences, were demonstrated for turpentines in *Pinus* and *Eucalyptus*. For example, *Pinus jeffreyi* has been treated as a variety of *P. ponderosa*. The turpentine distribution shows that it has strong affinity with the group **Microcarpae**, not the group **Australes,** to which *P. ponderosa* pertains (Mirov 1961).

Bate-Smith & Swain (1966) reviewed the possible taxonomic value of monterpenoid cyclopentanoid lalcones, known as *iridoids*. Of these, asperuloside is common to *Rubiaceae*, aucubin to *Buddleiaceae*, *Cornaceae*, *Scropulariaceae* and *Orobanchaceae* (Fig. 8.2). Why the twigs from the above families turn black, as herbarium specimens? It is due to the fact that, on hydrolysis, aucubin forms a black precipitate, which may cause the darkening. *Buddleia*, which contains aucubin, was removed from *Loganiaceae* to *Buddleiaceae*, a position near the *Scrophulariaceae.*

Sesquiterpene lactones are another group of bitter tasting toxic principles found rare, except in *Asteraceae*. Lactucin and lactucopikrin are the typical bitter principles in the family. The distribution of different sesquiterpene lactones and their specificity in 13 tribes of *Asteraceae* was demonstrated by Herout & Šorm (1969).



XXIII Aucubin

Fig. 8.2 Structure of aucubin

8.1.1.5 Non-protein Amino acids. There are *non-protein* amino acids in plants, which are far more ubiquitous and structurally diverse though patchier in distribution. The discontinuous distribution of non-protein amino acids attracts the attention of a taxonomist. For example, canavanine, which occurs in *Canavalia* of *Fabaceae*, is not found outside the subfamily *Faboideae*. Another, lathyrine, is so far found only within the genus *Lathyrus*.

8.1.2 Macromolecular Systematics

8.1.2.1 Non-semantides. These are the complex polysaccharides such as starches that are commonly found in the forms of grains. These are not involved in information transfer. Examples are the concentric grains of maize and eccentric grains of potato, which can be observed under a microscope (LM, SEM and TEM). The diagnostic nature of these has been demonstrated in all classical books of anatomy.

8.1.2.2 Semantides.

8.1.2.2.1 Serology. The study of origins and properties of antisera is termed *serology*. The phenomenon of immunity was long recognized in connection with long-lasting resistance of human to infections by disease-causing bacteria from whose attack they had earlier suffered. Kraus, in 1897, showed that foreign blood serum could be antigenic. Immune blood sera may be used as reagents to identify antigens similar to those involved in the production of immunity.

The technique of serology is based on the immunological reactions shown by mammals when invaded by foreign proteins. The animal develops antibodies, each specific to an antigen with which it forms a precipitin reaction. The first reaction (control) is called *homologous* (standard or reference) reaction and the rest (compared) as *heterologous* reactions. It was quickly realized that the specific antigen-antibody reactions provide a unique method of molecular recognition. Soon, serology was realized as a technique offering insight into the evolutionary relationships, i.e. the phylogeny of the organisms studied, rather than as an aid to classification *per se* (Smith 1976). Germany supported several outstanding schools of serotaxonomic research (e.g. School at Koeningsberg). Kolz (1971) studied the serology of Fabaceae. He gives the glossary of terms used in serology.

8.1.2.2.2 Electrophoresis. Nowadays, the individual antigen-antibody reactions can be recorded separately by allowing the antigenic material and antiserum to diffuse towards one another in a gel. As different proteins travel at different rates, different reactions occur at different positions in a gel. It is called *double-diffusion serology*. Otherwise, the antigens are separated unidimensionally in a gel by electrophoresis, and then allowing them to diffuse towards a trough of antiserum (Fig. 8. 3). This method is called *immuno-electrophoresis*. The advantage with the first method over the second is that the precipitation reactions of several different antigen mixtures to a given antiserum can be observed simultaneously on a single gel, though the separation of constituent reactions is better with the second method. Hybrids of *Phaseolus vulgaris* x *P. coccineus* have been identified by immuno-electrophoresis and it was found that the F_1 plants showed complementation of the precipitate bands of the parents.

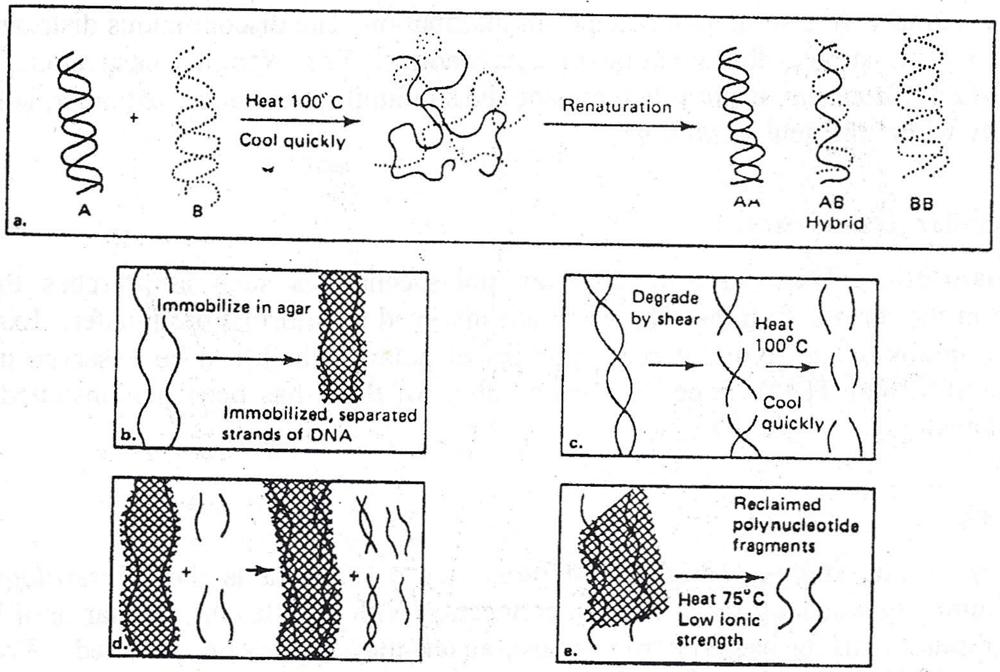


Fig. 8.3 Protein separation techniques.

(a) Principle of DNA hybridization technique; (b-e): Schematic representation of DNA – agar procedure.

Jensen (1968) studied the intergeneric relationships of *Ranunculaceae*. The proteins extracts (antigens) from the mature seed of 20 genera were injected intraperitoneally into rabbits. He used a number of techniques like Boyden procedure, immuno-diffusion and absorption, to reveal the relationships as depicted in Fig. 8.4.

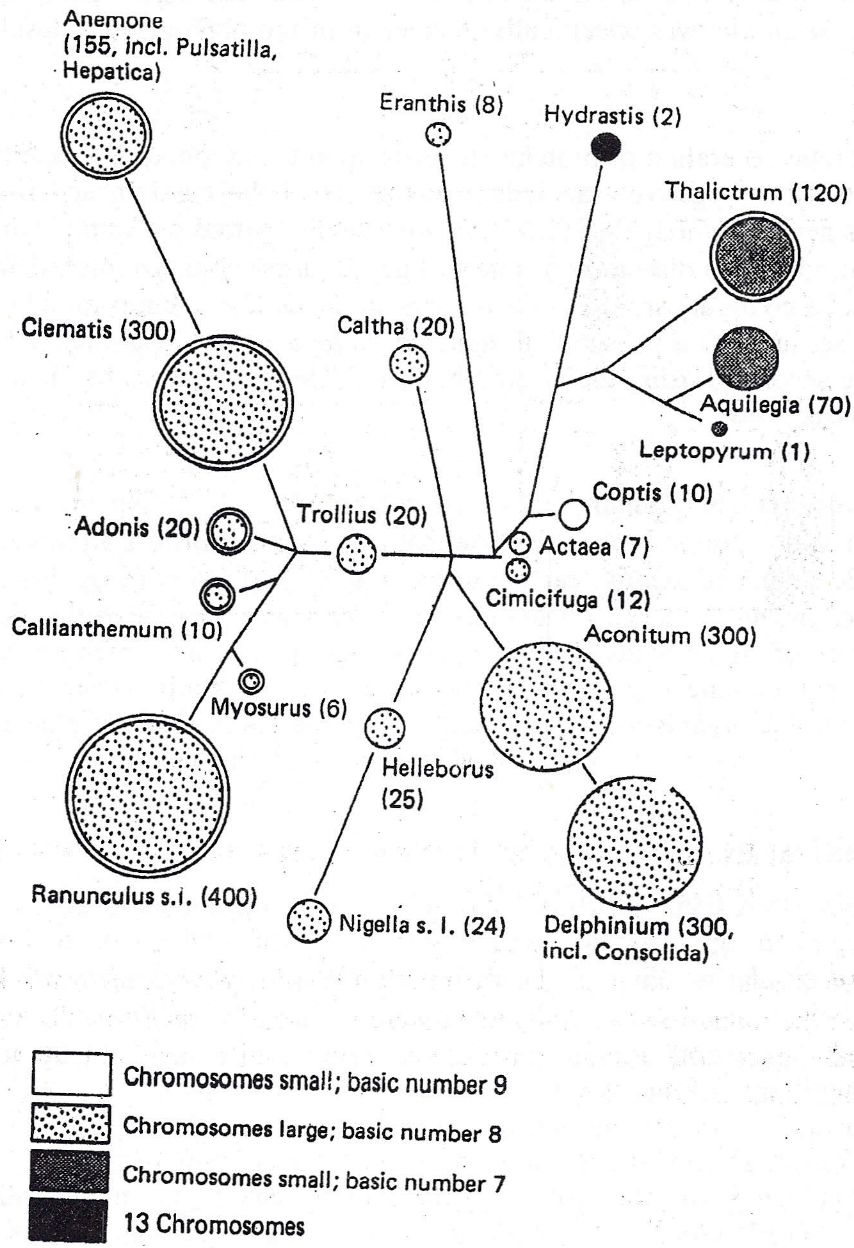


Fig. 8.4 Relationships among the genera of *Ranunculaceae* based on serological evidence.

The application of serological methods in a critical taxonomic group like *Bromus* (Smith 1972) was productive. Earlier, based on anomalous serological reactions, Smith (1968) established that *Bromus pseudosecalinus* was specifically distinct from morphologically closely similar species, *B. secalinus*.

Electrophoretic separation of proteins depends upon the amphoteric properties whereby they are charged positively or negatively according to the pH of the medium and travel through a gel at various speeds across a voltage gradient. This is usually carried out in acrylamide gel. The column may be composed of two discontinuous gels (a gel of larger pore size placed above a gel of smaller pore size) placed contiguously (*disc electrophoresis*). Or the column may be with a gel of single pore size and set up with a pH gradient (*isoelectric focusing*). Closely related storage proteins and enzymes ca be separated using the electrophoresis. The research has resulted in the recognition of *allozymes* and *isozymes*.

8.1.2.2.3 Amino acid Sequencing. It is a more modern development, aiming to identify pure proteins down to the atomic level. It is now possible to break off the amino acids one by one from the polypeptide chain and identify each in turn chromatographically (*fingerprinting*). Then, build up stepwise the complete sequence of amino acids. This technique investigates the variation in the precise sequence of amino acids in a single homologous protein through out a range of organisms. For example, cytochrome c is an ideal molecule as it is relatively small, stable, coloured and ubiquitous in aerobic organisms. It sequencing in 25 species of vascular plants has been determined (Boulter 1974).

8.1.2.2.4 Nucleic Acids

8.1.2.2.4.1 DNA/DNA Hybridization. The ability of the nucleic acids to form 'molecular hybrids' by base pairing opens up a vast, new and exciting field which allows us to make direct estimates of overall generic similarity. First, in brief, the strands of DNA extracted from one organism are untwined to form a single-strand polynuleotide chain and then allowed to hybridize *in vitro* with DNA extracted from another organism. The amount of re-association (*annealing*) is taken as a measure of similarity of nucleotide sequence (Fig. 8.5). The homologies between them are expressed quantitatively by measuring their absorption in UV. In *Cucurbita*, DNA/DNA hybridization results showed that *C. palmata* is most distinctly related of the taxa compared. It is a xerophyte. The xerophytic cucurbits are genetically isolated and in the distribution of cucurbitacin and fatty acids. The DNAs of *C. lundelliana*, *C. pepo* and *C. maxima* are similar (Goldberg *et al.* 1972). Earlier, Whitaker & Bemis (1965) believed that *C. lundelliana* is a progenitor of the above two species.

8.1.2.2.4.2 DNA/RNA Hybridization. In this technique, the RNA is hybridized with the complementary DNA of related plants. Mabry (1976) used this technique in *Centrospermae*, concluding that the anthocyanin-bearing *Caryophyllaceae* and *Molluginaceae* are close to betalain families though different. *Bataceae*, with the absence of betalains and p-type sieve-element plastids the presence of glucosinolates, are a distinct family and not really centrospermous (Fig. 8. 5).

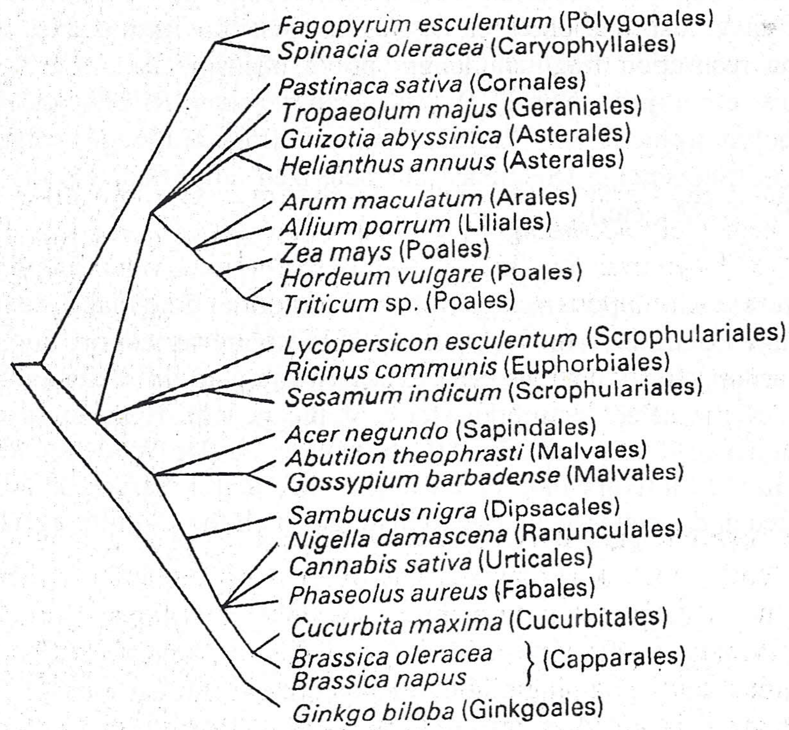


Fig. 8.5 16S r-RNA homologies in plants.

8.1.2.2.4.3 Protoplast Hybridization. It is also a good taxonomic tool where genetic incompatibility is a major problem. Protoplast or Somatic cell hybridization is a process in which genomes of two somatic cells are combined *in vitro* into a single nucleus in a single hybrid cell which is capable of long-term proliferation (Levin 1975). The genomes of both parental cells continue to function in the hybrids, and in most instances the genomes of the two parental cells are retained essentially complete in the hybrids. Carlson *et al.* (1972) succeed in mixing the protoplasts of *Nicotiana glauca* and *N. langsdorfii* and obtained flowering hybrids that were identical with the sexual hybrids. Protoplast fusion was made possible between *Glycine* x *Vicia*, *Petunia* x *Nicotiana*, etc.

8.1.2.2.3. Molecular Markers. A marker must be *polymorphic*, i.e. it must exist in different forms so that the chromosome carrying the mutant gene chromosome can be distinguished from the chromosome with normal gene. The polymorphism in the marker can be detected at three levels: morphological (differences in phenotype), biochemical (differences in proteins) and molecular (differences in the nucleotide sequence of DNA). A *molecular marker* is a DNA sequence that is readily detected and whose inheritance can be simply monitored. Genetic polymorphism is defined as simultaneous occurrence of a trait in the same population, or two or more discontinuous genotypes ariants.

A marker must be evenly and frequently distributed throughout the genome. The experimental procedure should be easy, fast, and cheap to detect. It must be reproducible. The first such DNA marker used was the restriction fragment length polymorphism (RFLP). Now, there are three approaches/techniques employed: Non-PCR based approaches RFLP), PCR-based techniques (Random amplified polymorphic DNA – RAPD; Amplified fragment length polymorphism – AFLP), and Targeted PCR and Sequencing (Sequence characterized amplified region – SCARs, sequence tagged microsatellites – STMs, etc.).

Ficus carica (anjure) is an important dry fruit crop with great potential for export and possibilies for cultivation in many countries. In Turkey, which is having an export business of millions of dollors, grows 11 Sarilop clones and the Sarizeybeck variety in different agroclimatic zones. To improve the quality of the select ones, the study of the genetic relatedness of these was made employing the techniques of RAPD and AFLP (Cabrita *et al.* 2001). While the RAPD markers could help to distinguish the 12 cultivars into 11 Sarilop clones and 1 Sarizeybeck variety, AFLP was found to be more suited and a better technique to distinguish all the 12 cultivars (Fig. 8.6).

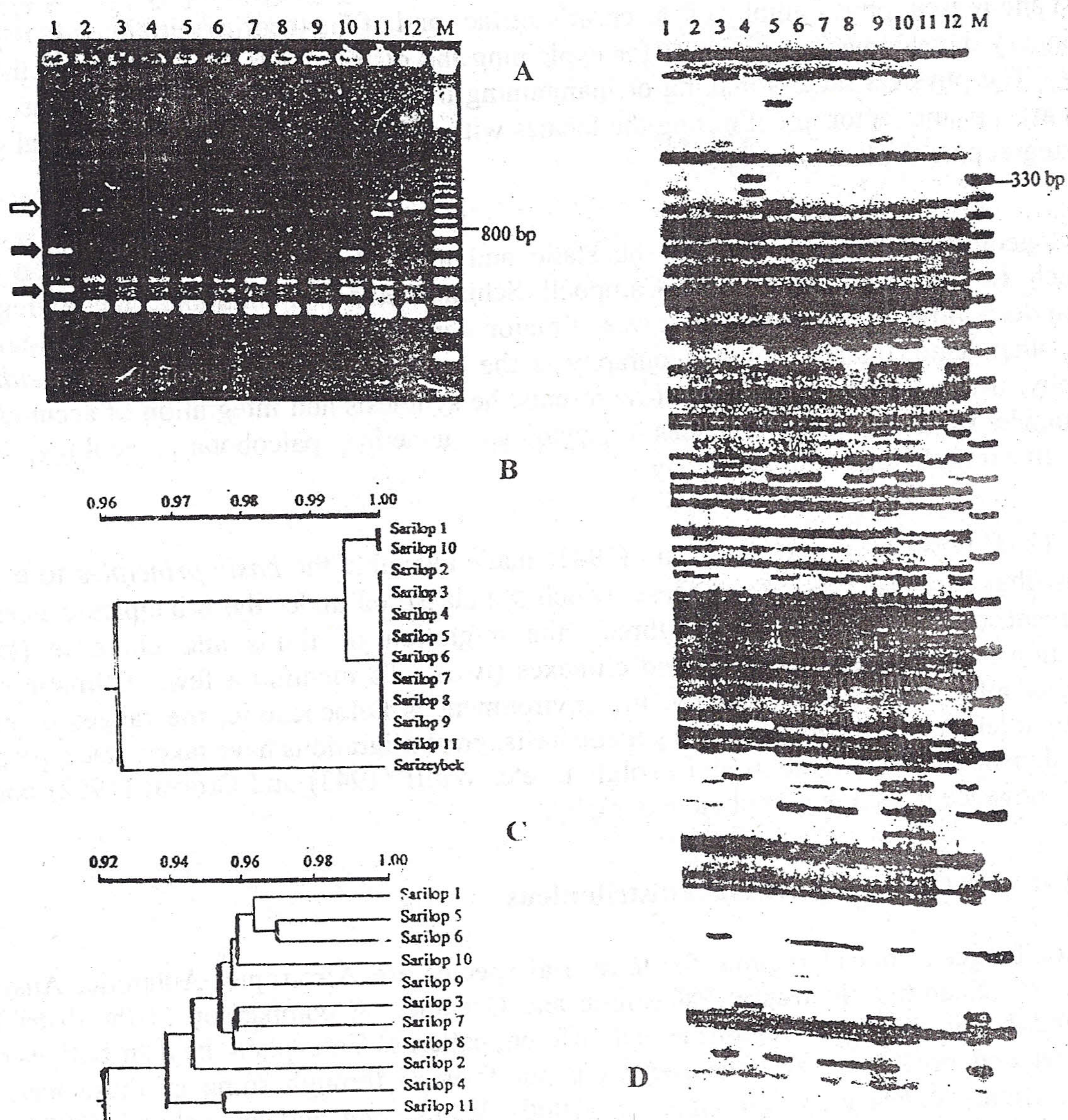


Fig. 8.6 Genetic relatedness phenogram generated by UPGMA method on the basis of RAPD and AFLP data. (A, B – RAPD: C, D – AFLP).

8.1 PHYTOGEOGRAPHY

The study of the geographical distribution of plants is called *phytogeography*. The appreciation of the past and present physiography of the earth's surface and of the theories pertaining to its presumed evolutionary development is essential for explaining the distributions of the plants in the past and present. The physical factors making or maintaining the continents, oceans, mountains, rivers and deserts are a prime factor in delimiting the locales within the biosphere. So, the physical geography is an integral part of plant geography.

Phytogeography has two phases, the static and the dynamic. Pioneered by the works of Grisebach, Engler, Drude, Raunkiaer, Campbell, Schimper and von Humboldt, the phytogeography has been descriptive in nature though it was of major significance to taxonomic and ecologic studies. On the other hand, dynamic phytogeography is the other means of denoting *interpretative* plant geography. It is a borderline science. It represents the synthesis and integration of accumulated and ascertainable facts of allied sciences of cytology, genetics, paleobotany, ecology, evolution, comparative morphology and phylogeny.

Good (1931), Mason (1936) and Cain (1941) made available the *basic principles* to explain the plant distributions. They are 13 of these, which are classified under the principles concerning the environment (six), plant responses (three), the migration of floras and climaxes (two), and perpetuation and evolution of floras and climaxes (two). To mention a few: Climatic control is primary, edaphic control is secondary, the environment is holocoenotic, the ranges of plants are limited by tolerances, tolerances have a genetic basis, great migrations have taken place, perpetuation of flora depends upon migration and evolution, etc. Wulff (1943) and Croizat (1952) contributed further to advance the subject of phytogeography.

8.2.1 Theories explaining the Plant distributions

The major biogeographical regions for terrestrial species are Afrotropic, Antarctic, Australasian, Indomalayan, Nearctic, Neotropic, Palaearctic and Oceanic. A comparison of the distribution of biomes and the biogeographic regions reveal different patterns. To explain the distributions of plants in the past and present several theories were put forward through some of these were proved incorrect. Guppy's *theory of differentiation* (1906), Willis' *age and area theory* (1922), Good's *theory of tolerance* (1931) are important. Wegener's *theory of continental drift* (1915), and the *theory of plate tectonics* (Wilson 1965; McKenzie & Parker 1967), etc. could profoundly influence the subject of biogeography. The phenomena like adaptive radiation, discontinuous distribution, endemism, migrations, and senescence also help to explain the plant distributions. Some of these aspects have already been dealt at length in Lesson 3 Unit I of this book.

8.2.2 Evolutionary Biogeography

Speciation occurs both on continents (*continental speciation*) and islands (*insular speciation*). These are linked to particular degrees of taxonomic differentiation. The greatest differentiations may be interpreted as stages of speciation. Continental speciation may be ascribed to different causes and will accordingly be qualified with a particular adjective (Bush 1975). They are called *allopatric* if they are the consequences of geographical isolation. Continental speciations are *sympatric* if they result from an isolating mechanism within a population of a given circumscribed area, without involving either a physical obstacle or distance. A third type of continental speciation might exist and stand in an intermediate situation, e.g. *stasipatric* or *parapatric* speciation (Salomon 2001). Insular speciation may describe the differentiations at work between a population settled in an island and the continental population from which the former stems – a situation termed as 'island and continent model' (Jacquard 1974). It may also portray the differentiation at work across time between the populations of the different islands of an archipelago. In it, the populations in question stem from a continental taxon that had formerly invaded one island of that archipelago; the descendents of the latter subsequently invade the other islands of the archipelago. This situation is termed 'archipelago model' (Wright 1940; Hudson 1988). It is assumed that insular speciation develops in successive stages: (i) settlement, (ii) colonization, and (iii) genetic divergence (Penny 1989). So, the success of insular speciation implies success at each of these three stages.

8.2.3 Endemism

It is a situation that is comprised of an element having one restricted region or area of distribution. As recognized by a phytogeographer and taxonomist, there are two types of endemism. Accordingly, we have elements (young infraspecific taxa, species or genera), which may not yet have attained their maximum area of spread as determined by their dispersal barriers. These are called *autochthonous endemics* (known as secondary, progressive or neoendemics). There are old or relic elements, which now occupy contracting and much smaller areas than before; these are the elements that are surviving but not contributing to the evolution of flora. These are called *epibiotics* (relics, palaeoendemics or conservative endemics). Endemics occupy taxonomically isolated positions. In Canary Islands, high proportions of endemics are diploids and are described as paleoendemics in the classical and cytological sense. On the other hand, several endemic genera (*Bencomia*, *Isoplexis*, etc.) of Macronesia are polyploids with no diploid relatives in the nearby regions. As per Favarger (1967), these are to be called palaeopolyploids.

In Andhra Pradesh, we have endemic taxa like *Cycas beddomei* (*Cycadaceae*) in Chittoor and Cuddapah, *Andrographis nallamalayana* (Acanthaceae) in Cuddapah and Kurnool, *Argyreia arakuensis* (*Convolvulaceae*) in Visakhapatnam, *Pimpinella tirupatensis* (*Apiaceae*) in Chittoor, *Cleome viscosa* var. *nagarjunakondensis* (*Cleomaceae*) and *Crotalaria paniculata* var. *nagarjunakondensis* (*Fabaceae*) in Nalgonda district, etc. All these and many other endemic plant taxa are either palaeo- or neoendemics, but confined to distinct phytogeographic zones within the state of Andhra Pradesh. The genus *Jatropha* of *Euphorbiaceae* (Raju & E.S.Rao 2004) with its endemic species likes *J. maheshwarii, J tanjorensis, J. tuberosa* and *J. wightiana*, is a good example to cleave the peninsular India into different phytogeographic regions. Besides, we have *Pterocarpus santalinus*, confined to Cuddapah basin.

8.2.4 Geographic Distribution of Plant Families

Thorne (1992) has estimated the number of families and subfamilies in *Magnoliophyta* as 437 (351 for *Magnoliopsida* and 86 for *Liliopsida*) and 400 (313 for *Magnoliopsida* and 87 for *Liliopsida*), respectively. These may be compared to the endemic families and subfamilies, which are endemic to different phytogeographic regions of the world (Table 8.1).

Table 8.2 Families and subfamilies of *Magnoliophyta* with limited distribution.

Major Geographic Units	Endemic Families	Endemic Subfamilies	Total*
1. Africa	21	18	38
2. South America	20	16	36
3. Asia (excl. Malesia)	17	10	26
4. Australia	14	16	30
5. North America	10	07	17
6. Madagascar	07	05	11
7. New Caledonia	05	00	05
8. Malesia (to Fiji)	02	00	02
9. Indian Ocean	01	01	02
10. Pacific Basin	01	00	01
Totals :	98	73	168

* Total families and additional subfamilies. (Data as per Thorne 1992)

Hydatellaceae, with two genera, are endemic to Australia and New Zealand. *Trithuria konkanensis*, the new species described from peninsular India (Yadav & Janardhanam (1994) connects it (Australasia) phytogeographically.

8.2. Phytogeography and Classification

A much-neglected approach to the phylogeny of *Magnoliophyta* is phytogeography. As demonstrated by Thorne (1989), useful clues to familial relationships can sometimes be obtained from the past and present distribution of taxa. Recently, Krutzsch (1989) analyzed a dozen phyletically important groups of *Magnoliophyta*. As a result of the study it is obvious that the present distributions of the plant taxa like *Alangium*, *Nepenthes*, *Nypha* and *Restionaceae* are not indicative of the past distributions. Similarly, many other *Cycadophyta* known from the fossil record in India no longer occur on the subcontinent. Numerous taxa have become extinct from Africa, presumably in Neogene time due to catastrophic climatic changes.

Thorne (1992) was perhaps the first to discuss the geography and classification of the *Magnoliophyta*. Phytogeographic explorations are still turning up numerous new species, genera and occasionally new families. These new taxa fill in phyletic gaps or otherwise clarify phylogenetic or phytogeographic problems. Examples are *Acanthogilla* (*Polemoniaceae*) from Baja California, *Anacampseros* (*Portulacaceae*) from Argentina, *Faika* and *Parakibara* (*Monimiaceae*) from Malesia, etc. We have four endemic species of *Jatropha* occurring in Peninsular India (Indian plate): *J. nana* occurs only in Deccan traps region near Pune, *J. tuberose* is confined to Darwar and Singhabhum cratons, *J. wightiana* is limited to southern granulite terrain in Tamil Nadu, and *J. maheshwarii* is restricted to southeastern coastal plains (Kanyakumari) in Tamil Nadu (V.S. Raju & E.S. Rao 2004).

Model Questions

a) Essay type:

1. Inscribe an essay on chemotaxonomy.
2. Write an account of macromolecular systematics.
3. Give a succinct report of micromolecular systematics.
4. Describe the role of phytogeography in taxonomy.

b) Short type:

Amino acids, Alkaloids, Flavonoids, Betalains, Terpenoids and steroids, Non-protein amino acids, Non-semantides, Semantides, Serology, Electrophoresis, Amino acid sequencing, Nucleic acids, DNA/DNA hybridization, DNA/RNA hybridization, Protoplast hybridization, Molecular markers, Insular speciation, Endemism.

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Lesson - 9

TAXONOMY IN THE SERVICE OF MAN

"Taxonomy is often thought of as a purely academic or even superficial subject of little relevance to the urgent needs of modern man. Such a view is far from truth, for plant taxonomists have an important role to play in man's betterment" (Stace 1980). The revival of taxonomy as a most relevant and current priority is at the very basis of the concept of Diversitas (de Castri and Younes 1996). The word diversitas here means Biological diversity (equals the concept of Variation pattern) which is now considered as an Index of a Nation's wealth. The exploration, inventory preparation , distinction between utility and non-utility biological diversity is a fundamental duty of a taxonomist. In 1992 Convention of Biological Diversity it has been cited affirming that the conservation of biological diversity is a common concern of human kind. A paragraph in preamble mentions "..... states have sovereign rights over their own biological resources. These are an integral and most valued segments of a Nation's property". It was held that land, gold, money, diamonds etc. are priority properties of a Nation. But it is clear even from history and current global understanding that Phytodiversity (plant diversity), the present concern of this chapter, is treated as a valuable property of a Nation. It is presently conveyed to the students that biodiversity study is an allotropic modification of taxonomic study. The treatment may also look like Botany in the service of man and if so, it will be doubly justified as the science of Botany had its beginnings of search for plants useful for food, clothing, shelter, drugs and Barter trade or otherwise. The evolution of trade is from barter through cash, or jewelry exchange or the proposals through GATT(general agreement in trade and tariff) and then Dunkel draft, and as on date the WTO (World trade organization), which all became a matter of all media. It is to be understood that the explanation of the virtually synonymous terms, Variation and Diversity are gene-based.
Trade linked biodiversity knowledge is the need of the hour for taxonomists.

The resurgence of serious taxonomic study is equal to the basic study of our phytodiversitry analysis. As is well known taxonomic study is at the molecular, micro and macro levels, the biodiversity analysis too is concerned with genes, species and ecosystems – a triology approach.

Misunderstanding is responsible for referring to taxonomy by some as Tax-on-me. This emphasizes the need for eliminating taxonomic illiteracy. If understood correctly and practiced well it becomes the basis of additional income or a profession or awards status of a consultant. Nair (2004) mentioned "Taxonomy ought to be an area of focus but neglected due to ignorance about its importance in achieving the hopes and aspirations of the people". He further commented that taxonomy is an integral part in terms of biodiversity protection, remediation, ecodevelopment, product development and quality evaluation. Taxonomy is significant in areas of forestry, social forestry, agroforestry, agrotechnology, pollution control (phytoremediation), ecotourism, landscape development, aesthetics, and several areas with relevance to human needs. Hariharan and Balaji (2002) from MS Swaminathan Research Institute stressed the need for synthesis of taxonomy, biodiversity and biotechnology and mentioned " Let us be optimistic in achieving a complete inventory of our biological wealth by eliminating our lacunae and reorienting ourselves towards the goal."

Taxonomic analysis of species also takes place from an ecological angle in diversity and vegetation studies in varied environmental conditions to settle the most value-returning population sample of a species (Sagar et al. 2003). Enriched taxonomic literacy is the need of the hour.

Taxonomy deals with mainly identification of plants among other aspects. The identification is the basic function for further exploration of the species. Identification is as important as the knowledge of alphabet a,b,c,d, etc. Without knowing alphabet it is impossible to progress in any language. Botanists are hesitant to develop expertise in the art of naming and field identification. Pursuing systematic studies on any species is only after correct identification and authentication of nomenclature. It is often said "What is in a name?" Everything starts with name only just as the name of a human being is primary requisite for his identification, certificates, rank, career, accounts, passport etc. The name should also be supported by a photograph the equivalent of which is a herbarium sheet for plants. Correct identification, nomenclature, herbarium preparation are indispensable functions of a taxonomist as important as knowing alphabet of a language. Is it feasible to claim expertise without fundamentals?

The teachers and students of taxonomy in the beginning were often shocked that modern taxonomic books dealt with the biological species concept, sub specific categories, interrelationships with ecology, genetics, evolution, molecular biology and phylogeny, relevance of numerical analysis and also the use of biotechnology skills in conservation and sustainability of the utility biodiversity as well as endangered non utility biodiversity.

Hi-story of taxonomy

It is clear that the evolution of taxonomy itself has several phases.

1. The pioneer phase or exploratory phase
2. The consolidation phase
3. The biosystematic phase
4. The encyclopaedic phase

Turril referred to 1 & 2 as Alpha taxonomy and 3 & 4 as Ömega taxonomy. All are aware of the scope and service rendered by Alpha taxonomy. If the depth, truth, technology and purpose of each one of these are appreciated – the role of Omega taxonomy proves its overpowering share in services rendered by the same. For a hi-story of taxonomy, any text book on taxonomy need to be consulted as additional reading material apart from what is given in this textbook (works of Lawrence, Heslop Harrison, Lyman Benson, Cronquist, Takhtajan, Porter, Davis and Heywood, Pullaiah, Radhakrishnaiah, Naik to cite a few. Presently it is contended that ALPHA taxonomy (from A to M) and OMEGA taxonomy (from N to Z) indicate the holistic scope of the subject.

ALPHA: means classical taxonomy, age of herbals, identification, nomenclature, preparation of floras, monographs, revisions, distribution, phytogeography, history of endemism, ecological life cycles, reproductive biology, analysis of natural biodiversity, macro propagation and classical conservation technology- dealing with species as the basic unit of taxonomy and embraces study from Species and above categories.

OMEGA: deals with individual and local population as the taxonomic unit and works out evolution and differentiation from population and above, virtually treating SPECIES as the top category. This is an integral approach in biological species concept, definition of species based on the potential limits to exchange genes, genecology, gene mutations, impact of range of variation and evolution, adaptive radiation, recognition of varieties, races, cultivars, ecads, ecotypes, coenospecies, comparium or category of subspecies and finally species, analysis of principles of incidence of hybridization, sympatry, allopatry, role of chromosomes, polyploidy, aneuploidy, haploidy, trisomics, nullisomics, experimental taxonomy and so on. Students ought to get in touch with the book "Stages in the Evolution of Plant Species" by Clausen, Keck and Hiesey who summarised experiments covering a quarter of a century. The work is also known as " The Californian Transect Experiments" a result of hard work of multidisciplinary manpower. Later to follow are the technology of instant speciation, manipulation of genes, recombinant DNA technology and other recent Biotechnological designing of " transcendental biodiversity" and anthropogenic variation. The recombinant DNA occurs in nature as a result of gametic fusion in sexual reproduction but the artificial recombinant DNA technology is named as Biotechnogical device which is an artificial one. These explain the scope of modern taxonomy imbibing all bioadvances in achieving newer and newer variation and evolution results all to the advantage of mankind in obtaining Green revolution, evergreen revolution, white revolution (milk) blue revolution (fish aquaculture), blue green revolution (of prokaryotic blue green algae, such as *Spirullina*, as a source of protein, and antioxidants), white gold revolution(cotton), green gold revolution (timber), gene revolution(may be called as super green revolution, of transgenics, gene banks, design of GEMs ie genetically engineered microorganisms and manipulation of higher plants including rice and other crops).

In all these instances sound taxonomic knowledge helps WHERE TO START? This explains the need to understand that taxonomy is a synthetic science and also a highly applied science. It is relevant to recall a great work by Chris Park (1997, p 461):- Why conserve wild life? To maintain essential ecological processes and life support systems, to preserve genetic diversity which is being dangerously impoverished, to ensure sustainable use by us and our children of species and ecosystems. Saving world heritage sites evolved as a responsibility of environmental taxonomist. Students are advised to refer IUCN since 1973 in CITES ie Consortium on International trade of Endangered Species. Chris Park described fundamentals immediately followed by applied aspects in each chapter. It is common knowledge that fundamental Sciences are fore runners of applied sciences. For instance: Botany is the father of Agriculture, Forestry, Herbal therapy, Horticulture, Sylviculture, Floriculture, preparation of a pollen atlas of a leading tourist destination to help tourists to avoid allergens and so on. This is universally accepted and uncontroversial. The emerging plant biotechnology also is an offspring of Botany with applied values and it is hence started as B.Tech Biotecnology- in several Engineering colleges, not to speak of its start in recent graduate, post graduate institutions and Universities. Mathematicians, computer software specialists, statisticians, biochemists, phytochemists formed a team in strengthening this field extremely relevant to a taxonomist.

Fundamental knowledge of taxonomy reinforces advances in this subject. Please think twice or more to appreciate this view point which signifies role of Taxonomy in the service of man. Bright ideas emerge in support of this convincing version which itself is taxonomic literacy.

Taxonomy, biodiversity and Biotechnology

Just as taxonomy has been classified into four phases, it is presently attempted to give taxonomy of phases of Biodiversity and their respective scope. This is an attempt made by the present author.

Taxonomy of phases of Biodiversity:

ALPHA : Species richness in homogeneous habitat.

BETA: Range of diversity across a gradient, measure of replacement or turn over of species.

GAMMA: Overall diversity within a larger region- community diversity in heterogeneous habitat.

OMEGA: Infraspecific/interspecific and inter/intra population variation- linked with biological species concept & biosystematics, super biodiversity, artificial biodiversity, synthetic biodiversity, anthropogenic

9)

biodiversity, transgenic and other biotechnologically introduced instant biodiversity and genetically engineered biodiversity. These manmade aspects defy traditional/basic taxonomic principles of nomenclature and classification and are designated as Transcendental biodiversity. Dealing with its taxonomy is a challenging problem and their status allotment leads to a new discipline of transcendental or ultra OMEGA taxonomy.
Let us recall the explanation of Pratibha et al (2004) about biodiversity though Jutro gave 14 definitions to the same. It means the availability among living organisms from all sources and the ecological complexes of which they are a part and includes diversity within species or between species and of ecosystems . It also referred to the following:

NBA: National biodiversity Act
SBB: State biodiversity boards
BMC: Biodiversity management committees

Further significant topics of taxonomic relevance of NBA are also included for students reference:
Benefit claimers: means the conservers of biological resources, their byproducts, creators, holders of knowledge and information relating to the use of such bioresources, innovations and practices associated with such use and application.
Biological resources: means plants, animals, and microorganisms or parts thereof, thie genetic material and byproducts with actual or potential use or value but does not include human genetic material.
Biosurvey and bioutilization: means survey or collection of species, subspecies, genes, components, and extracts of bioresources for any purpose and characterization inventorization and bioassay.
Equitable benefit sharing: as per section 21 of NBA- sustainable use of components of biodiversity in such manner an such rate that does not lead to the term decline of biological diversity maintaining its potential to meet the needs and aspirations of present and future generations.

For the general convenience and motivation of the students, for a ready reference , taxonomy of phases in Biotechnology also are given here as designed by the author.
The attempt is to illustrate the interrelationship of taxonomy, biodiversity and biotechnolgy especially at the genetic and molecular level.

Taxonomy of the phases in Biotechnology: (on a par with biodiversity)

ALPHA: Fermentation, formation of curd and cheese, vinegar

BETA: Conventional agricultural practices for food, clothing, shelter, medicine
Musical instruments, play goods , manipulation by breeding better culltivars, and cellulose products

GAMMA: All above manipulated by human advancement in Science and Technology, urge for betterment +; advanced practices of hybridization, improved agronomic targets, vaccination, artificial cultures, seedless fruits, antibiotics, plant and animal protection technologies, cloning of desired cultivars, vegetative propagation etc.

OMEGA: Plant and animal transformation, transgenic plants, enzyme immobilization, organelle implantation, recombinant DNA technology, modern genetic engineering, immuno biotechnology, drug designing and so on. These lead to origin of SUPER SPECIES, ARTIFICIAL SPECIES, or in other words OMEGA BIOTECHNOLOGY implies TRANSCENDENTAL BIODIVERSITY OR MOLECULAR TAXONOMY. The time consuming principles of natural evolution are surpassed. It is instant evolution with origin of new taxa, taxonomy of which is essential to make the biotech advances more significant leading to conservation of biodiversity as gene banks, gene pools, DNA storage process and also leading to DNA fingerprinting in identifying relationships and hence it is biotechnological taxonomy. It is already a matter of common knowledge but taxonomists are to be informed that it is ultramodern taxonomy giving phylogenetic hi-stories of genetically engineered taxa. What is their evolutionary status? What is their nomenclature? Is it sufficient to refer to them as x, y,..z? What is their biochemical status? Are they mere monsters?

Nair (2004) equated deep study of taxonomy with evolutionary biology, alternatively referred to as New systematics, New taxonomy, Biosystematics, Biotaxonomy, Evolutionary taxonomy by various modern taxonomists viz: Huxley, Heslop- Harrison, Davis & Heywood, Solbrig, Stace, Radford et al, and almost equal to biodiversity analysis eg: Heywood et al (biodiversity treatise), de Castri & Younes who all had as basis of newness "The Origin and evolution of species" by Charles Darwin. This is basis of predarwinian taxonomy and postdarwinian taxonomy already dealt with. This also lead to proposals of Phenetic and Phylogenetic classifications. Classification is a corollary but immediate services are obtained by species identification, nomenclature, subspecific variation , molecular basis of extractable services from the species to choose and recommend for economic purpose the most value yielding sample from either the ubiquitous or endemic or endangered species of World trade importance.

Taxonomy and herbal medicine

The study of Botany itself started with a search for herbs for health. The science of Ethnobotany is a chapter in any recent textbook of Taxonomy. The world realized that traditional herbal medicine shows little side effects and its usage spread rapidly even in advanced American and European countries. The present turnover is more than 6200 crores of rupees. It is expected to reach Rs. I lakh cr by 2015-2020 and Rs 5 lakhs cr by 2050 as per World Bank's estimate. Europe has $2800cr share, Asia $1080cr share, Japan $ 980crores share. India has $ 690cr share. In India the turn over is Rs 2500cr. An increase of 25% year is envisioned. However India's export is of the share of 0.5% in the world. From another angle, it has been found that China exports 70%finished products and 30% crude, India exports only 20-30% finished products and the rest crude. India has 8000 medicinal herbs and 2500 aromatics. Of these only 100 medicinal herbs and 250 aromatics figure in International market. Even these, 90% are still obtained from the forests.

Central government established National Medicinal Plants Board. It started CIMAPS
(Central institutes of medicinal and aromatic plant research institutes). There is one in Bodiuppal region in Hyderabad city for giving information to students. There is NDRI (National drug research institute) in Lucknow.

Guidelines for the success of the herbal medicine market :

Medicinal herbs are valuable natural products with potential global market already made a mark. Students are advised to motivate themselves by reading articles such as that by Sukhdev (1997) and a recent one : Ayurveda and Natural products drug discovery by Bhushan et al (2004).

Disbelief, doubts, questions and lack of confidence in herbal medicine are mainly due to wrong identification of the medicinal herb. It is taxonomists job to provide correct identification and show the same in the field to the traders and act as their botanical consultant. This prevents adulteration when field collection is assigned to nc ices in the subject. For instance the valuable *Phyllanthus amarus* is adulterated with *P. maderaspatensis, P. simplex, P. urinaria, P. pinnatus.* The valuable *Boerhavia diffusa (*purarnava) is adulterated with *Trianthema portulacastrum*. Bark of *Wrightia tinctoria* is mixed with *Holarrhena antidysenterica (* roots of which are however medicinal for a different purpose) and that of *Saraca indica* with *Trema orientalis*. Unless specialist taxonomist certifies the identity of the species the drug cannot be relied. This is the main reason for loss of confidence in herbal medicine. The articles by Sukhdev (1997), Barnett (2000), Natesh (2001) and book by Rao CK(2000) and several ethnobotanical works are recommended to students for further study. The problems are more with polyherbal medicines suggested to include seeds of a species, bark, root, leaves etc of several other species . You are aware that list of herbs comprising herbal medicines in the market have to be printed as a mandate . The nomenclature is impressive but it is to be believed only. The authentic identity of each of these herbs is a taxonomist's professional job and not that of a trader or manual helpers. With such a paramount role, why Botanists do not render this valuable human service? Some companies may be seeking the help of taxonomists for field identification but several may not. This may not be voluntary adulteration but due to ignorance of the species identity. It is said " where ignorance is a bliss it is folly to be wise". This dictum does not hold good in respect of herbal identification. The crude drugs are supplied mostly in dried or powdered form which increases cheating activity. The taxonomist should not only be thorough with field id as well dried crude form id of each medicinal species. It is as valuable as food adulteration and this should be started as part of taxonomy curriculum.

How work on herbal medicine is becoming polytechnical can be illustrated by an instance.

Instance of *Phyllanthus emblica:* The Indian Gooseberry

Umashankar and Ganesaiah (1997) virtually studied the mapping of the genetic diversity of this species from population samples from 3 states, the Karnataka, Tamilnadu and Maharashtra and conducted isoenzyme analysis. The fruits of this species contain Vitamin C. They show antioxidant, anti inflammatory and antimutagenic properties . They also contain polyphenols (ellagic acid, gallic acid, tannic acid) The plant is known since decades as remedy for common cold, scurvy, cancer, heart diseases. It is one third of a popular drug called "Triphalachurna" the other two being fruits of *Terminalia chebula* and *T. bellerica.* It is a part of Brahmla Hair oil . The amla extract is water soluble and effectively scavenges free radicals responsible for initiating LPO. It is also found to be pancreatoprotective. Its antioxidant properties have been highlighted by several subsequent workers.

To add to this is research work on another source of Indian gooseberry. It is *Phyllanthus indofischeri* (Ganesan 2003). This endemic to Deccan plateaeu and certain drier parts of South India (herbarium with FRLHT and ATREE of Bangalore) in contrast to the widely distributed *P. emblica* They are not sympatric in the same forest. Both the species are valuable for sacred religious occasions eg."Kshirabdi dwadasi" in AP and "Uthana dwadasi" in Karnataka. *P. indifischeri* is to be conserved on a war footing because of its scarcity as it is introduced by businessmen as cultivar "Krishna" in Tamilnadu and "champakad large" in Kerala.

Is not the role of taxonomy in the service of man becoming clearer with this single example? Service to humanity is service to God and service to plant species is service to humanity. It is also well known " Vruksho Rakshati Rakshitaha"

Taxonomic notes on herbal oral insulin mimics

The range of herbal medicine for polydisastrous diabetes is cited for the benefit of student who should be an expert in the field identification and the ethnobotanical hi-story of each one of these species. The World diabetes day is on November 14th the birth day of Frederik Banting, the insulin discoverer. This is emphasized because India is the diabetic capital of the world according to many pharmaceutical companies with Chinas and US prospective followers; it is estimated that in developed countries there are 51-72 million and in developing countries 84-228 million diabetics! In some places there are NGOs conducting awareness camps since 3 years : eg APOORVA foundation in Mysore in which activity taxonomists can help in popularising herbal insulin mimics with correct identification. The biodiversity of the disease also is to be understood as Hansen (2002) from Denmark recognised in Type II diabetes, multiple gene forms as well as monogenic forms. Balasubramanyam and Mohan (2001) inspire taxonomists by their article on Orally active insulin mimics to enable taxonomists to be expert field identifiers of the concerned species.

For ready reference a few species are listed here . (After Dahanukar et al 2000)

Phyllanthus amarus: shows hypoglycaemic effect, reduces oxidative stress, efficient antioxidant,(free radicals and O reduce immunity likely to result in DNA disturbances, a sort of acquired immunodeficiency not necessarily HIV caused AIDS-present comment); *Ocimum album and O. sanctum*: leaf powder antihyperglycaemic; *Prunus amygdalus:* seeds, non oil fraction soluble in ethyl ether effective; *Artemisia pallens*: aerial parts extract activity similar to tolbutamide, lowers fasting blood sugar, cholesterol, triglycerides and total lipids; *Aegle marmelos*: leaf extraxt useful in regeneration of damaged pancreas, activation of ealate dehydrogenase enzyme; *Camellia sinensis*: hot water extract preventive and curative; *Inula racemosa*: alcohol extract potentiates insulin sensitivity, *Pterocarpus marsupium*: heartwood extract has pterosupin, pterostilbene, activity comparable to metformin, restored normal glucose levels in 70% patients *Capparis decidua*: lowers oxidative stress; Salacia oblonga: chloroform eluted fraction works like tolbutamide; *Lantana camara*: leaf juice hypoglycaemic.

Gita Thiagarajan et al (2003) recorded cytoprotective antioxidant properties in *Withania somnifera* due to its compounds glucowithanolides and this " Aswagandha" is a component of several polyherbal drugs for diabetes. Sangwan (2004) stressed the multiple uses of this species. Popular critical account of the current status of the drug quality is summarised by Vibha Varshney (vide Down to Earth, March 2004 issue p.15). The taxonomist can take up such interdisciplinary issues for the benefit of mankind.

A drug Institute in New Delhi deals with a pancreatic tonic (US patent No 5,886,029). The constituent species occur in India as well which need taxonomist's intimacy with them for further work. To cite the species, the active principle in parenthesis: *Pterocarpus marsupium,*(epicatechin) *Gymnema sylvestre* (gymnemic acid), *Trigonella foenumgraecum*(sapogenins, trigonellimum,tripothylcoumarin) , *Tinospora cordifolia* (tinosporin), *Syzigium cuminii*(B-cytosterols, glucosides, jamboium), *Momordica charantia*(kaantin, momordicin, ascorbic acid) , *Cinnamomum tamala*(cinamaldehyde, eugenol, cinamic acid, linol, caryophyllin); *Ficus racemosa* (B-cytoveriglucoside, tannins, wax, silica, phosphoric acid) and so on.

Kausik biswas et al (2002) confirmed antihyperglycaemic properties of *Azadirachta indica* (with sulphur, margosin, nimbine, nimbinine, nimbidine).

List of antidiabetics or insulin mimics after Parnotta (2001) all are from peninsular India, a matter of great value to taxonomists. Each one is suitable for R & D projects for confirming the claim of ethno botanical information a fertile activity of taxonomists indeed. A herb in need is a friend indeed.

Boerhavia diffusa(roots), *Biophytum sensitivum*(leaves contain insulin like principle, used by tribals Bhills & Dhankals of Gujarat), *Bacopa monnieri* (whole plant, also in memory plus), *Aegle marmelos*(fruits and roots), *Chloroxylon sweitenia*(bark powder), *Curcuma longa*(rhizome infusion), *Abutilon indicum*(raw leaves), *Alternanthera sessilis* (whole plant, drug LONIC), *Catharanthus roseus* (petals after Yoganarasimhan in Parnotta 2001), *Casearia tomentosa*(root decoction, tribals of Sundertgharh Dt, Orissa), *Derris indica* (flowers, Gujarat tribals), *Enicostema axillare*(whole plant decoction, Bhavnagar dt. tribals), *Helecteris isora* (root juice in Konkan), *Holoptelea integrifolia* (bark and leaves), *Ichnocarpus fruitescens*(root powder & milk), *Ficus racemosa, F. benghalensis, F. religiosa*(bark, roots, and figs) *Lagerstroemia speciosa* (leaves, dried fruits as herbal tea in philippines), *Mangifera indica* (kernel of unripe fruits, used by MP tribals, *Physalis minima* (whole plant, in Siddha), *Psoralea corylifolia*(seed and sedoil)*Tinospora*

cordifolia ((mature stem thi s species is "tridoshaharam tippa teega") *Sida rhombifolia* (root extract) *Solanum nigrum* (whole plant), *Striga gesnerioides*(whole plant), *Syzigium cuminii*(root bark, fruits infusion), *Tridax procumbens* (leaf powder plus *Cicer arietinum* as 2:1 orally by tribals of Udaipur Dt. Rajasthan), *Urena lobata* (root tonic tribals W. Maharashtra & those of South AP)
To add to this exhaustive list there are several other species. A few are cited further:
According to Jain (1997), *Scoparia dulcis and Hibiscus tiliaceceus* are folk remedies for diabetes. Apparao (2003) cited *Caralluma tuberculata* as a reputed cure for diabetes, reduced blood glucose levels, showed antiinflammatory and analgesic activities. 19 steroidal glucosides were isolated from this.

Apart from ethnobotanical data, it is significant to know that some cited magnesium deficiency as cause for diabetes mellitus. Ehtesham (2001) established a molecular link between obesity and diabetes. Oral consumption of the ubiquitous aquatic weed *Ipomoea aquatica* reduced blood glucose levels considerably (Rao 2003, present author, and recommended for aqua culture in water bodies as additional source of income for farmers resorting to the aqua-pharming of this weed.)

Further the success of herbal therapy depends also on the selection of the most efficacious sample given its wide range of distribution and biodiversity. Thus advanced biotechnological skills also now became a part of the search for drug samples.

Taxonomic understanding of each drug species should be both at the alpha and omega levels to provide useful database convincing to users of the herbal medicines. This elevates the status of individual taxonomists as well as the economic status of the concerned species. The end of World War II ushered in the glamour of modern medical science with its spectacular discoveries..Chemical "magic bullets" produced by big pharmaceutical companies and the promise of "pill for every ill" overshadowed herbal medicaments (Natesh 2001). The existing stage points out the intensive competition to be put forward by the herbal medicine experts with the merit which is absolutely result oriented and also wipe out the psychological slavery to the chemotherapy (any chemical used as medicine is equated by me as chemotherapy ,a word usually associated with cancer therapy). Herbal therapy is a biochemical synergistic therapy of more than one herb or from single herb but the biochemical in its natural home is felt to be more effective encapsulated with the natural tissue which too may have its role in action. There is general renaissance of herbal medicine in recent times due to lower side effects, greater efficacy and lower cost and an eco friendly drug therapy. Genetic engineering can be used to improve quantity of drug, more efficacious bye product and saleable to larger population to meet the market demands. Also the manufacturer can retain the engineering technical skills confidential as trade secrets. The herbal medicine is also referred to as fringe medicine, alternative medicine, or as traditional medicine(as per WHO) as complementary medicine or as orthodox medicine. Various herbs are in fact basis of several allopathic, homoeopathic, ayurvedic, Siddha or Unani medicines. Asian, African and Latin American zones mostly depend on the plant remedies, felt as immediately accessible, relatively safe, cost effective, efficacious and culturally acceptable to primary health care. A report prepared by the Export-Import Bank of India (Anonymous 1997) has estimated that the international market of medicinal plant- related trade is in the region of US$ 60 billion, and growing annually at the rate of 7%. The current global market is pegged at US $ 62 billion . Europe's share is nearly half of the total. Germany dominates the European trade.

These statisitcs are really staggering and indicate commercial potentialities that can better be exploited by taxonomists and help enrich economic status of India.

Plants have a further a role, as already stated, in allopathic armentarium design (table 1 from Natesh 2001)

TABLE 1- EXAMPLES OF CRUDE DRUGS THAT HAVE RECEIVED CLINICAL/PHARMACOLOGICAL SUPPORT FOR THEIR THERAPEUTIC CLAIMS* (From Natesh 2001)

Botanical Name	English/Hindi/ Sanskrit Name	Key Constituents	Type of Activity
Acorus calamus	Vacha	?	Tranquilizer
Adhatoda zelyanica	Vasa	Vasicine	Bronchodilator
Aesculus hippocastanum	Horse chestnut	Aescine	Astringent, antiedemic
Allium sativum	Garlic	Allin; allinase	Cholesterol-lowering, antihpertensive.
Andrographis paniculata	Bhuinimba	Andrographolide	Hepatoprotective
Arctostaphylos uva-ursi	Uva-ursi	Phenoplic-heterosides	Antidote for urinary tract inflammations
Artemisia annua	Qinghao	Artemisinin	Antimalarial
A. absinthium	Wormwood	Sesquiterpene lactones	Gastrointestinal disorders
Asparagus racemosus	Shatavari	Shatavarin-I	Antiabortifacient
Azadirachta indica	Nimba	Gedunin	Antimalarial
Bacopa monnieri	Brahmi	Bacosides	Memory enhancer
Boerhavia diffusa	Punarnava	?	Diuretic, anti-inflammatory
Butea frondosa	Palasha	Palasonin	Anthelmintic
Cassia angustifolia	Senna	Sennosides	Bowel stimulator, antiabsorptive.
Centella asiatica	Mandookaparni	Asiaticosides	Skin diseases, psychotropic
Chamomilla recutita	Chamomile	Chamazulene, Bisabolol, lypophyllic flavonoids	Anti-inflammatory Antispasmodic
Crataegus monogyna, C. oxycantha	Hawthorn	Glycosyl flavonoids? Procanthocyanidins?	Positive inotropic, antiarrhythmic
Curcuma longa	Turmeric/Haridra	Curcumin	Anti-inflammatory
Echinacea spp.	Cone flower	Polysaccharides	Immunomodulator
Ephera spp.	Ephedra	Ephedrine	Bronchodilator, Vasoconstrictor.

Botanical Name	English/Hindi/ Sanskrit Name	Key Constituents	Type of Activity
Ginkgo biloba	Ginkgo	Bilobalide, Ginkgolides, Flavonoids	Anti-ischemic, Antihypoxidotic, PAF- antagonistic, Memory enhancer.
Harpagophytum Procumbens	Devil's claw	Harpagoside	Anti-inflammatory and antiexudative
Hollarrhena Antidysenterica	Kutaja	Conessine	Antidysenteric
Hypericum perforatum	St. John's wort	Hypericins	Antideppressant
Hyperzia serrata	?	Huperzine A and other alkaloids	Active cognition enhancer, facilitates memory and motor activity in the aged
Panax ginseng, P. quinquefolius	Ginseng	Ginsenosides	Adaptogen
Phyllanthus amarus	Bhoomyaamlaki	?	Hepatoprotector
Picrorhiza kurroa	Katukaa, kutki	Picroside, kutkoside	Hepatoprotector
Piper methysticum	Kava	Methysticine and related pyrones	Anesthetic, anticonvulsant, central muscle relaxant
Plantago ovata	Psyllium	Mucilages, hemicelluloses	Laxative
Prunus africana	Pygeum	?	Benign prostratic hyperplasia
Psoralea corylifolia	Bakuchi	Psoralen, bakuchiol	Antileucoderma, antibacterial
Silybum marianum	Milk thistle	Silymarin	Antihepatotoxic, promotes ribosome formation and protein synthesis
Serenoa repens	Saw Palmetto	?	Benign prostratic hyperplasia
Swertia chirayita	Kairata, Chirayta	?	Febrifuge
Valeriana officinalis	Valerian	Valepotriates	Hypnotic

Anti Hepatitis herbs are cited in table 2.

TABLE- 2 Purported anti- hepatitis herbal taxa

Allium sativa ,Aloe indica (Ghikanvar), Andrographis paniculata (Kalmegh), Boerhaavia diffusa (Punarnava), Buplerum falcatum ,Berberis aristata (Daru haridra), Cichorium endivia (kasani), Curcuma longa (Haldi), Chelidonium majus, Dictamnys, Duchesnia ,Emblica officinalis (Amalaka), Embelia ribes (Vidang) ,Eclipta alba (Bhringraja), Fumaris officinalis (Pitpapra), Glycerrhiza glabra (Yashtimadhukamu) , Luffa echinata (Bindaal), *Phyllanthus niruri* non. L. (=*P. fraternus* (Wight) Webster) , Picrorrhiza kuroa (Kutaki), *Piper nigrum* (Kalimirich), *Piper communis* (Erand) ,*Sinymarin* (Milk thistle), *Tephrosia purpurea, Tinospora cordifolia*(Galo) , *WIthania somnifera* (Aswagandh *,9-11 granules).*

There are thus several species but *Phyllanthus amarus* of Euphorbiaceae a seasonal small herb with dwarf branches is known as an effective remedy for jaundice as per my own experience during 1970s in NU campus, Kaza and Nambur villages. There were efforts to patent it in USA which were effectively snubbed by us as it is our traditional knowledge and intellectual property of our rural folk (vide Mashelkar 2002 exhorting to the need of designing a TKDL(Traditional knowledge digital library), and also his contribution: Chitrakoot declaration, 2003 in a convention of the National Botanical Research Institute, Lucknow, conveying Ayurveda as a new discovery engine.)

Lot of biological diversity is also known in the hepatitis virus labeled as Hepatitis A, B, C, D, E etc. According to WHO 170 million people are effected by Hepatitis C. From the root clones of *P. amarus* are now extracted interferon –a and ribavirin to control C, and the turnover is of the US $ 26000 per year. A general traditional medicine strategy 2002 to 2005 has been put forward by WHO, Geneva in 2002, very relevant to emphasize renaissance of herbal medicine which could shape into a privilege of a taxonomist, in fact.

The watercress *Nasturtium officinale* is a multi vitamin source with Vitamins A,B,B2, C,&E, minerals I, Fe, P- a detoxifying herb, medicine for brain disorders since 5 BC, blood cleanser, diuretic and cure for bronchitis. There is Euphorbiaceous multivitamin species *Sauropus androgynus* live plant specimens of which can be seen in Forest sylviculture park at Rajahmundry EG DT. Identification of this and distinction from the weed species *S. quandrangularis* can be done by taxonomists alone.

To inspire students of taxonomy , a few antitumour herbs are also cited : *Catharanthus roseus:* roots source of vincristine, vinblastine etc, administerd as injection in Leukaemia, chewed flowers also recorded as antidiabetic; *Taxus baccata:* source of taxol known as specific for uterine cancer; *Podophyllum emodi*: spource of anticancerous podophyllotaxine,etoposide, tenoposide and the campothecine from wood extract of *Nothopodytes nimmoniana* breaks single stranded DNA in mammals and recorded as anticancerous; The vegetables cauliflower and cabbage are considered as preventive; there are several common herbal sources (please refer Annadata periodical in Telugu of November 2002).
The enumeration will be unending and hence a comma is kept here for this aspect of herbal taxonomy.

Taxonomic knowledge about the PHYTOREMEDIATION:

Icipact (2001) contained several research papers on aquatic plants absorbing metal pollutants in pollution control. The transfer of metals to water bodies and biota occurs due to phenomena : bioconcentration, bioaccumulation and biomagnification and so on. There are several flowering plants to be identified first and then studied in detail for their potentiality in reducing heavy metal pollution in aquatic media. A few examples are cited here.

Lead and Copper are absorbed in different ranges *by Elodea canadensis* , *Littorella uniflora, Myriophyllum alternifolium, Potamogeton crispus* , *P. perfoliatus.* Bioindicators of metals are *Ceratophyllum demersum, Myriophyllum spicatum, Potamogeton pectinatus, P. perfoliatus, Zanichellia palustris, Hydrilla verticillatas* (cadmium uptake) , *Vallisneria spiralis.*

Trace metal and heavy metal absorbers and uptakers are *Eichhornia crassipes*, and duck weeds. Cadmium uptake by tomato cultivars has also been on record. Removal of Arsenic by *Garcinia gambosa* also was reported (Chandrasekhar et al from IICT: In
Icipact 2001).

Margaret Greenway (in Icipact 2001) presented a review of constructed wetlands for water pollution control. *Phalaris arundinacea, Baumea articulata, Carex fascicularis, Phylidrum languinosum, Schoenoplectus mucronata, Arabidopsis thaliana, Arundo donax, Typha angustifol*ia are a few that received trials. Further work is pending in enriching this list. What are the species and from where to obtain them? are the job requirements of a taxonomists.

Several Brassicaceae have been enlisted by Palmer et al (2001) as useful in phytoremediation. Keen art of identification, introduction, propagation and ecophysiology and persistence of the various genera and species demands taxonomic expertise. The heavy metal pollution remedying species are cited for ready reference.

Cadmium: *Thlaspi caervulescens;* Lead: *Alyssum wolfanianum, Thlaspi spp.* ; Nickel: nearly 50 species of *Alyssum* , 4 species of *Bornmuellaria, Cardamine, Naccera, Peltaria, Pseudosempervivum;* Selenium: Species of *Stanleya*
Strontium: *Arabis stricta;* Zinc: *Arabidopsis thaliana, Cardaminopsis, Cochlearia, Noccaea, and Thlaspi.*

Identification of botanical pesticide source species

Nearly 2000 species are known to contain insecticidal toxic substances (Varma and Dubey 1999). Most well known is *Chrysanthemum cinerariefolium* = pyrethrum. Consumption of pyrethroids is more than 1000 tons in India. Combination of *Blumea lacera* increases pesticidal action. It is taxonomists that can identify , show and collect these. Otherwise there is chance of adulteration with other species of *Blumea* and even *Chrysanthemum*. Unawares, the pesticide source collectors are resorting to taxonomic work. For the benefit of the reader a few more species are enlisted to point out taxonomic value in this regard. Table 3 shows important families having number of species with anti-insect properties (Dhaliwal and Koul 2001).

Table 3: Important plant families having number of species with anti insect properties.

plant family	number of plant species
Annonaceae	12
Apiaceae	23
Apocynaceae	39
Asteraceae	147
Cryptogams	58
Cupressaceae	22
Euphorbiaceae	63
Fabaceae	157

Lamiaceae	52
Leguminosae other than Fabaceae	60
Liliaceae	24
Meliaceae	> 500
Moraceae	26
Myrtaceae	72
Pinaceae	52
Poaceae	27
Ranunculaceae	55
Rosaceae	34
Rubiaceae	38
Rutaceae	42
Solaceae	52
Verbenaceae	60

Azadirachta indica: seeds source of 100 tetranotriterpenoids, nonisoprenoids, azadirachtin(atleast 30 commercial brands in market), shows antifeedent properties.

Artemisia capillaris: fungicide source; *Ocimum suave*: grain protectant; *Eugenia aromatica*: flower buds grain protectant; *Pogostemon heyanus, Ocimum basilicum:* essential oils insecticidal; *Ocimum canum, Citrus medica, Cymbopogon citratus:* sources of fumigant essential oils against post harvest fungal diseases; *Carum curvi*: insecticide in Netherlands, trade name TALENT; *Chenopodium ambrosioides*: essential oil against damping disease; *Acacia nilotica* : aqueous bark controls blue mould rot.

Only 5-15% of the existing species have been studied from this angle. Some cite the seed powder of *Annona squamosa* to be insecticidal.. Field exploration for investigation on other potential sources for authentic determination is a valuable job requirement of a taxonomist.

Taxonomy and horticulture

All botanists and taxonomists need knowledge of identification, nomenclature, origin and propagation technology of horticultural species which are eye feasting, provide landscape luxury, enrich botanical paradises, and tourism, source of job and considerable income. Few realize that it is not the job of an illiterate gardener and horticultural traders who may have picked up some knowledge just as a compounder dominates a qualified physician or a laymen running a computer institute while they are more recognizable with the help of qualified technical personnel. Origin, evolution, designing new cultivars, their ecophysiological requirements need taxonomic knowledge. After Bailey's Manual of cultivated plants (several diagrams in this are from Lawrence's Taxonomy of vascular plants). Sales men are not science experts. Taxonomists can be leaders and pleaders for salesmen. There are lot of economic resources and high export potential. This area needs synthesis of knowledge of morphology, ecology, ecophysiology, diversity, preservation and conservation recognised of late as limbs of taxonomic studies. Work of Barbier et al (1994) on Paradise Lost? The ecological economics of biodiversity motivates studies in this area.

The biodiversity is also covered by law , the NBA- National Biodiversity act of 2002. This enhances the value of taxonomists. This knowledge helps general Botany students in interviews for jobs . The agrobiodiversity which has globalization potential has to be managed appropriately by ICAR to sustain and claim our research efforts by using our brains or intellect called hence as Intellectual property Rights (IPR). Explanation of this is also an important question in interviews for all students of science especially Botany. The effective management of genetic resources , their roots, synthesis, and engineering new recombinations, inventorization, surveying, collection, conservation, characterization, evaluation, documentation, exchange, utilization, dealings with TRIPS & WTO are relevant to taxonomists directly. This is sure to lead taxonomists in designing a horticultural revolution.

Taxonomy and Phytogeography

The relevance of taxonomy to phytogeography and vegetation studies is a part of the present syllabus. Continuing the omnipresence of taxonomy, it is knowledge of phytogeography that helps in assessing phytobiodiversity and phytotaxonomy. A taxonomist is the qualified person utilizing all technology available including GIS (Geographical Information System); remote sensing to map and account the biodiversity hotspots in the world. The global biodiversity hotspots are:

1. The tropical Andes(Venezuela, Colombia, Ecuador, Peru, Bolivia)
2. Madagascar
3. Brazil's Atlantic forest region
4. The phillippines
5. Meso American forests
6. Wallacea (eastern Indonesia)
7. Western Sunda(in Indonesia, Malayasia, Brunei)
8. South Africa's cape floristic region
9. The Antilles
10. Brazil's Cerado
11. The Darien and Choco of Panama, Colombia and Ecuador
12. Polynesia and Micronesian island complex including Hawaii
13. South West Australia
14. The Eastern Meditarranean region
15. Eastern Himalayas
16. The Guinean Forests of West Africa
17. The Western Ghats of India and islands of Sri Lanka
18. New Caledonia
19. South Eastern Australia & Tanzania

Hotspots are areas rich in species, locales of endemic species. India is a major megadiversity nation and the biogeographic zones are useful for taxonomists to account for the biodiversity of species

1. Trans Himalayan Ladakh mountains
2. Himalayas, NW, W, central and eastern
3. Thar desert
4. Semiarid Punjab'plains, Gujarat and Rajputana
5. Western ghats, Malabar plains
6. Deccan peninsula, central hoghlands, Chota Nagpur, Eastern highlands, central plateau and south deccan
7. Upper and lower Gangetic plains
8. West and east coast and Lakhdweep
9. North east hills, Brahmaputra valley
10. Andaman and Nicobar islands

Taxonomy, forest biodiversity and afforestation

The identification, nomenclature and economic yield level classification of forest flora is very important. The forests are renewable natural resource because of their potential regenerative capacities of the plants. Forests are sources of food, clothing, shelter, fuel, various drugs, and varied minor forest produce often called as the Non timber forest produce (NTFP). What species are to be saved, regenerated, micropropagated: can be enlisted by a taxonomist correctly. Data on tree value needs to be prepared. Relative economic losses can be drafted and provided to mankind and media for wide publicity. The fact that a valuable drug source tree can yield $600 m /year considering the world market. Exports are well justified with such basic information and appeals to the world communities and the commercial WTO. This richness is superior in tropical rain forests compared to the generally less biodiversity of temperate forests.

The reasons for deforestation are summarized as follows (Anjaneyulu 2004)

1. Destruction of forests and habitat loss
2. Overexploitation of forest wealth
3. Overgrazing in forest area
4. Shifting cultivation in forests
5. Urbanization of forest area
6. Industrialization in forest area
7. Unchecked illegal trade of forest produce
8. Smuggling and biopiracy of forest resources
9. Diminishing green cover
10. Mining for ores
11. Intrusion of river valley and hydroelectric projects
12. Making approach roads
13. Exploitation of NTFP
14. Loss of land fertility due to soil erosion
15. Incidence of droughts and famines
16. Increased indiscriminate devegetation
17. Desertification & wasteland expansion
18. Ill planned penetration of tourism business
19. Unequal globalization
20. GREED rather than NEED.

A taxonomist can study and prepare inventory of susceptible species, publish and permeate knowledge of the threatened species following the dicta of International Union for Conservation of Nature (IUCN 2000). The following is the taxonomy of the eroding biodiversity taxa.

Threatened	T
Near threatened	NT
Vulnerable	VU
Endangered	EN
Critically endangered	CEN
Extinct	EX

Species classification with annotated risk factors is the applied duty of a taxonomist.
(for further reading Jadhav 2003 is recommended)

Social forestry species

To reduce pressure on the general forests and maintain their sustainability ,cultivation of certain species in the core of social life areas and close by in residential areas in rural as well as urban locales can be better suggested, planned, monitored by a trained taxonomist who alone can distinguish one from the other and also analyse the biodiversity range of each species to choose the best genotype that adapts to the ambient environmental fluctuations and yield high biomass (Phytoenergy) for fuel, fodder, or green shield that prevents soil erosion. The species should be fast growing, drought resistant and relatively disease free. Several have been experimented with all over the country lead by the BES! (Bioenergy Society of India) and DNES(Department of Non conventional Energy Sources). Few examples are here:

Acacia auriculaeformis, Casuarina equisetifolia, Caesalpinia pulcherrima ,Dalbergia sissoo, Eriodendron pentrandrum, Eucalyptus hybrids, Gliricidia maculata, Leucaena leucocephala, Pongamia pinnata,

These species were raised by the Dept of Botany, Nagarjuna University as an implementation of a HDEP (High Density Energy Plantation) project sanctioned by DNES in nearly 70 hactares during 1986-92. The energy species are recurring source of income. Energy returns of each species and the biodiversity therein need detailed study and each species can offer a potential research problem for doctoral thesis work. The species are also taxa which are most suited in regreening of degreened wasted lands.
Thousands of hactares in various parts of AP and India are supported by DNES in enriching cultivation of energy species. Several taxonomists are associated with this activity.

Windshields & Cyclone shelters along beaches

Casuarina equisetifolia (The Casuarina) and certain avenue trees near beach approach roads provide green remedies for the above unforeseen disasters. A taxonomist can study further and recommend more species suitable for mitigating these disasters.

Green belt Species

The industries have been ordered to grow certain trees which minimise pollution, act as CO2 sinks and other pollution absorbers and also to create an ecofriendly environment in that area. Taxonomists are well suited to participate in such green belt programs
and apart from recommending the species, they can help by adding data on ecological efficiency of the species in their potential pollution control. : Examples are cited here for student's ready reference:

All HDEP species listed above and *Albizzia amara, Alstonia scholaris Azadirachta indica,Bushes of Bougainvillaea,Caesalpinia coriaria,Cassia montana, C. renigera, C.siamea , C. sophora,Calophyllum inophyllum,Delonix regia ,Enterolobium saman,Mimusops elengii* and *M. hexandra,Peltophorum pterocarpum Syzigium alternifolium,*
Laymen and Scientists usually ask Botanists about the species and want details and if Botanists reply that they do not have touch with these, it is ridiculous. At least they should refer to a taxonomist for consultancy.

Help of taxonomic knowledge in harnessing wastelands

Wastelands are in fact wasted lands with potentiality for cultivation but abandoned due to economic and other practical issues. Table 4 summarizes an estimate of wastelands in India which can be hardnessed with suitable green wealth sources- petrocrops and also appropriate herbs of medicinal and other miscellaneous values. The contribution is most fitting when done by a taxonomist with field identification expertise , growth and survival patterns of the various species concerned.

Table :4 Estimate of Wastelands in India to be greened with petrocrop taxa
And drug species

State/Union	Non-forest Area	Extent of Waste in '000 of ha Degraded Forest area	Total
Andhra Pradesh	7682	3734	1141
Assam	935	795	1730
Bihar	3896	1562	5458
Gujarat	7153	683	7836
Haryana	2401	74	2475
Himachal Pradesh	1424	534	1958
Jammu & Kashmir	531	1034	1565
Karnataka	7122	2043	9165
Kerala	1053	226	1279
Madhya Pradesh	12947	7195	20142
Maharashtra	11560	2841	14402
Manipur	14	1424	1438
Meghalaya	815	1103	1918
Nagaland	508	878	1386
Orissa	3157	3227	6384
Punjab	1151	79	1230
Rajasthan	18010	1933	19943
Sikkim	131	150	281
Tamil Nadu	3392	1009	4401
Tripura	108	865	973
Uttar Pradesh	6635	1426	8061
West Bengal	2177	359	2526
Uts	889	2715	3604
Total	93691	35889	12958

A few deserving species already with national and international demand are cited for ready reference and taxonomists to pick up field identification talent.

Parthenium argentatum, Calotropis procera, Lantana camara, Simmondsia chinensis, Jatropha curcas, J. gossypifolia, J. glandulifera, J. panduraefolia, J. podagrica, seven species of the genus *Chamaesyce,* several species of *Euphorbia* (leafless, glabrous with cylindrical stems; leafy, herbaceous with rich latex source; leafy, prostrate or spreading erect annuals), *Azadirachta indica, Pongamia pinnata , Calophyllum inophyllum, Schleicheria oleosa, Pittosporum resiniferum and P. eriocarpum.*

A case in point is *Eichhornia crassipes* from which an aviation fuel butanediol has been extracted as aper a report from NEERI (National environmental engineering research Institute, Nagpur). The lignocelluloses, latex, oils, edible or nonedible , the fats and lipids, and several ingredients of phytomass is modified as green fuel or biodiesel sources. The solar energy fixing potential of green plants is harvested as utilizable energy. The MOE &F, Bio energy Society of India, The DNES (department of non conventional energy sources), various national laboratories and Universities are looking for more phytomass yielding energy species

Endemics

The Botanical Survey of India published various accounts on endemism and and endemic species restricted to certain areas which afford a congenial environment for these species Ex situ efforts of cultivation and conservation of these species do not succeed unless the exact habitat is artificially fabricated. A critical search and research for these species is a taxonomist's job and rearing them in situ or ex situ is a real service to preserve segments of biodiversity. Please refer to lesson 4.8.3 for more details on endemism.

Conservation Procedures

Singh(2002) summarized the conservation strategies. In situ: cultivate at the native habitat ; exsitu: cultivate elsewhere from the original habitat recreating their ambient environment such as in green houses, phytotrons in botanical gardens, or utilize biotechnology skills in micro propagation of the endangered species or develop their germ plasma banks, pollen banks, seed banks, gene banks or DNA banks. The conservation efforts can be integrated from molecular to macro levels to save the endangered biodiversity at any cost. Conservation of biodiversity and sustainability have been recommended for a radical reassessment by Adams (1996). Kellert (1996) pointed out the effects of loss of biodiversity on physical, emotional and intellectual well being of the people. Barbier et al (1994) even earlier stressed the ecological economics of biodiversity and referred to the loss as" Paradise Lost" . A classic work on the causes and consequences of extinction of species by Ehrlich and Ehrlich (1982) is useful to all taxonomists. The use of taxonomy in the service man is thus showing border less dimensions. The works of Heywood et al, de Castri and Younes (1996) have already been cited. The planning responsibilities of a taxonomist reached a stage of "perform or perish". The taxonomist should be aware of the global concern shown by World Bank, World Watch Institute, UNDP, UNESCO, IUCN, IUBS, CITES, WWF, CGIAR, UNEP, CIFOR, MOE&F , BSI, DNES and so on concerned with conservation and enrichment of biodiversity as an Index of a Nation's wealth.

Identification of Plant Indicators

Knowledge of identity of plant indicators of environmental conditions can be better done by a trained taxonomist. There are several instances of cursory indicators of climate: Temperature, Light, Rainfall, Relative humidity of representatives of evergreen, semi evergreen, deciduous, scrub jungles, mangroves, sclerophylls, grasslands etc. The terminology itself is derived by the qualities of the indicator species and there are several floras of each of these climatic situations. The recognition of plants as mesophytes, xerophytes, lithophytes, halophytes, etc. is based on indicator species. If soil is considered: sandy soils, acidic or alkaline soils, grasslands, iron rich soils, low lying lands, uplands, waste lands, salty soils, marshes etc each one of these are explained by respective examples of species, correctly enlisted by a taxonomist better than others. There are also illustrative examples of plant indicators of mines, gems and so on.
More data is found in Sharma (2001) and several books on Ecology and Environment.

Role of taxonomist in Ecosystem studies

The main role of a Phytotaxonomist is to prepare a full statement of the primary producers (photosynthetic taxa) in any given ecosystem, a foundation data for picturising the trophic chains, trophic webs, energy flow pattern, ecological pyramids,
and information on gross and net productivity, an estimation of photosynthetic activity, an indication of efficiency of solar energy fixation. The comparative statement of relative efficiencies helps in preparation of

a compendium of highly productive species or ecosystems. Writing a flora with productivity data is an unending realm of work fetching research and employment opportunities to taxonomists.

The same series of events prevail in studying a cropland ecosystem as well. The hybrid crop, transgenic crop, clonal crop, male sterile crop - such data comprise the taxonomists diary of the biodata of the cultivar and helps in indexing the molecular levels responsible for the higher productivity of a crop cultivar as well as its early maturation and disease resistance and general "curriculum vitae" of a commercial crop. Singh SP (2002) cited the combination of ecosystem services and biodiversity in environmental conservation.

How a taxonomist can be of help to mankind.

Basic qualification: capacity to identify phytobiodiversity of species in the field, certify its nomenclature and maintenance of herbarium.

Professional opportunities for taxonomists (also indicates their job requirements).

1. field collection of authentic utility species from wilderness and supply to the concerned company trading them.
2. General crude drug supply to private pharmaceutical companies
3. Search and research on specific individual species for supplying to the drug dealers or synthetic drug manufacturers recommending effective population sample.
4. Self maintenance of a medicinal plant nursery
5. Create awareness and conduct courses to workers who require this sort of taxonomic literacy.
6. Maintenance of herbaria in schools, colleges, Universities, private botanical companies, local government administrative offices supervising landscape, horticulture and parks as nodal reference points. There are serious omissions in most educational institutions.
7. Training students in field exploration, collection, identification, preservation, herbarium development, and keys for identification and storage of data on floppies or CDs for retrieval.
8. Maintenance of nursery of horticultural species.
9. Publication of annotated notes on each ornamental species with eco-physiological details
10. Enrich floras of cities, towns, rural areas, - wild, cultivated, introduced ornamentals, drugs and others of economic value. A big omission of several floras is they enlist only wild flora and not bother about cultivated species, a feature of demand by most of the public, privates, students, laymen, even botanists and surprisingly including taxonomists.
11. Develop instructive model plant propagation units for education, also provide most needed species or their propagules
12. Provide botanical consultancy for botanical gardens, parks, landscape, nurseries, avenue trees, seasonals, annuals, lawns and so on.
13. Botanical consultancy for social forestry, hedges, fuels, crop rotations, green manures and other sources of green wealth
14. Consultancy about taxonomic status, parentage, technology about transgenic crops, somatic hybrids and so on
15. Professional taxonomic consultancy about identification of species, medicinal, or other economic utility for starting research work on biology, cytology, cytogenetics, ecology, or biotechnology of the species.
16. Botanical consultants and suppliers of all specimens for class work , musea mounts, herbarium and life cycle charts and demonstration samples(several companies are already in the field , few making use of trained taxonomists.(This proves that Taxonomy is not tax-on-me but income- taxonomy).

17 Professional practical leaders of field exploration to help colleges and University students where this expertise is getting endangered. The taxonomist is most suitable to lead people as guides of ecotourism, prepare inventories of pristine botanical paradises and suggest remedies for ecodegradation of tourism spots. They can strengthen this role by publishing botanical wealth brochures and also seek employment as caretaker CIDs of endangered biodiversity and prevent biopiracy.

There is no exaggeration in the versatile roles prescribed for a taxonomist in the service of man. There is, however, obvious need for interactive synthesis of the basics and ethnic knowledge with such applied fields like horticulture, biotechnology , green crop gene revolution , agroforestry, and various new interdisciplines.

The syllabus hence is to be revised in future to foresee professional taxonomists as botanical consultants.

CONCLUSION

Support taxonomy, conserve taxonomy, master taxonomy, practice taxonomy, generate taxonomic consultants. Let not taxonomists be "an endangered species". Wipe out all misunderstanding about taxonomy. Make genuine effort to spread the foundation ser vice which taxonomist alone can provide. A mastery of a subject alone keeps an expert in demand whether medicine, engineering, science, teaching or preaching. The same is true of taxonomy. Masters of taxonomy are a very useful human resource for developing as well as developed nations. This HRD should get top priority. Taxonomists have to learn more and more about more and more whereas other specialists learn more and more about less and less. Consummate taxonomists are the friends of the society. This branch deserves to be started as a compulsory course in all bioscience courses emphasizing the multiple applications of the subject from microbes to macrobes, from genes to species and communities. Nurturing of efficient taxonomists is sure to metamorphose as an index of a Nation's academic wealth as well as economic wealth.

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PLANT ECOLOGY
(Unit-III)

LESSON – I

ECOSYSTEM CONCEPT

Objectives

1. Introduction to ecology
2. Scope of modern ecology
3. Concept of ecosystem
4. Structure and functions of ecosystem

1.1 Introduction

What is ecology ?

The word "ecology" is derived from the Greek work "oikos" meaning "household" and "logos" means "study". Thus ecology is the study of organisms under their house-hold conditions. Ecology in its present form deals with the study of organisms in relation to their abiotic environment as well as the interrelationships of the organisms and their abiotic environment. In other words, ecology deals with the structure and functions of nature.

The word "Ecology" was proposed in 1869 by Ernst Haeckel, a German biologist but some of the concepts of ecology, such as `food chains and population regulation' were studied as early as in 1700 by Anton van Leeuwenhoek, best known as the premier microbiologist.

1.2 Scope of modern ecology

1. It is the only subject that deals with the interrelationships of all organisms and their environment.

2. It deals with the higher levels of biological organization i.e. populations, communities and biomes while other sciences deal with the lower levels of biological organization such as molecules, organelles, cells, tissues, organs and organisms.

3. It is an interdisciplinary science. It receives knowledge and inputs from various branches such as Botany, Zoology, Chemistry, Microbiology, Mathematics, Physics, Statistics, Genetics, Evolution, Physiology, Taxonomy and others and it contributes to the growth of other branches.

4. Ecology is a quantified natural history. Therefore, quantification in terms of numbers, volumes, size, biomass etc are the important considerations in Ecology.

5. The philosophy of science has always been `holological' but in practice it was `merological'. However, the ecological approach is always holistic (derived from `whole') (Note: Refer point No.8 below for clarification).

6. Ecology is an applied science. The principles and concepts are now used in divergent fields such as sustainable development, population regulation, integrated pest management, pollution control, energy management and others.

7. Ecology is described as a pleasant science by Paul Colinvaux (1973).

8. It is a science of integration. In other subjects, we gain knowledge by dissecting and dismantling the whole system into its components and then their structure, functions etc are studied (merological approach). But in ecology we become wiser by putting the different things in their place and by studying them as one entity (holological approach).

1.3 Branches of ecology

There are several branches in ecology based on such features as the type of abiotic habitat, vegetation, communities, populations, functions and so on. For instance, aquatic ecology, terrestial ecology are based on the habitat while autecology, population ecology, community ecology are based on the levels of biological organization; and forest ecology, grassland ecology, desert ecology etc are based on the predominant vegetation. Ecology is also known as Environmental Biology.

1.4 The philosophy of ecology

1. Ecology is basically biocentric in its approach and hence man is considered as one among the several different species. Therefore, it doesn't descriminate between man and other organisms.

2. It recognizes the inseparable interrelationships as well as the interdependencies of the organisms and their abiotic environment.

3. It believes that no organism lives in isolation when separated from its environment.

4. The interactions of the organisms and their environment lead to the formation of a functional system, the only one which contains both the living and non-living components while the rest are either biotic or abiotic systems.

5. There is no organism which is useless or worthless. Every organism has its own intrinsic value though not an economic value. The fact of occurrence of an organism shows that it has a place and a role to play in the complex web of nature.

6. Ecology places emphasis an holism and seeks synthesis between reductionism and holism but not separatism.

7. The unit of study in ecology is the "ecosystem", with appropriate attention to organisms, populations, and community subsets and the supraset of biosphere.

8. According to Raymond Dasman, John Milton and Peter Freeman (1973) `ecology' is neither an emotional state of mind nor a political point of view. It is a science complete with a large body of knowledge, principles to organize the knowledge and a potential ability to predict future events.

9. The emerging science of ecology has already given rise to a new branch known as "futuristics".

1.5 ECOSYSTEM

The word "ecosystem" was coined by a British ecologist, A.G.Tansley in 1935. But the concept of ecosystem was much older. Karl Mobius (1877) used the word "biocoenosis" for a community of organisms in Oyster. S.A.Forbes (1887) described the lake as a "microcosm". "Holocoen" of Friederichs (1930), "biosystem" of Thienemann (1939), "geobiosystem" of Sukachev (1944), "bioinert body" of Vernadsky (1944) and the "holon" of Koestler (1969) are more or equal to the ecosystem of Tansley (1935) but the word "ecosystem" gained universal acceptance because it is an english word derived by the merger of the words "ecology" and "system" whose concept and meaning are very clear. Ecosystem is thus equivalent to an ecological system.

Ecosystem may be defined as an unit of a given area in which the living organisms function together and interact with their physical environment leading to flow of energy, cycling of materials (nutrients) and clearly defined biotic structure. A system is composed of some structural components (subsystems) each with a defined function but all the functions of the all the components are integrated in such a way that they function as a single entity. If we think of such systems like the respiratory system, circulatory system, excretory system, digestive system, reproductive system, we realize how each one of them is composed of different structures with designated functions and how they are integrated together to discharge a specific activity and how all the systems are integrated to function as one individual with homeostatic (cybernetic) controls. All the systems mentioned above are biological or living systems. We are also familiar with other systems like the communication systems, computer system etc. in which there are no living components and hence they are abiotic systems. But an ecosystem (ecological system) is the only system which is composed of both living (biotic) and nonliving (abiotic) components or subsystems. Hence, it is much more complex than any of the physical or biological systems. Like any other system, an ecosystem is also composed of certain structural components each with specific function and the system as a whole is capable of functioning as an unit.

1.6 Structure of an ecosystem

An ecosystem is composed of the following components (Fig.1-1)

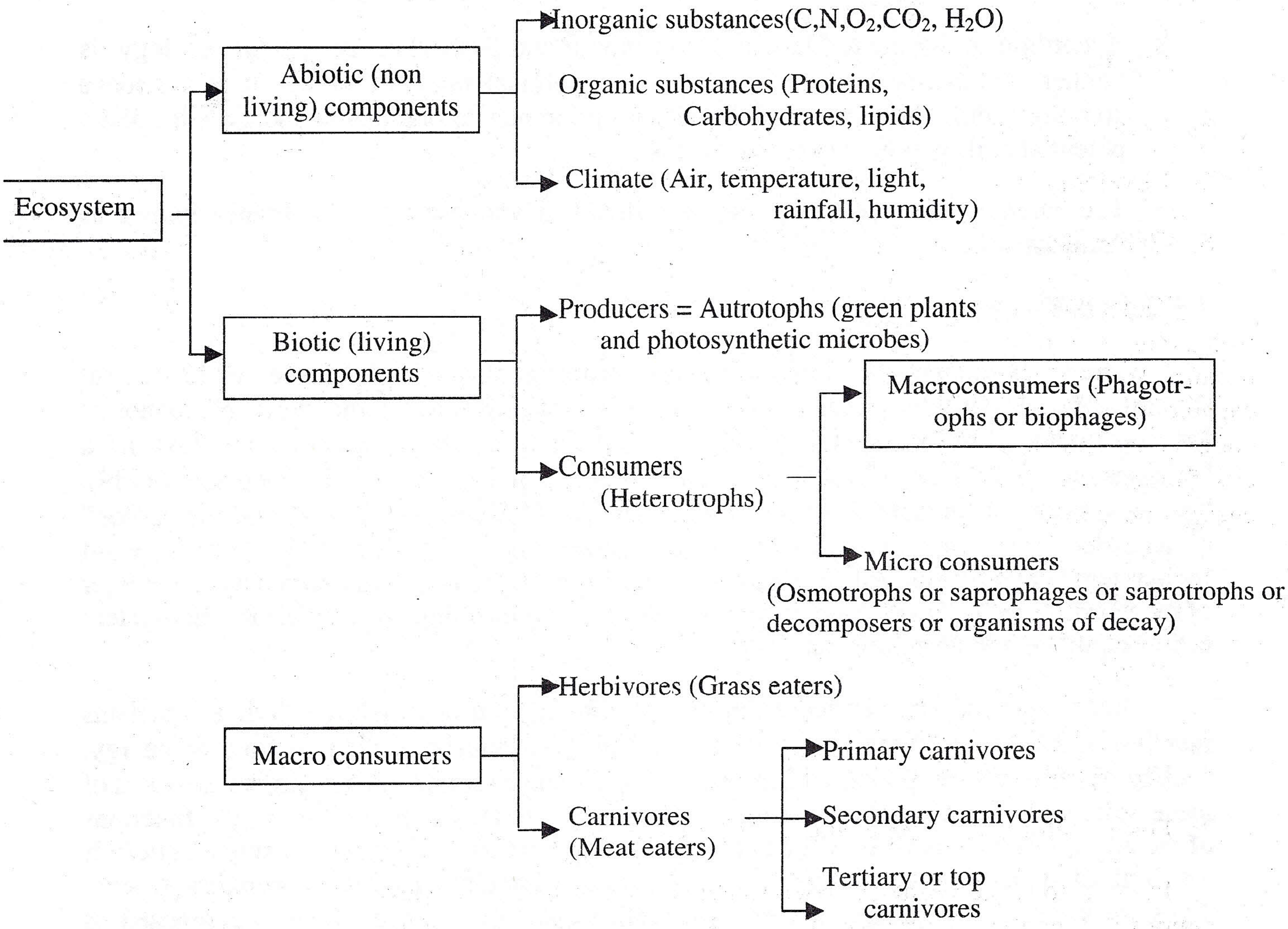


Fig.1.1 : Components of an ecosystem.

The producers in an ecosystem obtain CO_2 from air, water and inorganic nutrients from soil and produce food materials by making use of solar energy by a process familiarly known as photosynthesis. All heterotrophs are either directly (herbivores) or indirectly (carnivores) dependent on producers for their food energy. The consumers are responsible for release and recycling of nutrients. The whole process of production, consumption and decomposition leads to a defined structure and function. The main functions of an ecosystem are:

1. Food chaims and food webs
2. Flow of energy
3. Biogeochemical cycles (nutrient cycles)
4. Diversity in space and time (spatial and temporal diversity)
5. Development and evolution (succession)
6. Cybernetics = homeostasis (self regulation).

Depending upon its size, the ecosystem may be small or big, it may be closed or isolated as in case of a laboratory culture or semiclosed like a pond or open like a forest or an ocean. An ecosystem with all the structural components is a complete ecosystem and it is capable of functioning and sustaining indefinitely. On the otherhand, if any of the components are missing, it can not function independently when cut off from others. Odum (1975) identified the following four basic types of ecosystems depending upon the source of energy and subsidy.

1. Unsubsidised, solar-powered natural ecosystems. (Eg. Open oceans, deserts)
2. Naturally-subsidised, solar-powered ecosystems (Eg: Tropical rain forests, estuaries, corals)
3. Man-subsidised, solar–powered ecosystems (Eg: Agriculture, aquaculture, agroforestry)
4. Fossil fuel-powered, parasitic ecosystems (Eg: cities and towns or urban ecosystems).

In order to simplify the complex systems, models have been developed. A model is a simplified version of the real world. It is a formulation that mimics the real world phenomenon based on which predictions can be made. It may be in a simple verbal or graphic form. A simplified functional diagram of an ecosystem is shown in Fig.1.2. The interrelationships are in Fig.1.3 and functional aspects in Fig.4.

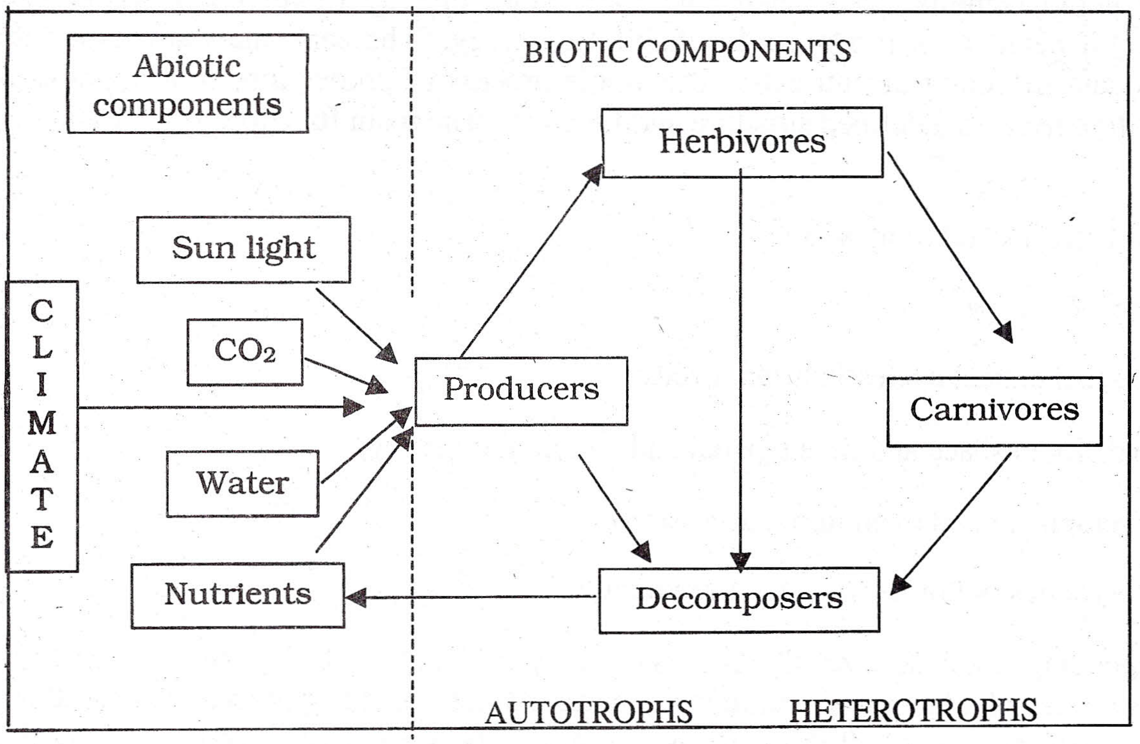


Fig.1.2 : Simplified ecosystem model.

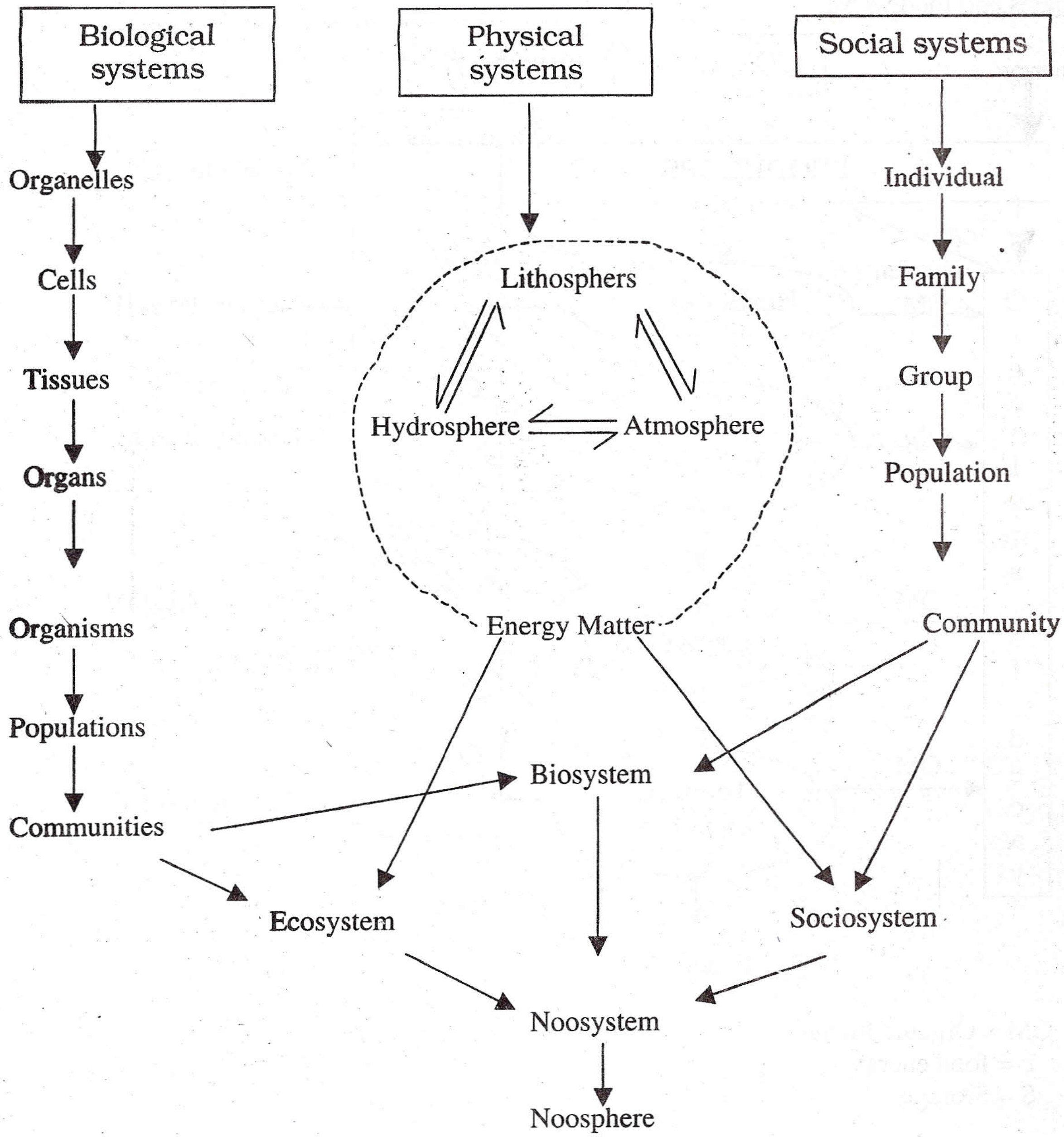
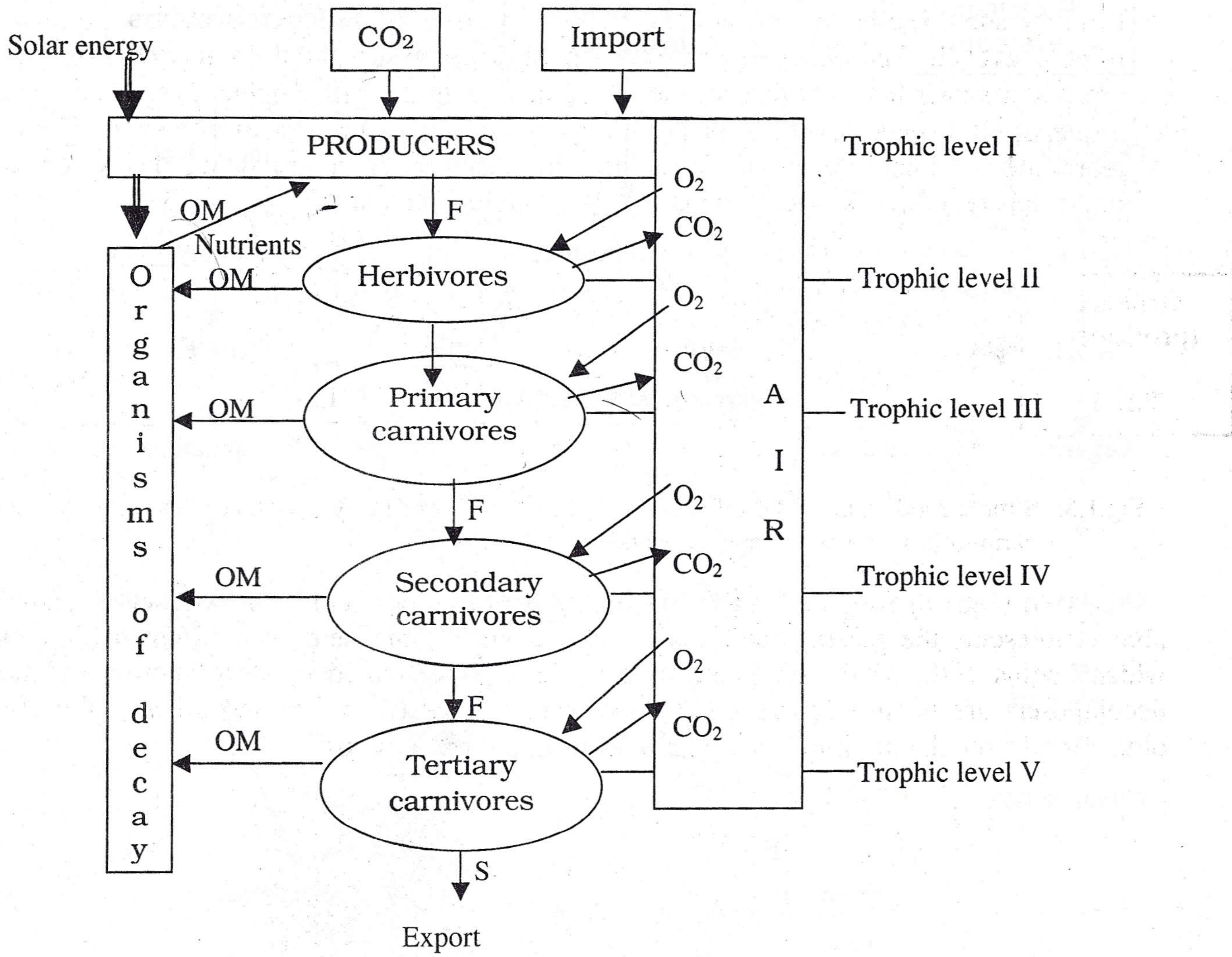


Fig.1.3: Diagramatic representation of the interrelationships among the different components subsystems and systems of Noosphere.

Food chains and food webs:



Where OM = Organic Matter
F = food energy
S = Storage

Fig. 1.4: Functional diagram of an ecosystem showing the transfer of food through a food chain exchange of gases and nutrients.

In an ecosystem, the producers, herbivores, primary, secondary and tertiary or top carnivores represent different levels of food or the trophic levels. The trophic levels are numbered starting from producers which represent the first trophic level. The number assigned to a trophic level indicates the number of steps that an organism or a trophic level is away from the ultimate source of energy (solar energy). Thus, the producers which occupy first trophic level are nearest to the sun and they are only one step away from the sun. The herbivores are two steps away from the sun and hence they represent trophic level II. The top carnivores are farthest from the sun and the solar energy should cross four stages before it reaches the top carnivores in the fifth trophic level. The linear sequence of trophic levels from producers to the top carnivores as shown in Fig.3.5 represents a simple, linear food chain. For instance, in a grassland, the following organisms represent different trophic levels of the food chain.

Grasses (producer) T.L. I	→	Grass hopper (Herbivore) T.L. II	→	Frog (P.C.) T.L. III	→	Snake(S.C.) T.L. IV	→	Vulture (TC) T.L. V

Fig.1.5: Simple food chain. Where PC, SC and TC stand for primary, secondary and tertiary (top) carnivores respectively and TL stands for trophic level.

Two types of food chains are recognized in any ecosystem. The food chain shown above represents the grazing food chain and the other is the detritus food chain (Fig.1.6) which begins with the dead organic matter which is consumed by decomposers and the decomposers are in turn consumed by protozoans, annelids, insects and others. We also obtain food from the detritus food chain by consuming mushrooms.

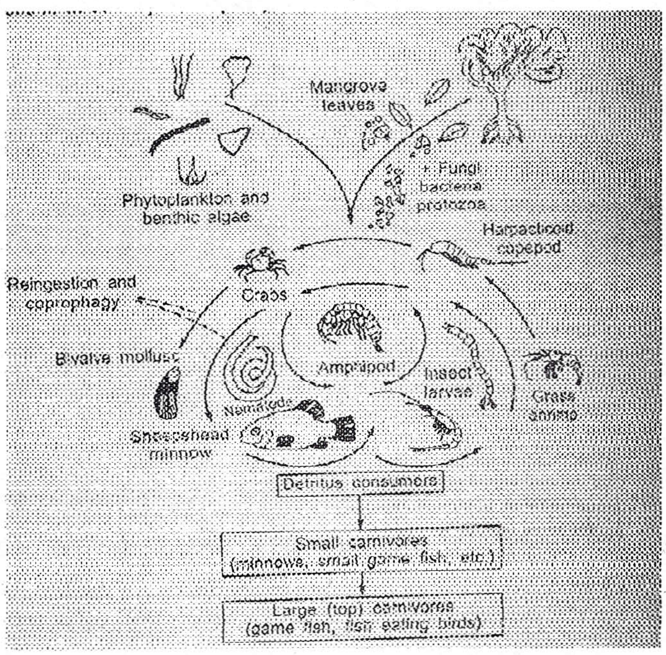


Fig. 1.6: A detritus food chain that begins with red mangrove leaves that fall into shallow subtropical estuarine waters. The decaying detritus particles are enriched by microorganisms and provide food for a key group of detritus consumers which in turn are food for fish.

1.7 Food webs

Under natural conditions, in any ecosystem, simple, linear food chains (as indicate above) are quite uncommon. If the food chains are so simple the ecosystem becomes highly unstable. Any disturbance in any of the links in the simple food chain can disturb the whole chain since the strength of the chain does not depend upon the strongest link but it depends on the weakest link. If the balance between the predator and prey is similar to a two pan balance, a stable equilibrium can not be attained. Therefore, no organism is totally at the mercy of any other organism. Hence, every organism in every trophic level tries to obtain food energy from all the lower trophic levels. For instance, a top carnivore like vulture does not depend only on snakes nor a snake depends only on frogs. A vulture can eat a snake, a frog, rat, a bird or a fish or even an insect. Similarly, a frog can eat a fish, snail, crab and insects. Such a network of transfers of food is known as a food web. A food web is diagrammatically shown in Figs. 7and 8.

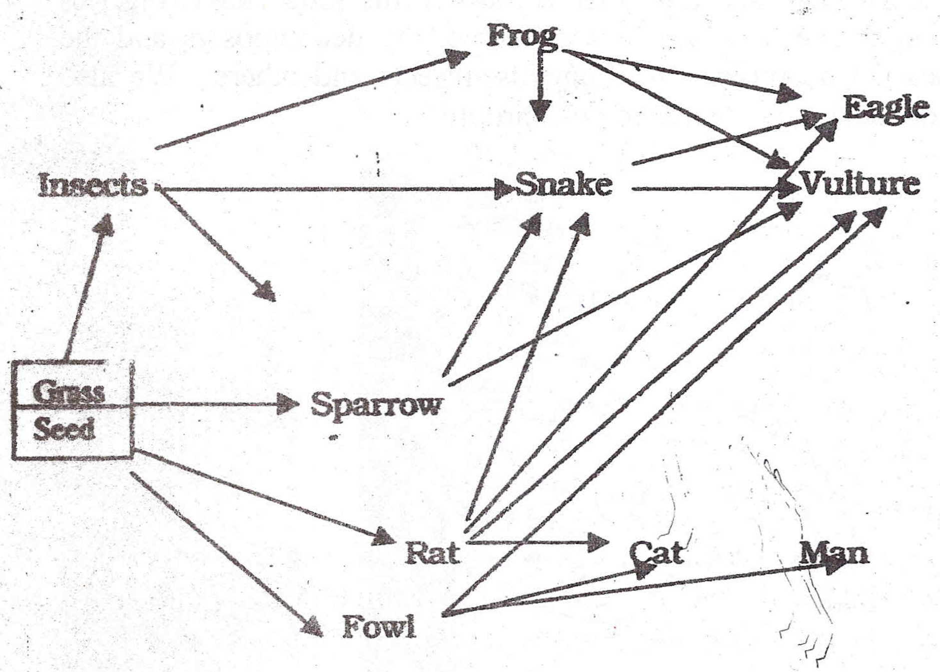


Fig.1.7 : Food Web. A predator and its prey may compete for the same food at a lower level.

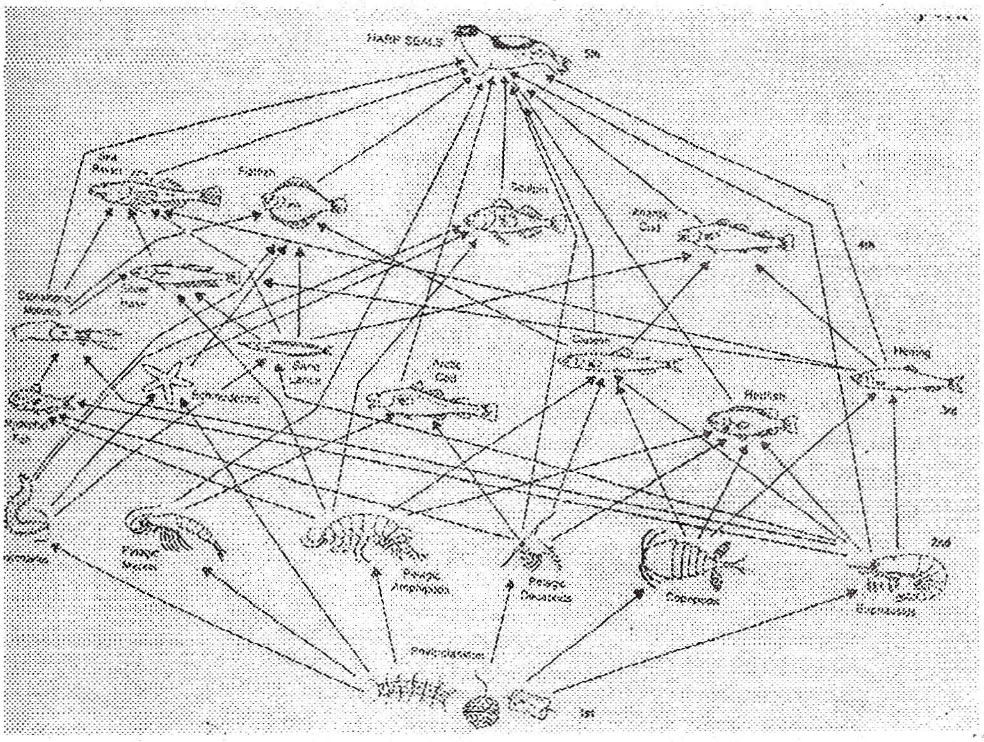


Fig. 1.8 : The food levels of the harp seal. The actual food web of the harp seal has many connections at several trophic levels. The maximum number of steps in the food chain between harp seal and sun light is six but the harp seal also feeds on intermediate trophic levels. For example, it feeds on amphipods at the third trophic level and on capelin at the fourth level. The harp seal thus competes with its own prey (capelin) for its food (amphipods).since the harp seal competes with other species, including other marine mammals and human beings, the entire food chain is very complex. (Modified from Lavigne et al., 1976).

1.8 Place of man in the food chain / food web

The primitive man was a carnivore, eating only meat obtained by hunting. But the modern man is predominantly a herbivore obtaining most of his food directly from producers. In spite of the above, man occupies the position of a top carnivore in an ecosystem. Hence, he is able to obtain food from all trophic levels down under. We are now trying to exploit the decomposers also to obtain food for human consumption through single cell protein (SCP) technology.

Summary

It deals with the aim, scope and objectives of Ecology; the concept, structure and functions of an ecosystem have been explained. The information given is very brief and several details and examples have been omitted deliberately to provide the essential information in a nut-shell. Hence, the readers are advised to consult any of the suggested books for further information.

Model Questions

1. What is ecology? Describe the scope and importance of ecology.
2. Define ecosystem. Describe the structure and functions of an ecosystem.
3. Describe the trophic structure of a natural ecosystem.
4. Describe the different components of an ecosystem and explain how they are integrated together.
5. What are the salient features of ecology?

PLANT ECOLOGY
(Unit-III)

LESSON - II

FLOW OF ENERGY

Objectives

1. Introduction
2. Energy flow models
3. Trophic structure and ecological pyramids
4. Biological magnification

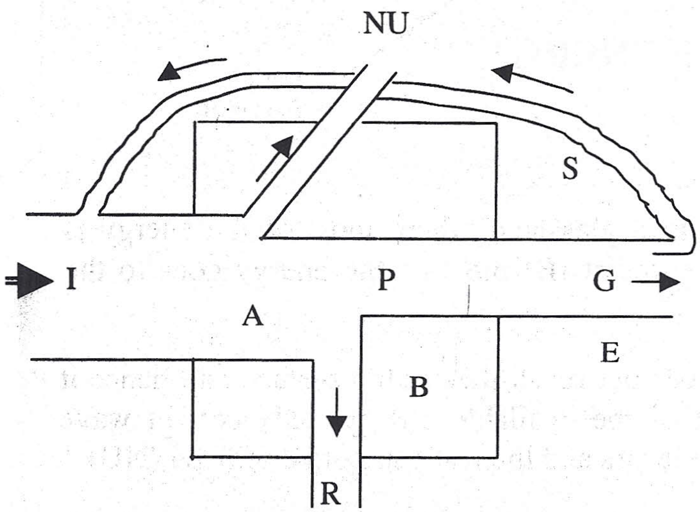
2.1 Introduction

Energy is best defined as the ability or capacity to do work. In other words, it means that work can not be done without spending energy. Energy occurs in different forms and states. We are familiar with kinetic energy and potential energy. We are also familiar with the electrical energy, solar energy, wind energy, hydorelectrical energy, geothermal energy and so on. Apart from the above, energy exists in the form of food and fuels. Thus there are diverse forms of energy. The transformation (change in form) of energy or transfer of energy in any ecosystem is governed by the principles of thermodynamics. According to the first law of thermodynamics, energy can neither be created nor destroyed but it can be transformed. For instance, the energy present in the fossil fuels like coal or diesel can be converted as electrical energy and the electrical energy in turn can be converted to light or heat energy. But it is not possible for us to create energy or to destroy it.

According to the second law of thermodynamics, transformation or transfer of energy does not occur simultaneously unless there is degradation of energy from a concentrated form to a diffused form. It is evident from the second law that neither the transfer nor the transformation of energy is 100% efficient. It is obvious that there is loss of energy whenever it is either transferred or transformed. The flow of energy in an ecosystem involves transformation of solar energy (light energy) into chemical energy of food by plants in photosynthesis and the transfer of energy from producers to others along the length of the food chain. According to the law of tedith or the 10% law, about 90% of energy is lost whenever there is a transfer and only about 10% is transferred to the next trophic level. As a result, the amount of energy reaching the top carnivores is so scanty that it can not provide adequate energy to support another trophic level.

2.2 Flow of energy

The flow of energy in an ecosystem can be explained by making use of the following diagrams (Fig.2.1 & 2.2).



I = Input or ingested energy

NU = Not used

A = Assimilated

P = Production

G = Growth

R = Respiration

B = Biomass

S = Stored energy

E = Excreted energy

Fig. 2.1 : Components of a universal energy flow model (Redrawn from E.P. Odum 1993)

2.3 Principles pertaining to flow of energy in an ecosystem

1. Energy flows in an ecosystem from producers to the consumers through food chains through a process of eating and by being eaten.
2. The flow of energy is always directional. It is neither cyclic nor reversible.
3. In any natural ecosystem, there are only two ways in which the energy from producers is transferred. Either the plant production (primary production) is consumed by the herbivores and then passed on to the carnivores (grazing food chain) or it is decomposed by the organisms of decay (detritus food chain). There is no other possibility in a natural ecosystem. Harvesting and burning are the two other possibilities which can remove lots of primary production from an ecosystem. The flow of energy through the herbivores and carnivores is known as the grazing food chain and that to the organisms of decay is known as the detritus food chain. Such a kind of simulataneous transfer of energy through the grazing and detritus food chains is illustrated by the "Y" shaped energy flow model. As shown in the model, the relative amounts of energy distributed between the two food chains varies depending on the ecosystem structure.

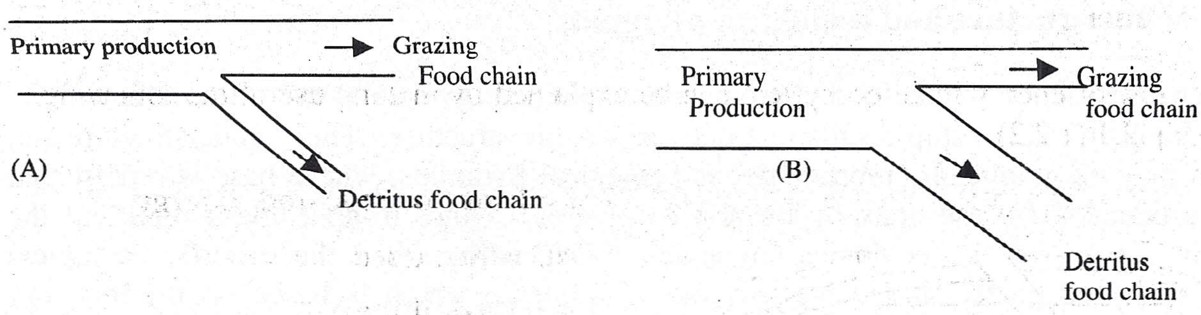


Fig.2.2 : `Y' shaped energy flow models (A) in a glassland where most of the energy is available to the herbivores while in a forest (B) most of the energy goes to the decomposers.

4. Nearly about 50% of the solar energy does not reach the earth's surface and hence it not available (NA) to the plants. Out of the available energy, only certain wave lengths of light can be trapped by the producers and the rest can not be utilized (NU).

5. Out of the total energy that is transformed in photosynthesis by plants, nearly about 50% is lost in respiration in the form of heat. However, the respiratory loss varies depending on the size –metabolism relationship and the environmental factors.

6. In any stable ecosystem, the input and the output energy will be equal in quantity but only the quality changes. While the input energy is in the form of solar energy, the output is largely in the form of heat and biomass.

7. Since all organisms are either directly or indirectly dependent on the primary production and since there is always loss of energy during its transfer, the energy demands of any trophic level can not exceed the energy supplies. It leads to a definite trophic structure.

8. During the flow of energy, there is degradation (loss) of energy but there is an upgradation of quality. All calories may be equal in terms of quantity but not in terms of quality. For instance, the work potential of fossil fuels is 2000 times greater than solar energy. If solar energy is concentrated by about 2000 times, it can replace fossil fuels in an automobile. This upgradation of quality is said to be responsible for the supremacy of the organisms at the end of the food chains. For instance, a top carnivore like a tiger can kill a much larger herbivore but the herbivore can not kill a smaller carnivore.

2.4 Trophic structure and ecological pyramids

The interaction of the food chain phenomenon (energy loss at every transfer) and the size metabolism relationship results in a definite trophic structure. The trophic structure and function may be graphically represented as ecological pyramids, whose base is represented by the producers and the apex by the top carnivores. Other trophic levels represent the successive layers of the ecological pyramids. Depending upon the criteria, ecological pyramids are recognized as (1) the pyramid of biomass, which is based on the total dry weight (biomass), or its caloric value (2) pyramid of numbers, in which the numbers of organisms in each trophic level are depicted and the (3) pyramid of energy, in which the rate of energy flow or productivity at successive levels is indicated. The pyramids of numbers and biomass may be upright with a broad base and a narrow apex or inverted with a narrow base and a wide apex or they may have various other forms depending upon the ecosystem, size of the organisms and rates of turnover. For instance, in an aquatic ecosystem, the pyramid of numbers is upright and the pyramid of biomass is inverted. But the pyramid of energy is always upright irrespective of the type of ecosystem as it is based on the directional flow of energy involving loss of energy at every transfer. The pyramid of numbers over-emphasizes the importance of smaller organisms while the pyramid of biomass over-emphasizes the importance of larger organisms. But the pyramid of energy on the other hand can depict the trophic structure of an ecosystem more accurately as it is based on the energy flow which in turn accounts for variations in size and numbers as well as the size-metabolism relationships.

2.5 Biological magnification or food chain concentration

It is evident from the flow of energy in an ecosystem that the amount of energy goes on decreasing along the length of a food chain. But all such substances which are neither digested nor excreted go on increasing along the length of the food chain. The concentration of such substances in living organisms is lower at the beginning of the food chains and higher at the end of the food chains. Such a kind of accumulation along the length of the food chain is known as food chain concentration. It is also known as biological magnification or bio-magnification or bio-amplification since the concentration of the substances or compounds or elements involved are magnified or amplified by the biota in a food chain.

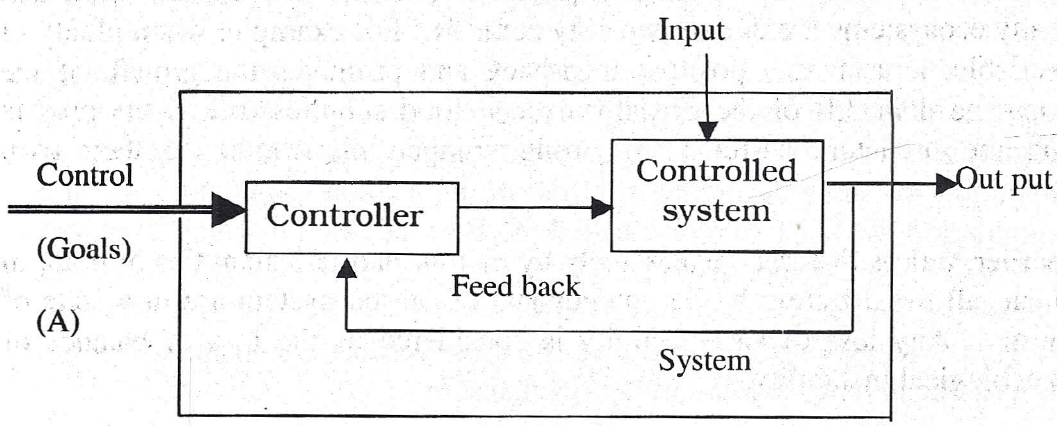
The problem of biological magnification was first noticed in 1950 in eastern Washington when extremely small quantities of radio active iodine, phosphorus, cesium and strontium released into the Columbia river by Atomic Energy Commission's Hanford plant have become accumulated in the tissues of birds and fish. A concentration ratio (amount of tissue / amount in water) of 2×10^6 was reported for radioactive phosphorus in the eggs of gees nesting on the Islands of the Columbia river. Thus, it was shown for the first time what was considered harmless could become extremely toxic to organisms at the end of food chains. Apart from the radioactive materials, several other non-degradable substances such as D.D.T (an insecticide), dioxins, polychlorinated biphenyls (PCBS) as well some toxic metals and heavy metals were also found to get concentrated biologically. It was also noticed that the concentration of the substances involved in biological magnification increased with age of the individual organisms in any trophic level. Rachel Carson, an American Hydrobiologist in 1962 through her book, `Silent Spring' showed how DDT was responsible for elimination of several predator birds through bioaccumulation of the pesticide. Large accumulation of D.D.T in a bird called the Bermuda Petrel which lives at a minimum distance of 450 km from the areas where D.D.T was ever used, clearly denoted the rapid spread and migration of the pesticides. Thus, D.D.T. the first broad-spectrum pesticide that brought a Nobel Prize to its inventor, Paul Muller, a Swiss Chemist was banned in USA in 1972 because of its extreme toxicity to non-target organisms.

2.6 Idiosyncratic concentration

Some of the substances involved in biological magnification are selectively absorbed and stored in certain organs or tissues of the organisms. For instance, radio active iodine is absorbed and stored in thyroid gland while the radioactive strontium which behaves like calcium is found to concentrate in bones of vertelrates and the shells of Mollusca. Similarly, DDT which is insoluble (but miscible) in water is highly soluble in fats. Hence, it accumulates in fatty tissues. Such a kind of selective uptake or absorption and accumulation is known as idiosyncratic concentration.

2.7 Homeostasis or cybernetics

All ecosystems attain stability in a stable environment through built in mechanisms of self regulation or cybernetics (derived from kybernetes meaning pilot or govern). The control systems of the ecosystems are internal, diffuse and invisible. The regulation is due to innumerable numbers of invisible links that control the flow of information and regulate all functions leading to a dynamic balance between production and consumption, natality and mortality, predators and prey, input and output through positive and negative feedback controls. Redundancy – presence of several species or components capable for performing the same function is one of the mechanisms of the stability. The stability of the ecosystem is either due to its ability to resist a change (resistance stability) or its capacity to return to the original condition when disturbed (resilience stability). For instance, the stability of a forest is due to its resistances since it is capable of remaining in a steady state in spite of all natural disturbances. But when the resistance is destroyed and when the forests are damaged, it takes several decades or centuries to get back the same forest or we may not get it back at all. On the other hand, it is easy to destroy an annual / seasonal grassland as it does not offer any resistances and it comes back as soon as the suitable conditions set in.



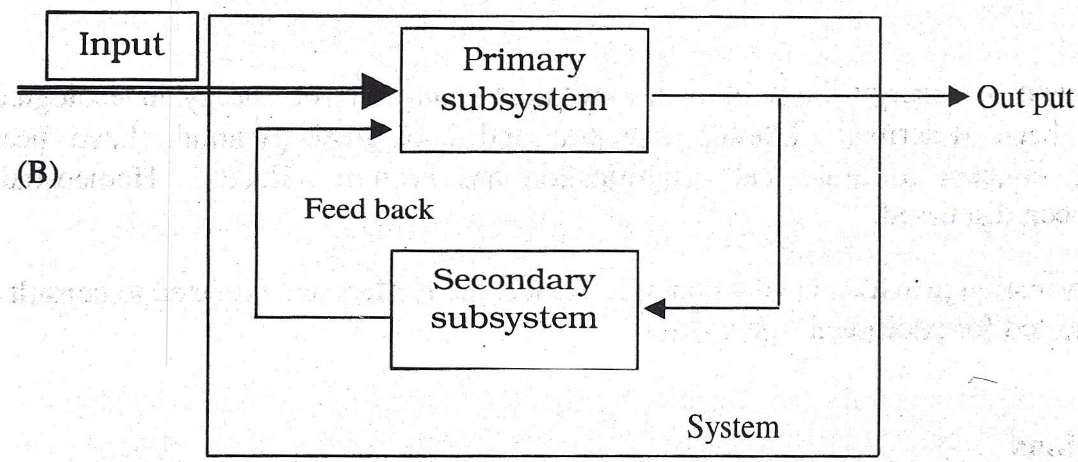


Fig: 2.2 A feed back control systems. A Man-made servo control mechanism and B feed back control system similar to an ecosystem with internal diffuse controls involving interactions between primary and secondary subsystems.

The feed back control systems operate something like a thermostat. For instance, in an automatic iron or a hot-air oven, the temperature is set or selected by us. It is called a set point. When electricity is supplied the input electrical energy is converted to an output of heat until the set point is reached. When once the set point is crossed, a part of the output (heat) becomes input (feedback) and the power supply is cut off automatically until the temperature falls below the set point. When the temperature falls below the set point, power supply is automatically restored.

Similar regulatory mechanisms operate in all higher organisms. For instance, thermoregulation and hormonal regulation in human beings can be cited as examples of self regulation. But the controls between prey and predator, between the down-stream and upstream units in any ecosystems are due to two way controls. For example, when plenty of prey (food) is available, it acts as a positive feed-back and promotes the growth of the predator. But when the demands of the predator exceed food supplies (prey), the prey is over-exploited and the predators suffer from strong competition leading to their own regulation.

As stated earlier, unless disturbed excessively by man or natural calamities or both, in a stable environment, all the different biotic components of an ecosystem are in a state of dynamic equilibrium. Any loss of such stability is considered as the loss of balance of nature. It leads to ecological instability.

Summary

The concept of energy, laws of thermodynamics and flow of energy in ecological systems have been described. Trophic structure and ecological pyramids have been described. The concept of biological magnification has been introduced. Homeostatic controls have been discussed.

The information provided is very concise. Hence, the readers are expected to consult the books suggested for additional information.

Model Questions

1. Define energy. With the help of an Universal flow model, describe the flow of energy in an ecosystem.
2. State the laws of thermodynamics and explain how the energy flow is governed by the laws of thermodynamics.
3. Describe the flow of energy through food chairs.
4. What is biological magnification? Explain how it occurs? Discuss the consequences of food chain concentration.
5. What is homeostasis? Explain the mechanisms of cybernetic controls.

Prof. K. B. Reddy

PLANT ECOLOGY
(Unit-III)

LESSON - III

BIOGEOCHEMICAL CYCLES or NUTRIENT CYCLES

Objectives

1. Introduction
2. Classification of biogeochemical cycles
3. Cycling of carbon
4. Nitrogen cycle
5. Phosphorus cycle
6. Sulphur cycle
7. Hydrological cycle

3.1 Introduction

The biomass of all organisms is composed of the chemical elements obtained from the abiotic environment of air (O_2, CO_2, N_2), water and soil. There are over 100 chemical elements but the maximum number of chemical elements found in the protoplasm of all organisms put together does not exceed 40. Among these, some elements like, C, H, O, N, P are found in all organizes and in large quantities while others are found in very low concentrations. If a chemical element is essential for the metabolism of an organism, it is considered a nutrient. Depending upon the quantities of the nutrients required by the organisms, they are divided into macronutrients and micronutrients. Quite often, than not, no relationship between the concentrations of the elements in the abiotic environment and biota is noticed. For instance, Carbon accounts for the bulk of the protoplasm while it accounts for 0.0365% of the atmospheric gases on volume basis at present and only 0.028% before industrialization. Similarly, bulk of the atmosphere is due to nitrogen but it represents a minor fraction in living organisms.

The life of every organism begins as a single cell, which grows by obtaining the nutrients from air, water and soil either directly (producers) or through food (consumer). All such elements tend to circulate in the biosphere in characteristic pathways from environment to organisms and back to the environment. Such, more of less circular paths are described as biogeochemical cycles (bios=life; geos= earth). Since the elements involved in such cycles are the essential inorganic nutrients, they are also known as nutrient cycles. Each element or nutrient has at least two reservoirs or pools. (1) the major reservoir is the large, slow-moving abiotic pool, and (2) the minor cycling or labile pool, a smaller but more active portion that is in rapid circulation, moving back and forth between organisms and their immediate environment.

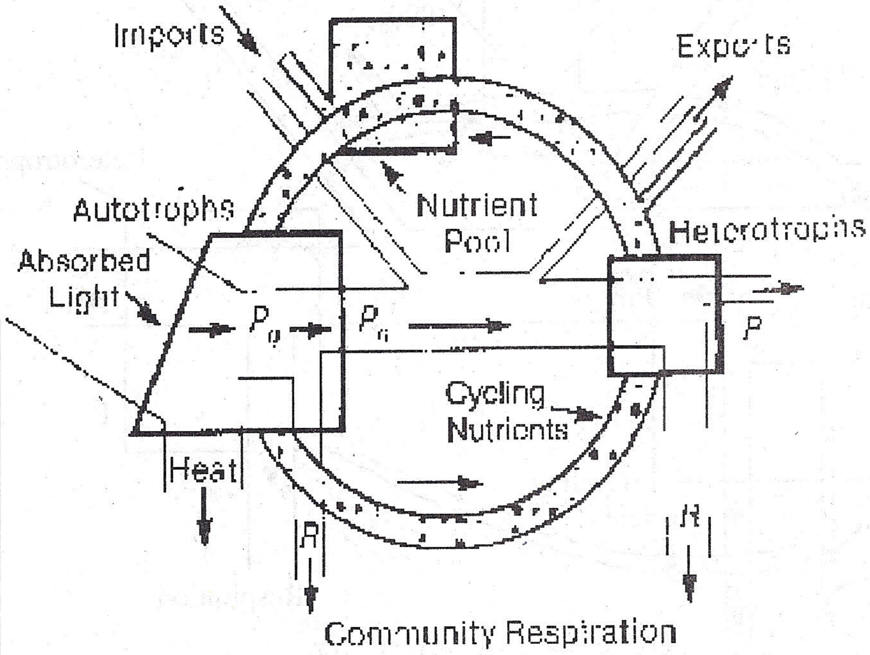


Fig. 3.1: A biogechemical cycle (shaded circle) superimposed upon a simplified energy flow diagram. Contrasting the cycling of material with the one way flow at energy P_g = gross production; P_n = Net primary production which may be consumed within the system by heterotrophs or exported from the system; P = secondary production; R = respiration, (After E.P.Odum, 1963).

3.2 Classification of biogeochemical cycles

From the stand point of biosphere as a whole, the biogeochemical cycles are divided into (1) the gaseous cycles where the chemical element occurs in a gaseous state in the reservoir pool (eg. Carbon, Oxygen, Nitrogen) and (2) the sedimentary cycle when the nutrient occurs in a solid state in the sediments or earth crust. (eg: Phosphorus, Calcium, Magnesium etc.). But certain elements like sulphur occur in solid state as sulphates / sulphides as well in the gaseous state as oxides of Sulphur (SO_2) or hydrogen sulphide (H_2S). Similarly, water occurs in the atmosphere and water cycles can not be treated either as gaseous cycles or sedimentary cycles. In case of gaseous cycles, cycling is perfect without any significant loss of nutrients but sedimentary cycles are imperfect and slow and hence there is leakage or loss of nutrients. The downward movement of an element in a sedimentary cycle is faster than the uphill movement. The link between the energy flow and biogeochemical cycles is shown in Figs. 3.1 & 3.2.

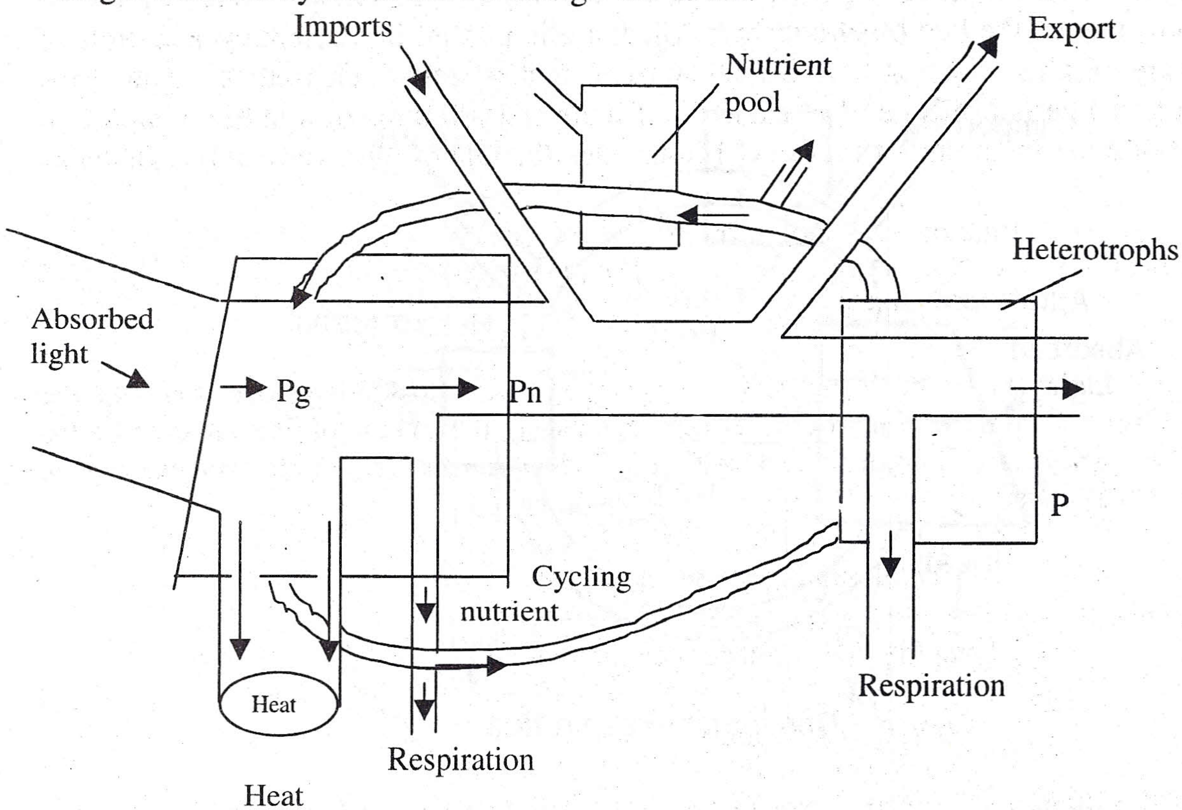


Fig.3.2 : Nutrient cycle super-imposed over the energy flow diagram.

The nutrients obtained by plants from soil, water and air are incorporated in plant biomass which is either consumed by the macro-consumers or decomposed by the macro-consumers and the nutrients are released for cycling. But before a nutrient is released or returned to the reservoir pool, it remains locked up in the protoplasm or tissues of the organisms for a certain period of time which varies depending upon the longevity of the organism / organ/ tissue as the case may be. For example the nutrients locked up in the trunk of a tree of long life span are out of the nutrient cycle until either the wood is burnt or decomposed but those present in the leaves or flowers or fruits are retained relatively for a short time. The period that an element remains in an organism is known as the residence time. The residence time is shorter for small organisms with rapid rate of turnover and longer for larger organisms with long life-span.

The total quantity of a nutrient present in any particular trophic level of a community is known as the `standing state' or `standing stock'. We can determine the standing state of a nutrients by multiplying the total biomass (dry weight) with the amount of nutrient present in every unit of biomass. For instance, if the total woody biomass of trees in a patch of a forest is say 100 tonnes and if the wood on an average contains 50% of carbon on dry weight basis, the standing stock of carbon can be calculated as 50 x 100/100 = 50 tonnes. Rate of turnover and turnover time are the two other concepts which are important in nutrient cycles. Rate of turnover represents the fraction of the total nutrient that is either released or reenters the system in a given period of time. For example, if there is 1000 units of a nutrient, and if 10 units go out or enter in an unit of time, say 1 hour, then the rate of turnover can be calculated as under.

$$\text{Rate of turnover} = \frac{\text{Rate of release or entry}}{\text{Standing stock}} = 10/1000 = 0.01$$

It means that about 1% of the nutrient is replaced by a new stock every hour. On the other hand, turnover time is the reciprocal of turnover rate. It indicates the amount of time required for the replacement of the whole standing stock by a fresh stock. The turnover time for the data given above can be calculated as under.

$$\text{Turnover time} = \frac{\text{Total quantity of the nutrient}}{\text{Quantity of the nutrient exchanged}}$$

$$= 1000/10 = 100 \text{ hours.}$$

From the illustration given above, if the rate of turnover is 0.01, its turnover time is 100 since only 1% of the nutrient is exchanged in the given period of 1 hour.

A quantitative study of nutrient cycles reveals that nutrient cycling is very rapid in tropics because of high temperatures and other conditions which favour rapid decomposition and slow in temperate and colder regions. Hence, the organic carbon content of the tropical soils is much lower than the temperate soils. In tropics the nutrients are intrabiotic (bound in the protoplasm of organisms) but in temperate and colder regions they are extrabiotic (present in the abiotic pool). Cycling of carbon, nitrogen, phosphorus, sulphur and water are given below.

3.3 CYCLING OF CARBON

Carbon is the most predominant element of protoplasm as it accounts for about 50% of biomass on dry weight basis. But, the amount of carbon present in the abiotic pool of atmosphere represents only 0.03% of the atmosphere by volume. A study of the photosynthesis reveals that CO_2 is obtained by plants (autotrophs) and it is converted to primary production which in turn is passed on to other consumers through food chains as already explained. The CO_2 thus fixed is released during respiration as shown in the following equation :

$$6CO_2 + 6H_2O \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} C_6H_{12}O_6 + 6H_2O$$

Thus the amount of CO_2 utilized in photosynthesis and that released in respiration are more or less equal and hence the concentration of CO_2 in the abiotic atmospheric pool should remain unchanged. However, the concentration of CO_2 has started increasing rapidly after industrialization, especially because the combustion of fossil fuels. The carbon present in the fossil fuels of coal and petroleum products belongs to the period when there were no human beings on this earth. For every tonne of fossil fuels burnt, about three tonnes of CO_2 is released. At a global level about 12.6 billion tonnes of CO_2 was produced during 2002. Out of this additional release of CO_2, nearly about 50% is absorbed by oceans and converted to insoluble carbonates and the remaining 50% is an addition to the atmosphere. On account of such anthropogenic production, the CO_2 in the atmosphere has increased from 0.028% (280 ppm) in 1900 to over 0.0365% (365pppm) by 2000. CO_2 a is major green house gas and it is responsible for global warming. A slight increase in CO_2 can increase plant productivity under optimum conditions but any rise in temperature due to global warming is going to reduce yields especially in tropics. It is predicted that if the average earth temperature increases by 1^0C from 15^0C to 16^0C, yield of cereals in tropics might decline by 10%.

3.4 NITROGEN CYCLE

Nitrogen is an essential macronutrient. It is found in such biomolecules like nuclei acids, amino acids, proteins and enzymes. Nitrogen accounts for over 78% of th atmospheric gases by volume but yet the plant growth, productivity and yields are limited b the deficiency of nitrogen as the atmospheric nitrogen is chemically inert and it can not b used directly by plants unless it is available in an oxidized state as nitrates or in a reduce state as ammonia. Nitrogen in the air gets oxidized to nitrate by natural factors such a lightnings and biological fixation or by a man-made industrial process. The nitrate incorporated in the synthesis of protoplasm (proteins, amino-acids) are degraded to ammoni during microbial decomposition. The ammonia is further oxidized to nitrates by th nitrifiers. At least three processes and several microorganisms are involved in nitrogen cyc (Fig.3.3).

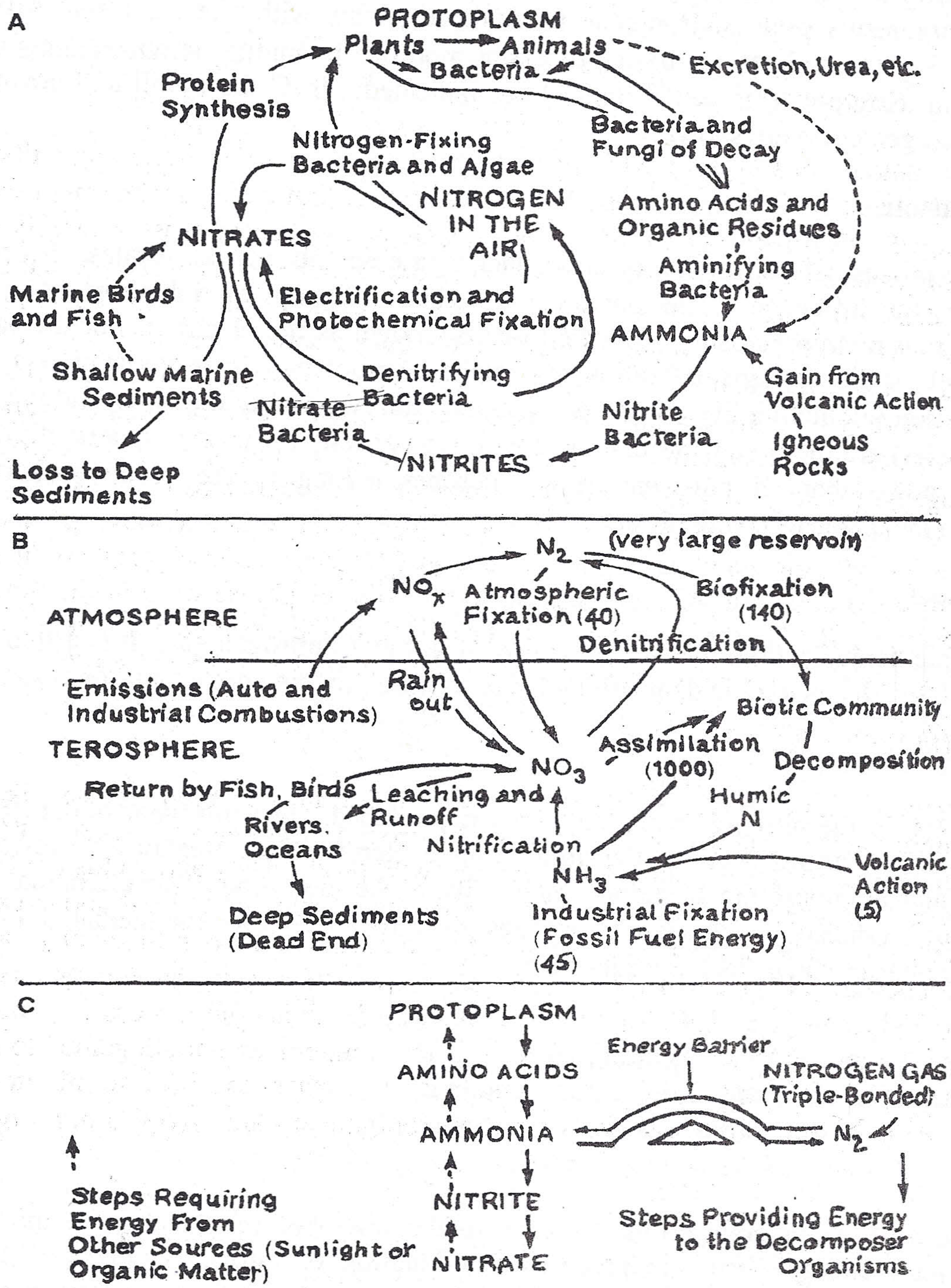


Fig.3.3: Nitrogen cycle (Explanation is on the next page).

Fig. 3.3 : Nitrogen cycle is represented in three ways. In **A** the recirculation of nitroge between the organisms and environment is depicted along with the microbial group responsible for key steps. In **B** the basic process as modified by human activities along wit the quantities in teragrams (1tg = 10^6 tonnes) are indicated. In **C** the uphill and downhi reactions in Nitrogen cycle are shown.

Nitrogen fixation

It is the process of conversion of atmospheric gaseous nitrogen to nitrates. It occur naturally under the influence of the powerful electrical discharge of lightnings or by th action of different microorganisms. The first one is known as the electrochemical fixatio and the second as the biological fixation of nitrogen. Root nodule bacteria of legumes nonsymbiotic, non-nodulating bacteria found in association with certain grasses and the blu green algal (BGA) are the organisms endowed with the capacity to fix atmospheric nitrogen It should be noted that all nitrogen fixing microbes belong to the group prokaryota Eukaryotes are incapable of fixing nitrogen.

Denitrification

Complete denitification involves reduction of nitrate to nitrogen gas. It is a step-wise processes mediated by anaerobic denitrifying bacteria which live in anoxic environments.

Nitrification

As shown in the nitrogen cycle, ammonia is produced when nitrogenous compounds are degraded by microbes such as the aminifying bacteria which breakdown proteins to amino acids and ammonifying bacteria which convert the amino acids to ammonia. The ammonia thus produced is oxidized to nitrates in a two step process mediated by two specialist microbes as shown as a formula here.

$$\underset{\text{Ammonium}}{NH_4^+} \xrightarrow{\textit{Nitrosomonas}} \underset{\text{Nitrite}}{NO_2^-} \xrightarrow{\textit{Nitrobacter}} \underset{\text{Nitrate}}{NO_3^-}$$

The down-hill reactions provide energy to the microbes involved while the uphill reactions require energy. But the process of production of nitrates from Nitrogen gas (nitrogen fixation) as well as the release of N_2 from nitrates (denitrification) require energy. Similarly, ammonia is produced by the chemical fertilizer plants from Nitrogen by making use of electrical energy and the release of nitrogen from ammonium does not provide any energy.

Production of oxides of nitrogen (NO_x)

Oxides of nitrogen (NOx) such as nitrous oxide (N_2O), nitric oxide (NO) and nitrogen dioxide (NO_2) are produced as pollutants during combustion of fossil fuels and biomass under the influence of high temperature. These oxides of nitrogen are responsible for global warming as the nitrous oxide (N_2O) is a green house gas, produces products of ozone at ground level (tropospheric Ozone) and contributes to acid rains.

Nitrate toxicity

Nitrates are important plant nutrients. They have been used in the production of explosives like dynamite (TNT). But when nitrates are present in drinking water in concentrations of over 90 ppm, hemoglobin in infants is converted to methamoglobin. When the concentration of methamoglobin reaches 70% of hemoglobin, the RBC fail to carry oxygen leading to asphyxation (death due to shortage of O_2) in severe cases. Compared to children, adults can tolerate a higher nitrate concentration upto 0.4 mg per kg of body weight per day but the concentration of nitrates in irrigation channels (also used for drinking water supply) sometimes exceeds 1000 ppm. When such water which is rich in nitrates is used for drinking purposes, highly carcinogenic nitrosamines are produced. Nitrosamines are proved to be teratogenic and mutagenic also. When rats are fed 5 ppm of N – nitrosodiethylamine, they developed malignant tumors. The mechanism of formation of nitrosamines is shown below.

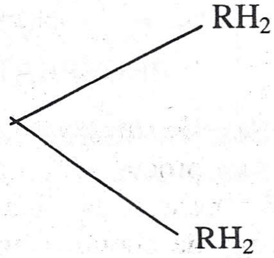
(1) NO_3^- ------------------------> NO_2^- (Nitrate reducing Bacteria)

Nitrate → Nitrite

(2) Proteins ---------> Amines (RNH_2)

(3) $NO_2^- + RNH_2$ ------------> O = N-N (Low pH)

Nitrite + Amines



N = nitrosamines

In view of the acute toxicity of nitrates, drinking water should not contain more than 45 ppm of nitrates.

3.5 Cycling of phosphorus

Phosphorus is a macronutrient present in such biologically important molecules like nucleic acids, ADP and ATP. Along with calcium, P is an important constituent of bones and teeth. The approximate ratio of C:N:P in protoplasm is 100:10:1. But yet the plant growth is quite often limited by the deficiency of phosphorus. Phosphorus along with nitrogen are responsible for eutrophication of water bodies, which results from the enrichment of water with nitrates, phosphates and other inorganic nutrients. Unlike C and N, the reservoir for P is phosphate rocks such as the Guano deposits of fossil bones. Erosion, leaching and application of phosphatic fertilizers like superphosphate or rock phosphate are the sources of Phosphorus Detergents also contain phosphorus (phosphate-free detergents are also available). The phosphorus cycle is in Fig.3.4.

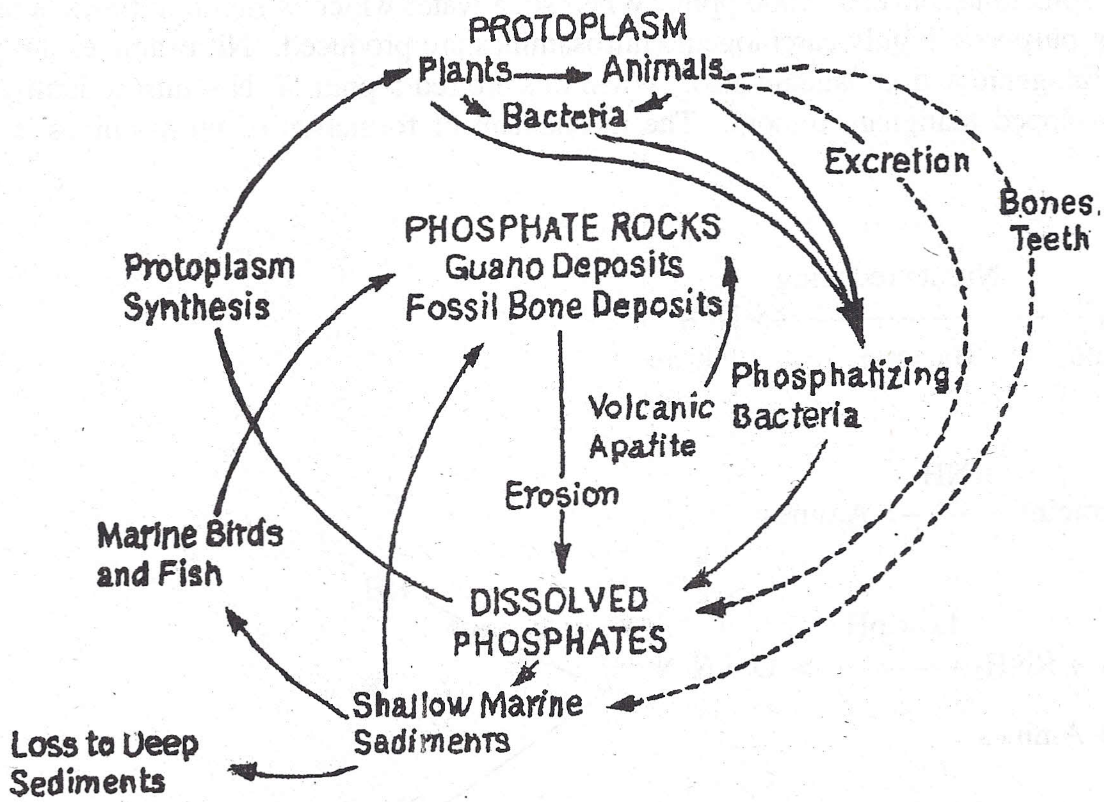


Fig 3.4 : The phosphorus cycle. Phosphorous is a rare element compared with nitrogen. Its ratio to nitrogen in natural waters is about 1 to 23 (Hutchinson, 1944). Chemical

erosion in the United States has been estimated at 34 metric tons per square kilometer per year. Fifty-year cultivation of virgin soils of the Middle West reduced the P_2O_5 content by 36 percent (Clarke, 1924). As shown in the diagram, the evidence indicates that return of phosphorous to the land has not been keeping up with loss to the ocean.

Annually about two million tonnes of phosphate is mined and used as fertilizer. Out of which about 60,000 tonnes is returned (cycled) and the rest is converted to insoluble or soluble phosphates and deposited in sediments. The down ward movement of P is much faster and the up-hill movement is slow. Hence, there is rapid loss of P which needs to be replenished. Certain bacteria and fungi in soils are found to mobilize P and make it awailable to the plants. The phosphatizing bacteria and VAM fungi promote plant growth by converting the insoluble phosphates to soluble ones. When the pH of the soil is reduced due to production of acids, bio-availability of P increases. Thus when sulphur is used as a fungicide, the availability of P to plants in alkaline soils improves owing to conversion of S to sulphuric acid. By the action of nitrifying bacteria, when ammonium is converted to nitric acid or when S is converted to sulphuric acid by the sulphur bacteria, solubilization of phosphorus is enhanced as shown under :

$$NH_4^+ \xrightarrow{\text{Nitrification}} HNO_3 \text{ (Nitric acid)}$$

$$H_2S \text{ and reduced S compounds} \xrightarrow[\text{bacteria}]{\text{Sulphur}} H_2SO_4 \text{ (Sulphuric acid)}$$

The microbes that produce acids at the sediment - water interface accelerate the production of soluble orthophosphates (H_2PO_4) or phosphic acid (HPO_4).

3.6 CYCLING OF SULPHUR

Sulfur is found in a few amino acids and hence it is an important component of proteins and enzymes. But the amount of sulfur required by the organisms is negligible compared to its availability and hence the plant growth is rarely limited by the deficiency of sulfur. Sulfur occurs in the atmosphere in the form of SO_2 and H_2S, in the sediments as sulphates and sulphides. Several different microbes are responsible for oxidation or reduction of sulfur as shown in the sulfur cycle. Colourless, green and purple sulfur bacteria oxidize H_2S to S and SO_4. Anaerobic sulphate reducing bacteria convert SO_4 to H_2S. Organic S is oxidized to sulphate by aerobic heterotrophic bacteria and the SO_4 is reduced to H_2S by anaerobic heterotrophic microbes (Fig.3.5).

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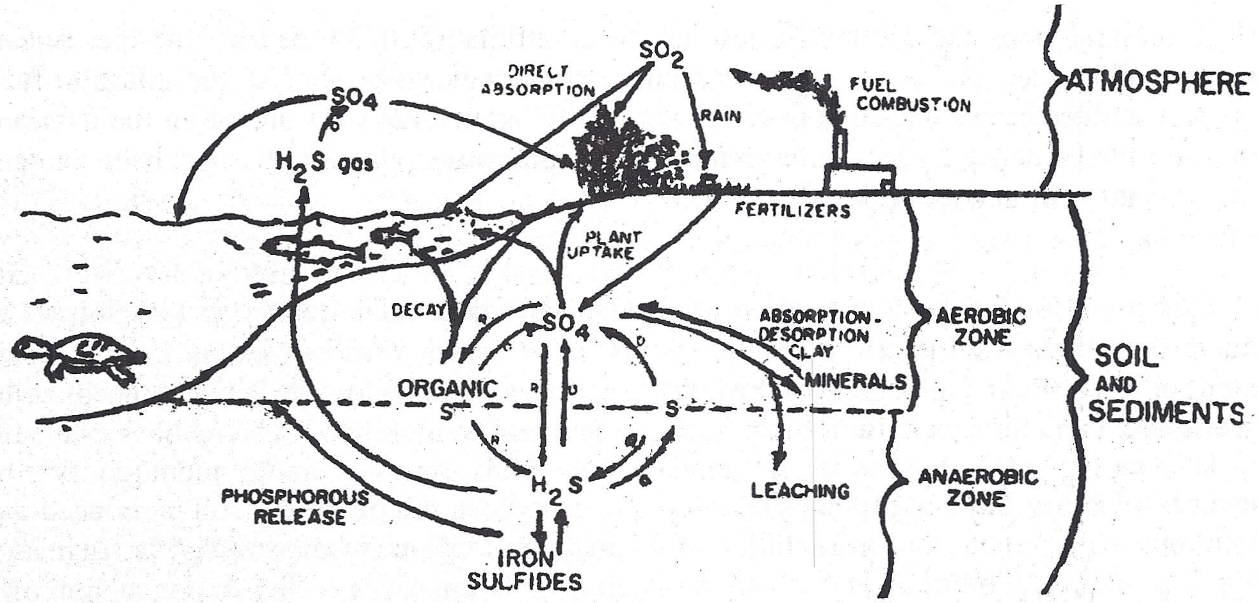

Fig 3.5 : The sulphur cycle linking air, water, soil. The centre wheel like diagram shows oxidation (O) and reductions (R) that bring about key exchanges between the available sulfate (SO_4) pool and the reservoir iron sulfide pool deep in soils and sediments. Specialized microorganisms are largely responsible for the following transformations: $H_2S \rightarrow S \rightarrow SO_4$ colorless, green and purple sulfur bacteria; $SO_4 \rightarrow H_2S$ (anaerobic sulfate reduction), desulfovibrio bacteria; $H_2S \rightarrow SO_4$ (aerobic sulfide oxidizers), thiobacilli bacteria; organic S $\rightarrow$ SO_4 and H_2S, aerobic and anerobic heterotrophic microorganisms, respectively. The metabolism of these various sulfur bacteria accounts for the incorporation of sulfate into organic matter, while animal excretion is a source of recycled sulfate. Sulfur oxides (SO_2) released into the atmosphere accounts of industrial air pollution and acid rains.

The main problem with S is the release of large quantities of oxides of sulfur (SOx), especially SO_2 as pollutant due to the combustion of fossil fuels like coal and petroleum products and extraction of metals from their oves by smeltering. Oxides of S are mainly responsible for acid rains in industrialized countries. Over 100 million tonnes of H_2S is produced by the decay of organic matter (68 million tonnes), ocean sediments (30 million tonnes) and about 3 million tonnes as pollutant.

Sulphur cycle is an example for interaction and interdependence of air, water and soil in regulation of biogeochemical cycles. It also indicates the interaction of geochemical and processes such as erosion, sedimentation, leaching, absorption and desorption, and biological processes such as production and decomposition. The largest reservoir for S is the soil and sediments while the atmosphere serves as a minor reservoir.

3.7 HYDROLOGICAL CYCLE or CYCLING OF WATER

Water is the most abundant but yet the most deficient inorganic compound which exists in nature in liquid (water), gaseous (water vapour) and solid (ice) state. A perusal of the hydrological cycle shown in Fig. indicates that the total quantity of water on the earth surface remains constant and any loss to space is only negligible. But yet there is severe water scarcity in several countries and quite a large number of countries are going to face acute water shortages sooner or later. The world bank warns that wars are going to be waged in future to have control over water resources. In fact, water which was considered to be a nonmarketable commodity has already become a product in great demand as evidenced by the fact that the market for water is increasing at the rate of 40% per annum.

About 71% of the earth's surface is covered by water. The total volume of water is about 325 million cubic miles or 1.4 x 10^9 km^3. Out of which 97.5% is salt water with a salt content of over 3% and rest 2.5% is freshwater with a salt content not exceeding 0.1%. Out of the total water, 1.7% is polar ice caps and glaciers and hence it is not accessible for human use. Thus only 0.77% of the water present in lakes, ponds, rivers, underground aquifers, soil and biota is accessible for our use. Out of the total fresh water utilized, 70% is used for agriculture, 20% for industry and the remaining 10% for domestic purposes at global level.

As the population and per capita consumption of water are increasing rapidly, the demand for water is rising. Ground water table is falling at an alarming rate. Alteration in monsoon cycles, increase in the frequency of El Nino, frequent droughts, destruction of forests etc reduce the water supplies and pollution renders the available water unfit for human consumption.

Summary

The importance of inorganic nutrients and their cycling with special reference to carbon, nitrogen, phosphorus and sulphur have been described. The impact of the human activity an nutrient cycles is also explained. The concept of rates of turnover and turnover times have been introduced. Nitrate toxicity and hydrological cycle are also briefly described. For further details, the readers are advised to consult the books suggested at the end of unit IV

Model Questions

1. What is a biogeochemical cycle? Describe the importance of decomposers in nutrient cycling.
2. Distinguish between a sedimentary cycle and a gaseous cycle. Describe the cycling of water.
3. What is a nutrient? Describe nitrogen cycle.
4. Explain how our own actions are responsible for altering the nutrient cycles?
5. Explain the importance of phosphorus and it's cycling.

Prof. K. B. Reddy

PLANT ECOLOGY
(Unit-III)

LESSON – IV
POPULATION INTERACTIONS AND NATURAL REGULATION OF POPULATIONS

Objectives

1. Introduction
2. Population attributes
3. Population interactions
4. Natural regulation of populations

4.1 Introduction

What is a population?

Population may be defined as a collection of individuals of the same species inhabiting any defined area and habitat. Thus, we can talk about urban population, rural population, population of Delhi, population of a small village or hamlet. Thus all individuals in a population belong to the same species.

What is a species?

A species may be defined as an assemblage of individuals which freely exchange their genes by interbreeding producing viable and fertile progeny of their own kind under natural conditions. Thus, there are usually no genetic barriers among the different individuals of a population which lead to reproductive isolation and speciation.

4.2 Population attributes

Like any living organism, a population is born, it grows, matures, reproduces and dies. In fact, these characteristics are common to all living organisms and hence they are described as the biological attributes. In addition to the above, populations have their own unique characteristics which result from the formation of groups. Hence, they are described as the group attributes. The main group attributes of populations are density, natality (birth rate), mortality (death rate) growth rate, migrations, dispersion, age distribution and interactions.

Density

In physical or material sciences, density is defined as the mass per unit volume but in populations it is measured and expressed either in terms of the number or mass per unit area or volume. Some examples are – 1000 trees per hectare, million bacteria per litre of water, 5 tonnes of fish per hectare of pond.

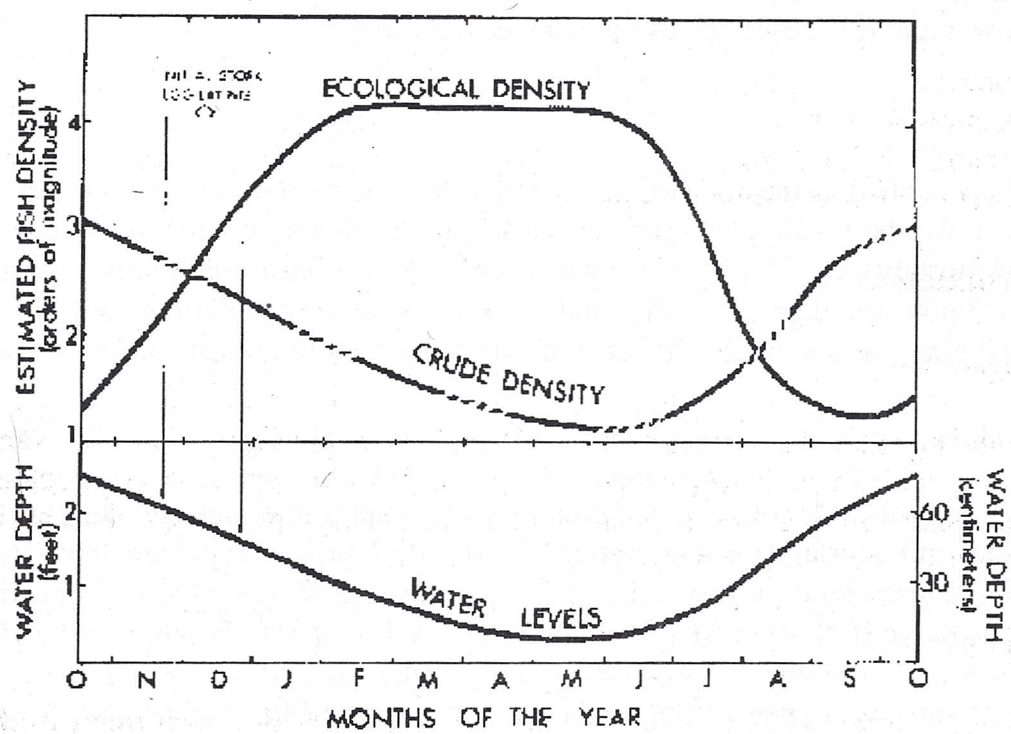

Fig. 4.1 : Ecological and crude density of fish prey in relation to the breeding of the stark predator. As water levels fall during the dry season in southern Falrido, the crude density of small fish declines (i.e. the number of fish per square mile of total area declines because size and number of ponds are reduced), but the ecological density (i.e, number per square meter of remaining water surface) increases as fish are crowded into smaller water areas. Nesting of the stark is timed so that maximum food availability coincides with greatest food demand by the growing nestlings (After Kahl, 1964).

It has a definite upper limit (maximum density) but the lowest limit is not defined. There can be a million bacteria in a gram of soil but not a million earth worms in the same soil. There can be 100 rabbits in a hectare of grassland but there can not be 100 elephants. Density can be described either as the crude density (number or biomass per unit area or total volume) or as the ecological density (density per unit area actually inhabited by the populations). Ecological and crude density of fish prey in relation to the breeding of a predator (eg. Stark) during different months as influenced by water depth is shown in Fig.4.1.

It is also known as the birth rate. It has an upper limit but the lower limit is not defined. It may be a positive value or zero but it can not be negative. The upper limit to natality is equivalent to the biotic potential of the species. It is equivalent to the reproductive capacity of the species under unlimited conditions. But under natural conditions, the natality is much lower and it is described as the realized natality.

Mortality

It is described as the antithesis of natality. It has a definite lower limit but not an upper limit. It can also be positive or zero but not negative. Since death is inevitable, a minimum amount of mortality can not be prevented even under the best conditions. Mortality is also dependant upon the age of individuals. For human populations and populations of commercial plants and animals, the rates of survival are more important for obvious reasons.

Growth Rate

The growth rate of a population depends upon the balance between natality + immigration and mortality + emigration. If N, M, I and E represent natality, mortality, immigration and emigration respectively, the growth rate of a population is positive if $N + I > M + E$, negative if $N + I < M + E$ and zero if $N + I = M + E$. If represented graphically in the form of curves with the population size as the dependent variable and time as the independent variable, depending upon the characteristic and habitat, we may have a J-shaped or S-shaped or sigmoid growth curve. The S- shaped growth curve has an equilibrium phase while the J-shaped curve does not have an equilibrium phase. Survival ship curves are illustrated in Fig.4.2. The logistic growth of *Drosophila melanogaster* and the population oscillations of yeast are shown in Figs.4.3 and 4.4 respectively.

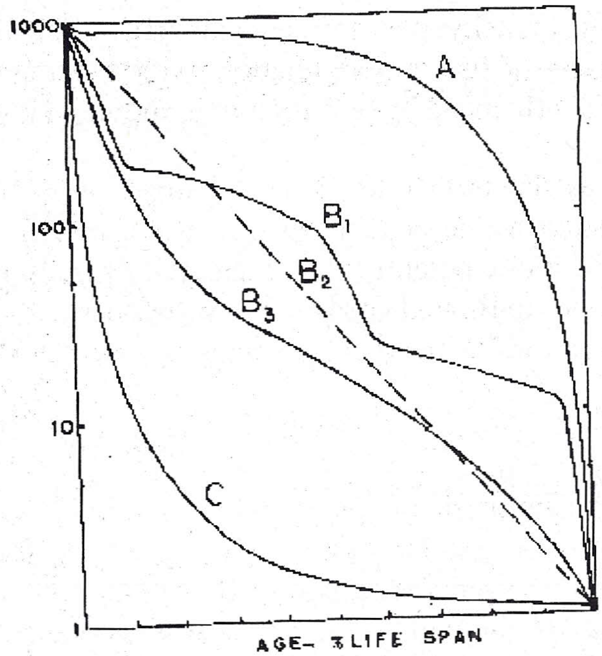

Fig. 4.2 : Several types of survivorship curves plotted on the basis of survivors per thousand log scale (vertical coordinate) and age as a percent of the life span (horizontal coordinate).Curve A is of the convex type, in which most of the mortality occurs toward the end of the life span. B_1 is a stair step type of curve, in which survival rate undergoes sharp changes in transition from one life history stage to another. B_2 is a slightly sigmoid type of curve that approaches B_2. Curve C is of the concave type, in which mortality is very high during the young stages.

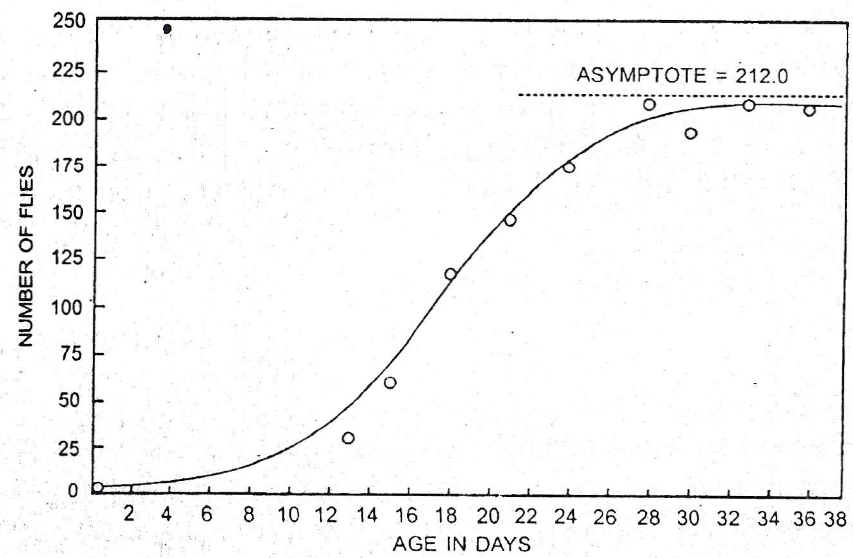

Fig.4.3 : The logistic growth of a laboratory population of Drosphila melanogaster

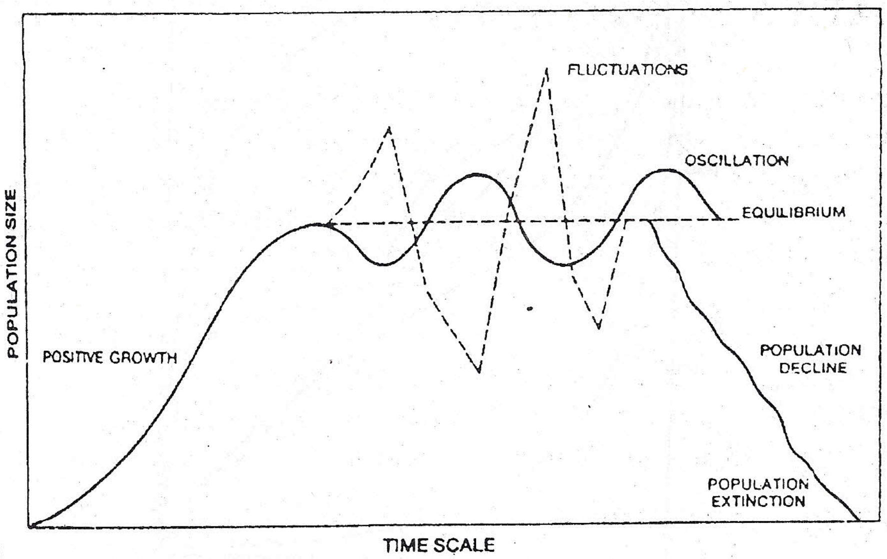

Fig. 4.4 : Stylized representation of the various phases of population growth form in yeast.

Migrations

Movement of individuals from one population to another and vice verse is known as migration. Inward migrations are known as immigrations and outward migrations as emigrations. The rate of migrations depend upon population density, competition and other environmental conditions.

Dispersion

It refers to the internal arrangement or distribution of individuals within a population. The individuals may be regularly or uniformly distributed as in case of man-made plantations or they may be randomly scattered (irregular distribution) or found in aggregates (clumped distribution) of different sizes.

Age distribution

Based on the importance of reproduction to the population growth, the individuals in a population have been assigned to three age groups by Bodenhimer (1938). They are: prereproductive, reproductive and post-reproductive age groups. Depending upon the relative duration of these phases, each species will have a characteristic age pyramid. In case of human beings an age pyramid with broad base indicates that the population is going to explore.

4.3 POPULATION INTERACTIONS

When populations of different species live in a community, the individuals interact with their own species (intraspecific interactions) and also with the individuals of other populations (interspecific association). If the outcome of an interaction is positive, it is indicated by +, if it is harmful, it is indicated by - and if it does not have any significant impact, it is indicated by 'o'. Haskel (1949) divided the interspecific interactions as indicated below in a Table 4.1.

Table 4.1 : Population interactions between two different species denoted by A & B. O, +, – indicate the outcome of interaction. + is positive and beneficial while – is negative and harmful. O indicates neutrality (no effect).

S. No.	Type of interaction	Species A	Species B	Nature of interaction
1.	Neutralism	0	0	It does not have any effect
2.	Competition of direct interference type	-	-	Mutual inhibition of both populations
3.	Competition of resource use type	-	-	Indirect inhibition due to resource depletion.
4.	Ammensalism	-	0	Population A is inhibited and B is unaffected
5.	Parasitism	+	-	Beneficial to parasite and harmful to host.
6.	Predation	+	-	Beneficial to predator but harmful to prey.
7.	Commensalism	+	0	Favourable to commensal but the host is unaffected
8.	Protocooperation	+	+	Favourable to both but not obligatory
9.	Mutualism or symbiosis	+	+	Favourable to both and it is obligatory.

The above interactions can be divided into positive interactions, negative interactions and neutral interactions depending upon their impact .

4.4 Natural regulation of populations

Under unlimited environmental conditions the populations attain their maximum biotic potential and continue to grow exponentially. But when the combined demands of the populations exceed the carrying capacity of the environment, populations are regulated at an equilibrium level because of the operation of environmental resistance. As a result, the populations tend to maintain at an equilibrium level. But the equilibrium is never static as the populations tend to oscillate because of the changes caused by the intrinsic and extrinsic factors. The mechanisms which are responsible for population regulation and dynamics are categorized into the density - dependent and density - independent regulatory mechanisms. The former to a large extent depends upon the density of the population. Hence it is an intrinsic (internal to the population) mechanism while the latter does not depend upon density. All such controls which result from the density such as the changes in natality, mortality, migrations, growth rate contribute to population regulation. For instance, if the growth rate per unit of a population is r, if the population size represented by the number of individuals is N and if the size of the population at the equilibrium or carrying capacity level is K, then the instantaneous growth rate of a population at any point of time is indicated by the equation :

$$\text{Population growth rate} = rN \left(\frac{K - N}{K}\right)$$

If N is small, the gap between K and N is wide and when K and N become equal, the population stops growing. When the density is lower and the size of population is small, population growth rate is limited because the product of rN is lower and at higher densities it is limited by the narrow difference between K and N.

The mechanisms of natural regulation include competition, parasitism, predation and migrations. The intensity of competition is usually directly related to the density of individuals. As the competition becomes severe, natality decreases, mortality and emigrations increase. Predation is a type of interaction in which the predator gets benefited and the prey is inhibited. Predation plays a very effective role in natural regulation of smaller prey species like insects by their predators such as lizards. But predation in larger organisms can not be as effective as in small insects since the larger predators may not be able to catch their prey even after a long chase involving greater risk to their life and limb. If a larger predator is injured during the dangerous hunting, it is going to be a virtual starvation for the predator. But a lizard on wall near a tube light in our house catches insects effortlessly with almost hundred percent success and without any risk. Predators, in turn are regulated by the prey. When plenty of food (prey) is easily available to a predator, the predator population increases rapidly.

Summary

Population has been defined. Group attributes of populations have been discussed. The concept of carrying capacity, environmental resistance, population growth curves and population regulation have been described. An outline classification of inter-population interactions has been given. Since the information provided is very concise, readers are expected to go through the topic of population ecology in any standard ecology text book.

Model Questions

1. What is a population? Describe the group attributes of a population.
2. Give an account the concept of carrying capacity.
3. Give an account of population growth and growth curves.
4. Explain the mechanisms of natural regulation of populations.
5. Give an outline classification of population interactions. Briefly explain the importance of inter-population interactions.

Prof. K. B. Reddy

PLANT ECOLOGY
(Unit-III)

LESSON – V
SUCCESSION : CONCEPTS, CLASSIFICATION AND GENERAL TRENDS

Objectives

1. Introduction
2. Stages in ecological succession
3. Theories and mechanisms
4. General trends
5. Concept of climax

5.1 Introduction
Definition

One of the functions of the ecosystem is development and evolution. The development and evolution of an ecosystem is commonly known as ecological succession. Ecological succession may be described as a directional change in community structure, function and process with time. It results from the modification of the physical environment by the community and from competition, coexistence interactions at population level. Thus ecological succession is community controlled. When uninterrupted by outside forces, succession is reasonably directional and hence predictable. Though the succession is a community controlled process, the rate of changes, limits to development and the patterns of change are determined by the physical environment.

Classification

Successions are classified based on when, where and how it occurs. They are divided into primary and secondary successions based on whether it commences in a habitat which was not inhabited by organisms or in a habitat which was denuded due to destruction of the communities that existed earlier. The xerosere and hydrosere are examples for primary succession and an old-fieled succession is an example for secondary succession. If the succession is initiated and sustained by the community, it is described as autogenic succession in which the changes are largely determined by internal interactions. On the other hand, if it is caused by external forces such as storms, fire, floods etc. it is called allogenic succession. Successions are also described as the progressive and retrogressive or regressive type. Degradative succession denotes the sequential colonization and replacement of different heterotrophic species on decaying materials. It terminates in total mineralization of biodegradable substances.

5.2 Stages in ecological succession

Clements (1916, 1928) recognized the following stages in an ecological succession.

Nudation: Formation of an open area due to denudation or destruction of the existing vegetation. Deforestation, ploughing, bull-dozing, levelling or any such practice which causes denudation is responsible for nudation. Nudation is the first step in a secondary succession.

Migration: When once an open area is formed, migration of propagules (any structure which helps in the propagation of a plant) from the nearby or surrounding communities takes place.

Establishment: When the propagules migrate, they have to establish in the denuded area. However, the process of establishment depends upon the soil, climate and the biotic factors.

Competition: When more number of species and individuals establish in an area, competition for space, nutrients, light, water etc. leads to elimination of poor or weak competitors and the dominance of stronger species.

Reaction: Reaction theory explains why certain species colonize an open area more rapidly than others. Those species which are capable of recognizing the changes in environment rapidly (for example the photoblastic seeds of weeds germinate when exposed to light and hence a crop of seedlings are produced field when a fertile fieled is ploughed) and responding rapidly (this is due to rapid rate of germination and rapid early growth) will colonize an open area faster and hence they become the primary colonizers.

Stabilization: In any mature community, the species and their populations are in a state of dynamic equilibrium as long as there are no major changes in the physical environment.

5.3 Theories and mechanisms

Several theories have been proposed and explanations have been offered to explain how a succeeding community replaces the preceding one and why the successional charges are reasonably directional. The prominent among them are:

Facilitation theory: According to this theory, a seral community modifies the environment in such a way that it is no longer suitable for its continuation. In other words the seral communities facilitate the invasion and establishment of the succeeding communities. This theory is valid in case of primary successions. For example, the lichens in xerosere bring about the disintegration (weathering) of rock and formation of soil which facilitates their replacement by liverworts and mosses.

Initial floristics: The species composition of a seral community depends mainly on the local flora at the time of initiation of succession.

Relay floristics: According to this hypothesis, the secondary and subsequent colonizers arrive in waves.

Tolerance and inhibition theories: They were proposed by Cornel and Slatyer (1977). Much work has been done on tolerance ecology after the theory of tolerance was proposed by Shelford (1913). Each organism has certain limits to each of the major ecological factors and an organism can not be found when conditions are unfavourable. According to inhibition theory, organisms are inhibited or suppressed under unsuitable conditions and such organisms tend to disappear.

Competitive exclusion or competitive elimination or Gause principle

It comes into operation when there is competition of the contest type between unequals. In such competition, the weaker one is eliminated and the stronger one becomes dominant.

C – S – R strategy:

The occurrence and distribution of any species is assumed to be dependent on disturbance as well as stress. The disturbance and stress may be low or high. Depending upon the degree of disturbances and stress, four different sets of conditions can occur as shown under :

		Disturbance	
		Low	High
STRESS	Low	C	R
	High	S	

When both the disturbance and stress are low, conditions are suitable for the growth of plants. Under such favourable conditions when several species and organisms compete, only the species with competitive (C) strategy service. When disturbances are high and stress is low as in cultivated lands, species with ruderal strategy (R) can become dominant. On the other hand, when disturbances are low and stress is high as in case of saline, alkaline soils, stress tolerant species (stress-tolerators) alone are capable of surviving. But when the stress as well as the disturbance are high, establishment and survival of the species is poor.

5.4 General trends in ecological succession

During a progressive ecological succession, the following changes are expected to occur in energetics, nutrient cycles, species and community structure and stability.

A. Energetics:

1. Biomass (B) and organic detritus increases as the organisms become larger.
2. Gross primary production (GPP) increases during primary succession. But during the secondary succession GPP may not show much increase.
3. Net primary production (NPP) decreases as the succession progresses towards the climax stage.
4. Community respiration (R) increases.
5. The production (P) respiration (R) ratio (P/R ratio) moves towards unity (P/R becomes equal to 1).
6. The B/P ratio increases and the P/B ratio decreases.

B. Nutrient Cycling:

7. Nutrient cycles become increasingly closed because of internal recycling of nutrients.
8. Turnover time and nutrient retention time (residence time) increase.
9. Cycling ratio (recycled/thruput or R/T) increases. It indicates that the recycling becomes more efficient.
10. Nutrient retention and conservation increases as the nutrient cycles become intrabiotic.

C. Species and Community structure:

11. Species composition changes (relay floristics).
12. Community diversity due to species richness increases. But in case of tropical ecosystems which are rich in species diversity the number species increase upto a certain stage only.
13. Community diversity due to evenness also increase But in case of tropical ecosystems due to the emergence of dominance evenness has been found to decline.
14. Species with r-strategies (rapid rate of reproduction, short vegetative growth and small propagules are the characteristics of r-strategy) are replaced by those with K-strategy (long life cycles, slow rate of reproduction and larger propagules).
15. Life cycles of the species increase in length and complexity.
16. Size of organisms and propagules increases (as the canopy closes, smaller propagules can not produces sudlings large enough to grow out of the think company to make an independent living).
17. Antagonistic or negative interactions among the populations of the communities are replaced by positive and mutualistic interactions.

D. Stability:

18. Stability due to resistance increases. For instance a tree or a forest is capable of offering lot of resistances against any kind of disturbance but when the resistance is overcome, it can not bounce back to the original condition immediately.
19. Stability due to resistance decreases. Resistance is described as the ability to return to the original condition when disturbed.

E. Overall strategy:

20. As the community proceeds towards the climax stage, efficiency of energy and nutrient utilization increases (Fig.5.1).

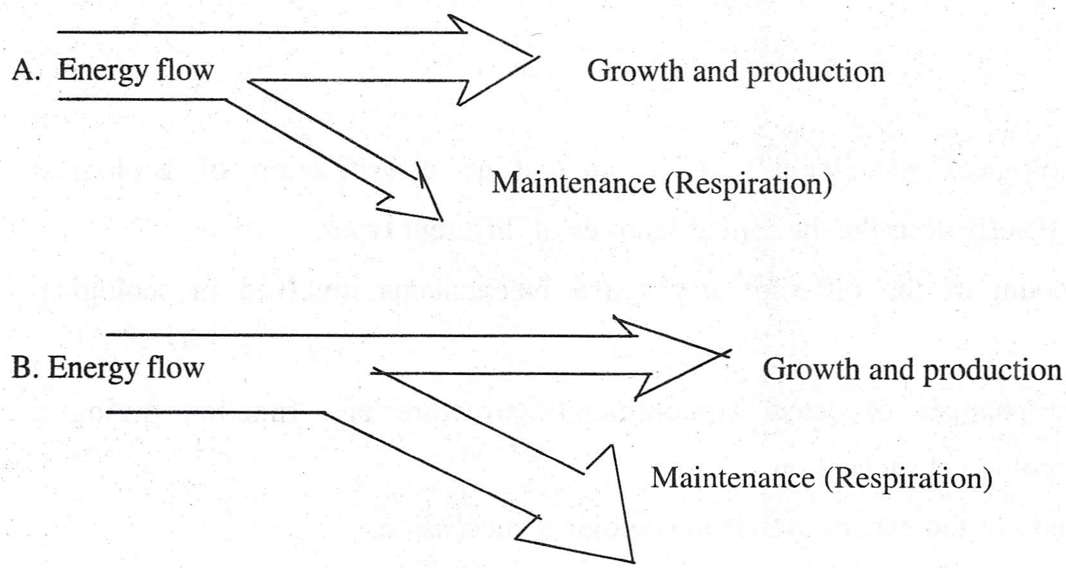

Fig. 5.1: Contrast in energy partitioning A. Energy flow in a seral (developing community). B. Energy flow in a mature (climax) community.

5.5 Concept of Climax

All progressive successions are presumed to end in a final stable community called the climax. There are two different theories about the climax. According to the monoclimax theory the final community is stable as along the climate of the area remains unchanged. Hence the final community is described as the climatic climax. Thus, according to the monoclimax theory, all progressive successions end in a climatic climax type of community whose stability is dependent upon the climate. But this monoclimax theory was bitterly criticized and opposed by several plant ecologists. They found the occurrence of different types of climax communities in any type of stable community whose stability is not due to climate but due to such factors as soil (edaphic climax) disturbances (disclimax), biotic pressure or fire etc. For instance, the grasslands of USA (prairies) are ecologically stable (climax type) but the stability of grasslands in India and Japan is due to burning, grazing and cutting.

Summary

All students of B.Sc., Botany are familiar with ecological succession, hydrosere and Xerosere. Hence Xerosere and hydrosere have been omitted. However, every attempt was made to define, describe and classify ecological successions, the process and mechanisms involved. General trends in ecological succession have been listed. But only a concise account is given with a view to provide the essential information in a nutshell. Hence, the reader is expected to consult any standard ecology text book for more information.

Model Questions

1. What is ecological succession? Give an outline classification of ecological successions. Briefly describe the salient features of different types.
2. Give an account of the different stages and mechanisms involved in ecological succession.
3. Describe the changes expected in community structure and function during a progressive ecological succession.
4. Give an account of the general trends in ecological succession.
5. What is a climax type of vegetation? Describe its formation and its characteristics.

Prof. K. B. Reddy

PLANT ECOLOGY
(Unit-iv)

LESSON – VI
ENVIRONMENTAL POLLUTION

Objectives

1. Introduction
2. Classification
3. Causes
4. Consequences
5. Control

6.1 Introduction

Environment in its broadest sense includes air, water, soil, climate and all organisms which influence an organism. Hence every organism is a part of the environment and nothing is apart from it. For convenience environment is divided into the abiotic (nonliving) and biotic (living) environment.

Pollution may be defined as an undesirable change in the physical or chemical or biological properties or characteristics of environment which can adversely effect the organisms. Any agent or factor or substance which is responsible for pollution is known as a pollutant. Thus a pollutant may be matter or energy. A pollutant is usually considered as a harmful or toxic substance but a pollutant often need not be a toxic substance. Any thing if present above or below the limits of tolerance of an organism or if found in place or at a time where/when it is not supposed to be present can become a pollutant. For instance, if fluoride is present either below 1.00 ppm (parts per million) or above 1.5 ppm in drinking water, it can become a pollutant. Nitrate is a very essential plant nutrient but its presence in drinking water may lead to nitrate toxicity such as the blue baby syndrome (methamoglobanemia) in children or formation of the carcinogenic nanitrosamines. Too much of a good thing can also become a pollutant.

6.2 Classification of pollution & pollutants

Based on the sphere in which pollution occurs, it is classified into air or atmospheric pollution, water pollution (hydrosphere) or soil pollution (geosphere or lithosphere). Based on the pollutants, environmental pollution is classified into primary and secondary pollution, noise pollution, radioactive pollution, thermal pollution, heavy metal pollution, pesticide pollution etc. It is also classified into different categories based on the activity that causes pollution. For example, industrial pollution, automobile pollution, domestic pollution, indoor pollution etc. Industrial pollution can further be classified based on the type of industry such as the thermal power plants, nuclear power plants, drug and pharmaceutical industries, agro-industries and so on. Pollution due to dust or aerosols or other suspended particles in air is the major cause of air pollution. Suspended particulate matter (SPM) may be composed of materials of different sizes as shown in Fig.6.1.

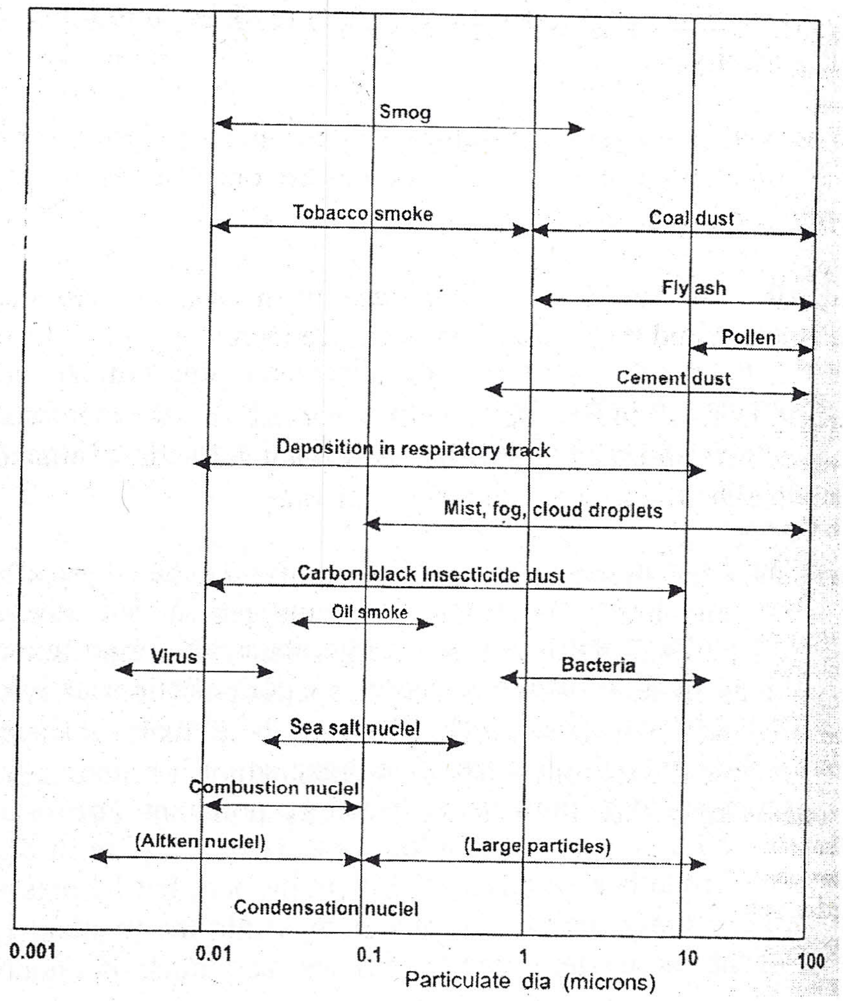

Fig.6.1 : Size of suspended particulate matter (SPM) present in the atmosphere. All particles below 10 μ diameter can get into our lungs and hence they are collectively known as the respirable dust or respirable SPM (RSPM) or SPM 10. Particles larger than 10 μ are physically obstructed in the upper part of the respiratory system.

6.3 Causes for environmental pollution

There are various causes for environmental pollutions. They can be summarized as under :

1) Decrease in land human ratio as the surface of the earth does not increase and as the growing numbers of people are required to share the same landed area, per capita space on earth surface gets reduced. Thus, the earth is getting over-crowded beyond its carrying capacity.

2) Per capita as well as the total consumption of resources is growing rapidly. As a result of over-use and over-exploitation of resources not only the resources are depleting but also the pollution levels are increasing.

3) Per capita as well as the total generation of waste materials, especially the nondegradable use and throw-away products are increasing much faster.

As a result of decrease in per capita space, over-use of resources and rapid increase in waste material output, the entire environment has become a big dust bin and the trash box of a rich man has become the living space of a poor person.

Pollution is thus the inevitable consequence of population growth, exploitation of resources and waste generation. Depending upon the process of utilization, manner of exploitation and the nature of waste and pollutants, the quality and quantity of pollutants vary. Combustion of fossil fuels is the root cause for air pollution. As shown in Fig.6.2 a primary pollutant like NO_2 which is produced when fossil fuels or biomass is burnt can trigger a chain of chemical reactions. Hence, the combined effect of pollutants is always higher than the total (sum) of their individual effects (Synergistic effect).

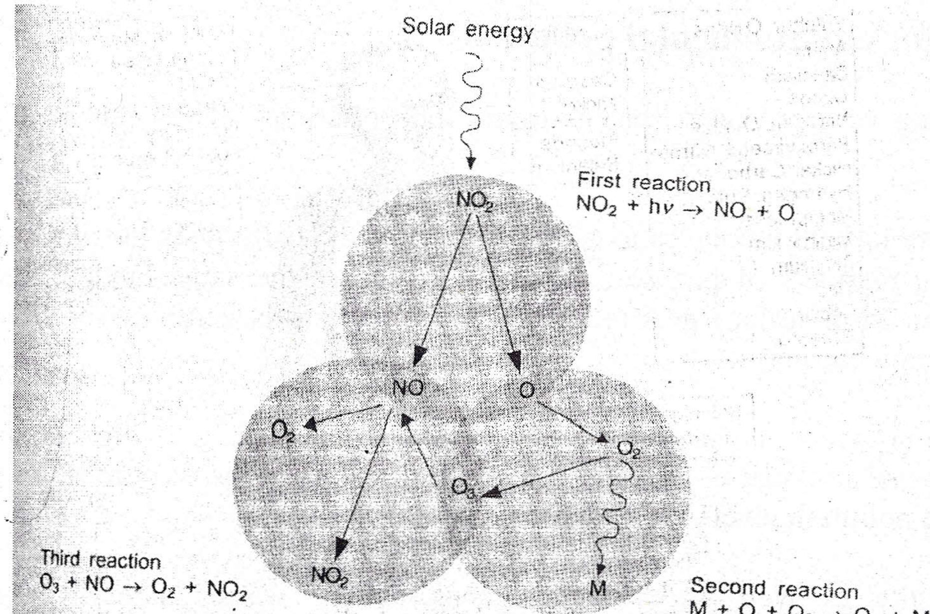

Figure 6.2 The cycle of chemical reactions initiated by NO_2. In the absence of hydrocarbons, the cycle initiated by NO_2 consists of three reactions. First, NO_2 absorbs solar energy, dissociating into a molecule of NO and a free oxygen atom, which is highly reactive. Second, the free oxygen atom then reacts with an ordinary oxygen molecule (O_2) to form ozone (O_3). Since the ozone formed in this way is unstable, having too much energy to exist for very long, it dissipates this excess energy by colliding with another molecule, transferring the excess as kinetic energy to that other molecule. If another molecule is not handy at the proper time, the ozone molecule will dissociate, leaving the free oxygen atom to try again. When a stable ozone molecule is formed, it can participate in the third reaction, reacting with the NO molecule produced in the first reaction, which forms nitrogen dioxide again. In this way all the molecular species exist in an equilibrium, and the primary result is that the energy absorbed by the NO_2 is transferred to the air as kinetic energy, warming the air.

6.4 Consequences of environmental pollution

The effects of pollutants depend upon the chemical nature of the pollutant, duration of exposure and concentration of the pollutant. The effect may be acute or non-acute, short-term (temporary) or long-term and chronic. It also depends upon the age, sensitivity and susceptibility of individuals. The effects of major pollutants on a human health are in Fig.6.3.

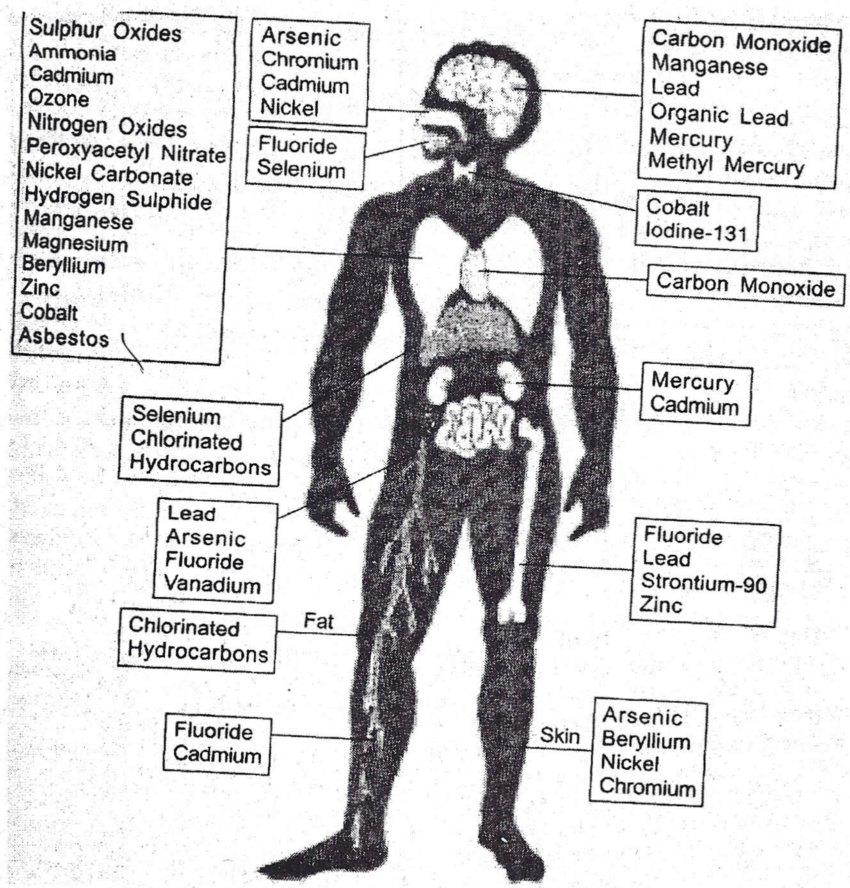

Fig. 6.3 : The site of effects of some major pollutants in human beings.

An average human being weighing about 65 Kg requires about 20 m3 of air (24 Kg) 2 to 3 litres of water (2 or 3 Kg) and 1 to 1.5 Kg of food (2000 to 2500 cal). We can live for several days without food, a few days without water and a few minutes without air. Fortunately nature has provided enough of the two most important things of air and water for every one. We are only struggling to obtain the third one (food) which can be produced only by green plants (photoautotrophs) and a few chemosynthetic bacteria. All the other organisms (consumers) are either directly or indirectly dependent on the food produced by plants. Whatever may be the technology if there is no rain (water), shine (sunlight) and soil, our factories can not produce the food, the fuel for all human beings.

The consequences of environmental pollution include the pollution of air and water, the most essential resources for life. Water has already become a marketable commodity. Water has become as expensive as milk though not more expensive. Disputes over sharing of water resources have become common. As warned by the world bank, in future wars are going to be waged to have control over water resources. Depletion of ground water, contamination and pollution of all water resources have become the greatest threats to our food security and health. If all waterborne microbial diseases can be controlled, mortality can be reduced and the life-span of people can be increased substantially. Apart from cholera, amoebiasis, typhoid, paratyphoid, jaunidce Schistosomiasis etc. caused by the microbes, presence of fluorides and arsenic in ground water, heavy metals, pesticides, toxic substances in lakes, reservoirs, rivers and other water bodies have become the common health hazards. Enrichment of water resources with nutrients such as nitrates and phosphates has been responsible for eutrophication of water. The symptoms of eutrophication are excess production which culminates in a significant increase in the biochemical oxygen demand (B.O.D) of water leading to total depletion of dissolved oxygen.

Pollution of air is primarily responsible for different types of respiratory ailments. It may cause temporary irritation of upper respiratory system or the long-term exposure may lead to chronic disorders especially in people who suffer from asthma. Inhalation of air-borne suspended particulate materials are responsible for silicosis, asbestosis, aluminosis etc.

Carbon moxoxide is responsible for breathlessness due to the formation of carboxyhemoglobin. Methane, H_2S, ammonia, chlorine and many other industrial fumes, accidental discharge of toxic gases like methyl isocynate (MIC gas), chlorine have claimed several lives (as in case of Bhopal gas tragedy).

On account of environmental pollution, death rates due to noninfectious diseases such as the environment-induced cancers, heart ailments, Kidney failures etc have started rising along with an increase in the environmental pollution establishing the synergistic link between pollution and health.

Pollution results in the loss or wastage of resources. For instance acid rains have caused extensive damage to the aeroplanes, bridges and other constructions built with corrosive materials. Pollution has been responsible for changes in the floristic, faunistic and the microbial biodiversity. Accidental oil spills due to discharge of crude oil over sea/ocean during transportation of crude oil across the oceans have been proved to be the direct or indirect cause for death of marine life including birds. Decline in fish populations of river Rhyne in Europe is due to the discharge of industrial effluents. Acid rains have been responsible for deforestation in industrial countries of USA and Europe.

Excessive use of pesticides such as D.D.T. in agriculture is attributed to the elimination of predator birds. All the major global environmental problems such as the ozone depletion, green house effect and global warming, tragedy of the commons, desertification, deforestation, depletion of the exhaustible and non-renewable resources are either directly or indirectly attributable to environmental pollution.

6.5 Control of environmental pollution

All countries have their own acts, rules, regulations, legislations and other legal provisions for control of pollution. Apart from the above, there are several international agreements, protocols and conventions to deal with the global environmental problems. For instance, the Montréal protocol for protection of ozone layer, the Kyto protocol for control of green house gas emissions, the conventions on biological diversity (CBD) for sustainable development of biodiversity, the IPCC (Inter governmental panel on climate change) are a few path breaking international actions for protection of environment. In India we have had a large number of acts such as the wild-life protection act, the forest protection act etc. and the environment protection act since 1986 (EPA – 1986). Rules and regulations have been framed to deal with different environmental problems in accordance with EPA 1986. We have set air quality and water quality standards and noise levels have been fixed. Information and data being collected with regard to the environmental carrying capacity for different regions.

Central and state level pollution control boards (CPCB and SPCB) have been established to enforce the rules and to regulate industrial pollution. Environmental impact assessment (EIA) has been made compulsory for all major developmental projects with significant impacts on environment. Monitoring and surveillance systems have also been established to compare the claims with facts and ground level realities. For all automobiles, norms and standards have been stipulated and the vehicles have to undergo periodic checks for obtaining the PUC (Pollution Under Control) certifications.

Industrial units are encouraged to adopt cleaner production technologies, waste minimization, waste recycling processes, effluent treatment systems and pollution control technologies and systems. Many industrial units have offered for international certification procedures and process. A definite change in the mind set of most industrialists and the realization that they can not continue to plunder the resources and abuse the commons have made them environment - conscious though not environment friendly.

Preference is given to pollution prevention rather than pollution treatment. EIA – Environment management systems (EMS), siting norms and criteria for location of industries, selection of proper technology and machinery have made it possible to bring down pollution per unit of industrial products. End of pipe line treatments are made compulsory to combat the pollution that could not be prevented.

Pollution is an environmental problem but its control in certain cases can become a social problem. For instance, when a polluting industry is closed, the workers/employees and their families who depend on them suffer. Thus in any poor country, people are prepared to die of pollution rather than to die of starvation. Hence proper environmental education and creation of proper awareness are essential for pollution control. Some data on phytoremediation are in Chaper IX, Taxonomy in the service of man.

Summary

Pollution and pollutants have been defined and classified. The importance of a clean environment, causes and consequences of pollution have been summarized. However, the information does not deal with any specific type of pollution or pollutant. Environmental pollution is such an important problem that every book on environment is a source of information on environment. The information incorporated above is neither intensive nor exhaustive. But it deals with the fundamentals of environmental pollution.

Model Questions

1. Define pollution. Explain why and how the environment gets polluted.
2. What is a pollutant? Describe the major pollutants of air and their impacts.
3. Describe the causes and consequences of environmental pollution.
4. How do you control environmental pollution?
5. "We cause pollution and we suffer from it" justify.

Prof. K. B. Reddy

PLANT ECOLOGY
(UNIT-IV)

LESSON – VII
CONSERVATION OF NATURAL RESOURCES

Objectives

1. Introduction
2. Classification of resources
3. Conservation of resources
4. Renewable energy sources
5. Alternate and additional sources of energy
6. Solar energy

7.1 Introduction

A resource may be defined as anything such as matter or energy which is useful to us either directly or indirectly. It includes both the animate (living) and inanimate (non-living) resources that may exist in solid or liquid or gaseous state. Thus the word resource includes everything that is beneficial but not harmful to the human beings. A resource may become a pollutant if it is either displaced or its concentration exceeds the limits of tolerance. Similarly, a pollutant can also be exploited as a resource.

7.2 Classification of resources

Oliver S. Owen (1971) proposed the following classification of resources as shown in Fig. 7.1.

Examples

1. Inexhaustible and immutable: Atomic energy, wind energy.

2. Inexhaustible and misusable: Solar energy, Hydel power.

3. Renewable: Biotic resources such as forests, wild-life, fish etc.

4. Non-maintainable but reusable: Precious stones and metals like gold, sliver, platinum etc.

5. Non-maintainable and non-reusable. Fossil fuels like coal and petroleum products.

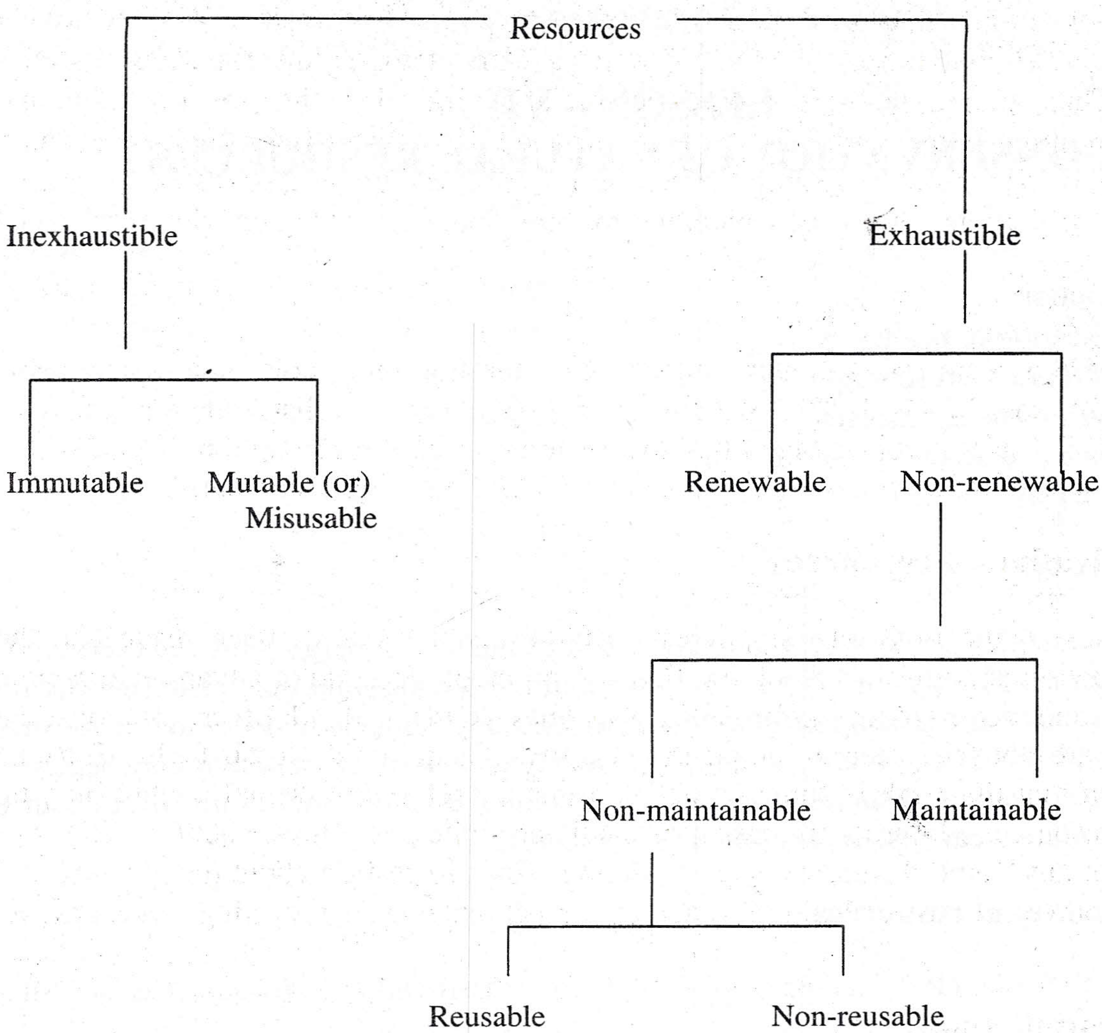

Fig.7.1: Classification of natural resources (based on Oliver S.Owen (1971).

There are various other classifications but they are neither exhaustive nor comprehensive. Frequently, we come across the terms such as energy resources, material resources, biotic resources, water resources, human resources and so on but all of them are covered by the classification given above.

7.3 Importance of resources

Per capita consumption of energy resources like electricity, coal, petroleum and other consumable resources like water, paper, metals and minerals are often considered as the indicators of economic development, either rightly or wrongly. But the very process of survival and existence of life on earth is totally dependent upon three natural resources of air, water and food. Among these three, only green plants and some chemosynthetic bacteria are capable of producing their own food materials from simple inorganic substances like water and carbondioxide. As stated earlier, in Lesson VI an adult weighing about 65kg requires at least 24kg ($20m^3$) of air, 3 litres of water and about 1.5 kg of food per day. We can survive for several days without food, only for a few days without water and for a few minutes without air. Thus, among the three resources essential for life, air is the most important and food is least in importance. Fortunately, we get air and water almost free. Hence, the entire struggle in life is for food only. But in future, we may have to buy air also just as we started buying water. If that happens, it is frightening to think about our own behaviour and social conduct.

The modern society is so much dependent on the non-renewable, non-maintainable and non-reusable fossil fuels that life without them would come to a halt unless alternatives are developed. It must be remembered that the exploitation and consumption of fossil fuels is mainly responsible for air pollution and deterioration of human environment.

7.4 Quantification of resources

Estimates of the total quantity of each of the resources have been made and the process of updation and revision of these estimates continues. In spite of advances in remote sensing (RS) and geographical information systemes (GIS) and all other technological advances, we are not fairly certain about the quantity of exploitable fossil fuels. But one thing is certain that the earth is finite in size and that a finite earth cannot contain infinite quantities of resources. In order to make reasonably accurate predictions about the status of any resource at any point of time we need a whole lot of information about the quantity and quality of resource, rate of consumption and its depletion, rate of recycling, regeneration, reuse etc.

7.5 Demographic quotient

It is indicated by letter Q. It denotes how long a particular resource will be available to the population and what will be its status at any given point of time. The following formula was suggested by Cloud (1968) for calculation of the demographic quotient:

$$\text{Demographic Quotient} = Q = \frac{\text{Total quantity of the available resource}}{\text{Per capita consumption}} \times \text{Population}$$

Though the above equation is apparently simple, there are practical difficulties in its usage. For instance, the total quantity of exploitable resource in most cases is not known with certainity. Similarly, per capita consumption varies depending upon the life-styles and economic development. Even the population figures in many of the countries are only estimates. Apart from the above, the Q value also varies depending upon the rates of recycling; development, availability and use of substitutes which vary depending upon the future technology. Since so many variables are involved, it is difficult to precisely calculate the Q value. Nevertheless, it warns us that the resources are exhaustible unless they are carefully maintained. We can use as much resources as it is generated so that its quality and quantity remains more or less constant. Unfortunately, the population as well as the per capita resource consumption are rapidly increasing without any corresponding increase in recycling or regeneration of resources. There is also a rapid loss of some of the resources into the environment in the form of pollutants. As a result, there is deterioration of resource quality and quantity along with pollution of air, water and soil.

7.6 Conservation of resources

Conservation is neither preservation nor a secure storage under protection. Conservation may be defined as sustainable utilization of resources in such a way that the needs of the present generation are satisfied without depriving the future generations of their share of resources. Leopold described conservation as living in harmony with nature.

The term conservation was coined by Gifford Pinchot in 1908. It is derived from the designation "Conservers", given to the British officials entrusted with administration and protection of natural resources. Conservation is also defined as the management of human use of biosphere so that it may yield the greatest sustainable benefit to the present generations while maintaining its potential to meet the needs and aspirations of future generations. Conservation embraces preservation, protection, maintenance, restoration, sustainable utilization and enhancement of natural environment. Conservation and development are often considered to be anatagonistic and incompatible but it is not true.

From the resource capital of nature, resources are drawn, utilized and waste materials and pollutants are released. As a result, resources get depleted and the environment gets degraded. Hence, it is necessary that we have to return to the resource capital whatever we have drawn as early as possible and as safely as possible. Similarly, minimization of resource use, maximization of resource utilization efficiency, waste reduction, recovery and recycling of resources are essential for conservation of resources. But the detailed methods of conservation of resources vary depending upon the nature of resource.

7.7 Strategies for conservation of resources

As long as the outflow and inflow or the rate of removal and addition become equal, a resource can be maintained infinitely. But the non-renewable, exhaustible, non-maintainable resources like fossil fuels can neither be recycled nor reused nor regenerated. Hence, these resources are only withdrawn without any chance of a recharge. But most of the biotic resources like forests, wild-life etc. are maintainable if properly managed and non maintainable if abused or misused. Therefore, we need resource-specific strategies for conservation of natural resources.

7.8 Conventional energy sources

We have come to depend too much on fossil fuels that every Nation is struggling for oil security. Oil is undoubtedly the major commodity that plays a decisive role in international politics. Unfortunately, these exhaustible, nonrenewable resources are not going to last long. In order to ensure that these fuels last longer, the best way is to minimize their use. Their use can be minimized by a number of ways as outlined hereunder :

Development of suitable renewable alternatives which may be used alone or in combination with fossil fuels

For instance, petrol is now mixed with ethanol which can be produced in large quantities. Similarly, tree-borne oils (T.B.OS) like the oils from *Pongamia, Jatropha* are tried successfully as suitable substitutes for diesel. More species can be found in the section Harnessing of wastelands Chapter IX Taxonomy in the service of man. Solar-powered cars, electrically charged battery operated cars, hybrid cars which are driven by solar energy as well as petrol or LPG or CNG are some of the alternatives. Hydrogen is considered an excellent fuel which can solve the twin problems of conservation of oil and prevention of atmospheric pollution. Unfortunately, the alternatives are more expensive and hence we continue to depend heavily on the exhaustible oil resources. Advances in technology, changes in manufacturing of substitutes may make them cheaper in future. In the meantime, incentives may be provided as a sort of encouragement for use of fuel substitutes in motor vehicles.

Improvement of public transport

If convenient public transport is made available, use of private and personal vehicles can be discouraged. For every kilogram of load or passengers per kilometer of transport, large public vehicles are more fuel efficient than personal transport. Per capita per km of transport by public transport requires less amount of fuel and produces fewer amounts of pollutants and requires less road space. Therefore, the use of public transport should be encouraged by providing rapid and dependable public transport.

Where the use of private vehicle is a must, car pooling may be encouraged to increase the occupancy of a car and to reduce fuel consumption, pollution production and traffic jams by reducing the number of cars on roads.

Proper tuning of the engine, maintenance of correct pressure in tyres, use of suitable fuel additives and lubricants can reduce fuel consumption and pollution production and increase fuel- use efficiency.

Use of bicycles for short distances should be promoted by allotting separate road space for cyclists as in China, Denmark and a few other countries.

Reduction in idling time by improving road conditions, prevention of traffic jams can also reduce fuel consumption and pollution.

As far as the fossil fuels are concerned, we should realize that every drop of fuel saved is a drop of fuel produced and a few grams of green house gas (GHG) emissions reduced.

Renewable resources

Renewable biotic resources like forests, wild-life, fisheries, crops, food etc. and abiotic renewable resources like water, air and land are renewable only if properly used and non-renewable if misused. Sustainable utilization of renewable resources is possible when they are managed by adopting comprehensive, holistic and integrated resource management practices based on ecological principles.

"In situ' as well as `ex situ' conservation of endangered species of plants and animals, afforestation, reforestation, conservation of biodiversity are some of the common practices suggested for conservation of biotic resources. In 1961, only about 70% of the planets biological productivity was consumed leaving a surplus of 30%. It increased to 120% in 1999. By the year 2050, we are going to consume between 180 and 220% of the Earth's biological capacity. Thus, we have already surpassed the carrying capacity of the earth. In order to sustain biotic resources it is essential that our consumption cannot exceed 100% of the biological productivity of the earth. The limited resources of the planet can be saved by the judicious use and sustainable development. If there is no halt to population explosion, if we don't change our affluent life styles, if the greed of the people continues to increase to exhaust the resources and pollute the planet earth we cause our own elimination. The philosophy of the Mahatma Gandhi as reflected by the following two statements attributed to the great soul are of immense value in resource conservation and environment protection.

1. The earth can only meet the needs of the people but not their greed.
2. Live more simply so that others can simply live.

Preserve and prosper; pollute and perish; the choice is ours.

7.9 ALTERNATE AND ADDITIONAL SOURCES OF ENERGY

Introduction

Definition of energy concepts, kinds and flow of energy have been given in lesson II of unit III. Classification of resources including those resources which are sources of energy is given earlier in this lesson. Unlike matter, energy does not have volume or mass and hence it does not occupy any space. The energy we obtain from fossil feels of coal and petroleum products is known the conventional energy and that obtained from sun, wind, biomass etc is the non-conventional energy. Non conventional energy obtained from renewable sources (solar energy wind energy, geothermal energy etc.) is known as the renewable energy. Additional sources of energy are obtained either from renewable or non-renewable energy, sources alcohol and bio diesel. They are obtained from tree borne oils (TBs). They can alcoholic fermentation of biomass and supplement fossil fuels and hence they may be treated as the additional sources of energy. We obtain clean electrical energy from the major hydel power plants but can be substituted with the energy produced from mini hydel power plants or the water mills.

Sustainable energy options

Fossil fuel consumption has been growing at the rate of 2 to 3% per year, with no end in sight. At the same time fossil fuel reserves are depleting very rapidly as they are non-renewable, non-reusable and exhaustible. Further extensive exploitation of fossil fuels has been directly and indirectly responsible for atmospheric pollution and global warming. Growing demand, rising cost and uncertainty or insecurity regarding the supply and availability of fossil fuels at affordable prices and the inevitable consequence of air pollution and global warming have made every one to think about energy management. For the management of both the environment and energy, sustainable energy option seems to be the best choice. As a result, there is a shift in our thinking concept and management of energy. The demand for energy is only going to increase. We need to satisfy the people by providing electrical energy to keep their homes cool during summer and warm during winter, to run their computers, washing machines, TVs, music systems and so many other gadgets that provide the human comforts. All this must be done at an affordable cost with minimum environmental impact. In order to do this, we have to be cautious and careful about the usage of fossil fuels and that we have to depend more on renewable, non-conventional, alternate and additional sources of energy.

7.10 Alternate sources of energy

In the mighty solar reactor, energy originates with the thermonuclear fusion of hydrogen to helium. Just about 0.1% of the solar energy on earth surface if converted to

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electrical energy it is adequate to supply the electricity needs of the world. The entire biomass produced by the plants is just equivalent to 0.1% of the solar energy. Solar energy can be put to work either directly or indirectly.

Direct uses of solar energy

1. **Solar hot water systems:** Hot water can be product by making use of flat plate collectors and the hot water produced by solar heating is stored in an insulated tank capable of retaining heat. Roof-top solar water heating systems have now become so common in many cities that they are found on many house tops.

2. **Solar space heating:** Air is heated in the solar heater and it is used for indoor heating. Sunlight is also allowed to pass through glass for lighting and heating purposes.

3. Solar energy is now widely used of evaporation of effluent water and for production of drinking water from sea water through distillation.
4. Solar cookers for cooking of food, solar driers for drying of grain/seed and food are some of the examples for direct use of solar energy.

5. Using solar photovoltaic cells (SPV) solar energy is converted to electrical energy. The energy may be converted to electrical energy and used for pump sets directly or stored in photovoltaic cells for subsequent use. Conversion of solar energy to electrical energy by making use of solar panels and storage batteries for street lighting especially in places where there is no electricity is becoming increasingly popular.

   Solar panels or photovoltaic cells in large numbers covering several square meters in different places are operating commercially. The power generated is supplied to homes directly or to the local power grid for distribution. With the development of thin and flexible photovoltaic films and the reduction in cost of solar panels, solar energy may become economically viable.

6. **Solar trough collectors (STC):** These are composed of long collectors which are trough shaped and tilted towards the sun. The light hitting the panels is collected, concentrated and reflected on to a pipe running down the centre of the trough. Oil or other heat absorbing fluid is circulated through the pipe. As the pipe is heated the fluid is heated and the heat is exchanged in a heat exchanger for production of steam. The steam is used for driving turbo generators. In Mojave desert of California 350 MW of electricity is generated by using the STC with a remarkable efficiency of 22% of the incoming solar radiation at a cost of 10 cents per kilowatt-hour (unit) which is only slightly higher than the power generated from coal.

7. **Experimental technologies:** In order to harness more of solar energy at an affordable cost, research for development of new technologies has been encouraged. 'Power tower' containing an array of sun-tracking mirrors, dish engine system etc are worth mentioning. Solar energy can be used for splitting of water to hydrogen and oxygen. The hydrogen may be trapped, bottled and used like LPG. But a sustainable technology is no currently available.

8. **Fuel Cells:** Instead of burning (combustion) the fossil fuel to generate heat, the energy of the fuel can be used for generation of hydrogen. Fuel cells requires less fuel as the fuel-use efficiency is about 45 to 60% compared to the 15% efficiency of the internal combustion engines. Instead of fossil fuels, solar energy and photoautotrophic algae can be used in fuel cells.

Indirect use of solar energy

In hydel power or hydroelectric power the driving force of water is used to run a turbine. Since solar energy has been responsible for evaporation of water, movement of water vapour, formation of clouds and precipitation the entire hydrological cycle is driven by the sun. Hence the energy obtained from hydroelectric projects is also derived from the sun.

Wind energy : Wind energy is also derived from the sun. Thus solar energy may be considered as the mother of all types of energies. The force of the wind may be connected to drive a motor for pumping water as in case of wind mills or it may be connected to a wind turbine to generate electrical energy.

Biomass energy: Woody biomass can be directly used to generation of steam. Non-woody biomass such as litter and garbage may be pelletized to produced coal or briquetted to producing fuel bricks or fermented to produce methane or alcohol. Thus, there are several options for production of energy from biomass. One of the most common and ancient methods of use of biomass is for cooking. In fact, fire wood provides more than 50% of rural energy needs. Biofuels, biodiesel are also derived from biomass, which in turn is derived from sun.

7.11 Additional renewable energy options

Geothermal energy, tidal power and ocean thermal energy conversion are the additional renewable energy options. The estimated potential for geothermal energy is 35,000 to 70,000 M.W. Tidal energy is quite efficient when the height of the tide is about 6m or 20 ft. Reversible turbines are becoming more popular as they can the directions. Ocean thermal energy conversion (OTEC) is in a state of infancy, which tries to make use of the temperature differences between the hot surface sea water and the cold bottom water. Ammonia is proposed to be used as a heat exchanger which absorbs heat from the surface water and as it is pumped to the bottom, it gets cooled and returned to the cycle. When ammonia vaporizes because of low boiling point, its pressure increases and that pressure is used to drive a generator.

Summary

Resources have been defined and classified. The importance of resources, quantification of resources and strategies for conservation and sustainable utilization of resources have been described. Strategies for conservation of resources have been suggested. The concept of demographic quotient has been introduced. A concise account of non-conventional energy sources and renewable energy sources has been given.

Model Questions

1. What is a resource? Give an outline classification of resources with suitable examples.
2. What is demographic quotient? Give an account of the different variables involved in the calculation of demographic quotient.
3. How do you conserve natural resources?
4. Give an account of alternate and additional sources of energy?
5. Describe the importance and the impact of fossil fuels.

Prof. K. B. Reddy

PLANT ECOLOGY
(UNIT-IV)

LESSON - VIII
PRINCIPLES OF PHYTOGEOGRAPHY

Objectives

1. Introduction
2. Flora and vegetation
3. Endemism
4. Continental drift

8.1 Introduction

The plant communities are never identical at any two different places. Even in a small place if we move from one part to another we notice some difference in structure, composition and physiognomy of the communities. With distances and difference in topography climate and biotic influences the vegetation changes. If we travel from Vijayawada to New Delhi by train, we will come across clearly different types of vegetation ranging from cultivated fields in plain lands to a scrub type of open forest in the heavily grazed dry hills in Adilabad district to dense forest in central Madhya Pradesh. On the other hand, if we go to the Himalayas, we will come across different types of vegetation which changes with latitude and altitude. As we move up the Himalayas the change in vegetation is again clearly marked but this is in respect to altitudinal distribution. Similarly, the animals also differ from place to place, e.g., Bengal tigers are found in India, Giraffees are found only in Africa and Kangaroos only in Australia. Plants and animals of any region are collectively called the biota. The study of world biota with regard to their origin, environmental interrelationships and distribution etc. is called biogeography. The science of biogeography has two major aspects, the historical one dealing with the origin of the biota of a region and the ecological one dealing with their environmental interrelationships. Historical biogeography takes into account geological features like origin of life, movements of land masses and possible climatic conditions in the geological past. Ecological biogeography that deals only with plant communities and vegetation is called Phytogeography. The classical approach of phytogeographical studies has been towards enumeration of the taxa of a region and on the basis of broad floristic differences, botanical regions have been recognized. With the aid of such information the causes and mechanism of evolution of different types of floras in different regions are also being studied. Thus, phytogeography has two major approaches of study: [A] descriptive or static phytogeography dealing with description of flora or vegetation of different botanical areas and [B] interpretive or dynamic phytogeography dealing with interpretations of causes of plant distribution. The interpretive aspects are based on certain basic phytogeographical and ecological principles. The list of phytogeographical regions is in Lesson IX in Taxonomy in service of man.

8.2 Flora and vegetation

The terms flora and vegetation refer to the plants and plant communities of a region. However, they differ in their meaning. Flora refers to the botanical composition of a place. It includes a list of all plant species found in that place. It doesn't make any distinction between a species which is most widely present and that which occurs rarely. Flora also indicates the taxonomy categories, classification and the way the species have come to occur over there. On the other hand, diversity is due to the dominance and abundance of certain species. For instance, a grassland, savanna and a forest may contain the same floristic elements but in a grassland grasses are most dominant while in the forest trees are highly important.

The distribution and occurrence of any species in any area depends upon the climate, soils and the limits of tolerance of the species. The relationship between mean annual rainfall and mean annual temperature on vegetation (biome) formation is shown in Fig.8.1.

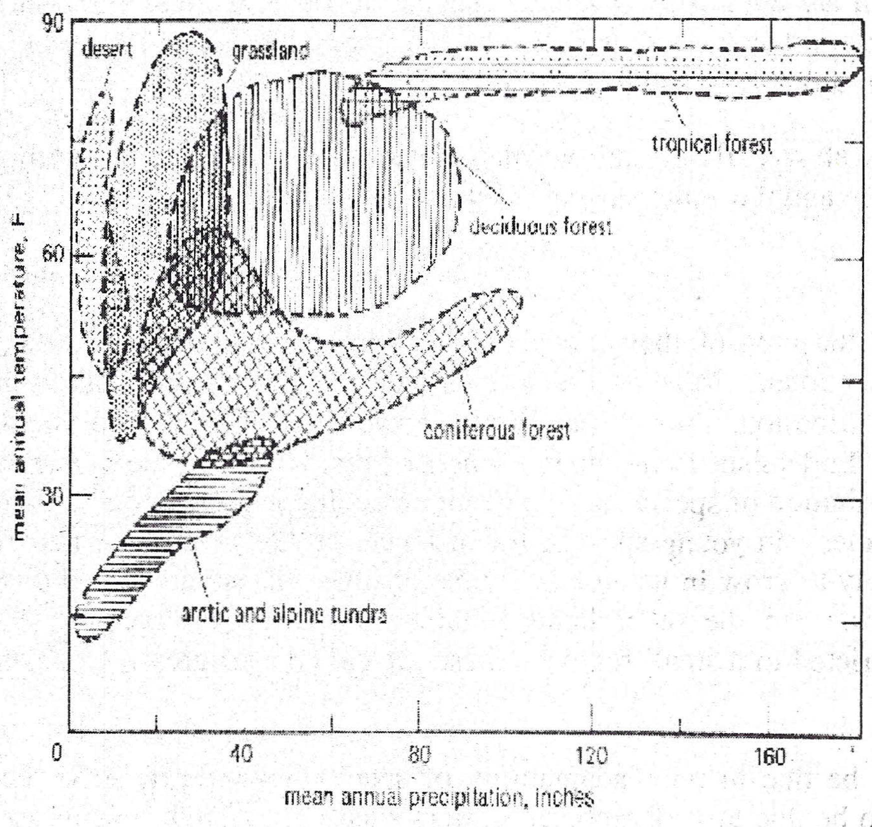


Fig. 8.1 : Distribution of six major biomes in terms of mean annual temperature and mean annual rainfall (in inches).

The major determinants of the climate are temperature, rainfall and solar insolation. The temperature of an area depends upon the altitude and latitude of the area. As we move from the equator towards poles, temperature decreases. Similarly, as we climb the mountain, temperature decrease with attitude. Under normal adiabatic conditions, the temperature decreases by about 6^0C for every 1000m in altitude. In order to notice a similar drop in temperature we may have to travel a distance of over 1000 km towards north or south from the equator. Temperature is also influenced by global ocean circulation patterns which move large amount of heat from the equator.

Rainfall to large extent is dependent on the global monsoon cycles. Rainfall is usually high in the equatorial belt and on high mountains and very low in dry deserts. The type of soils, their structure and physico-chemical properties also play an important role in the formation of a particular type of vegetation. The vegetation, climate and soil maps of any region or the world when superposed on each other, reasonably good correlation can be noticed. While the temperature influences the evaporation, precipitation and transpiration, rainfall determines the development of vegetation and soil formation. When a particular type of vegetation is formed, it can modify the soil and climate. Thus in all those areas where the temperature and rainfall are high tropical rain forests and red laterite soils are found. When the rainfall is not heavy but it occurs periodically and keeps the upper layers of the soils moist, grasslands, and prairie type of soils are found.

Apart from the above, flora and vegetation are also influenced by migrations, introductions, cultivation and the anthropogenic factors.

8.3 ENDEMISM

Species differ in the area of their distribution. Some are spread over a wide area. These are called cosmopolitan. Most of the species which are not cosmopolitan have still quite wide regional distribution. Some species are, however, restricted to a small region. These are endemics. Endemism is the phenomenon of restriction of species or taxa in a small region. The distribution of species is dependent on ecological and geographical factors and the age of the species. In young species, for instance, the distribution is narrow in the beginning and it is likely to grow in its area in course of time. These are called progressive or expanding endemics. On the other hand certain old species on account of gradual dwindling become restricted to a small region. These are called retrogressive or contracting endemics.

Endemism may be due to poor adaptability of species to wide range of ecological conditions. It may also be due to geographical barriers such as sea, high mountains deserts, wetlands etc. Evaluation of age of the endemic species helps greatly in determining its nature. If the species is of great geological antiquity with extensive distribution in the past but in the present time restricted to a narrow region either due to the geographical revolutions and or geographical and climatic changes. This is actually a relic of the past extensive flora and therefore, this is called relic endemism.

In certain regions around which the changes in environment are abrupt as in climatically isolated regions like islands, mountain tops etc. the number of endemics are more frequent. Wulff [1943] has shown that the Alps mountain in Europe have 200 endemic species. The islands of Madagascar have 66%, New Zealand has 72% and Hawaii 82% endemics.

The endemics of ancient origin are called relic or conservative or ancient or **paleo-endemics** and the newly developed endemics are called **secondary**, **progressive** or **neo-endemics**. Even among endemics some are restricted to very localized spot and these are called **local endemics**. Some times here and there a few mutants appear which do not compete successfully and therefore, disappear quickly. These are often referred as **pseudo endemics**.

In India the high mountain ranges of Himalayas form a range of distinctive climate especially at high altitudes. Chattarjee (1939) has estimated that as many as 3169 dicot species, or about 28% of the Himalayan dicots, are endemic to the region. Some of the well known endemic tree species of India are *Ficus religiosa, Ficus benghalensis*, *Feronia elephantum, Aegle marmelos* which are incidentally of some religious importance. Some important species like *Piper nigrum, Elettaria cardamomum* and oil crop S*esmum indicum* are also endemic to India. A species of *Cycas (C.beddomii)* is endemic to Tirumala Hills of A.P.

8.4 PLATE TECTONICS OR THE THEORY OF CONTINENTAL DRIFT

Many scientists have tried to understand the causes behind shifting weather patterns and long-term changes in climate so that we can predict what the future climate of any given region will be as a result of either human or natural causes. To date, the ability to make exact predictions is still elusive. However, everyone agrees that over the long term, change is inevitable. One slow, but spectacular, global change is that continents are continually on the move toward different relative positions on Earth; their movement helps us to understand earthquakes and volcanic activity. Let us look at the theory behind this movement of continental landmasses, known as plate tectonics or the theory of continental drift.

Tectonic Plates

The interior of earth is molten rock kept hot by the radioactive decay of unstable isotopes remaining from the time when the solar system was formed, about five billion years ago. Earth's crust, which includes the bottom of oceans as well as the continents, is a relatively thin layer [ranging from 10 to 250 Km] that can be visualized as huge slabs of rock floating on an elastic layer beneath, much like crackers floating next to each other in a bowl of soup. [An elastic layer of rock consists of rock that flows under heat and pressure.] These slabs of rock are called tectonic plates. Some 14 major plates and a few minor ones make up the Earth's crust as shown in Fig.8.2.

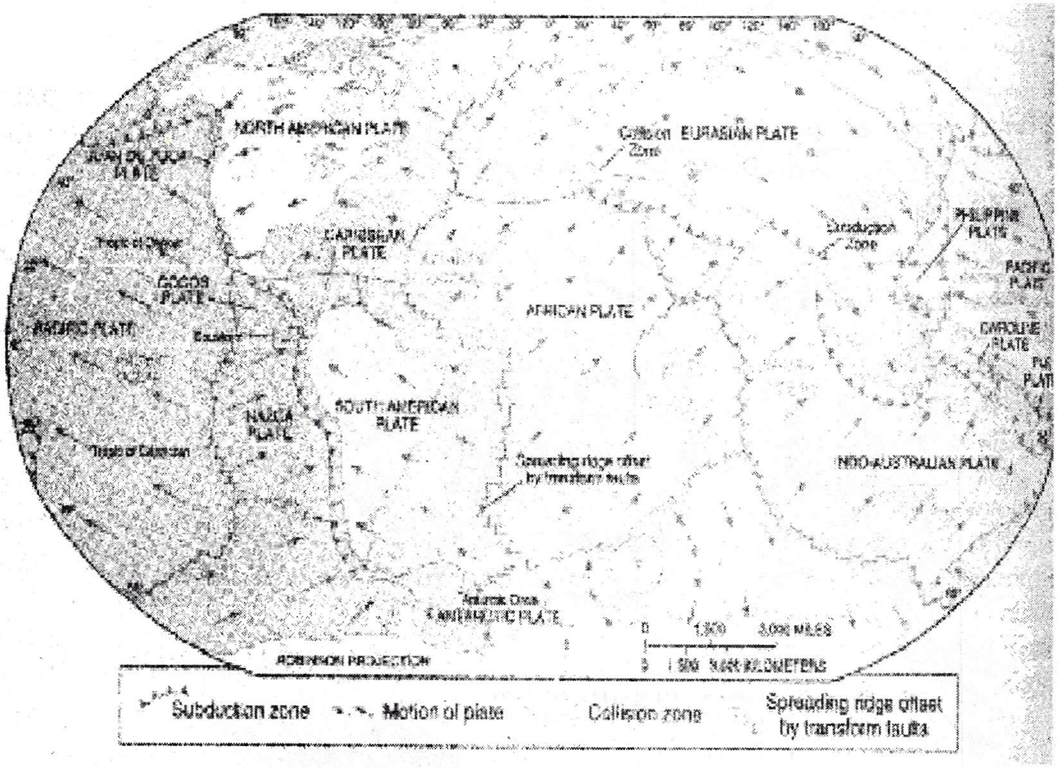


Fig. 8.2 : The 14 major tectonic plates making up Earth's crust and their directions of movement. The arrows in the figure indicate 20 million years of movement. (From GEOSYSTEMS; Introduction to Physical Geography 3/e by I.W.Christopherson. Copyright © 1997 by Prentice Hall, Inc).

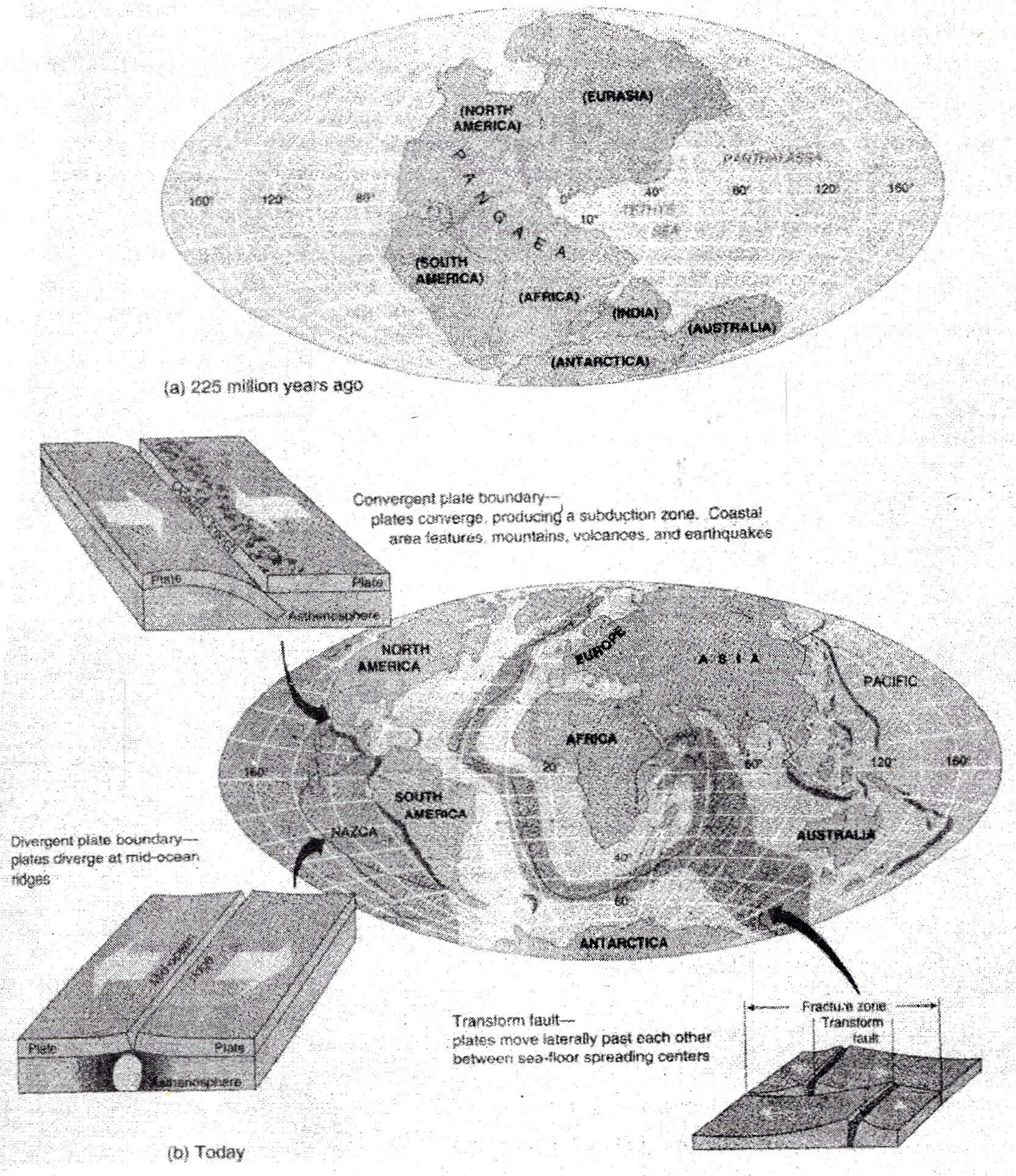


FIGURE 8.3 ***Drifting continents.*** (a) Similarities in types of rock, the distribution of fossil species, and other lines of evidence indicate that 225 million years ago all the present continents were formed into one huge landmass that we now call Pangaea. (b) Slow, but steady, movement of the tectonic plates over the intervening time caused the breakup of Pangaea and brought the continents to their present positions. (From GEOSYSTEMS: Introduction to Physical Geography 3/e by Robert W. Christopherson, Copyright © 1997)

During Devonian there was no difference between the flora of the South and North. But the Permian flora of Southern continents was different from that of the north. During the Permian, the Southern flora was dominated by seed ferns, *Glossopteris* and *Gangamopteris* which is usually known as the *Glossopteris* flora. South America, South and Central Africa, Australia, India and Antarctica are known as the Gondwana land. On the otherhand, North America including Canada, Greenland and Eurasia (Europe and Asia) are known as *Laurasia. Glossopteris* flora was present in Gondwana land but not in Laurasia. Before the disappearance of *Glossopteris* flora, all Southern continents were affected by giant glaciation. This glaciation affected India also which is now a part of Asia. Before the glaciation, the Carboniferous flora of South and North were similar. Both the areas had tropical climate, tropical flora and fauna.

The theory of continental drift was proposed by a German Scientist Alfred Wegener in 1915. This theory did not receive considerable support until 1960 when an American geophysicist Harry Hess provided the much needed support in favour of the theory of continental drift or plate tectonics. According to this theory the plates are not stationary and they are still moving very slowly. The evidence indicates that about 225 million years ago all the continents were positioned as one major continent, which we now call *Pangaea* (Fig.8.3). Within earth's semi-molten interior, hot material rises toward the surface and spreads out at some locations, while cooler material sinks toward the interior at other locations. Riding atop these convection currents, the plates move slowly, but inexorably, with respect to one another, as crackers might move if the soup below were gently stirred. The spreading process of the past 225 million years has brought the continents to their present positions and accounts for the other interactions between tectonic plates. The average rate of a plate's movement is about 6 centimeters per year, but over 100 million years this adds up to almost 8,000 kilometers in the fastest moving segments. Harry Hess (1960) showed that the ocean flora is less than 150 million years old while the continental rocks are older than 3500 million years. Hess theorized that the great convention currents being heated material to the surface from the interior of the earth. The energy moves continents apart. As the continents move they collide with each other. Such collisions are responsible for the formation of mountains such as the Himalayas and Urals. As the tectonic plates move, trenches are formed on the ocean floor where the old floor is consumed. As the plates more, the spreading ridges may extend under an existing continent resulting in its fragmentation and formation of a ridge in between. As the fragments move apart, they get separated by the widening ocean. The moving units are therefore areas which may contain continental masses or ocean floor only. The tectonic plates along with their cargo of plants and animals seemed to have moved at the rate of about 5 to 10 cm per year with an average of 6cm. These movements must have affected life in several ways though the changes were slow and gradual, noticeable only over a period of millions of years. The most obvious changes must have resulted from the movement of super continents relative to the poles and equator. During the long journey, the different land masses must have come to lie in the cold polar regions or in the hot equatorial regions or in the dry subtropical regions or in the cool and damp temperate regions.

Splitting of the single large land mass *Pangaea* into Laurasia and Gondwana land and their subsequent fragmentation and drifting along with their load of flora and fauna must have created barriers for migration and gene flow within a continuous population. Such separation of populations and their subsequent evolution into separate species or subspecies is known as '*Vicariance*'. On the otherhand establishment of land bridges owing to collision with other land masses facilitates migrations.

Summary

The topic deals with the principles of phytogeography. The importance of climate and soil on vegetation has been described. The major geographical events such as plate-tectonics and the concept of endemism and endemic species have been briefly described. However, the reader is advised to refer to any standard book on phytogrography for further information.

Model Questions

1. What is phytogeography? Give an account of the principles of phytogeogrophy.
2. What is endemism? Give an account of endemism and endemic species.
3. With the help of suitable evidences, describe the process of continental drift.
4. What is plate tectonics? Give an account of Alfred Wegeners theory of continental drift.

Prof. K. B. Reddy

PLANT ECOLOGY
(UNIT-IV)

LESSON - IX

FLORISTIC REGIONS OF THE WORLD

Objectives

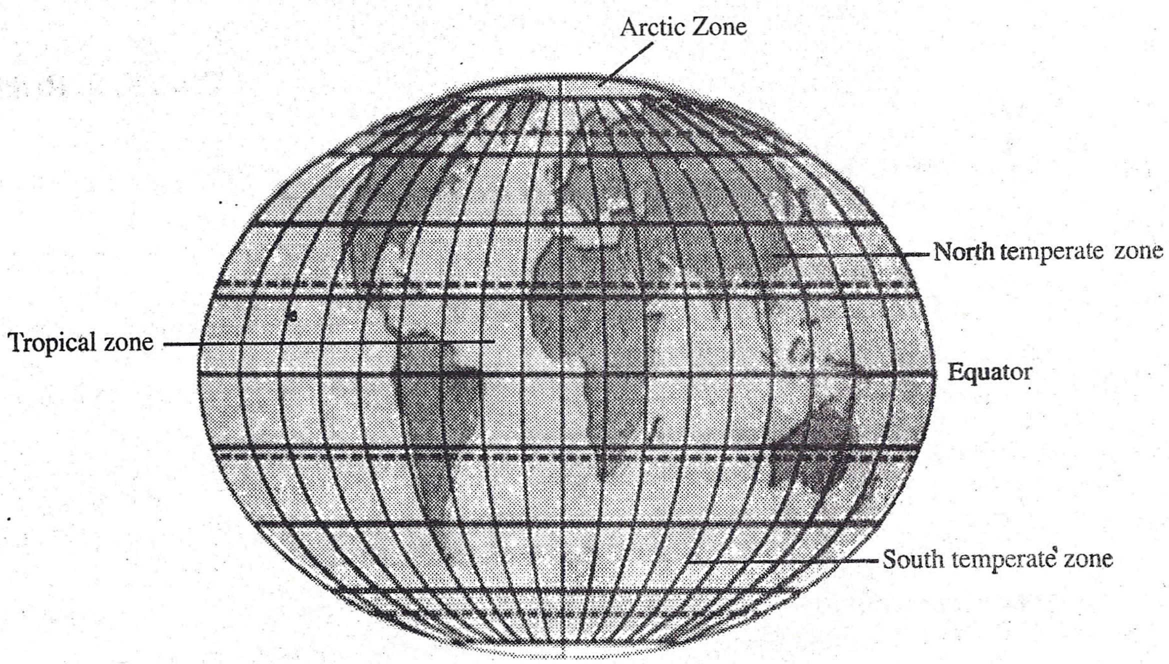
1. Introduction
2. Arctic zone
3. Temperate zone
4. Tropical zone

9.1 Introduction

The earth is divided into the following broad vegetational belts as shown in the Fig. 9.1.

The broad vegetation zones of earth are :

[I] The Arctic, [II] the North Temperate, [III] the Tropical and [IV] the South Temperate Zone.



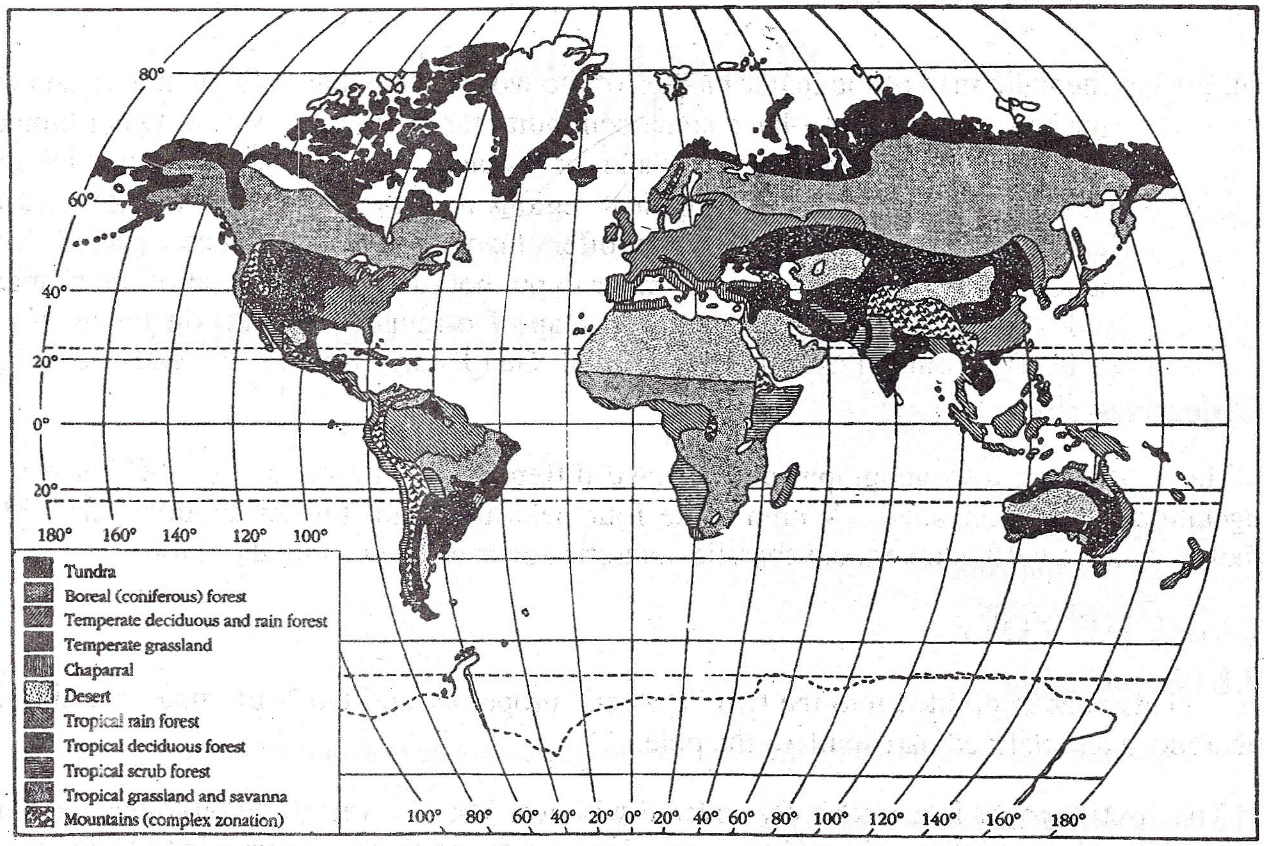


Figure 9.1. The major biome types of the world. (Redrawn by permission from E. P. Odum. 1959. *Fundamentals of Ecology.* Philadelphia W. B. Sunders Co.)

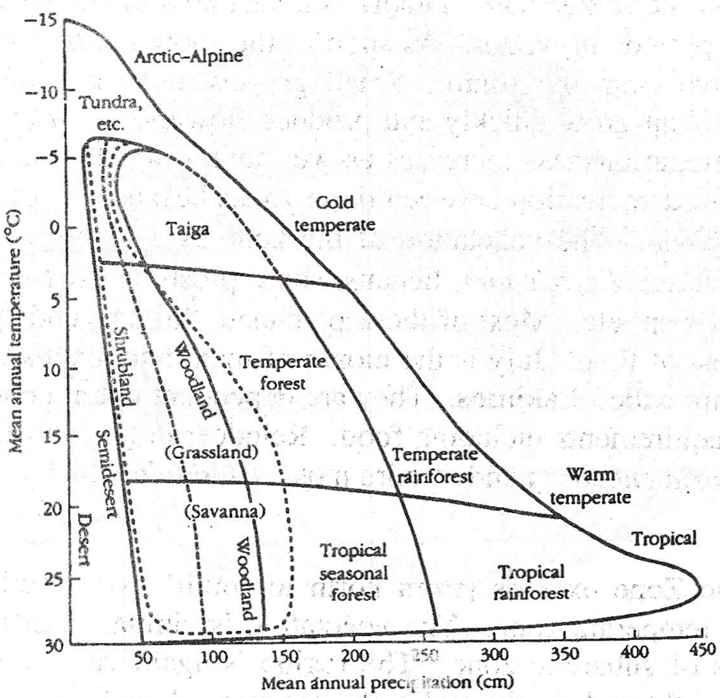


Fig. 9.1 : Schematic map of the major biomes of the world. Note that only the tundra and the northern conifer forest have some continuity throughout the world. Other biomes of the type (temperature grassland or tropical rain forest, for example) are isolated in different biogeographical regions and, therefore, may be expected to have ecologically equivalent but often taxonomically unrelated species. The pattern of the major biomes is similar to but not identical with that of the primary soil groups as mapped in. based on map of original vegetation in Finch, V.C., G.T. Trewartha, Physical Elements of Geography, New York, McGraw Hill, 1949).

These belts are also geographical and have different climatic conditions. Climate and vegetation go hand in hand. Within these four belts there are further subdivisions. The whole region of north temperate, subarctic antarctic zones is called Boreal or Holarctic.

9.2 ARCTIC ZONE

This zone is divided into the two [1] Arctic proper around the North pole, and the [2] subarctic, a less defined part south of the pole.

[1] The Arctic proper is permanently covered with ice. There is very little biological activity and only highly specialized plants like some algae are found there. Some what further south of 80^0 latitude grow large varieties of flowering annuals for a few weeks during the summer when the ice melts temporarily. This zone is called the **tundra zone**. Mosses and lichens form a thick mat on the frozen soil. Tundra is a vast area of barren land where life remains inactive over long periods in winter. As soon as the snow melts, animals come out of their hibernation or arrive from the south. Small grasses and some of the Rosaceous family members lying dormant grow quickly and produce flowers and fruits. The variety of plant species and their gregariousness increases as we move towards south of the subarctic zone. There is no clear cut demarcation between these zones because of temperature variations due to extension of the sea. The vegetation of the zone as a whole is chiefly constituted by mosses *Polytrichum* and *Erytrichum*, lichens, some prostrate growing grasses, *Cranberries*, *Rhododendron*, *Salix* sp. etc. Most of these perennate through underground root stocks that lie dormant for most of time. July is the month of maximum exposition of life. Humans in the tundra region are called **Eskimos**. They are dependent upon a common animal **reindeer** for most of their requirements including food. Reindeer in turn mostly eats lichens *Cetraria islandica* and *Cetraria cucullata* and 'tundra moss' *Cladonia* which is also a lichen.

[2] The Sub-Arctic Zone extends [from north to south] from southern arctic zone to the northern limits of temperate zone. The vegetation is similar both in North American and Euro-asian regions of subarctic zone. The region is again very cold. Bogs are abundant. Trees are of low height and shrubs and herbs are more characteristic in June and July. Tree

species are mainly represented by *Firs, Pinus* and small *Juniperus* among Conifers and *Betula*, *Salix*, *Populus* some oaks and chestnuts among angiosperms are common. Many arctic species of *Rhododendron* are also found in this region. The ground is covered with *Lycopodium, Equisetum, Pyrola*, several orchids like *Goodyera*, marsh marigold, insectivorous *Drosera* etc. Mosses and lichens are also abundant. In the Alaskan region there are dense forests of tall evergreen trees of spruce, *Tsuga heterophylla, Chamaecyparis nootkatensis*. At its coastal region the giant seaweeds *Macrocystis* and *Nerocystis* are abundantly found.

9.3 THE NORTH TEMPERATE ZONE

The north temperate zone extends roughly between 30^0 N. lat. and 55^0 N. lat. On account of some differences in vegetation and geography the north temperate zone is divided into two major sections: [1] the Old World or Eastern hemisphere consisting of Europe, part of North Africa and Northern Asia and [2] the New World or Western hemisphere comprising of northern parts of North America.

9.3.1 The North temperate belt of the Eastern Hemisphere

The vegetation of the north temperate zone of the eastern hemisphere may be divided as follows:

[a] **Western and Central Europe**: It constitutes a natural botanical region demarcated in the north by the subarctic and in the south by mountain barriers like the Alps. The British Islands are rather less cold due to the Gulf stream, a warm water current. The forests of western and Central Europe are dominated by several tall Coniferous trees like *Pinus sylvestris, Picea excelsa, Abies pectinata* and to some extent *Taxus baccata*. Among the angiosperms, oaks like *Quercus pedunculata*, *Q.robur* and *Q.sessiliflora*, ash tree [*Fraxinus* sp.], maple [*Acer platanoides*], chestnut [*Castania sp.*] are more important. Among the ground vegetation, *Hieracium*, thistle, *Salvia*, several species of *Campanula*, *Viola* sp., *Dianthus* and some orchids are commonly found besides several wild roses, anemones and buttercups. At high altitudes the tree populations decrease and grassy expanses are common with anemones, primroses, buttercups and many other beautiful flowers that grow along with grasses forming thick cushions during June and July.

The British Islands with a warm climate for their high latitude has somewhat different types of vegetation although the species content is much the same as described above for Western Europe. A few Mediterranean elements of the south are also found here like strawberries. Moors, bogs and peats are common in the U. K.

[b] **The Mediterranean flora** extends between about 30^0 and 40^0 N latitudes south of mountain ranges in Europe and in Asia around the Mediterranean Sea. The climate of this

region is rather warm temperate type highly suited for the growth of several economically important fruit trees. *Quercus ilex, Pinus pinea, P. pinaster, Populus sp.*, and olives are the common trees. Various nut trees and oranges are also common. Many foreign elements like palms, cacti, Acacias and beautiful flowering species are now commonly found in this region. In the Asian region of Mediterranean as in Arab countries, there are high mountains and expanses of sandy deserts on account of the low rainfall. Vegetation is rather poor. *Artemisia tridentata, Atriplex sp., Alhagi sp., Polygonum sp., Phoenix dactylifera* [date palm or kharjur] etc. are more conspicuous. In this region human culture had developed in very ancient times and wild varieties of many important crops like wheat, barley, grape, and pomegranate are still to be found. Walnuts [or Akhrot, *Juglans regia*] are cultivated for economic purposes.

[c] **Northern Africa**: This region is essentially similar to the Mediterranean of Europe and consists of northern parts of Morocco, Algeria, Libya and Egypt. The Moroccan region has the high mountains. On the whole the rainfall is scanty and the vegetation is sparse. In cooler regions on mountains conifers like *Pinus halepenis, Callitris quadrivalvis, Cedrus atlantica* are common besides the broad-leaved oaks [several species of Quercus]. Several herbaceous and shrubby species occur in deserts. *Stipa tenacissima* – a grass in this region is used in the manufacture of paper. Succulent xerophytic *Euphorbia* sp. and *Mesembryanthemum*, and hard woody *Acacia* sp. arcommon. The Sahara desert is a strikingly barren expanse without plants for miles. Around springs or oases *Phoenix dactylifera, Carissa, Astragalus* etc. are found. Around the Nile river and its delta rich crops of rice, wheat, legumes, vegetables and good quality cotton and many edible fruits are grown. *Salix* and *Acacia* also grow there.

[d] **The Himalayas, Eastern Asia and Japan** are the other parts of the temperate Eastern Hemisphere region. The vegetation of the Himalayas, the highest range of mountains in the world, is described in detail under the title "Flora and Vegetation of India" separately.

Tibet, China and Japan have a very diverse type of vegetation. China, being a country of dense human population and a very ancient human culture, has lost much of its original vegetation due to extensive cultivation. The conifer trees of China and Japan are *Cryptomeria, Sciadopitys, Cephalotaxus, Torreya*, etc. Maiden hair tree *Ginkgo biloba*—the only survivor of a vast group of antiquity dating back to 200 million years is still found growing naturally in China. *Cycas* is also common. Among angiospermic trees several *Rhododendron* spp., *Citrus*, palms and bamboos are quite characteristic in some regions. Camphor [*Cinamomum camphora*] *Magnolia, Begonia, Lilium auratum,* beautiful *Pittosporum tobiva* and many varieties of lilies are other important species. In fact horticulture has received highest attention in Japan.

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9.3.2 The North Temperate zone of the Western Hemisphere

It consists of parts of United States and Canada lying mostly between 30^0 to 55^0 N. latitude.

The Eastern coastal region of the United States and Canada in the temperate belt have some very characteristic species not met with in the interior of the continent, like *Shizea pusilla*—a tropical fern. The forests are composed mostly of conifers and deciduous trees like *Acer saccharum, Betula* sp., red spruce, *Pinus strobus, Abies balsamea* and *Thuja occidentalis*. The coastal land is rocky. On lower altitudes *Epigea repens, Myrica carolinensis*, some wild cherries, plums, roses, and a number of orchids like *Cypripeaium acaule* are abundant. In coastal waters, species of *Fucus* and *Ascophyllum* are quite characteristic. In the New England region trees of *Ulmus americana* and *Castania dentata* are abundant in the inland wet areas. *Typha* and *Zizania aquatica* [wild rice] grow abundantly along lake margins. Lake vegetation, consisting chiefly of *Potamogeton, Vallisnaria*, and *Elodea* is very much the same throughout the world. In the southern parts of the United States, some rich forests have developed. Some larger trees are *Liriodendron tulipifera, Liquidamber styrauciflua, Magnolia grandiflora, Magnolia acuminata.*

Other important North American tree species of the temperate belt in the East are *Taxodium distichum, Pinus rigida, P. palustris, P. caribaea, Quercus rubra, Q.macrocarpa, Carya microcarpa, C. alba, Fraxinus sambucifolia* [Cotton wood tree] *Tilia Americana,* a mangrove tree *Rhizophora mangle*, royal palm *Oreodaxa regia* etc. The ground vegetation at some places is represented by *Dionea muscipula* [Venus-fly trap, an insectivorous plant], *Arundinaria macrosperma*, royal fern *Osmunda regalis, Viola* sp., Buffalo grass, *Buchloe dactyloides*, some species of *Bouteloa, Stipa* and a cyadophyte *Zamia floribunda.*

To the west on the rocky mountains and slopes of the Pacific side the entire area is, indeed, a vast expanse of rugged mountains of high peaks, covered with forests of different types. Some low-lying areas are even below sea level. There is a vast expanse of desert in southern Arizona and south eastern California. The coastal region has an equable climate as against the extreme of cold and hot seasons found in the interior.

The major forest trees in different parts are *Pinus ponderosa* associated with *Pseudotsuga* at about 2000 metres, *Picea* sp., *Pinus flexilis* at 4000 metres, and *Abies laciocarpa* at even higher altitudes. On the humid Pacific coast are tall *Larix occidentalis, Abies grandis* and *Taxus brevifolia.* In Northern California there exists a long stretch of forests of the world's tallest trees—the *Sequoia semipervirens.* These trees are over 100 metres tall and with a trunk of more than 6m in diameter. *Sequoia* or redwood trees form almost pure stands as other species scarcely withstand the competition for light against such gigantic trees. *Pasania densiflora, Arbutus* sp. are the chief associated trees. In areas receiving heavy rainfall the *Sequoias* are replaced by *Abies grandis.* Further towards the coastal region are *Rhododendron californicum* and *R. occidentale*. In the absence of *Sequoias* in open spaces *Quercus* and *Aesculus californica* also occur.

The ground vegetation also differs from place to place. In salt marshes *Salicornia herbacea* and *Rumex maritima* are common. In peaty soil *Monotropa uniflora, Pyroria, Goodyera*, etc. grow profusely. At high altitudes trees are replaced by meadow lands with several species of *Saxifraga, Epilobium latifolium, Castilleia, Mimulus sp., Primula farinosa* etc.

In the Colarado desert of Arizon and south eastern California there are large varieties of xerophytic plants. *Larrea, Parkinsonea* and *Fouqneria* form characteristic bushes. The California fan palm *Washingtonia filifera* commonly grows in these regions. *Cacti of wide* varieties are most characteristic in deserts. *Agave, Ephedra* and *Prosopis* are also common. *Cereus giganteus, Ferocactus* and *Echinocactus* are some of the cacti predominantly found in Arizona.

9.4 The tropical zone

The tropical zone is also broadly divided into the [i] Palaeotropics of the Old World or Eastern Hemisphere tropics and the [2] Neotropics or the New World or Western Hemisphere tropics.

The Palaeotropics have two distinct botanical areas: [a] Tropical Africa and [b] Tropical Asia comprising of India, Pakistan, Burma, Thailand, Indonesia, etc.

Tropical Africa is a large landmass of uneven topography with the greater part of the area at a relatively high altitude of over 1000m above sea level making the climate some what subtropical. The Sahara desert receives very little or no rainfall while some other regions receive high rainfall. Thus a variety of vegetation patterns from very dense and diverse to scanty and sparse types are met within this belt. In equatorial regions on coastal land the mangrove plants like *Rhizophora mangle, Avicinia nitida*, etc. grow. On less swampy but highly saline soils *Caesalpinia crista* and *Cassytha filiformis* occur. Gradually from the coastal to the inner region of the continent there appear *Pandanus* sp., *Phoenix spinosa* and some leguminous shrubs and the oil palm *Elaeis guieneensis*. In the interior very dense forests of tall trees supporting lianas like *Landolphia kirkii* [yielding rubber], *Quisqualis indica, Clerodendrum splendens*, etc. grow. Important species are *Ficus, Bombax* sp., *Khaya senegalensis, Diospyros ebenum* [mahogany] and several leguminous trees. On the ground *Candida indica, Cyperus papyrus, Zingiber, Phragmites* and *Saccharum* occur abundantly. In eastern Africa *Sterculia tomentosa* is quite common. The most remarkable of all plant species found in the South Western Coast of Africa is *Welwitchia mirabilis* a member of Gnetales in the Gymnosperms. It does not occur anywhere else in the world and is restricted to a small region of Africa. In East Africa many plants common to India also

16)

grow. These are the Indian fan palm *Borassus flabeliformis, Tamarindus indica, Ficus.*, *Asparagus, Clematis, Phaseolus, Cassia fistula, Erythrina*, etc. Several species of *Acacia, Albizzia, Zizyphus, Bauhinia*, etc. also occur in open forests. In rain forests *Syzigium* trees are common.

The Asiatic tropics: Important botanical regions of the Asiatic tropics are Arabia, part of Pakistan, India, Burma, Srilanka, Thailand, Indonesia, Philippines, etc. The vegetation of India has been described separately. In Arabia the rainfall is extremely low and temperature is high except along the high mountains where it rains abundantly. Otherwise, it is all desert condition and plants are adapted to extreme xeric conditions. Several species of *Acacia, Prosopis*, are quite common. *Coffea arabica* the coffee plant is supposed to be a native of Arabia. *Katha edulis* (kaath) is cultivated for its leaves with narcotic properties. Dragon's blood tree, *Dracaena cinnabari* is restricted to the Hagier mountains on Socotra island of Yemen. Date palms are also found near water bodies. Srilanka is very rich in diversity and density of plant life. The climate is equatorial, i.e., warm and humid which favours high plant productivity all the year round. Most of the ground is under intensive cultivation of crops like rice and sugarcane, and fruits of *Eugenia*, banana, papaya and mango. Hill slopes and many other regions are under the cultivation of tea. To some extent coconut and rubber are also grown commercially. Very little area is left under natural vegetation. Ferns of a wide variety like *Ophioglossum pendulum, Lygodium, Helminthostachys, Gleichenia* sp., *Botrychium* are commonly found. In the famous botanic garden at *Paradeniya*, a wide variety of tropical plants like giant bamboos and branching palms are grown. A number of orchids, beautiful flowers of roses, violets and fuchsias are also abundant.

Burma, Thailand, and other areas around them are mostly under the cultivation of rice. The common trees are mostly of Jack fruit [*Artocarpus integrifolia*], orange, banana and mango. *Areca catechu* [supari] yielding betel nut is another beautiful plant of this region.

Malaysia and the group of islands of Indonesia as Java, Sumatra and Bali have very high rainfall and rich soil that bears one of the most luxuriant vegetation to be found anywhere in the world. Large varieties of palms like *Nipa fruticans, Onchosperma horrida,Crystostachys sp., Arenga saccharifera, Caryota urens*, etc. are common. Ferns are also widespread. *Durio zibethinus* a fruit tree belongs to this region. Its fruit is regarded as one of the most tasteful but at the same time it smells very offensively bad, and the local people eat it with gusto. Forest trees are *Albizzia, Diospyros, Eugenia*, etc. infested with lianas. *Nepenthes* or pitcher plant is commonly found in Malaysia. *Dendrocalamus giganteus* grows to tall heights on hill slopes. In Borneo almost everywhere sago palm, bananas and coconuts are grown. Many ferns and beautiful orchids grow epiphytically. *Wormia pulchella* a beautiful yellow flowered shrub is found growing almost everywhere. Java is regarded as the richedst place from the point of view of vegetation. The soil is exceedingly rich because of its volcanic origin. Rice is extensively cultivated besides rubber, coffee, condiments and spices, sugarcane, tobacco, *Cinchona* etc. An exceedingly large variety of trees grow in Java. Important ones are *Albizzia, Pterocarpus, Tamarindus, Cassia, Bombax, Durio* and *Artocarpus. Dendrocalamus* is also very common.

The Neotropics includes Mexico and a major part of South America. The temperature, moisture and topography are very similar everywhere in the western hemisphere and hence the vegetation is fairly homogeneous. Around the equator in South America exists one of the densest and largest expanses of forest in the Amazon basin.

The Mexican region is quite hilly and the plateau is high. In regions of low rainfall, there grow a number of xerophytes like tall cacti [*Pachycereus*], *Agave* and *Yucca.* Much of the land is under cultivation of crops of wheat and maize and a variety of fruits and vegetables. Comparatively cooler region at higher altitudes are full of trees of *Pinus, Spruce, Quercus, Populus* etc. Mountain peaks are under grass vegetation containing several grasses, sedges, members of Compositae, Rosaceae and Cruciferae. The wet lower regions are more tropical in look with abundant growth of mosses, bamboos, palms and epiphytic orchids. The vegetation of South America is very dense and most extensive due to high rainfall, rich alluvial soil around the river Amazon and its tributaries, and the equatorial climate. A large expanse of forest is of the flood forest type which remains under inundated condition for the greater part of the year. In the ecotone region between flood forests and uplands the soil has a better combination of soil moisture and air and it bears a thick forest. In drier regions savanna type of grassland is found.

The most widespread trees are *Bertholletia excelsa, Maximiliana regia, Euklisia* sp. etc. In mangrove conditions Rhizophora is most extensive. *Lacythis* and *Bombax* sp. are other trees found fairly extensively. A large number of epiphytes of Bromeliaceae, Araceae and Orchidaceae with hanging roots are conspicuous. A variety of ferns, bananas, *Zingiber*, Cannas and arrow-roots are extensive on the ground. A species of travelers tree *Ravenala guyanensis* is also found here. On less wet areas forests of a large variety of leguminous trees like *Cassia, Bauhinia*, and *Inga*, etc. are abundantly found besides *Ficus* sp., *Artocarpus* sp. etc. Cultivation of para rubber [*Hevea braziliensis*] is being done on an extensive scale.

The south temperate zone

Some of the extreme southern region of Africa is in a temperate belt with vegetation showing a transition of tropical and subtropical elements into the temperate type. The fernlike gymnosperms—*Encephalortos* and *Stangeria* are native of this region [Natal]. On the hills of Kilimanjaro the temperature is low and conifers like *Podocarpus* and *Callitris* are dominant. On lower, wet regions *Salix* and *Phragmites*, and in dry regions *Andropogon* and *Panicum* grasses and *Acacia giraffe* are common. Australia and New Zealand being isolated from the rest of the land mass through oceans have a large variety of endemic species specific to this region. There is very little scope of altitudinal distribution of climatic zones in Australia due to the absence of any high mountain and the general climate is rather dry.

In the northern part of Australia, floristic elements are similar to those of South East Asia such as palms *Caryota, Borassus* and betel nut *Areca.* Towards the south, trees of *Araucaria* are very common. *Eucalyptus* attaining great height is a typical Australian tree occupying large areas. A large variety of *Acacias* are also abundant. Another very characteristic tree of this continent is *Casuarina.* Among ground vegetation *Drosera*, some orchids, a cycad-*Macrozamia* some *Lycopodium, Psilotum, Temesipteris*, etc. are of great botanical interest. Newzealand on the otherhand is more hilly and forests are composed of conifers like *Agathis, Podocarpus Dacrydium* and others. Many ferns like *Dicksonia squarosa, Hemitelia smithii, Trichomanes reniformae, Todea superba* and *Cyathea medularis* are abundant. The only palm in Newzealand is *Rhopalostylis* sp. which often supports epiphytic growth of *Astelia solanderi* a liliaceous plant. A large number of species of *Metrosideros* of the family Myrtacaece is another characteristic of the island. In the matter of bryophytic flora Newzealand is probably richest with exceptionally gigantic *Dawsonia superba* [a moss] and *Monoclea foresteri* [a liverwort].

Summary

This topic deals with the floristic regions of the world. It explains how the climate, altitude and latitude influence the vegetation. Major biomes of the world and the characteristic species of plants have been listed.

Model Questions

1. Describe the major biomes of the earth.
2. Give an account of the floristic regions of the world.
3. Describe the climate, flora and fauna of the tropical belt.
4. Give an account of the climate, flora and vegetation of temperate biome.

Prof. K. B. Reddy

PLANT ECOLOGY
(UNIT-IV)

LESSON – X
FLORA AND VEGETATION OF INDIA

Objectives

1. Introduction
2. Botanical regions of India
3. Vegetation of India
4. Forests vegetation

10.1 Introduction

India is one of the 12 centres of megadiversity with at least two hot spots in the Eastern Himalayas and the Western Ghats. Its biodiversity index is 0.8. About 15000 species of flowering plants and 600 species of pteridophytes have been reported from India. Orchidaceae, Leguminosae and Poaceae are the most dominant families of Indian flora. India has the lofty Himalayan mountains towards the north extending from east to west, Bay of Bengal on the East, Indian Ocean towards the south and the Arabian sea on the west. There are also tall mountains chains of the eastern and western ghats, Vindhya and Satpura mountains of central India, river valleys, deltaic plains as well as the Thar desert of Rajasthan.

Indian subcontinent has a wide variety of climate ranging from the frozen mountain tops of the Western Himalayas to dry deserts of Rajasthan to warm and wet regions of Assam, Bengal and Western ghats. As a result, the flora and the vegetation also varies from the tropical evergreen rain forests of Assam to the dry deserts.

10.2 Botanical regions of India

India has been divided into 9 botanical provinces of (1) Eastern Himalayas (2) Western Himalayas (3) West Indian deserts (4) Gangetic plain (5) Assam (6) Central India (7) Malabar (8) The Deccan (9) Andaman, Nicobar and Lakshadeep islands.

1) **Eastern Himalayas:** It extends from Sikkim to the end up to the North East Frontier of Assam (NEFA). Rainfall is much higher and temperature is warmer than the Western Himalayas. Species richness, diversity and vegetation diversity are higher than the Western Himalayas. These zones can be recognized in the Eastern Himalayas.

a) **Submontane Eastern Himalayas:** Because of hot and humid climate, dense tropical forests of *Shorea robusta* are found up to 1800m altitude. In the riverarian regions *Dalbergia sissoo, Acacia catechu* are abundant. Mixed deciduous forests of *Terminalia, Anthocephalus cadamba, Lager stromia, Toona ciliata, Bauhinia, Pterospermum* are predominant.*Michelia champaca* and the bamboo *Dendrocalamus* are the other important plants.

b) **Temparate Eastern Himalayas:** It ranged from 1800 m to 3800 m in altitude. It may be divided into the lower temperate region where several dicots like oaks, *Michelia, Syzigiun* are found and the upper cooler temperate region with dominant conifers like *Juniperus, Cryptomeria, Picea, Abies, Tsuga* are found along with endemic *Rhododendron* species. *Arundinaria* is the common bamboo of this region.

c) **Alpine Eastern Himalayas:** It extends from 3800m and the vegetation is devoid of trees. Grasses and the shrubs of *Rhododendron* and *Juniperus* represent the charactertic vegetation. Eastern Himalayas on the whole has more of tropical elements, greater variety of oaks, *Rhododendrons* and only a few conifers. It is a meeting ground for Chinese and Japanese species.

Western Himalayas:

It extended from the central region of Kumaon to the North Western region of Kashmir. Like in the Eastern Himalayas, the vegetation is divisible into the submontane temperate and alpine regions.

a) Submontane Western Himalayas:

It extended between 300 to 1500 m in altitude. The forests are dominated by timber trees of *Shorea robusta* in areas with over 1000 mm of rainfall. The riverine regions support *Dalbergia sissoo, Eugenia jambolana, Cedrela toona* and *Ficus glomerata*. In the drier regions, xeric elements like *Zizyphus, Carissa, Acacia, Mallotus* with patches of thorny succulents of *Euphorbia* are common. *Pinus roxburghii* (chirpine) is dominant between 1000 and 1500m.

b) Temperate or Montane zone:

It ranges in altitude from 1500 to 3500m.Chir pine is gradually replaced by *Pinus excelsa* (blue pine). *Cedrus deodora* (Deodar) is abundant and forms pure forests between

1600 to 1800m. in Kashmir, *Crocus sativus* (saffron), apples, peaches, walnuts, almonds and a variety of fruits are cultivated.

c) Alpine Zone:

It extends beyond the tree line from 3500 m. In the lower regions *Rhododendrons, Juniperus, Betula* etc. are found in the form of bushes. Above 5000m the mountain tops are permanently covered with show.

3. West Indian Deserts:

It includes parts of Punjab, Rajasthan, Cutch, Delhi and Gujarat. Climate is hot and dry but winters are cold. Rainfall ranges from 100 to 700 mm. Historical evidence indicates that there were forests some 2000 years back. Xerophytic shrubby species of *Acacia arabica, Prosopis spicigera, P.juliflora, Salvadora persica, Capparis aphylla, Tamarix dioca, Zizyphus nummularia* etc. are the characteristic trees. The Aravalli hill ranges around Mt. Abu support thick growth with *Boswellia serrata* (salai), *Sterculia urens* and *Anogeissus pendula*. In drier habitats with 100 to 150 mm of rainfall. *Acacia catchu, Butea monosperma* with bright red flowers *Euphorbia* sp. and *Acacia senegal* are common. Irrigation facilities provided during the recent past has promoted agriculture. Shelter belts and wind breaks have been developed to prevent the expansion of the desert.

4. The Gangetic plain:

This is one of the most fertile regions with flat alluvial soils. It extends from eastern U.P. to Bihar and Bengal. Several tree species are found along the riverine valleys of the Western Himalayas such as *Dalbergia, Shorea* etc. are common to the Gangetic plains. The common trees are *Butea monosperma, Terminalia arjuna, Diospyros melanoxylon (tendu) Madhuca indica, Cordia dichotoma, Sterculia urens , Boswellia serrata, Flacourtia ramontchi, Acacia leucophloea, Emblica officinalis* etc. Most of the Gangetic plain is under cultivation of wheat, barley, chick pea, garden pea in the west and rice in the east. The common trees in human habitations are *Mangifera indica* (Mango), *Ficus bengalensis F.religiosa* (peepal), *Azadirachta indica* (Neem). The swamps of Ganga delta support extreme halophytes. The *Sundarban* region of Bengal is the only mangrove forest to support the Royal Bengal tigers. *Rhizophora conjugata, R.mucronata, Kandelia rheedii, Ceriops, roxburghiana, Burguiera gymnorrhiza, Avicennia alba, A.marina, Sonneratia acida, S.apetala, Acanthus ilicifolius, Nipa fruticans, Excoecaria agallocha, Phoenix paludosa* are the common mangrove species of Sundarbans.

5. Assam:

It receives the heaviest rainfall. Cherrapunji used to receive the world's highest rainfall of over 1000 Cm. Excess rainfall and warm climate are responsible for the development of dense forests. The important evergreen tall broad leaved forest species are: *Dipterocarpus macrocarpus, Mesua ferrea, Michelia champaka, Shorea robusta, Endospermum chinense, Polyalthia jenkinsii, Dillenia indica, Artocarpus chaplasha, Alstonia scholaris, Sterculia alata, Morus laevigata, Stereospermum chelonoides* and others. Others characteristic species are the bamboos like *Banbusa pallida, Dendrocalamus cylindrica, Saccharum arundinaceum, Themeda* and *Phragmites* sp. Among the conifers, *Pinus khasiya* and *P.inularis* are prominent in Assam hills.

6. Central India:

It comprises Madhya Pradesh, parts of Orissa, and Gujarath. The area has hilly terrain, Depending upon the rainfall, mixed deciduous forests, Sal forests, scrub jungle with spiny thickets of *Carissa spinarum, Mimosa rubicaulis, Zizyphus rotundifolia, Acacia leucophloea, A.catechu* are quite abundant. *Diospyros melanoxylan* (Tendu) *Butea monosperma, Terminalia tomentosa, Tectona grandis, Anogeissus latifolia* are the common dicot trees.

7. Malabar:

This region comprises the western coast of India extending from Gujarath in the North to Kanya Kumari in the South. This region receives heavy rainfall. There are four different types of forests, namely (a) tropical moist evergreen forests (b) mixed deciduous forests (c) subtropical or temperate evergreen forests on mountain tops and (d) the mangrove forests along the east coast of the Arabian sea. The tropical wet evergreen forests are typically multistoreyed. *Dipterocarpus indicus, Sterculia alata* are the tallest trees. *Cedrela toona, Tectona grandis, Dalbergia latifolia* are the other tall trees. *Derdrocalamus strictus* and *Bambusa arundinacea* are the prominent bamboo species. The high Nilgiri hills have subtropical or temperate climate. *Eucalyptus*, Cinchona and tea are cultivated. The common wild trees are *Eurya japonica, Gordonia obtusa* and *Michelia nilagirica.*

8. The Deccan:

This region is comparatively drier with abut 1000 mm of rainfall. The central mountain ranges and the eastern ghats have dry decidous forests. *Santalum album* and *Dalbergia latifolia* (Rose wood), *Tectona grandis, Hardwickia binata* are the important trees. Besides the above, several xerophytic bushes of the Central Indian region also occur in the Deccan region. Most of the plains are under extensive cultivation of paddy, sugarcane, jowar etc. Mango, Tamarind and Neem are common in human habitations.

9. Andamans:

This area is represented by the islands of Andaman, Nicobar and Lakshadweep. Coastal vegetation is represented by the mangrove forests and in the interior ever green forests dominated by *Beech* species are found. *Calophyllum, Dipterocarpus, Lagerstromia, Mimusops, Terminalia* and *Rhizophora* are the other prominent trees.

10.3 Vegetation of India

Depending upon rainfall, temperature and biotic influences, the vegetation of India is represented by two types i.e. the forest and the grass land types. Forests occupy about 75 million hectares (23% of land surface). An outline classification of the Indian vegetation is given in Fig.10.1.

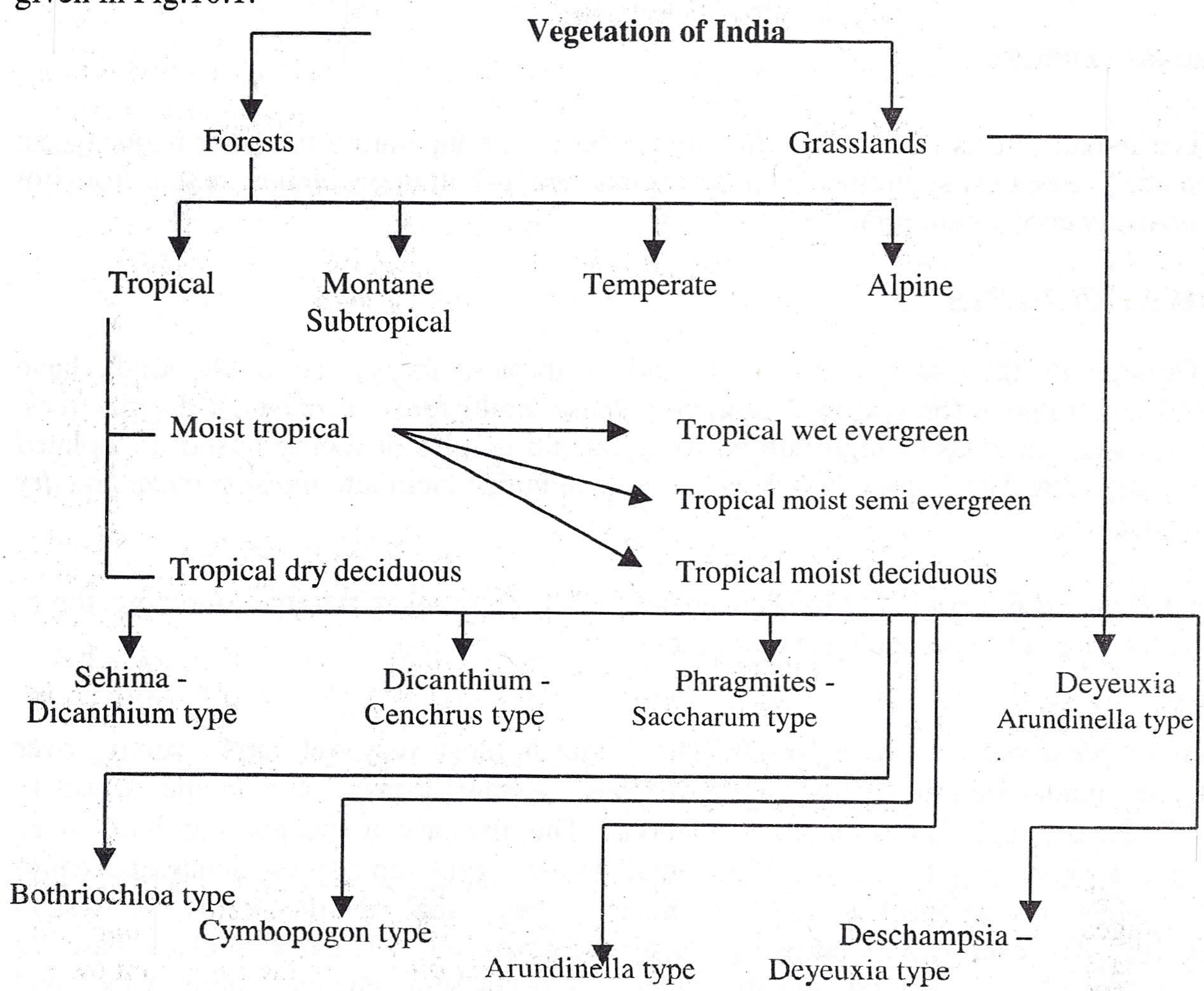

Fig 10.1: Classification of Indian vegetation.

The 8 different types of grasslands are formed mainly due to destruction of forests and hence they are rich in forest species. They are considered to be a disclimax type and their stability is attributed to grazing, burning, cutting, ploughing and other man-made disturbances. In a grassland, grasses and sedges account for about 30% of the total species but they contribute 90% biomass.

TROPICAL FORESTS

Throughout the warmer plains of Indian tropics, forests of many kinds have developed. The tropical forests range from very dense, multistoreyed forests of diverse trees, shrubs and lianas in areas of high rainfall to dry, scrub jungles of thorny bushes in isolated patches on dry areas. Therefore, it is desirable to distinguish them in to *moist tropical* and *dry tropical* categories.

10.4 Forest vegetation

The Indian forests can be classified on the basis of temperature into four major types: (1) tropical, (2) montane subtropical, (3) temperate and (4) alpine, which represent from hot to progressively cooler conditions.

(1) TROPICAL FORESTS

Throughout the warmer plains of Indian tropics, forests of many kinds have developed. The tropical forests range from very dense, multistoreyed forests of diverse trees, shrubs and lianas in areas of high rainfall to dry, scrub jungles of thorny bushes in isolated patches on dry areas. Therefore, it is desirable to distinguish them into *moist tropical* and *dry tropical* categories.

(A) *Moist Tropical Forests*: The moist tropical forests are divided in to the following three types, on the basis of relative degree of wetness.

(i) *Tropical wet evergreen forests:* They occur in those very wet parts receiving over 250 Cm. of annual rainfall on the Western Coast, Assam, Bengal, and in the Andaman islands. These are regarded as climax formations. The diversity of species is high and trees usually attain great heights of over 50m. Small trees, shrubs, epiphytes, lianas and dense ground vegetation are packed into so many storeys making the entire ecosystem impenetrable. The canopy remains evergreen all the year round. The tree trunks at base are usually buttressed. Grasses on the ground are almost absent whereas palms, canes and bamboos are often present. In the southern wet evergreen forests the dominant trees which occupy the uppermost strata are the *Dipterocarpus grandiflorus, D.pilosa, D.indicus, Hopea odorarta, H.parviflora, Artocarpus chaplasha, A.hirsuta, Measua ferrea etc.* On most of the trees epiphytic orchids of diverse types grow. In the second and third storeys also there are many species, chiefly *Mangifera, Emblica officinalis, Michelia* sp., *Syzigium* sp., *Ervatamia heyneana, Lagerstroemia speciosa, Strobilanthes, Ixora,* etc. The common climber species are *Ventilago, Jasminum. Calamus, Smilax. Pothos, Caesalpinia, Rubia and Gnetum.*

(ii) *Tropical moist semi-evergreen forests* are better developed in the northern than in the southern region of the country. Dominant trees usually shed the leaves for a brief period. In the north, these forests have developed in northern Assam and Bengal and parts of Orissa receiving heavy rainfall. There are some elements of evergreen nature like *Artocarpus, Michelia* and *Eugenia.* The principal deciduous species are of *Terminalia, Tetrameles* and often *Shorea*. Other species which occur in selected regions are *Odina wodier, Dillenia pentagyna, Stereospermum sp., Amoora rohituka,* etc.

(iii) *Tropical moist deciduous forests* have a number of tall trees which shed their leaves for a brief period and some other species are evergreen and semi evergreen. They are common in moist areas of Kerala, Karnatak and southern M.P. in the south and parts of northern M.P., U.P., Bihar, Bengal and Orissa in the north. These forests have tall tees (30 to 40 metres or even more) forming a closed canopy. The well known teak and sal forests belong to this category. In southern India, the moist deciduous forests are dominated by *Terminalia cernulata, Grewia sp., Garuga pinnata, Salmalia malabaricum, Terminalia paniculata, T.bellerica, Tectona grandis, Pterocarpus marsupium, Adina cordifolia, Lannea grandis,* etc. Teak and sal usually grow in separate stands, the former being a calcicole and the latter probably a calcifuge. However, in Bastar area the two species are found to grow together. The sandal trees in Karnatak state grow in areas receiving 100-250 Cm. rainfall between 700 and 1500m altitude. They often grow in association with *Artocarpus, Melia, Albizzia, Dalbergia* etc.

In the northern half, *Shorea robusta* reaching around 30 to 40m is the dominant plant in forests of Gorakhpur and Tarai regions of U.P., Khasi Hills (Assam) and northern Bengal. The other more common associates of sal are *Terminalia tomentosa, Dillenia, Eugenia* and *Boswellia* sp. Both the sal and the teak forests are under intensive management practices of the forest department.

(B) *Tropical dry deciduous forests* of India are composed mostly of such trees which remain leafless for several weeks in the dry season. The tropical dry deciduous forests can also be distinguished into the northern and southern regions.

The northern deciduous forests are extensively distributed in the Punjab, U.P., Bihar and Orissa in regions which are neither wet nor too dry. The trees are of moderate height with a sparse canopy. Thorny scrubs, grasses and some bamboos are also present in many regions. In Punjab and western U.P. forests *Anogeissus latifolla, Acacia catechu,* *Terminalia tomentosa, Boswellia serrata* are dominant with subdominants and societies of *Dendroçalamus strictus, Emblica officinalis, Woodfordia floribunda,* etc. *Shorea robusta* forests are also scattered on somewhat wet regions. Many of the forests in U.P., Bihar and Orissa have degraded under intense biotic pressure to thorn scrub forests with extensive open areas dominated by grasses and thorny scrub on forest margins. In the interior *Shorea robusta, Terminalia arjuna, Boswellia serrata, Buchanania lanzan, Diospyros melanoxylon* assume dominance. The southern tropical deciduous forests are located in the dry areas of peninsular India in the States of Maharashtra, Tamilnadu, Karnataka and Madhya Pradesh. The forests are of mixed type composed of deciduous trees with scattered patches of densely growing grasses intermixed with shrubs. *Terminalia, Anogeissus latifolia, Pterocarpus marsupium. Tectona grandis, Ougenia dalbergioides, Stephegyne parviflora, Boswellia* sp. form the top canopy followed by smaller plants of *Dendrocalamus, Bambusa, Lantana, Helecteris, Woodfordia,* etc. Common grasses are *Andropogon, Panicum* and *Heteropogon*.

(2) SUBTROPICAL MONTANE FORESTS

These are cooler than the tropical and warmer than the temperate forests. They are restricted to the hills of the Nilgiri, Mahabaleshwer and Pachmarhi and extensively on the Himalayas up to 1500 metres altitude. The southern forests have rather dense growth of trees of low stature with a number of ferns in their shade. The periphery and forest openings are occupied by shrubs, dicot weeds and grasses

Common trees are *Eugenia, Actinodaphne, Canthium, Memecylon, Mangifera and Ficus.* The climbers are *Piper trichostachyon, Gnetum scandens, Smilax macrophylla* and *Vitis elongata.* The northern subtropics have rather tall trees with an open canopy which makes possible the growth of a second storey of trees. In the eastern Himalayas, due to higher humidity, bamboos and many epiphytes, including orchids and ferns, are more abundant. Most of the trees are evergreen. Conifers and *Quercus* usually form separate stands.

(3) TEMPERATE FORESTS

These forests in India occur usually above 1600 metres altitude chiefly on the mountains of the Himalayas and Nilgiris. The Himalayan temperate forests have oaks and conifers in abundance. Conifers in the region are regarded to be in seral or successional stages. These are more common on northern slopes. Oaks form relatively stable evergreen pure stands on the southern slopes. The conifer trees here usually reach upto 20 to 25m. The altitudinal zonations and floristics have already been described earlier.

The southern temperate vegetation is principally represented by the 'Sholas' or extensive growth of grasses and evergreen forests on the Nilgiri and other hills on altitudes usually above 1300 metres. The forests are very dense because of heavy rainfall. Between 1000 and 1300m. tall trees of *Balanocarpus utilis, Hopea parviflora, Artocarpus hirsuta, Salmalia malabarica, Hardwickia binata,* and many others form dense closed canopy forests. Climbers *are Piper nilghirianum, Hoya sp., Jasminum sp., Dioscorea sp., Thunbergia,* etc. In extensive areas there are stable grasslands which are regarded to have been formed secondarily under the influence of fire and biotic effects.

(4) ALPINE VEGETATION

The word alpine is derived from the word alp meaning high mountain. This type of vegetation is distributed extensively throughout the Himalayas well above 3000m. With increasing altitude around 4000m trees are replaced by a sparse growth of small plants of *Sedum, Primula, Saxifraga* and patches of lichens.

Summary

Botanical regions of India and flora of different areas have been described in the lesson. The readers are advised to go through the specialized text-books on phytogeography for additional information.

Model Questions

1. Distinguish between flora and vegetation. Give a brief account of botanical provinces of India.
2. Compare and contrast between the flora and vegetation of eastern and western Himalayas.
3. Give an account of the forest vegetation of India
4. Give an account of the botanical diversity of India.
5. Why India is considered as one of the centers of mega diversity? What are hot-spots?

FOR FURTHER INFORMATION IN PLANT ECOLOGY (UNITS III & IV) READERS MAY GO THROUGH THE FOLLOWING BOOKS

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