NETAJI SUBHAS OPEN UNIVERSITY

STUDY MATERIAL

POST GRADUATE GEOGRAPHY

Paper : 2

Groups : A & B

GROUP A : CLIMATOLOGY
&
GROUP B : SOIL AND BIOGEOGRAPHY

PREFACE

In the curricular structure introduced by this University for students of Post-Graduate Degree Programme, the opportunity to pursue Post-Graduate course in any subject introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation.

Keeping this in view, study materials of the Post-Graduate level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Co-operation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing and devising of proper lay-out of the materials. Practically speaking, their role amounts to an involvement in 'invisible teaching'. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials, the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that they may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great deal of these efforts is still experimental–in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

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Second Reprint : October, 2019

Printed in accordance with the regulations of the Distance Education Bureau of the University Grants Commission.

POST GRADUATE GEOGRAPHY
[M.Sc]

PAPER : PGGR-02

GROUPS : A & B

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NETAJI SUBHAS OPEN UNIVERSITY

PGGR – 02
Groups A & B
Climatology
&
Soil and Biogeography

Group A — Climatology

Group B — Soil and Biogeography

UNIT 1 ❑ CLIMATOLOGY AND ITS RELATION WITH METEOROLOGY

Structure

1.0 Introduction

Climate has immense influence on almost everything on the earth's surface. Climate interlinks all the spheres namely lithosphere, hydrosphere, atmosphere, biosphere and noo-sphere (related to brain work of human beings) that are studied in geography, through a system, called climate system. Climate is a very dynamic system, and is quite sensitive to any kind of change occurring in it.

Weather and climate are two basic terms used in atmospheric sciences including climatology and meteorology, but they are defined variously. However, the elements of weather and climate are more or less the same. The commonly observed atmospheric variables constituting both weather and climate are- sunshine, atmospheric temperature, dew point temperature, pressure, cloud conditions, precipitation, wind characteristics and prevailing weather, e.g. visibility, thunder storms, cyclones etc. The basic relation between weather and climate can be stated by the fact that 'climate is the integration of weather, and weather is differentiation of climate' (G. F. Taylor), meaning a composite of weather conditions including departures of normal conditions, for over a long period of time constitutes a climate. So the difference between the two is mainly based on time. Weather can be simply defined as the over-all condition of the atmosphere of a locality in a specific time; and climate is the nature of change of weather throughout the year in that locality. Barring few extreme conditions, called departures from the normal, climate of a locality usually remain the same for a long period of time, say three to four decades, unless and until there is any sudden or repaid intervention acting adversely in that climate system, resulting in appreciable change in it. The normal time period of thirty to forty years is taken to define a climate, because of the fact that during this period an average condition of weathers can be found, although there is no appreciable change in climate itself.

1.1 Climatology and its relation with meteorology

According to Critchfield (2004), 'climatology (<Greek klima= slope or inclination of the earth's axis, i.e. related to latitude + logos= discourse or study) is the science that seeks to describe and explain the nature of climate, why it differs from place to place, and how it is related to other elements of the natural environment and to human activities'. Two important disciplines related to Climatology are aerology (or aeronomy) and meteorology. The former one deals with physical and chemical properties of the atmosphere, particularly of its different layers, and is relevant to aviation, astronomy, space science etc. The latter one, that is meteorology (<Greek meteor= things above) is more closely related to climatology, as it explains relatively short period status of the atmosphere, and the process responsible for the making of weather and climate. Aristotle was perhaps the first to coin the word 'Meteorologica' (c 350 B. C.), a treatise on the physical condition of the lower atmosphere. Climatology is primarily a part of meteorology, but it does not entirely belong to meteorology, as much of it is geographical. According to E. T. Stringer, climatology is an applied science- whose methods are strictly meteorological but its aims and results are geographical. Meteorology primarily deals with the physics, chemistry and dynamics of the atmosphere. The fundamental principles of science in relation to radiation, temperature, pressure, humidity, winds, precipitation and their consequence are the subject matter of meteorology. The geographical or spatial aspects of these weather or climatic parameters are essentially included in climatology.

Climatology- its nature, scope and divisions

Simply to say, climatology is the study of earth's climates. A related branch of knowledge called climatography consists of the basic presentation of climatic data in written or map form. Based on the approaches of study climatology may include five important branches, namely physical, dynamic, synoptic, historical and applied. Physical climatology deals largely with physical processes in terms of energy exchange in the earth-atmospheric system. Dynamic climatology is primarily concerned with the atmospheric motions and their effects. Synoptic climatology studies regional (i.e. regional climatology) or local (i.e. local climatology) atmospheric circulations and related weather and climatic conditions. Paleo-climatology or historical climatology is the study of development of climate trough time, for instance study of climate change on the basis of geologic or historical records. Applied climatology seeks to explore the interactive relation between climate and other elements of the earth, more specifically various aspects of human activities. Knowledge of general climatology

(i.e. theoretical aspects) in combination with other branches of knowledge has evolved new investigations in application of climatology in the form of, for example, bio-climatology, agro-climatology, urban climatology etc.

Tools and techniques of analysis of climate systems have given a separate way of classification of climatology, like: (a) descriptive climatology- involving description of climatic elements of a place; (b) statistical/ mathematical climatology- involving statistical/ mathematical techniques and formula for analysis and interpretation of climatic data, (c) synoptic climatology-involving of a condensed view of local or regional atmospheric elements and circulation patterns in a chart form, called synoptic chart, and (d) satellite climatology-involving, acquisition of weather/ climatic data from weather satellites, like TIROS, GOES, INSAT, METEOSAT etc. Radiosondes or Rawisondes involving balloon carried instruments and other forms of remote sensing data are also included in this category.

In brief, following are some of the important characteristics of climatology:

i. It is a branch of atmospheric science and it has very close relation to meteorology and geography.

ii. It involves dimensions of both time and space, and classification of climatology incorporates the elements of these two dimensions.

iii. Climatology includes both theoretical and applied aspects of studies involving various branches of knowledge of science, technology, mathematical sciences, agriculture etc.

iv. Application of climatology has resulted in emerges of new sub-disciplines like agro-climatology, urban climatology etc.

v. Recent climate change and its consequences have a positive outcome of climate studies, in these days, resulting in a renewal of importance to the study of climatology.

vi. It is possible to find out tremendous scope of works to be done in climatology in respect to its academic importance as well as various fields of application.

1.2 Agro-climatology

Although the terms agro-meteorology and agro-climatology are very often used synonymously, there are certain differences. Application of all factors of weather especially in micro (or field) level is the subject matter of agro-meteorology. Agro-climatology, a branch of applied climatology, seeks to describe relationship between

climatic elements and systems of agriculture, and thereby it is close to the discipline of geography, that covers relatively larger spatial units as its field of study. In practical purposes, however, this distinction is seldom maintained. Whatever may be the difference, for the present purpose, the term 'agro-climatology' is being deliberately used to make it closer to geography. Agro-climatology studies the different aspects of climate that have relevance to agriculture. The study of agro-climatology helps to rationalize the selection of crops according the environmental conditions like character of land, availability of water, sunshine, temperature etc. of an area. This helps in improving productivity through effective management of soil-water, pest control and other adverse conditions.

Phenology, the study of organisms as affected by climate through a calendar (indicating changes of time), is a term commonly used in agro-meteorology, but it is quite relevant here also. It is a descriptive study of the development of organisms, e.g. flowering, growing, maturity etc. of plants in relation their environment. Although the development of different stages of organisms is coded in their genetic systems, this may be highly influenced externally, with the critical supply of available energy, moisture and nutrients. Study of phenology is important for the following counts: (i) optimization of crop yield in an environment matching the life cycle of the crop, (ii) achievement of stable productivity through effective management of cropping system, and (iii) introduction of new crops in an area.

Some of the important aspects of climate influencing agriculture can be summarized as follows :

(a) ***Sunshine and sunlight-*** Duration and intensity of these two climatic/ weather elements are important in regard to plant growth. Too much of sunshine may retard photosynthesis, but an optimum of it is beneficial to plants for their transpiration. Bright sunshine is helpful during maturity of crops and their harvest. Sun light helps in formation of chlorophyll that accelerates photosynthesis. World pattern of agriculture exhibits a direct relation with the availability of sunlight in terms of amount, intensity and duration.

(b) ***Temperature-*** Germination of seeds and growth of plants require suitable temperature, ideally between 18-24 °C. this is why length of growing season in the tropics is greater than that of the temperate and arctic regions. Extreme temperatures, e.g. too cold or too hot retards germination, plant growth, and can be detrimental to the life of plants.

(c) ***Pressure*** **and** ***winds*** are two important climatic elements influencing plants. Nature of air masses is highly related to the pressure condition of a region.

Warm-dry air masses as well as cold-dry air masses have considerable damaging potential to the standing crops. Similarly hot-dry winds or cold-dry winds cause severe damage to crops. Strong wind damages tree crops, while dust storms can play havoc.

(d) ***Humidity-*** Most of the plants favour high humidity condition of the atmosphere. This increases the efficiency of water utilization of plants, as it helps to enhance photosynthesis.

(e) ***Rainfall*** is perhaps the most significant factor determining variation of cropping pattern throughout the world. Almost all of the agricultural activities like sowing, germination, shooting, stalking and heading, maturing, harvesting and threshing are affected by the pattern of rainfall in an area. Prolonged absence of rainfall may cause drought condition leading to failure of crops. Effectiveness as well as reliability of rainfall is important for the success of an area's agriculture. Rainfall effectiveness is the measure of the difference between total actual rainfall and total possible evapo-transpiration or potential evapo-transpiration. Reliability of rainfall is a matter of probability and it can be determined statistically.

(f) Other climatic elements influencing crops are *dew, hoarfrost, mist* and yog. In some dry areas of the world some agriculture is possible by using these minor but important climatic elements. However, in humid regions these are detrimental to plants, as they favour growth of insects, pests and diseases.

Agro-climatology in Indian perspective

In spite of rapid industrialization India is still an agricultural country with nearly 65 percent of its population directly of indirectly engaged in agricultural activities, and more than 25 percent of the country's income comes from agriculture. The following important considerations can be taken into account for agro-climatic studies in India:

(a) The principal economic activity of India is agriculture. Besides, many industries of the country are based on agriculture, e.g. jute and cotton textile, sugar, vegetable oils, spices etc.

(b) The climatic condition of the country is diverse, ranging from humid tropical in the south to dry-tropical in the northwest and cold continental in the Himalayan mountain areas. Due to the vast expanse of the country and diverse relief the distribution of temperature is not uniform. The temperature conditions differ seasonally. However, as a tropical country, in general,

temperature is no significant constraint for luxuriant vegetative growth in the country.

(c) Rainfall is the most important climatic factor controlling agriculture of India. The time-space distribution of India's rainfall is highly erratic. The monsoon rainfall is concentrated within four months (June-September) when about 80 percent of India's rainfall occurs. Spatially, southwestern and northeastern parts of the country gets considerable amount of rainfall within this short period. But other parts of the country, especially the northwest receive the least amount of monsoon rain.

(d) Reliability of water supply through effective irrigation in India is still a distant dream, although many large river valley projects have been commissioned during the last decades. More than 40 percent of net sown area the country is not yet covered by any irrigation facility. The irrigated areas too very often suffer from scarcity of water supply due to failure of the monsoon.

Under these contexts agro-climatic studies in India can help by (a) timely weather forecasts of both short and medium range; (b) selecting suitable crops in relation to environmental conditions of different areas of the country; (c) finding out suitability of crops for different crop-seasons, i.e. *Kharif* (monsoon), *Rabi* (winter) and *Boro* or *zaid* (summer) (d) maximization of yield through investigating crop-weather relationship; (e) minimization of insects, pests and diseases causing damage to crops; and (f) long-term planning for agricultural development through delineating different agro-ecological zones and safe growing periods of individual crops.

Agro-climatic regions of India

Agro-climatic rationalization seeks to fulfill, in general, the following two objects: namely, (i) development of a scientifically managed farming system, keeping in mind the selection of crops to be cultivated in a particular set of environment; and (ii) identification of the best suitable areas for a new crop to be introduced in the country for cultivation, so that the new crop can adopt the new environment.

Several attempts have been made in India for the regionalization of the country on the basis of suitability of agricultural practices in relation to climate (i.e. agro-climatic regions), and also on the basis of homogeneity in terms of climate, vegetation, soil, topography, water resources, cropping and farming systems etc. (i.e. agro-ecological regions). Using Thornthwaite's *moisture index (Im)* method (1948) India Meteorological Department (IMD) based on thirty years (1931-1960) data published

and agro-climatic atlas of India in 1978. The regions along with their characteristics are given in the following table.

Agro-climatic regions		**Characteristics**			**Distribution in India**
Main types	Sub-types	Approximate Annual total rainfall (mm)	Moisture Index (1m)	Description	
Per-humid (A)	Ar	>1200	>100	Little or no water deficiency	Northeast India and south of west coast
	Aw			Moderate winter water deficiency	North Indian plains
Humid (B)	Br	1000-1200	20 to 100	Little or no water deficiency	Southern part of north Indian and Bengal plain
	Bw			Moderate winter water deficiency	Western part of north Indian plain
Moist Sub-humid (C_2)		750-1000	0 to 20	—	Central Indian plateau region
Dry Sub-humid (Ci)	C_1s		–20 to 0	Moderate summer water deficiency	North and eastern part of the Peninsula, northern part of Jammu & Kashmir
	C_1d			Little or no water surplus	
	C_1w			Moderate winter water deficiency	
Semi Arid (D)	Ds	500-750	– 40 to –20	Moderate summer water deficiency	Gujarat, Karnataka and south Maharastra
	Dd			Little or no water surplus	
Arid (E)		<500	-60 to-40	—	The Thar desert region

Note: Moisture Index (Im)= (100S-60D)/ PE, where PE= Potential Evapo-transpiration (PE)
i.e. water need, S= water surplus and D= water deficit, calculated on annual basis.

The main drawbacks of this regionalization are that: (a) diurnal variation of temperature

has not been considered, and (b) the importance of soil moisture has not been taken into account.

The Ministry of Agriculture, government of India has identified fifteen agro-climatic zones (better to be termed as agro-ecological zones) based on topography, soil type, rainfall, altitude, temperature, water resources, cropping pattern and fanning system (Refer *The Hindu Survey of Indian Agriculture, 1989).* Each zone is again divided into a number of sub-zones. The classification has been prepared for planning and development of agriculture and allied activities. The zones are as follows: (1) Western Himalayan, (2) Eastern Himalayan, (3) Lower Gangetic Plains, (4) Middle Gangetic Plains, (5) Lower Gangetic Plains (6) Trans Gangetic Plains, (7) Eastern Plateau and Hills, (8) Central Plateau and Hills, (9) Western Plateau and Hills, (10) Southern Plateau and Hills, (11) East Coast Plains and Hills, (12) West Coast Plains and Ghats, (13) Gujarat Plains and Hills, (14) Western Dry Region, and (15) The Islands. This classification is relatively comprehensive but partly agro-climatic, as climate is just one of the bases of regionalization.

1.2 Applied Climatology

Applications of climatology in regard to various areas of human interest and activities are termed as applied climatology. There are many areas in which man can potentially use his knowledge of climate. Human being has practiced the use of climatic information since primitive era. For example, the ancient people could understand the suitable areas where the required plants would grow, availability of games for hunting and where to live under adverse climatic condition. Then with the settlements man started growing food crops, and afterwards other crops having full knowledge on the suitability of climatic conditions required by individual crops. Many industries also necessitate certain type of climate, for instance, flourmills, sugar mills, jute and cotton textile, film etc. transport and communication networks largely depends on particular type of climate, and a clear knowledge of an areas climate helps to a great extent. Fog, for instance, is a serious problem for aviation and also for water transport. Supply of water through pipelines is highly affected by the climatic condition of a severe cold climate area. Human comfort is largely a function of climate. Pests and pathogens favour different climatic conditions. So, medical persons can utilize knowledge of climate for better management of different diseases. Critchfield (2004) has identified a number of areas concerning applied climatology that can be outlined below:

- Study of water resources- the role of climate on the hydrological cycle and

global distribution of water resources, surface and underground, in relation to precipitation and evapo-transpiration; accumulation and ablation of snow; run-off and flood.

- Impact of climate on biosphere- with reference to forestry and forest fire, soil formation and soil erosion, effects of winds on ocean currents and sea fishing.
- Impact of climate on agriculture and food- concerning phenology, drought, insects and diseases, introduction of new plants and animals in a different climatic area, aquaculture, etc.
- Study of energy production and management- e.g. wind energy, tidal energy etc.; selection and scheduling of transport and manufacturing activities.
- Human bio-climatology comprising comfortability, weather and health, study of diseases in relation to weather.
- Influence of climate on housing, e.g. selection of site, orientation of building, different aspects of heating and cooling, etc.

The important areas of applied climatology studied in India (Subrahmanyam, 1983) include agriculture, forestry and hydrology. Some of the studies are on urban planning with reference to atmospheric pollution and environmental management.

1.3 Concept of macro and microclimate

M. M. Yoshino has classified four groups of regional or local climates on the basis of spatial scale, such as micro-climate, local climate, meso- climate and macro-climate, and accordingly their studies involve classification of climatology, e.g. micro-climatology, local climatology etc. The following table can be usefully consulted for the classification.

Time-space dimensions of weather systems

Motion system	Horizontal Scale (Km)	Vertical Scale (Km)	Time Scale (Hour)	Examples
Planetary Scale	5×10^3	10	2×10^2 to 4×10^2	Monsoon circulations
Macro Scale	5×10^2 to 2×10^3	10	10^2	Mid-latitude or tropical cyclones, depressions
Meso Scale	1 to 10^2	1 to 10	1 to 10	Thunderstorms
Micro Scale	$<10^{-1}$	$< 10^{-2}$	10^{-2} to 10^{-1}	Small-scale wind eddies, Urban Heat-Island

Source: After Barry, 1970

Macroclimates cover large areas and include many types of micro and mesoclimates. In terms of spatial extent this can be studied as climates of continental level, if not, at least at country level, e.g. climate of India, Japan etc. The circulation patterns are also relatively large, e.g. the Monsoon circulation, trade winds, Jet Streams etc.

Microclimates can of an agricultural field or of an individual house. The important factors of microclimate are temperature, humidity conditions and air pressure. The pollution aspect of microclimate regulating the air quality influencing the ambient environment of flora and fauna is very important. Data in regard to microclimate are not easily available from published sources, so it is worthy to go for fieldwork to collect microclimatic data. This is useful, for example, to study the extent and intensity of urban heat island in a particular city. Impact of urban land use on its weather can also be an important aspect of microclimatic study.

1.4 Concepts of climatic resources and climatic hazards

Climate itself is a natural phenomenon, although in the recent years much has been talked about the influence of man on modification of contemporary climate, called climate change. During the recent time some of the human activities are said to be responsible for rapid changes in climate through the process of global wanning- i.e. increase of global mean temperature due to anthropogenic forcing, like excessive deforestation, burning of fossil fuel, and agricultural practices emitting greenhouse gases. However, earth's climate never remained static. It has undergone various changes during the past, and the aspect is studied as paleo-climate (i.e. climate of the past). Historically, man-climate relationship is very interesting throughout the development of human civilization. In the past human activities were mostly regulated by physical/ natural forces operating on the surface of the earth. For example, a round the year high temperature and high humidity conditions has created an unpleasant environment for the Congo (Zaire) people to live a rudimentary life, half-naked having houses on branches of trees; on the other hand the Tundra people put on tight clothes made of skin and live in igloos. Food, shelter, life support systems, economic activities, habits and movements of people were highly dominated by climate. In many areas of the world climate is still one of the chief factors regulating the life and living of human beings. The definition of climate as *resource* or *hazard* depends on whether it is beneficial to man or not. Under many occasions climate is a resource to mankind. The suitable weather and climate has made the earth livable and life has become possible on this beautiful planet. Man is constantly and continuously using various essential elements of the atmosphere, both directly and indirectly. The weather plays

important beneficial roles to man through providing water at the time of need, evaporating it to suit his requirements, and storing it as snow for future demand. Although man has become able to regulate the supply of water need, he still largely depends on the natural processes of climate system. All life forms on the planet earth are heavily depending on climate, which is normally a resource to them. To man a particular type of weather can be a resource or a hazard depending on the intensity and time of its need or otherwise. For instance, in a country with seasonal rhythm of summer and winter, too much hot or cold are regarded as hazards, as in India heat waves and cold waves are responsible for loss of many lives. It is to be noted that during the hot and humid summer months the people of Indian plains rush to the hill stations not to experience the beauty of the mountains but to have a respite in the cool weather there. The transhumance activity can be cited a classic example of climate being a resource as well as a hazard for the tribal herdsmen. The beneficial aspects of climate can be referred in the study of applied climatology. The climate hazards are the extreme events having potential to cause damage to man. These can be momentary storms to prolonged drought. These can be direct atmospheric event like lightning or hailstorms and indirect like floods and water logging. Again these can be of a local phenomenon like dust storm or lightning and can be quite extensive like heat or cold waves or mid-latitude cyclones.

1.5 Weather forecasting

Climate is usually regarded as an integration of normal weather events that occur sequentially throughout the year. So, similar weather events lasting for few minutes to several moths are important for various useful activities of man, e.g. agriculture, pisciculture, industry, transport, trade and commerce etc. These activities are highly correlated with the familiar or expected (called normal) weather conditions. Any departure from these normal weather events are regarded as extremes, and theses may cause severe inconveniences to man. Therefore, foretelling about the future weather events is not only an important job, but it is highly challenging too. A scientific prediction of weather events is called weather forecasting. This should be timely (i.e. well in advance) and accurate so that it is capable of being effectively utilized by the persons/ society going to be affected, if there be any kind of departure from the expected or normal.

Almost every person has something to get the benefit of an effective weather forecasting. For instance, our daily work habit is substantially regulated by a day's weather. Farmers take decision of their crops to be grown according to the nature of weather expected in a growing season, policy makers of a country rely on long term

whether forecasts, military men stationed in harsh climatic region regularly keeps watching on the nature of weather changes. However, many of them rely on past experiences and others depend heavily on accurate forecasts made by various agencies. A good and reliable weather forecast can prevent disaster through preparedness.

In the past weather prediction was mainly done as *weather lores,* on the basis of experience of the people. Some learned peopled were quite famous in foretelling weather events. The bases of their prediction were nature of cloud, some atmospheric phenomena, nature of flora and fauna etc. mention may be made of *Lilabati sulra (Khana bachand)* that consists of many weather lores have much relevance even in the present days.

Inventions of different instruments to record atmospheric temperature, pressure, wind direction and speed made remarkable advancement in the system of weather forecasting. Now the process of weather forecasting has become more complex but accurate as this is done by taking into account many recordings of atmospheric conditions for different periods through sophisticated instruments and the reading are analyzed through high-end computing systems. Presently the general steps taken in weather forecasting are- collection of records representing overall condition of the atmosphere for a convenient area and period, processing of the data for further analysis and mapping, inference drawn on the basis of data base, and forecasting made in terms of general atmospheric condition and conventional models used for various weather systems.

As per WMO (World meteorological Organization) convention a set of primary observations of atmospheric conditions including air temperature, humidity, wind speed and direction, atmospheric pressure, cloud type, cloud cover, cloud base height, visibility and precipitation are recorded four times a day for every 6 hours based on Greenwich Mean time (GMT), starting midnight through 6 am and noon to 6 pm. The readings are taken at the meteorological stations and upper air measurements are taken by radiosondes or rawinsondes (i.e. automatic atmospheric recording instruments having radio transmitter fitted in a balloon). Satellites like TIROS (TV Infrared Observing Satellite), Geostationary Operational Environmental Satellite (GOES) and satellites of the National Oceanic and Atmospheric Administration (NOAA) of the United States, and Meteorological Satellites (METEOSAT) are now regularly in use of collection of atmospheric data. In our country INSAT series are very helpful in collecting weather related data.

Types of weather forecasting

The weather forecasting system can be discussed under two categories: (I) on the

basis of the method of forecasting and (II) on the basis of duration of validity of the forecasts. Sometimes the forecasts can be application based, like aviation, shipping, agriculture, forestry etc.

Methods of weather forecasting are of four types: (a) ***Synoptic method-*** until the late 1950s this was a very popular method employing synoptic chart that depicts overall weather condition of an area of a given moment. On extrapolation of this synoptic (meaning coincident in time) condition into the future on the basis of observed trends a reasonably good prediction could be done, (b) ***Statistical/ Climatological method-*** a predictive relationship is worked out on the basis of past data, and on the basis of this relationship forecasting is done for the future events based on current data/ trend. This method is commonly used for long range forecasting. But too much reliance of past data incorporates error in prediction due to variability of weather events, (c) ***Numerical/ Dynamic method-*** a physical law based method with the assumption that weather events follow such laws. The thermodynamic principle applicable to gas is applied for the atmosphere too, and in terms of general circulation of the atmosphere in relation to its heat and moisture properties, prediction is done accordingly. Short-term weather forecasting, for example in case of a cyclone, prediction can be done fairly accurately, (d) ***Ensemble method-*** this is in fact a method to test the validity of a weather forecasting method. Computer-based simulations of wether events are run for several times with slight change of one or more parameters and the results are matched with real world situations. If the match is close for a period of more than ten days, then weather forecasting is done on the basis of the simulation. On the basis of validity of reliable weather forecasting it can be of three categories: (a) ***Short range-*** covering for the next 24 hours or up to 3 days. This is primarily based on the current tendency of weather events. Short range forecasts may be three types, such as (i) ***Persistent method-*** where it is assumed that the with existing rate of movement, e.g. of a mid-latitude cyclone, the weather of an area ahead of the cyclone with remain more or less the same after a given time, say few hours. But any change in weather associated with the storm is not taken into account in this method, (ii) ***Continuity method-*** it is assumed that weather conditions prevailing in the upwind will remain unchanged and will continue in the downwind. This type of extrapolation can be done in case of a thunderstorm or dust devil, (iii) ***Now-casting method-micro*** scale short-lived weather events like tornadoes, hailstorms etc. are very much site-specific. These necessitate immediate forecasting, which is quite difficult. For example, with the help of *Doppler radar* it is possible to forecast a tornado just before twenty minutes or so.

(b) ***Medium range-the*** forecast is done for the next 3 days up to 3 weeks. This

is done on the basis of average trend of weather of the past few days. Although the reliability of the forecast is less, it is quite helpful for the public in general.

(c) ***Long range-*** this covers the period of a month or more than that. This can be for a season or for a year. Such forecasts try to predict any kind of departure from the normal (the average/ or expected) weather events. Only the general weather conditions like temperature and precipitation are predicted. For the purpose of prediction many weather parameters are taken into account for a vast area, usually at continental level, in conformation with the general circulations of the atmosphere. Some extreme events like El Nino and ENSO (El Nino Southern Oscillation) are also taken into account.

In India regular meteorological observations were started in 1793, but the first meteorological observatory was set up in 1823 (in Mumbai). The India Meteorological Department (IMD) started functioning since 1875.'Presently it has 35 meteorological sub-divisions with 317 hydrometeorological observatories, 125 agrometeorological observatories and over 4500 rain gauge stations. Weather forecasting is done for short, medium and long range and is disseminated through the public broad casting systems like All India Radio and *Door Darshan.* Regular weather bulletins and warnings are promulgated for the fishermen going to the deep seas.

1.6 Questions

A. Descriptive/long analytical type

1. Describe the nature and scope of climatology.
2. Discuss about the different aspects of agro-climatology.
3. Discuss with examples the nature of climate as resource and hazard.
4. Classify and define the various branches of climatology.
5. Describe the different methods of weather forecasting.

B. Short answer type

1. What is phenology?
2. Differentiate between micro and macro climates.
3. What is now-casting method of weather forecasting?
4. What is urban climatology?
5. What is the use of a synoptic chart?

1.7 Suggested Readings

1. Barry, R. G. and Chorley, R. J. (1998)- Atmosphere, Weather and Climate; Routledge, London (7th Edition)

2. Critchfield, H. J. (2004)- General Climatology: Prentice-Hall of India Private Limited, New Delhi, Fourth Edition
3. Lenka, D. (1998)- Climate, Weather & Crops in India; Kalyani Publishers, Ludhiana
4. Oliver, J. E. and Hodore, J. J. (2003)- Climatology: An Atmospheric Science; Pearson Education (Singapore) Pte. Ltd., Delhi, First Indian Edition
5. Singh, S. (2007)- Climatology; Prayag Pustak Bhawan, Allahabad
6. Subrahmanyam, V. P. (ed./ 1983)- Applied Climatology, Heritage Publishers, New Delhi
7. Thompson, R. D. (1997)- Atmospheric Processes and Systems; Routledge, London

UNIT 2 ❑ ATMOSPHERIC DISTURBANCES

Structure

1.0 Introduction

Atmospheric circulation is very important to produce weather systems as well as to modify them in an area. Study of weather and climate in relation to this atmospheric motion is called synoptic climatology, as it is done with the help of a synoptic chart showing atmospheric circulation pattern in a regional scale. The usual circulation of the atmosphere produces weather and climatic events called *normal,* but any departure from these usual weather or climatic events is called a *disturbance* or an extreme; and when this abnormal behaviour of the atmospheric events a potential to cause havoc to man, these are called *atmospheric hazards.*

1.1 Atmospheric disturbances

A significant deviation from the normal condition of the atmosphere is called the atmospheric disturbance. Traditionally climatology used to study the distribution of general character of the atmosphere in terms of temperature, pressure, and precipitation etc. called normal. Sudden, extreme, difficult to predict weather events are known as weather disturbances, and as they show departure of the overall normal character of the expected condition of atmosphere of an area in a particular time frame, these are also called *atmospheric disturbances.* These disturbances can be many but, the can be grouped on the basis of duration, as follows :

Mean duration	Weather events
Milliseconds/instantaneous	Lightning
Minutes	Tornadoes, Hailstorms, Thunderstorms Dust storms
Hours	Blizzards, Fogs, Flash floods, Nor'westers
Days	Heat waves, Cold waves, Cyclones
Weeks	Floods
Months	Drought
	Source: Oliver and Hidore, 2003

Atmospheric disturbances can be a manifestation of cumulative effect of prolonged deviation from the normal, e.g. drought. They can be very local, like a lightning or tornadoes, to regional like floods or thunderstorms, to a continental event like heat waves or cyclones.

Tropical Cyclones

Definitions and characteristics

Henry Piddington, a former sea captain serving as President of the Marine Court of Calcutta, first used the term *'cyclone,"* in a presentation to the Asiatic Society of Bengal around 1840, as a derivation from the Greek word *'kyklon'* which means moving in a circle, like the 'coil of the snake'. Tropical cyclones are intense, circular low-pressure systems with strong cyclonic circulations and vigorous airflows. These weather disturbances have a variety of different regional names and period of occurrence: e.g. in the Bay of Bengal (Indian Ocean) they are called cyclones (April-July and September-November) and also in South Indian Ocean -near Malagasy (November-April), typhoons in north-west Pacific (July-October), hurricane in the north Atlantic and in south-west Pacific (June-October); and willy-willies (in loose sense, actually it is a dust storm occurred in December-April) in northern Australia. On the basis of wind speed the World Meteorological Organization (WMO) in Geneva has classified the tropical cyclones of all intensities under the following four categories:

Category	Wind speed			
	Knots (nautical mile* per hour)	Metre per second (mps)	km per hour (kmph)	Beaufort Scale Force
Tropical depression	up to 33	up to 17.1	up to 60	7
Tropical storm (moderate)	34 to 47	17.2 to 24.4	60 to 90	8 or 9
Tropical storm (severe)	48 to 63	24.5 to 32.6	91 to 120	10 or 11
Hurricane/ cyclone/ typhoon	More than 63	More than 32.6	More than 120	12

Note: * 1 nautical mile= 1' (minute) arc distance on a Great Circle, e.g. the equator.

The general characteristics of tropical cyclones can be outlined below:

(i) Their diameter is usually small, within 50 km; but may extend up to 600 km.

(ii) The storms themselves travel slowly (about 20 kmph) but erratically.

(iii) The average low pressure at the center is quite low about 950 millibar (mb), but may attain as low as 882 mb (Hurricane Gilbert in the Caribbean in September 1988).

(iv) Due to intense low pressure at the center, the pressure gradient is also very high (around 1 mb per km) producing a wind speed of more than 350 kmph.

(v) The center, with an average diameter of 15 km, of the cyclone is remarkably calm, and is called 'eye'.

(vi) Tropical cyclones mainly occur in the summer months, when their frequencies as well as rain bearing capacity are quite high.

(vii) Their frequency has progressively increased during the last few centuries, probably as a reflection of global warming.

Origin and structure of tropical cyclones

The exact mechanism for the origin of tropical cyclones is still poorly understood. Sometimes it is said to origin due to development of a front-like situation between land and sea winds. But more acceptable concept in this regard is its thermal origin over warm tropical seas (or oceans), development of which is related to the release of latent heat of condensation. The ***general conditions necessary for the origin and development*** of tropical cyclones can be summarized (Ayoade, 1983; Singh, 2007) as follows: (a) a continuous supply of abundant heat and moisture; (b) a suitable heat source, usually a large tropical water surface; (c) low level convergence, turbulent vertical motion of air, and strong anticyclonic (diverging) circulation in upper troposphere; (d) high Coriolis deflection to generate a cyclonic movement; (e) weak vertical wind shear; (f) existence of weak tropical disturbances favouring intensification the storm; etc.

A tropical cyclone structurally looks like a cylinder extending from a low base up to the top of the troposphere. The cylinder consisting mainly of cumulus clouds widens out in its upper reaches. The cylindrical form is also associated with spiraling bands of stratocumulus and cumulus at lower levels, and cirrus or cirrostratus at higher levels. The central calm area, called 'eye' is a funnel of about 10-20 km diameters, through which adiabatic warming takes place due to subsidence of high-level air in it. This entire air column is almost cloud-free, except very thin cloud within 1.5 km from the base of the cyclonic vortex. The central calm area is surrounded by a spiral band of very strong winds associated with dense cumulonimbus clouds. Beyond this spiral band an annular belt with relatively low humidity and less cloud density occurs, in which the wind speed is also progressively lesser.

Track of movement of tropical cyclones

The usual path of movement of tropical cyclones is a.curve. In the northern hemisphere they first travel towards west and then turn to northwest. They take a north and northeast direction at about 25° of latitude. Thus a tropical cyclone entering in extra-tropical region gets a parabolic shape with its axis parallel to the equator and concavity facing the east. Regarding the track of movement of tropical cyclones following general observations can be outlined:

(i) Between the equator and 15° of latitude they follow the trades and therefore they are directed to the west,

(ii) Between 15° and 30° the track of movement is very uncertain; although usually they travel towards north in northern hemisphere and towards south in southern hemisphere,

(iii) Beyond 30° they turn towards the east and get the character of temperate cyclones, as the energy in them is reduced.

Distribution of tropical cyclones and weather characteristics

Warm seas and oceans between 5°-20° latitudes are the favoured areas of origin of tropical cyclones. There are six such major regions (Singh, 2007), namely (1) West Indies, Gulf of Mexico and Caribbean Sea; (2) Western North Pacific Ocean including Philippines Islands, China Sea and Japanese Islands; (3) Arabian sea and bay of Bengal; (40 Eastern pacific coastal region off Mexico and Central America; (5) Southern Indian Ocean off Madagascar; and (6) Western South Pacific Ocean, in the region of Samoa and Fiji Island and the east-north coast of Australia.

Tropical cyclones are associated with severe decrease of pressure due to increase in air temperature, leading to high velocity wind. In the initial stage cirrus and cirrostratus clouds appear, but soon cumulus clouds overtake it with heavy rains particularly in the zone of high velocity winds. Thunders and lightning are very common phenomena especially when the cloud character changes to cumulonimbus. This type of rough weather persists for few hours, and with the passage of the cyclone the over all weather becomes clear. Hazards related to tropical cyclones

High velocity winds and intense rainfall are coupled with storm surges creating havoc in the low-lying coastal areas where a cyclone hit. According to Saffir and Simpson hurricane damage scale, the damages and associated storm surge (in metre, m) can be summarized (on the basis of Oliver and Hidore, 2003) as follows: (i) ***minimum damage*** (1.5 m surge)-causing damage to vegetation and mobile houses, (ii) ***moderate damage*** (1.6-2.5 m)-uprooting and blowing trees, damage to roof tops,

(iii) ***extensive damage*** (2.6-4.0 m)- to structures, buildings, trees etc. (iv) ***extreme damage*** (4.1-5.5 m)- major damages to buildings and structures, severe inundation, and (v) ***catastrophe*** (>5.5 m)- severe damages to heavy structures, huge loss of property and life.

Storm surges are very destructive in low-lying coasts, and the potentiality of destruction increases in estuaries when incursion of seawater is blocked by river floodwater leading to piling up of huge water to spread over the low-lying areas. In the USA the states of Florida, Texas, Louisiana and North Carolina are frequently hit by tropical cyclones (hurricanes) and severe damages occur. Damage to property and loss of life occur mostly due to inundation and flying planks and timbers by strong gale winds.

Adjoining areas of the Bay of Bengal are frequently worst hit by tropical cyclones. Bangladesh is a traditional victim of the storm and associated hazards. In India, Tamil Nadu, Andhra Pradesh and Orissa, and parts of West Bengal are affected by cyclones. The Super Cyclone (29th October, 1999) of Orissa is probably the strongest cyclone in India that severely affected almost one-third area of the state. The cyclone generated a storm surge of about 9 m high inundating up to 20 km inside the landmass, which remained marooned for more than a week. Cyclonic storms and depressions occurring in the Bay of Bengal and the Arabian Sea area have three distinct periods, as follows: (1) April and May- the pre-monsoon summer months, (2) June to September- the four monsoon months, and (3) October to December- the post-monsoon period. January, February and March- these three months experience only very few and relatively weak storms. Average frequency of cyclones and the high intensity storms (within brackets) in the Bay of Bengal and the Arabian Sea area are given in the following table, from which it is evident that cyclonic activities are more frequent in the Bay of Bengal.

Months	The Bay of Bengal	The Arabian Sea
January	4(1)	2(0)
February	1(1)	0(0)
March	4(2)	0(0)
April	18(7)	5(4)
May	28(18)	13(11)
June	34(4)	13(8)
July	38(7)	3(0)
August	25(1)	1(0)
September	27(8)	4(1)
October	53(19)	17(7)
November	56 (23)	21(16)
December	26(9)	3(1)

Extra-tropical cyclones and anticyclones

An understanding of extra-tropical cyclones and anticyclones requires some of the basic fact concerning air masses and fronts. Therefore a brief discussion on these aspects has been done as introductory to the topics as prescribed in the syllabus.

Fronts

V. and J. Bjerkness, H. Solberg and T. Bergeron coined the term 'front' during the First World War to denote a surface of air mass conflict or separation, as analogous to the military dispositions and activities in the war zone. A front can be defined as a narrow zone of thermal discontinuity (called *baroclinic zone)* in air mass properties. This is transitional layers of about one kilometers thickness, and slopes very gently up towards the cold air mass. Within this layer there is turbulent mixing between the two air masses. In the zone of separation, where warm air replaces cold air a *warm front* is developed, similarly where cold air replaces warm air a *cold front* is originated. Sometimes existence of two more types of fronts is recognized. These are- *occluded front,* a situation when cold front overtakes warm front and warm air is completely displaced from the ground surface; and *stationary front,* when two contrasting air mass converge but remain parallel and stand still. The occlusion of fronts can occur in two ways: (a) when the cold air behind the cold front is colder than the advancing cold air that is ahead of warm front, the cold front overtakes warm front, the *cold front occlusion* occurs; and (b) when the air behind the cold front is warmer than the advancing air that is ahead of warm front, the retreating air overtakes the advancing air, the *warm front occlusion* occurs. The process, through which fronts are created or are intensified, is called *'frontogenesis'* the initial process of cyclonic development (called *cyclogenesis).* This is common in low-pressure regions where two contrasting air mass- warm and cold, converge. If airflow pattern diverges the existing fronts weakens. This occurs due to subsidence of air from higher level, leading to development of anti-cyclones and disappearance of fronts, called *'frontolysis'. Fronts and weather*

Vertical motion in the air masses is responsible for the associated weather conditions. If the air in the warm sector rises relative to the frontal zone the front is usually very active, and is called *'ana-fronts'1 (ana* means up). When warm air sinks relative to the cold air mass, it becomes less intense and it is called *'kata-fronts' (kata* means down). Since a warm front moves at about 50 kilometer per hour, the entire warm front cloud sequence takes about 18 hours to pass by a given location, giving rain and drizzle for some 6 hours at a stretch. In a very active cold front thunderstorms and tornadoes are quite common features of cumulus clouds, and

precipitation takes the form of torrential rain showers along with hailstorms. *Major frontal zones of the world*

The two low-pressure belts, namely- equatorial and sub-polar, are principal converging zones of air masses, but there are other potential areas where contrasting air masses create fronts. The most prominent frontal zones in the Northern Hemisphere conspicuously found both in summer and winter are- the Polar and the Arctic fronts. The other major front, called the Mediterranean Front, occurs only in winter season.

The *polar front* is found in both of the hemispheres, and it is more prominent over the Atlantic and the Pacific Oceans. In northern winter it shifts towards the equator. The *Arctic Front* lies roughly parallel to the shores of the Arctic Ocean both in summer and winter. The *Mediterranean Front* is created in winter, when European (Pm or pc) air mass converges with North African (Tc) air mass. In summer the Mediterranean region comes under the influence of sub-tropical anti-cyclone with hot and dry air. Two trade winds *(not air masses in true sense, as there is no temperature contrast between the two)* converge in the equatorial low-pressure area, forming a front-like zone that shifts with the apparent movement of the sun.

Extra-tropical cyclones

Fronts, together with traveling high and low pressure systems, are responsible for the development of mid-latitude or temperate or extra-tropical cyclones. These are also called wave cyclones or depressions due to occurrence of low pressure in the center and increasing pressure outward. On the basis of their shape, may be roughly circular or elongated/ elliptical (like wedge) or oval, they are variously called *lows,* or *troughs.* General characteristics of extra-tropical cyclones can be outlined as follows:

(i) They are usually found in the temperate region between 35° to 65° latitudes of both the hemispheres,

(ii) They are originated due to convergence of contrasting air masses- i.e. warm moist tropical and cold dry polar,

(iii) They move in a easterly direction due to the influence of westerly winds (as effect of Coriolis force is high in these high latitudes)

(iv) Their diameter ranges between 200 and 3000 km, but mostly within 800 to 1500 km. The vertical extent of them is usually within 10 to 12 km from the earth's surface,

(v) The speed of extra-tropical cyclones also vary, the average is about 30 to 50 km per hour. The wind speed increases with height and decrease of temperature,

(vi) The weather pattern is more complex, particularly in winter. Within a period of 2 days as many as four depressions may pass over an area experiencing varied changes of weather within a short period of time.

Origin of extra-tropical cyclones

Frontogenesis in extra-tropical cyclones or depressions must fulfill three conditions, namely (i) existence of two adjacent air masses of contrasting temperature, (ii) a strong converging atmospheric circulation to bring the air masses close to each other, and (iii) sufficient Coriolis force to ensure warm air does not just lie on the cold air (Ayoade, 1983). A number of postulations and theories have been developed by different meteorologists since the second half of nineteenth century; among them *polar front theory* and *baroclinic theory* are front-runners.

Polar front theory: This is also known as wave theory, which was propounded by Norwegian meteorologist Vilhelm Bjerknes and his son Jakob Bjerknes in 1918. This theory is primarily based on formation of fronts. According to theory the life-cycle of an extra-tropical cyclone undergo six successive stages as follows: (1) ***Initial stage-*** during this two contrasting air masses lie parallel to each other, a stationary front is created; (2) ***Incipient stage-*** a wave-like unstable front is created due to penetration of warm and cold air masses into one another's territory; (3) ***Mature stage-*** warm and cold fronts are fully developed and isobars become almost circular, warm air ascends over cold air; (4) ***Narrowing stage-*** fast advancement of cold front narrows down warm sector- the two fronts come very close; (5) ***Occlusion stage-*** advancing cold front overtakes the warm front leading to occlusion; and (6) Final stage- warm sector completely disappears along with the occlusion, resulting in dying of the cyclone.

Baroclinic wave theory: This is actually an assemblage of conceptual developments based on information of upper air circulation to provide a satisfactory explanation of ***cyclogenesis-*** the formation of cyclones. Although polar front theory is still accepted as a valid theory to explain origin and development of extra-tropical cyclones, its inadequacy is felt in regard to its consideration of surface data only. In comparison baroclinic wave theory relies mostly on upper air knowledge in addition to surface data. Some of the important postulations of baroclinic wave theory are: (1) the cyclones and anticyclones are part and parcel of general circulation; (2) observations of upper winds show that the circulation is wave-like and within the waves there are troughs and ridges; (3) the waves of variable lengths and magnitudes migrate eastwards (as observed across the USA); (4) occurrence of the westerly jet stream can be attributed to the fact that winds aloft move from warmer to cooler areas due to strong Coriolis deflection; (5) exchange of heat and moisture between the tropics and polar region is possible through these weather process, etc.

Track of movement of extra-tropical cyclones

Normally extra-tropical or mid-latitude cyclones travel with the prevailing westerlies and therefore they are usually directed from west to east. But owing to differential heating condition over the surface of movement they use to be deflected towards south on continents and towards north over the oceans. The following important features in regard to movement of mid-latitude cyclones may be noted:

(a) In a west-east direction of the polar front the warm air from the south continually lower the pressure towards east, leading to shifting of the centre of the depression to the east.

(b) In a northerly directed polar front the pressure difference is reduced very quickly and after moving a relatively short distance the depression disappears.

(c) In a southerly directed polar front the depression can move far off its source region and covers a large area. Due to surface heating it gets the energy to sustain for relatively longer time. The Mediterranean cyclones are typical examples of this category.

Weathers associated with extra-tropical cyclones

Weather characteristics associated with extra-tropical cyclones vary greatly over an area due to its moving nature and also different stages of its development over time. However, on the average, the following sequence of weather can be observed over a given location associated with the passage of a depression: (a) *Ahead of the warm front-* with the slow but steady rise in temperature there is fall of atmospheric pressure and increase in wind speed and occurrence of precipitation; (b) *At the warm front-* rise of temperature, decrease of wind speed, almost no precipitation; (c) *In the rear of the warm front-* little or no change in temperature, steady wind, intermittent rain and drizzle; (d) *Ahead of the cold front-* pressure falls and wind speed increases, some rain; (e) *At the cold front-pressure* rises suddenly followed by increase in wind speed, fall of temperature and humidity, occurrence of heavy rain accompanied by hail and thunder; (f) *In the rear of the cold front-* fine spells of rain followed by low humidity and continuous rise in atmospheric pressure. Therefore, it is obvious that the people residing in a frequently occurring extra-tropical cyclonic region are in great difficulties to adjust with the rapidly changing weather conditions.

Extra-tropical anticyclones

F. Galton was the first to use the word anticyclone in 1861 to denote a diverging air circulation to all directions from a high-pressure area. Anticyclone is just opposite in character from that of a cyclone. Wind moves outward in a clockwise direction in

the northern hemisphere, form a high-pressure core to the low-pressure marginal areas. In the southern hemisphere the direction of wind is just opposite. Some of the important characteristics of anticyclones can be outlined below:

(i) In an anticyclone high pressure lies at the center, and pressure progressively decreases outward. The pressure gradient is comparatively low, ranging between 10-20 millibars. The isobars resemble concentric circles or sometimes 'V'-shaped wedges.

(ii) Circulation of wind is clock-wise in the northern hemisphere, and anti-clock-wise in the southern hemisphere. The average velocity of movement of the entire cyclone is low, about 50 kmph. The wind speed in anticyclone varies with the pressure gradient, but it is quite low in comparison with cyclones.

(iii) As the origin of anticyclone is related to accumulation of descending air the associated weather remains almost dry and clear, as in case of sub-tropical high-pressure areas. This is because a descending air becomes warmer absorbing more moisture. Besides, in an anticyclone the cold air has very little moisture content, so it remains rainless, (iv) While passing over large water bodies (seas and oceans) anticyclones may pick up moisture and produces some rains in the form of drizzles.

(v) Cold anticyclones, particularly those originating in continental areas of high latitudes in winter, e.g. in Siberia, are very cold. While coming down to the low latitudes (e.g. as Western disturbance in western and northern India during January-February) they cause severe cold waves.

(vi) Anticyclones do not have front but sometimes, 'wind shear and convergence may generate frontal activity in the trough of low pressure between two anticyclones. The resulting front often has north-south alignment and is known as *meridional front'* (Critchfield, 2002).

Types of anticyclones

Anticyclones are usually categorized into three types, namely- cold anticyclones, warm anticyclones and blocking anticyclones.

Cold anticyclones develop over the continental interiors of high latitudes due to excessive radiational cooling. The cold air mass is accumulated vertically to the extent of 2 to 3 km. Air temperature in the morning falls below dew point favouring formation of dense fog. *Warm anticyclones* develop usually in the subtropical areas. These are result of subsidence of convergent upper air in the low latitudes. Warm anticyclones on land are associated with clear weather, but on the sea surface owing to vertical turbulent mixing there are chances of formation of clouds.

Blocking anticyclones are found during high index cycle (strong zonal Westerlies) in the higher latitudes due to breaking of anticyclonic cells away from the Rossby Waves. When established these anticyclones persist for several days. They extend up to the upper troposphere disrupting the flows aloft. These anticyclones block the eastward passage of depressions along their normal path. Blocking anticyclones are associated with fair and warm weather.

1.2 Tropical disturbances

Thunderstorms and Tornadoes

Among the tropical weather systems thunderstorms and tornadoes are very important in terms of their destructive presence. Both are considered as tertiary type of atmospheric phenomena as they use to be short in duration and highly localized in their operation. But both thunderstorm and tornado are quite quick in their movement so that very difficult to cope with the damages associated with them.

Thunderstorms

Thunderstorms are intense local storms associated with dense cumulonimbus clouds produced due to rapid updraft (convection) of moist air; and include torrential rain, hail, lightning and thunder, and gusty squall winds near the earth's surface. Sudden heavy downpour from cumulonimbus clouds is often called *cloudbursts.* Thunderstorms usually occur in the tropics but they are not uncommon in the mid-latitude regions.

Injuries and fatalities are common hazards associated with thunderstorms. Lighting when struck on buildings may damage it substantially and it also causes loss of life. Hailstones are quite dangerous for grazing animals and also for standing crops. Localized downdrafts with strong wind (called downbursts) can cause much damage on the ground surface, bn

Conditions of origin and stages of development

The preconditions for origin of thunderstorms are the presence of rising unstable (warm and moist) air with a vertical extent of about 8 km, throughout which ELR is usually greater than both DALR and SALR, called absolute instability. Latent heat energy released through condensation of rising air is quite responsible for the development of thunder clouds. The common processes for initiation of thunderstorms are (Critchfield, 2004): (a) heating and convection in moist air over warm and surface, (b) passage of cold and moist air over warm water, (c) forced ascent of conditionally unstable *[Note:* in such situation Dry Adiabatic Lapse Rate (DALR) is greater than Environmental Lapse Rate (ELR) or normal lapse rate up to Lifting Condensation Level (LCL), and above LCL due to release of latent heat ELR is greater than

Saturated Adiabatic Lapse Rate (SALR)] air along zones of convergence or at mountain barriers, (d) radiation cooling at upper levels, or (e) advection of cold air aloft. The life-cycle of a thunderstorm is usually very short, about 1 to 2 hours and has a very small size, diameter normally does not exceed 25 km. Three stages of development of a thunderstorm can be recognized: (1) *the developing stage-* characterized by strong updrafts, development of cumulus (thunder) clouds and almost no precipitation; (2) *the mature stage-* the intensity of the thunderstorm is the highest, some downdrafts occur although updrafts are still very strong, development of an anvil-head cumulonimbus cloud at the top of the troposphere (at about 18 km above the ground surface), and intense but localized precipitation along with thunder and lightning; (3) *the dissipating stage-* down drafts prevail over updrafts, moisture in the cloud is exhausted resulting in decrease of rainfall intensity, and the clouds disintegrate into stratiform (altostratus and cirrostratus).

Types of thunderstorms

Conventionally thunderstorms can be classified into three types, as follows:

(1) ***Air mass thunderstorms-*** they are found locally where lapse rate is steeped due to intense solar heating. They occur usually in the afternoon, e.g. *Kalbaishakhi* in West Bengal

(2) ***Line thunderstorms-*** they are organized in bands, called *squall lines,* in the direction of winds at lower level. These are originated and powered by mechanical lifting of conditionally or convectively unstable air mass by highland barriers, as in North Bengal and in the states of Meghalaya and Assam. These also occur in the afternoon.

(3) ***Frontal thunderstorms-*** they occur at day or night time, but in the mid-latitude only, usually along the cold fronts, where unstable air is forced to ascend.

Lightning in thunderstorms

The flash of light accompanied by discharge of atmospheric electricity is called lightning, and thunder is the noise created by sudden heating and expansion of air along the path of lightning. Origin of lighting in thunderclouds is still poorly understood. But is seems that this is due to difference in electric potential between the earth's surface (negatively charged) and the atmosphere (positively charged). In a thunder cloud there is accumulation of both positive and negative charges produced during break of raindrops and/ or ice crystals. Sparks occur between the centers of charges when the potential difference is over 100 million volts or so. The discharge

of potential through lightning may occur within the cloud or between cloud and ground.

Tornadoes

The tornado has its origin in Spanish word *'tornado'* meaning twisting (earlier *'tronada'* meaning *turning).* It is an extremely intense vortex (i.e. a twisting funnel of converging spiraling air) of small horizontal extent that comes down from the base of a cumuliform cloud. The exact mechanisms and characteristics of tornadoes are not yet fully known due to the facts that: (a) tornadoes are short lived, having erratic path of movement and are highly localized, usually within a very small area, and (b) no meteorological recording instrument can withstand against the violent winds of tornadoes. Thus, the characters of the storm are largely an estimation based on the damages created along the passage of a tornado. However, following characteristics of tornadoes can be generally accepted:

(i) These are probably the most violent storms on the earth's surface. The estimated wind speed of rotation is about 3 to 4 hundred kilometers (km) per hour, against which no anemometer can survive.

(ii) There is a sudden drop of atmospheric pressure, the average being more than 25 millibars along the passage of a tornado. This intense pressure difference between inside and outside of closed buildings cause 'explosion' of such structures, instead of being blown over.

(iii) The surface path of most of the tornadoes is quite narrow varying few meters to less than two kilometers; and the average length of passage is about 40 kilometers,

(iv) Tornadoes are very short lived, on the average they stay about 15 to 20 minutes, but sometimes the duration may be longer.

(v) Usually they rotate in a cyclonic (counter-clockwise) direction. But the movement of a tornado on the ground surface is very erratic. Speed of movement of the tornadoes on the surface varies from near stationary to about 100 km per hour.

Origin of tornadoes

The essential preconditions for formation of tornadoes are- (a) presence of a warm and very moist air mass; (b) existence of unstable vertical temperature profile; and (c) presence of a mechanism to start rotation. For this reasons they usually occur in conjunction with severe thunderstorms, squall lines or severe cold fronts. Tornadoes mostly occur in the tropical air, as supply of energy through moisture is abundant in

this region. However, they may also occur elsewhere having favourable conditions to form.

It may be noted that tornadoes occurring in conjunction with scattered storms usually have less duration and they have erratic path of movement, but those associated with squall lines or severe cold fronts live longer, with more regular and longer path of movement.

Global distribution tornadoes and associated hazards

The Great Plains of the USA, having farourable cold air of the Rocky Mountains and warm moist air of the Gulf of Mexico, is the foremost tornado region of the world. Spring and early summer are the most likely seasons of their occurrence in this region, and here they appear mostly in the late afternoon in coincidence with diurnal heat maxima. Other regions of the world experiencing tornado menace are the coastal or near coastal regions of Europe, Australia, Japan, Argentina, South Africa, and the Gangetic Plains of India and Bangladesh. Tornadoes in the sea are known as water spouts, having a relatively small diameter column of condensed water vapour in the low-pressure vortex. These are found in the offshore region of China, Japan and the USA, where cold continental air pushes over warm water. They constitute serious hazards for smooth movement of sea vessels. In hot deserts, tornadoes do not give any precipitation but raise enormous dust, and hence they are aptly called *the dust devils.* A large, well-developed tornado funnel when touches the ground surface destroys most of the things on its passage. Sometimes a number of tornadoes may occur in groups, called *tornado outbreak* to create severe damages. The deadliest component of tornadoes is the uprooted trees, their branches, torn roofs of buildings and structures- together called *tornado missiles.* The severity of tornadoes is assesses on the basis of its destructive activities, on the basis of which T. Theodore Fujita of Chicago University has developed a relative severity scale, popularly known as the *Fujita Scale,* in the late 1960s (Oliver and Hidore, 2003). Forecasting of tornadoes is very difficult due to unpredictable nature of the storm. However, recently developed *Doppler Radars* can be successfully used to predict the likeliness of occurrence and path of a tornado, at least 20 minutes earlier, so that some protective measures can be taken beforehand.

Dust storms

Definition and causes

A *dust storm* or *sandstorm* is a climatological phenomenon common in arid and semi-arid regions. This arises when a gust front passes or when the whirl wind force

exceeds the threshold value of entrainment where loose sand and dust are removed from the dry surface. Particles are transported by saltation and suspension causing soil erosion from one place and deposition in another. The phenomena is very common in the Sahara and drylands around the Arabian peninsula.

Although used synonymously the term sandstorm and dust strom have distinctve meaning. The term *sand strom* is used usually in the context of desert sandstorms, especially in the Sahara, when, in addition to fine particles obscuring visibility, a considerable amount of larger sand particles are blown closer to the surface. The term *dust storm* is used when finer particles are blown long distances, especially when the dust storm affects urban areas. Drought and wind contribute to the emergence of dust storms, as do poor farming and grazing practices by exposing the dust and sand to the wind. Particles become loosely held mainly due to drought or arid conditions.

As the force of wind passing over loosely held particles increases, particles of sand first start to vibrate, then to leap (or saltate). As they repeatedly strike the ground, they loosen smaller particles of dust which then begin to travel in suspension. At wind speeds above that which causes the smallest particles to suspend, there will be innumerable dust grains moving by a range of mechanisms: *suspension, saltation* and *creep.*

Impacts of sand stroms and dust storms

A sandstorm can move the whole a sand dune. Dust storms can carry large amounts of dust, so much so that the leading edge of one can appear as a solid wall of dust as much as 2 km high. Dust and sand storms which come off the Sahara Desert are locally known as a simoom or simoon. The *haboob* is a sandstorm prevalent in the region of Sudan around Khartoum. In the Thar desert region of India it is called *andhi* as visibility is completely obscured. The Sahara desert is a key source of dust storms. Saharan dust storms have increased about ten times during the last ffifty years causing topsoil loss in Niger, Chad, northern Nigeria, and Burkino Faso. According to Andrew Goudie, in Mauritania there were just two dust storms a year in the early 1960s, but presently there are about 80 a year.

Dust storms cause soil loss from the dry lands, and they also remove organic matter and the nutrient-rich lightest particles, thereby reducing soil fertility and agricultural productivity. The abrasive effect of the storm damages young crop plants. Other important effects are: reduced visibility affecting aircraft and road transportation; reduced sunlight reaching the surface; increased cloud formation enhancing the heat blanket effect; impovershment of human health due to breathing of fine dust particles. Hoever, dust can have beneficial effects where it deposits. For example, Central and

South American rainforests get most of their mineral nutrients from the Sahara; iron-poor oceans regions get iron; and dust in Hawaii increases plantain growth.

Some notable dust storms (ref. Wikipedia and other internet sources)

- A series of dust storms displaced hundreds of thousands of agricultural workers in the central United States and Canada during the Dust Bowl (1930- 1940).
- On the afternoon of February 8, 1983, a huge dust storm originating in the Mallee region of Victoria, Australia covered the city of Melbourne.
- On Saturday afternoon of February 24, 2007, a large dust storm originating in the West Texas area of Amarillo covered much of the North Texas area. Strong winds caused extensive property damage to fences, roof shingles, and some buildings. The DFW Airport was severely affected, causing extensive flight delays into and out of the DFW area. Area residents suffered respiratory problems and allergic reactions, causing many people to visit hospitals.
- In June 2007, a large dust storm struck Karachi Pakistan and areas of the Sindh and lower Balochistan, followed by a series of heavy rainfalls which resulted in a death toll of nearly 200.
- On 12th May 2007 a powerful dust storm swept the northern state of Uttar Pradesh in the Friday night leaving behind at least 27 dead and dozens injured. Most of the people died in the Sultanpur district. 9 people were killed when trees fell on their houses, as 15 others died in different parts of the district in accidents caused by the powerful wind and reduced visibility.
- Dust blew over the border between Pakistan and India on June 10, 2007. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this image on the same day. The picture shows the dust plume, appearing as a tan blur, obscuring the landscape below.

Nor'Westers

In general Nor'westers are warm, relatively dry, gusty winds. But the this general term has been used to describe several different types of winds occuring in many parts of the world. For example, in New Zealand a wind pattern called the *Nor'west arch* is found to produce hot, dry weather on the east coast of the South Island.. Some of these storms may be progressive thunderstorm called *derechos* (Spanish word meaning 'right' or 'straight'). These are long-lived, widespread convectively violent winds that are associated with a fast-moving band of severe thunderstorms, usually occur in North America. Typical Nor'westers occur in Bangladesh and adjacent

portions of India during the late spring and summer. Here these storms known as a 'Nor'wester' may be a progressive derecho, as small line of thunderstorms take the multiple bow-shape (in Spanish *'bow echo')* and can travel for hundreds of kilometres. A ***squall*** is a sudden and sharp increase in wind speed that is usually associated with active weather, such as rain showers, thunderstorms, or heavy snow or hails. Squalls refer to an increase in the non-sustained winds over an extended time interval. A ***squall line*** is an organized line of thunderstorms. It is classified as a multi-cell cluster, meaning a thunderstorm complex comprising many individual updrafts. They are also called multi-cell lines. Squalls are sometimes associated with hurricanes or other cyclones, but they can also occur independently. Most commonly, independent squalls occur along fronts, and may contain heavy precipitation, hail, frequent lightning, dangerous straight line winds, and possibly funnel clouds, tornadoes and waterspouts. Squall lines require significant low-level warmth and humidity, a nearby frontal zone, and vertical wind shear from an angle behind the frontal boundary The strong winds at the surface are usually a reflection of dry air intruding into the line of storms, which when saturated, falls quickly to ground level due to its much higher density before it spreads out downwind. In England, a squall associated with tempestuous weather is known as a *blunk. Thunderstorms in India*

During the pre-monsoon summer months, particularly in April and May severe thunderstorms form over the eastern and northeastern parts of India, i.e. in the Gangetic West Bengal, Jharkhand, Orissa, Assam and parts ofBihar, and other north-eastern states of India. As they move from northwest to southeast these storms are known as 'Nor'westers'. Locally these are also known as 'Kalbaishakhis' as their maximum occurrence is in the month of *Baishakh* (mid- April to mid-May). In south India almost similar thunderstorms brining rainfall locally called *'mango showers'* occur in summer. But in the northwestern parts of the country thunderstorms are associated with severe dust storms, locally called *'andhis'. Nor'westers*

Nor'westers are typical summer weather phenomenon of the Ganga-Brahmaputra Deltaic Region along with its plateau and mountain fringe areas. Undercutting of moist Bay air by wedges of cold air extending from the Brahmaputra valley is believed to be one of the principal causes of nor'westers. Some of the salient features of nor'westers can be outlined below:

(i) In the western part of South Bengal the storm mainly occurs in the afternoon and evening. None of them occur during late night or in the morning. Towards east of this area the frequency of occurrences increases in other hours.

(ii) They use to occur with peak frequency in night (between 15-19 hours) in the submontane areas of North Bengal.

(iii) Number of thunder days is more in South Eastern Bengal than other parts of the region. Here the storms are spread all over the day perhaps due to its proximity to the Bay of Bengal, continuously supplying required moisture.
Classification of nor'westers and associated weather

On the basis of origin and movement nor'westers can be classified into the following types (IMD, 1983):

South Bengal Type (Type-A): This usually starts in Chhotonagpur Plateau region, in the states of Jharkhand and Southern part of West Bengal in the afternoon and proceeds in a northwest-southeast direction. The speed of movement of the storm system is between 45-65 kilometerss per hour (kmph). The average speed of associated squalls is between 70-100 (kmph), and these move in a northwesterly to northerly direction.

The beginning of the storm is heralded by rising dust plumes. Sometimes concentration of the dust is so high that it obscures visibility to a large extent. The dry source region contributes immense dust and thus the storm very often resembles dust storms. Due to short life span of the storm, the intensity of rainfall is very high, although the total amount of rainfall varies between few millimeters to few centimeters. Hail sometimes occur in the beginning of the storm or may occur while the storm is on the move. In general the total precipitation increases from northwest to southeast, where the duration of the storm is also longer. Most (about 45 percent) of the thunderstorms (nor'westers) in the Ganga-Brahmaputra Deltaic region are of type-A.
North Bengal Type (Type-B, C and D): These types are of thunderstorms are found in the foothill areas of North Bengal and Assam. Those starting from the sub-montane districts of the North Bengal are classed as Type-B. They mostly occur in the night and early morning, and moves down from north to south, with a relatively slow movement o the disturbance (usually within 20-35 kmph). Hails are rare, but plenty of rainfall occurs from this type. Type-C starts from the eastern hills and is rarest of all the types. The associated squalls of this type come from northeast. Type-D starts from the foot of the Khasi Hills and characteristically they are quite similar to type-B.

Some small numbers of local thunderstorms, in addition to those already discussed, are locally found, and are termed as 'local thunderstorms'. They originate mostly in the afternoon due to local relief condition or excessive heating.

Structure and mechanism

Any direct measure of the vertical or lateral extent of these thunderstorms is not yet available. However, calculating the area of precipitation in a particular hour helps

to find reliable estimates. Squalls as reported are plotted on synoptic charts for appropriate hours. From these it is found that the storms have usual extension of few kilometers to about 300 kilometers along the direction of movement and few kilometers to about 150 kilometers side-wise. So the spatial extent is relatively small. Soundings of upper air show that vertically they are extended between 5 and 13 kilometers from the surface depending upon the relief, heat and moisture conditions.

The mechanism of nor'wester can be associated with the general pressure condition of north Indian plain, which is overlain by a low-pressure trough having west-east direction. The accentuation of the trough and local wind circulation pattern is highly influenced by relief, diurnal distribution of insolation and distribution of land and water. This time the upper wind is roughly westerly, facilitating free ingression of moist bay air. The intense heating of the Chhotonagpur Plateau region pulls moist air from the Bay of Bengal, and during the afternoon there is accentuated fall of pressure over this plateau surface due to trigger action of high relief leading to latent instability. The initiation of thunderstorms starts at the boundary of the moist air; and sustenance of storm is probably caused due to the cold down draft within the thunderstorm that provides the subsequent triggering effect. The storm moves eastwards till the moisture supply is exhausted. Mechanism of all other types is the same as that of type-A (as discussed here) but the triggering effect is given by local relief features, like type-B: the Himalayas, Type-C: Eastern Hills, and type-D: Khasi Hills. The magnitudes of the ice, snow and liquid water depend on the stage of their life cycle.

Recent studies based on Doppler Weather Radar (DWR) and satellites indicate that the nor'westers occur generally when the Convective Available Potential Energy (CAPE) increases above 1500 J per kg. They have updraft speeds up to 3-4 m per second, while the downdrafts have magnitudes of about 0.4 - 0.5 m per second. The updrafts can extend up to 8-9 km altitudes. The estimated total amount of hydrometeors (i.e. ice crystals, etc.) inside the Nor'westers is up to 600-800 mg per kg. Large amount of ice and snow exist at upper levels, while liquid water is present in the lower levels.

1.3 Questions

A. Descriptive/long analytical type

1. Differentiate between tropical and extra-topical cyclones in terms of their origin and weather characteristics.
2. Discuss the structure of a tornado and its potential damaging effect.
3. Describe the weather hazards related to tropical cyclones.

4. Classify the extra-tropical anticyclones and describe their characteristics.
5. Classify nor'westers of the Bengal Delta Region

B. Short answer type

1. What are atmospheric hazards?
2. Differentiate between dust storms and sand storms.
3. What is the cause of lightning in thunderstorms?
4. What is a squall line?
5. How are fronts related to extra-tropical cyclones?

1.4 Suggested Readings

1. Ayoade, J. O. (1983)- Introduction to Climatology for the Tropics; John Wiley & Sons, New York
2. Critchfield, H. J. (2004)- General Climatology; Prentice-Hall of India Private Limited, New Delhi, Fourth Edition
3. Oliver, J. E. and Hodore, J. J. (2003)- Climatology: An Atmospheric Science; Pearson Education (Singapore) Pte. Ltd., Delhi, First Indian Edition
4. Singh, S. (2007)- Climatology; Prayag Pustak Bhawan,. Allahabad
5. Subrahmanyam, V. P. (ed./1983)- General Climatology; Heritage Publishers, New Delhi, pp-142-159
6. Thompson, R. D. (1997)- Atmospheric Processes and Systems; Routledge, London

UNIT-3 ❐ Global warming-causes and consequences, impact on global water balance, EL Nino and La Nina/ ENSO phenomena-mechanism and impact on biosphere

Structure

3.1. ❐ Introduction

Throughout its geological history the earth has experienced several changes in its climate comprising alternate cooling and warming episodes. Recent increase of global temperature is quite unprecedented as it is relatively rapid, and one of the causal factors is human intervention itself This recent warming phase of climate change is widely known as *global warming*. According to IPCC (Intergovernmental Panel on Climate Change), 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level' (Climate Change 2007: Synthesis Report). The report highlights the point of observation that, since 1850, eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature.

Analysis of temperature data shows that during the last about one and half-century global mean temperature is rising rapidly, especially in the later part of the period. It is also to be noted that the 20th century was the warmest of the centuries in the last millennium, the 1990s was the warmest decade of the century, and 1998 was the warmest year of the century. The rise of temperature is more in the higher latitudes of the Northern Hemisphere, as in the Arctic region increase of temperature during the last 100 years was more than twice that of the global mean temperature.

Land surface have been warming faster than the oceans. Observations

show that since 1961 average temperature of the oceans has increased to a depth of about 3000 m and oceans have taken up more than 80 percent of the heat energy added due to greenhouse processes in the climate system. Recent observations of lower and mid-troposphere temperature through balloons and satellites also show that the trend is similar to that of the surface observations.

3.2. ❐ Evidences of global warming

Besides the instrumental observations, as are outlined above, many temperature-dependent phenomena occurring at one or other places on the earth can be cited as evidences indicating warming of the globe, as follows-

- ***Breaking up of the Antarctica's ice sheets-*** e.g. the Larsen ice-self disintegrated in 1995, Larsen B and Wilkies ice-selves broken away in 1998-99; the West Antarctic ice-sheet is shrinking at the rate of about 120 m per annum.
- ***Melting of earth 's mountain/ valley glaciers-*** e.g. glaciers of Mt Kenya has completely melted in the 20 century, and those of Alps in Europe has shrunk by more than 50 percent during the period, while glaciers of the Himalayas are retreating very fast.
- ***Rise of sea level-*** during the last 1961- 2003 period global mean sea level has increased at the rate of 1.8 mm per annum, and at the average rate of 3.1 mm per annum during 1993-2003. The Indian Ocean has warmed up to a depth of 800 m during the last twenty years. It has been estimated that since 1993 the contribution of sea level rise can be attributed to 57 percent due to volume expansion of sea water as a result of increase of temperature, 28 percent due to melting of mountain glaciers and ice-caps, and the rest due to loss of polar ice sheets.
- ***Thinning and retreat of the Arctic ice pack***-since 1979 area of the Arctic sea ice has shrunk by more than 40 thousand square kilometers. Satellite data since 1978 show that, on the average, the Arctic ice has shrunk by 2.7 percent per decade, and 7.4 percent per decade during summer.
- ***Melting of permafrost in the Northern Hemisphere-*** in Alaska the mean annual temperature of the layer above frozen sub-soil has increased by 3.4°C during about a ten year period before 1998. In China the rate of

retreat of permafrost region towards north is about 1.5 km per annum. Since 1900, in the Northern Hemisphere, permafrost areas have decreased by 7 percent, and the decrease has been up to 15 percent during spring.

- ***Change in distribution pattern of precipitation-*** during the period 1900-2005, precipitation has increased significantly in eastern parts of North and South America, northern Europe, northern and central Asia. But it has declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. Globally, the extent of drought-prone area has increased since the 1970s.

- ***Spread of tropical diseases-*** diseases like malaria, cholera, yellow fever, dengue fever and many other tropical diseases are spreading towards higher latitudes and also higher altitudes due to increasing warm environmental conditions.

- ***Changes in plant and animal life-*** since 1951 temperature of the sea surface off the coast of California has increased by 1.5°C, which has led to about 80 percent decline of zooplankton. Due to warming Adelie penguins have found it difficult to adjust in the Antarctica, and thereby its population has dropped by 40 percent during 1975-2000. Severe coral bleaching (large scale deaths of corals in tropical seas and oceans) during the recent past is directly related to rise of sea temperature in these regions. It is also found that the tree lines in mountain ranges are moving at higher elevations.

- ***Threat of becoming environmental refugees-*** The top administrative authorities of the Republic of Kiribati, an island nation (a group of 33 small islands previously called Gilbert Islands, having a total area of only 861 square kilometer and a population around 0.1 million) in the South West Pacific has appealed on the World Environment Day (05 June, 2008) to the international agencies to evacuate them and rehabilitate elsewhere as the island's drainage system has already been destroyed, crops have been failed, and the crisis of water has become severe due to intrusion of salt water owing to rise of sea level-a possible consequence of global warming.

3.3. □ Global warming-causes and consequences

Evidences of the contemporary global warming, as mentioned above, are hard facts that the earth is experiencing today. Many possible consequences of recent climate change due to global warming are frequently discussed at various platforms so that some mitigation strategies can be taken up by different agencies. It is to be noted that the processes of climate change, whether warming or cooling, are very much related to the change of atmospheric composition. Throughout the geological history of the earth the changing nature of atmospheric composition, especially CO2, has played a significant role in climate change. The cooling phases are known as ***icehouse,*** whereas warming phases are called ***greenhouse*** conditions.

(A) Causes of global warming-the science of greenhouse effect

In order to maintain an energy balance, the earth must emit about the same amount of radiation as it absorbs from the sun. The terrestrial radiation occurs in the infrared part of the spectrum and hence is strongly affected by water vapor, clouds, carbon dioxide, and ozone and other trace gases. The ability of these gases to absorb and emit in the infrared allows them to effectively trap some of the outgoing radiation that is emitted by the surface, creating a situation called ***greenhouse effect.***

It is important to note here that owing to the greenhouse effect of the earth's atmosphere, the mean annual temperature of the earth is about 15°C; otherwise it would have been around -18°C; which means the earth is warmer by about 33°C due to the presence of the atmosphere. Therefore, a distinction should be made between natural greenhouse effect of the atmosphere and the so-called greenhouse effect that is widely discussed in these days. The much discussed present day greenhouse effect is mostly a result of anthropogenic intervention in the form of increasing injection of carbon dioxide, methane, etc to the atmosphere. The contemporary greenhouse effect can be better termed as *enhanced greenhouse effect* that is responsible for rapid increase of earth's mean temperature, and has already resulted in so many debates throughout the world because of its far reaching adverse consequences.

Svante Arrhennius, a Swedish chemist was the first to establish in 1896 a relation between increasing concentration of carbon dioxide and recent global warming. According to his estimate a doubling of carbon dioxide level in the atmosphere may result in the increase of about 5°C surface temperature

of the earth. S. H. Schneider in 1950, on the basis of studying several climate models dealing with prediction in change of thermal conditions, concluded that a doubling of carbon dioxide from 300 ppm to 600 ppm might lead to increase of the earth's average temperature by 1.5° to 3°C. On the basis of General Circulation Model (GCM) S. Manabe and R. T. Wetherald predicted in 1975 that a doubling of carbon dioxide level would lead to increase of the earth's surface temperature by 2.9°C. The IPCC report (2001) based on Atmospheric Oceanic Circulation Model (AOGCM) suggested that by the end of the 21st century the concentration of atmospheric carbon dioxide would be within 540-970 ppm resulting in an average increase of temperature between 1 to 5.8°C.

Emissions of long-lived Greenhouse Gases (GHGs)

The radiative forcing of the climate system is dominated by long-lived GHGs. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70 percent between 1970 and 2004 (Figure-1). Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and it represented 77% of total carbon dioxide-equivalent (CO_2-eq) emissions and concentrations. GHGs differ in their warming influence (i.e. radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO_2 as defined below :

- *"CO_2-equivalent emission* is the amount of CO_2 emission that would cause the same time- integrated radiative forcing, over a given time horizon, as an emitted amount of a long lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon. For a mix of GHGs it is obtained by summing the equivalent CO_2 emissions of each gas. Equivalent CO_2 emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses.
- *CO_2-equivalent concentration* is the concentration of CO_2 that would cause the same amount of radiative forcing as a given mixture of CO_2 and other forcing components"- (IPCC Report, 2007).

3.4 ❐ Source and impact of the major greenhouse gases

The major greenhouse gases, their sources and characteristics can be summarized in the following table.

Greenhouse gases	Source of origin	Characteristics			
		1750 AD	2000 AD AD	Increase (in percent)	Atmospheric life-time (years)
Carbon dioxide (CO_2)	Deforestation, Change of land use, Burning of fossil fuels	280 ppm	368 ppm	31	10-200*
Methane (CH_4)	Freshwater wetlands, Wet rice fields, Bio-mass burning, Enteric fermentation in cattle	700 ppb	1750 ppb	151	12
Nitrous oxide (N_20)	Break down of nitrogen rich fertilizer in soil, Livestock waste. Bio-mass burning, Burning of nitrogen-rich fuel, Nitrate-rich ground water	270 ppb	316 ppb	17	114
Chlorofluoro-carbons (CFC-1I)	Propellant in aerosol sprays, Solvent in air conditioning and Refrigeration units, Production of plastic foam for packing food, etc.	0	282 ppt		45-260

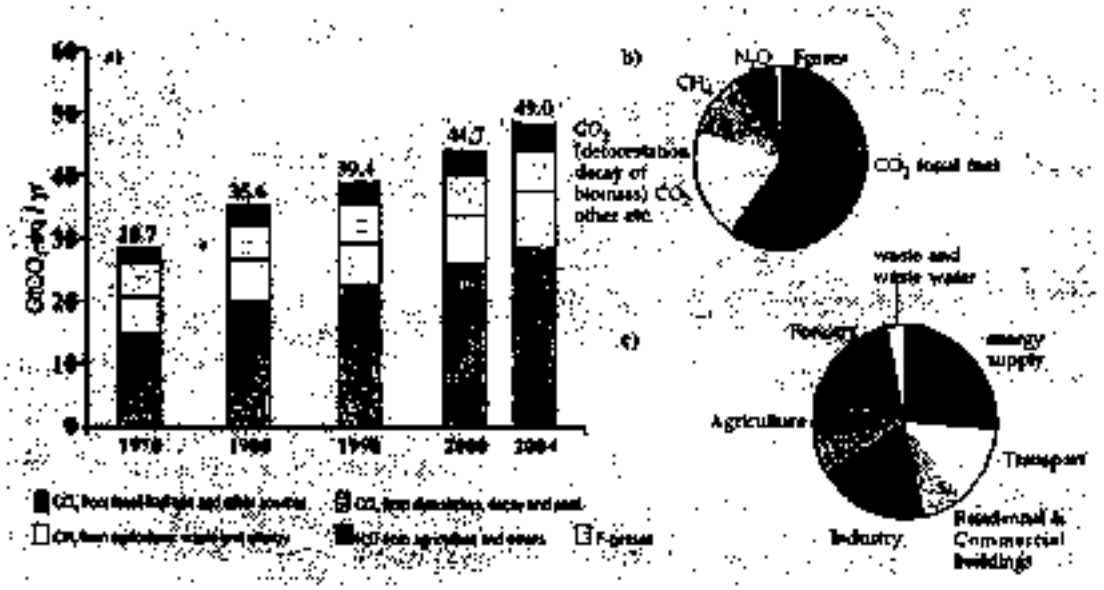
Note: m=million, b=billion, t=trillion, ppm= parts per million, so as ppb and ppt; 1750 AD more or less corresponds to pre-industrialperiod, and the year 2000 AD can be taken as contemporary.

* Lifetime of CO_2 in the atmosphere can be short (about 10 years), i.e. the residence time of a single molecule of CO_2 before dissociation; and long (more than 100 years) i.e. CO_2 derived from fossil fuels remaining in the atmosphere ocean system before being secluded as humus or deep-sea sediment. This latter type is very important in regard to global warming as CO_2 already released in the atmosphere will go on increasing earth's temperature for the next hundred years or so.

Detailed scientific study under the leadership of Intergovernmental Panel of Climate Change (IPCC) has shown that the earth's mean temperature has increased by 0.5°C during the last one hundred years that can be attributed to anthropogenic influence on greenhouse effect. It is also believed that if the process goes on at the present rate the highest temperature may be recorded

during the middle of the twenty first century in the last two thousand years.

Figure-1: Global Anthropogenic Emission of greenhouse gases (GHGs)

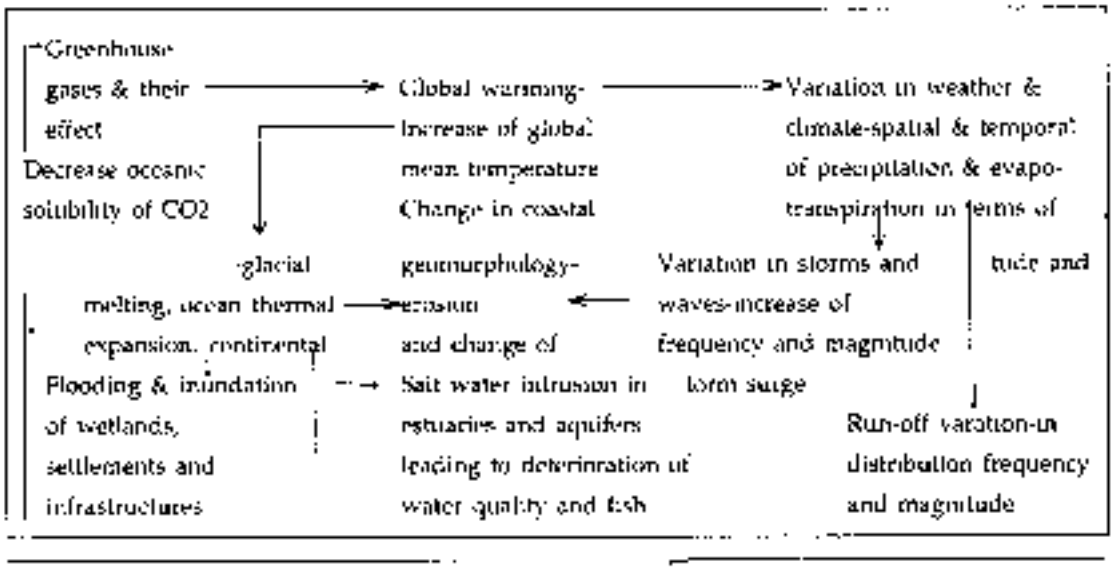


a) Global annual emissions of anthropogenic GHGs during 1970-2004; b) Share of different anthropogenic GHGs in total emissions in terms of CO2-eq (eq= equivalent); and c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO2-eq *Note:* Forestry includes deforestation. *Source:* **IPCC Report, 2007**

(B) Consequences of global warming

The immediate impact of (enhanced) greenhouse effect is the rise of mean global temperature, popularly known as global warming. Some of the probable consequences of greenhouse effect are as follows: (i) *Climate change*- leading to change in the distribution pattern of global temperature and precipitation due to change in global atmospheric circulation; (ii) *Rise of sea level-due* to heat related volume expansion of the ocean water and addition of ice-melt water in the oceans; (iii) *Submergence of low-lying coastal plains,* and its impact

on water resources, habitats, bio-diversity, human settlements, health etc. and (iv) *International conflicts, cooperations and politics* over reduction and management of carbon dioxide emission, among the countries. Although there could be some beneficial effects of carbon dioxide and its resultant global warming through increase rate of plant growth; but this negligible positive effect may not be actually realized due to many negative effects of global warming. The physical consequences of global warming can be shown with help of a Flow Chart, as given below.



Source: Trivedi, P. R. (Ed)- Encyclopaedia of Ecology and Environment, (vol-2, p-60) IEE., New Delhi

Impact of global warming on global water balance

According to the Human Development Report, 2006 of United Nations Development Programme (UNDP, New York) the global water-use per person per day (in litres, during 1998-2002) can be shown in the following table. This clearly shows that many developing countries in South America, Africa and Asia are water stressed by some way or other.

Water availability (in litres)	Countries (with actual average amount)
>400	The USA (580), Australia (490)
301-400	Italy (380), Japan (370), Mexico (360), Spain (3200, Norway (310)
201-300	France (280), Austria (250), Denmark (210)
101-200	Germany (190), Brazil (180), Peru (170), Philippines (160), UK (150), India (140)
>100	China (80), Bangladesh, Kenya (40), Ghana, Nigeria (30), Ethiopia (20), Mozambique (10)

Note: *Below 50 litres availability is called* ***Water Poverty;*** *many high rainfall areas have low water availability and acute water crises. Source: FAO- 2006. UNDP-2006*

The UNDP Report also states that 'Many of the world's most water stressed areas will get less water, and water flows will become less predictable and more subject to extreme events' (P-15). According to IPCC Report (2007) some of the salient features of impact of global warming on global water balance can be outlined as follows:

(1) Climate change is expected to enhance current stress on water resources due to high population growth and resultant land use change. Wide spread losses of glaciers and reductions of snow covers will further reduce the availability of water in the 21*A* century.

(2) The change in river regime conditions will adversely affect hydropower potential and agro-industrial economy of more than one-sixth of the world population in the HimaJayan region alone.

(3) Run-off is expected to increase by 10 to 40 percent during the mid-21st century in the higher latitudes and in some tropical wet areas, including densely populated East and South East Asia. But run-off will decrease by 10 to 30 percent in some dry areas of mid-latitudes and dry tropics due to decrease of rainfall and increase of evapo-transpiration. Many semi-arid areas of the Mediterranean, western USA, southern Africa and northeastern Brazil will experience decrease of water resources. Drought-prone areas will increase by their extent necessitating more water through irrigation, and as such adverse impacts will be seen in

agriculture, water supply in urban-industrial sectors, energy production and health.

(4) The beneficial impacts of increased precipitation will be tempered by negative impacts due to seasonal shift of run-off, water quality and flood risks. There will be negative change in fresh water supply systems.

(5) Frequency and level of flood will increase by 2080 and more than 20 percent more people of the world will be affected by flood and related hazards in riverine and coastal plains.

According to the UNDP report (2006) more than 200 million people in South Asia have been facing (in 2005) water stress, i.e. availability of water being less that 1700 cubic metre (cum) per capita per annum. The figure has been projected as 2000 million in 2025, when severe water stress (1000 cum) will be felt by 250 million people of this region. Among the many projected outcomes identified in the report, for both global and regional scale, the following are worthy of mentioning.

(i) There would be marked reductions in water availability in East Africa, the Sahel and southern Africa due to rise of temperature but decline in rainfall.

(ii) Accelerated glacial melt leading to medium term reductions in water availability in many countries of East and South Asia, and Latin America.

(iii) Disruptions to Monsoon patterns in South Asia with the potential for more rain but also fewer rainy days, meaning increase of frequency of both flood and drought.

(iv) More rainfall in some sub-Saharan countries, but due to more evaporation loss, effectiveavailability of water will be less.

(v) Rising sea levels resulting in freshwater losses in river delta systems in the countries like Bangladesh, Egypt and Thailand.

In reference to India, recent studies (De, 2001) suggests that in the country temperature may rise regionally varying 0.5 -1.0 °C to 3.0-3.5°C with a change of rainfall ranging between 10-30 percent and 50-70 percent respectively. Rainfall is anticipated to increase during the Monsoons both Southwest and Northeast. However, the intensity of rainfall may rise leading to low infiltration and consequent floods. Rise of temperature in certain areas may increase evapo-transpiration causing droughts. Rupakumar *et al* (1992) has identified

certain areas of increasing Monsoon rainfall of 10 to 12 percent above hundred year normal along the West Coast, north Andhra Pradesh, and northwest India; and decreasing trend of –6 to –8 percent below hundred year normal in Madya Pradesh and adjoining areas, Northeast India, parts of Gujarat and Kerala. These are, however, smaller in dimension although quite significant in regard to evidences of climate change in India.

A *Down to Earth* (published by Center for Science and Environment, New Delhi) report of July 31, 2004 based on United Nations Framework Convention on Climate Change (UNFCC) official document of emission of greenhouse gases on future of climate in India highlighted that from 1994 to 2040 the likely increase of average temperature of the country is 2 to 4°C, with rise of more rapid minimum temperature (about 4°C), and shortening of mean rainy days by more than 15 days. This indicates rise of intensity of rainfall and more evapo-transpiration leading to drying up of many river basins of the country by 2040.

(C) Negotiations and agreements over reduction of greenhouse gases

It has been estimated that carbon dioxide alone is responsible for about fifty percent of the increase in greenhouse effect. The industrially developed countries of the world emit too much carbon dioxide as a result of burning of fossil fuels in generation of electricity, running motor vehicles etc. Although total amount of carbon dioxide emission in the developing countries, like India, is also considerably high, here per capita emission is very low compared to the developed nations of the world. The rice producing countries of South Asia are very often blamed for their high methane emission from wet paddy fields and livestock. It is said that heat absorption capacity of methane is twenty times higher than carbon dioxide. But it is also true that the lifetime of methane is only ten years, which is 50-200 years in case of carbon dioxide. Moreover, the emissions of carbon dioxide in the countries of Europe and North America are related to huge energy consumption to ensure a high standard of living, whereas methane emission in the developing countries is due to their life sustaining traditional activities. However, both are detrimental for human civilization and suitable measures should be taken.

Debates and agreements

Rise in global temperature was one of the prime agenda in the *Earth Summit* of United Nations Conference on Environment and Development (UNCED)

in Rio de Janeiro city of Brazil in 1992. In die summit an attempt was made to reach an agreement to reduce the emission of greenhouse gases at 1990 level by the year 2000. But due to lack of any concrete measures and non-cooperation of the developed countries, especially the USA, nothing appreciable could be made in this regard.

Prior to the Rio Conference (1992), the first World Climate Summit, 1979 was held in Geneva (Switzerland), and Conference on Industries and Climate, 1980 in Vienna (Austria). An agreement was signed in September 16, 1987 in Montreal, Canada by thirty-five developed countries to reduce production and consumption of the CFCs i.e. chlorofluorocarbons (to check ozone depletion mainly, but it has powerful greenhouse effect in the atmosphere). This is known as *Montreal Protocol. Toronto Summit* was held in Toronto, Canada in 1988 to reduce emission of 20 percent carbon dioxide by the year 2005, but the developed countries opt out to reach any agreement on the pretext of lack of any reliable data on carbon dioxide emissions. United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) then constituted *Intergovernmental Panel on Climate Change* (IPCC) in 1988 to study climate changes, with special reference to recent global warming and other related issues. The Second World Climate summit (1990) was held in London to constitute Intergovernmental Agreement Committee and to transfer appropriate technology to the developing countries to have a check on their emissions of greenhouse gases.

In 1997 the third summit (the first one in Berlin in June, 1995 and the second one in July 1996 held in Vienna to reduce carbon dioxide but both of them failed due to lack of agreement) of the advocates of climate change to reduce global warming was held in Kyoto city of Japan during December 1-10, where resolutions were taken to reduce 5.2 percent of emissions of carbon dioxide from 1990 level by eleven industrialized developed countries. This is known as the *Kyoto Protocol* or Agreement or Kyoto thermal Treaty. According to the agreement industrial countries (e.g. Russia and Japan) can have mutual transfer of fixed quota (say 6 percent) cut in the emission of greenhouse gases. If one country (Japan) is not in a position to fulfill the quota then it can approach other country (Russia) to cut additional amount to fulfill the sum of quotas of the two countries in lieu of royalty (here Japan has to pay royalty to Russia). This procedure of cutting down of greenhouse gases, especially carbon dioxide, is termed as *carbon trading* or hot air trading. The

importance of the Kyoto protocol is that it is the first step to curtail emissions of the industrialized countries.

December 1-15, 2007 witnessed the United Nations Climate Change Conference in Bali (Indonesia) where 190 participating nations attended to prepare a road map for reduction of human-induced global warming in view of expiry of Kyoto Protocol in 2012.

2. El Nino and La Nina

El Nino or La Nina (pronounced as *ElNee-nyo* and *Lah Nee-nyah)* are two Spanish terms coined to describe the warming and cooling phases respectively of water in the Pacific Ocean. Following are some of the interesting facts and characteristics concerning El Nino and La Nina.

- El Nino was first discovered hundreds of years ago (first reported c. 1541) by fishermen off the coast of Peru.
- El Nino means *'Little Boy''* and was named after the Christ child, because it usually starts around Christmas. El Nino is officially called ENSO (i.e. El Nino Southern Oscillation).
- La Nina means *'Little Girl'*. It is also called El Viejo, which means *''old man'* or an ENSO cold event, hi the past it was also called *anti-El Nino.*
- El Nino is a natural event that recurs in more or less regular cycles (on the average every four to five years) and it affects the Pacific region from Peru to Indonesia. La Nina occurs roughly half as often as El Nino.
- El Nino and La Nina are the most powerful phenomenon on the earth and alter the weather and climate across more than half of the planet. This is because the local warming (due to El Nino) of the world's largest ocean has repercussions for global atmospheric circulation of winds and waters.
- Although some of the effects of El Nino may be beneficial, the phenomenon is better known for the havoc it can wreak: harvests can be lost, fishery yields reduced and oceanic ecosystems endangered threatening food security in many regions. The disturbance can produce droughts in southern Africa, parts of India, Indonesia, Australia and certain regions of the Americas; floods in Kenya, Argentina and the United States; erratic monsoons in South Asia and extremely high temperatures in Japan and some regions of Canada.

Difference between E1 Nino and La Nina

El Nino	*La Nina*
• By definition it is an event, most pronounced in the South Pacific Ocean, which reverses the normal flow of wind and water • El Nino is the extreme warm phase • Rain and flooding along the Pacific Coast • Warm water disrupts food chain of fish, birds, and sea mammals • Tornadoes and thunderstorms in southern US are associated with it • Fewer than normal hurricanes in the Atlantic	• It is a condition of strengthening of the normal circulation over the South Pacific Ocean • La Nina is the extreme cold phase • Snow and rain on the West Coast • Unusually cold weather in Alaska • Unusually warm weather in the rest of the USA • Drought in the southwest of the USA • Higher than normal number of hurricanes in the Atlantic

Some of the important characteristic changes that heralds the occurrence of El Nino are as follows:

(i) Rise in air pressure over the Indian Ocean, Indonesia, and Australia,

(ii) Fall in air pressure over Tahiti and the rest of the central and eastern Pacific Ocean ,

(iii) Trade winds in the south Pacific weaken or move towards east,

(iv) Warm air rises near Peru, causing rain in the northern Peruvian deserts,

(v) Warm water spreads from the west Pacific and the Indian Ocean to the east Pacific. It takes the rain with it, causing extensive drought in the western Pacific and rainfall in the normally dry eastern Pacific.

El Nino and La Nina Years during the one hundred years

La Nina	*El Nino*
1904-05, 1909-10, 1910-11, 1915-16, 1917-18, 1924-25, 1928-29,1938-39, 1950-51, 1955-56, 1956-57, 1964-65, 1970-7], 1971-72, 1973-74, 1975-76, 1988-89, 1995-96, 1998-99, 1995-96, 1999-2000, 2000-01, and 2007-08	1902-03, 1905-06, 1911-12, 1914-15, 1918-19, 1923-24, 1925-26, 1930-31, 1932-33, 1939-40, 1941-42,1951-52, 1953-54,1957-58, 1965-66, 1969-70,1972-73, 1976-77, 1982-83, 1986-87, 1991-92, *1993-94*, 1994-95, 1997-98, 2002-03, 2004-05 and 2006-07

The El nino episodes of 1982-82 and 1997-98 were very strong, adversely affecting many countries. From the table it seems that the occurrence of El Nino periods have been more frequent during the recent past. However, there are some debate as to whether global warming can be associated with this kind of increase of the intensity and/or frequency of El Nino episodes.

3. ENSO phenomena- mechanism and impact on biosphere

The full form of ENSO is El Nino Southern Oscillation. This is associated with appreciable change of ocean-atmospheric system in the southern hemisphere, which includes El Nino. ENSO replaces the Walker Circulation (i.e. the normal latitudinal circulation) and once the process starts it is self-perpetuating. During this warm phase sea surface temperature is increased by more than 3°C and it occupies the region within 7.5° latitude both side from the equator.

(A) Mechanism of ENSO phenomena

The mechanisms which may cause an El Nino event are still under investigation. It is yet difficult to find particular patterns which may show causes or allow forecasts of the phenomenon. As the phenomenon is located near the equator, events in both hemispheres may have an effect. Some of the major theories relating to the origin and mechanism of El Nino and ENSO are as follows *(ref www.wikipedia.org)*:

- *Jacob Bjerknes* in 1969 suggested that an anomalously warm spot in the eastern Pacific can weaken the east-west temperature difference, causing weakening in the Walker circulation and trade wind flows, which push warm water to the west. The result is increasingly warm water toward the east.
- *Wyrtki* in 1975 proposed that increased trade winds could build up the western bulge of warm water, and any sudden weakening in the winds would allow that warm water to surge eastward. However, there was no such buildup preceding the 1982-83 event.
- *Recharge oscillator*: Several mechanisms have been proposed where warmth builds up in the equatorial area, that is dispersed to the higher latitudes by an El Nino event. The cooler area then has to recharge warmth for several years before another event can take place.
- *Western Pacific oscillator*: In the western Pacific, several weather conditions

can cause westerly wind anomalies. For example, cyclones north and south of the equator force west-to-east winds in between. Such wind may counteract the typical easterly flows across the Pacific and create a tendency toward continuing the eastward motion. A weakening in the westward currents at such a time may be the final trigger needed to shift into an El Nino.

- Equatorial Pacific Ocean may tend to be near El Nino conditions, with several random variations affecting behavior. Weather patterns from outside the area or *volcanic events* may be some of such factors.

Southern Oscillation

The Southern Oscillation (SO) is an irregular see-saw in which atmospheric pressure and wind patterns shift across the Pacific. When normally high pressure in the eastern Pacific decreases and normally low pressure over Australia and northern Indonesia rises, conditions are right for an El Nino event to develop. As warm water shifts eastward, so do the convection and heavy rains caused by the increased buoyancy of air warmed by the underlying water. As warm water piles up in the east, upwelling of cold, nutrient-rich water is inhibited. Latent heat of condensation further warms the air, which further decreases atmospheric pressure in the east, etc. The thunderstorms that have shifted from the western to the central and eastern Pacific disrupt high-level jet stream circulation by pumping warm air and moisture high into the atmosphere. This has a far-reaching effect on weather patterns.

The Southern Oscillation is an oscillation in air pressure between the tropical eastern and western Pacific Ocean waters The strength of the Southern Oscillation is measured by the *Southern Oscillation Index (SOI)*. The SOI is a record of the monthly or seasonal fluctuations in the normalized surface air pressure difference between Tahiti (in French Polynesia in the southeastern part of Pacific Ocean) and Darwin (Australia).

Positive Southern Oscillation Index (SOI)

(a) Tahiti pressure is greater than that of Port Darwin

(b) Pressure high over East Pacific and low over the Indian Ocean

(c) Low rainfall over East Pacific and probability of normal Monsoon over Indian region

Negative Southern Oscillation Index (SOI)

(a) Port Darwin pressure is greater than that of Tahiti

(b) Pressure high over the Indian Ocean and low over East Pacific

(c) Probability of bad low rainfall or bad Monsoon over Indian region

El Nino episodes, which are associated with negative values of the SOI, are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds, and a reduction in rainfall over eastern and northern Australia. Conversely, La Nina episodes are associated with positive values of the SOI and are accompanied by stronger Pacific trade winds and warmer sea temperatures to the north of Australia. Waters in the central and eastern tropical Pacific Ocean become cooler during this time.

In normal years when there is no El Nino or La Nina, atmospheric pressure is greater in the eastern Pacific than in the western Pacific. Because wind flows from higher to lower pressure, the trade winds blow from east to west. Warm water piles up in the western Pacific, and sea level is higher (by about 30 cm) lhan it is in the east. Upwelling of cold, nutrient-rich water occurs along the western coast of South America. In some years, this pattern intensifies, so that sea-surface temperatures are colder than usual in the central and western Pacific. This condition is referred to as La Nina and is similar to normal patterns, except that circulation is increased and convection is enhanced over Indonesia.

Walker Circulation and Southern Oscillation: Sir Gilbert Walker, director general of observatories in India, while studying the monsoon system of Asia noticed (c. 1930) that there was a cyclical, interannual variation in the atmosphere over the southwest pacific Ocean, and he called this pehomenon as Souhtehrn Oscillation. This oscillation is associated with major chnages in pressure, wind and precipitation pattern over the southwest Pacific and the Indian Ocean. Studies conducted during MONEX (1978-79) show that Southern Oscillation extends across the Pacific Ocean. Since El Ninio has great impact on the Southern Oscillation, together they are called El Nino Southern Oscillation (ENSO).

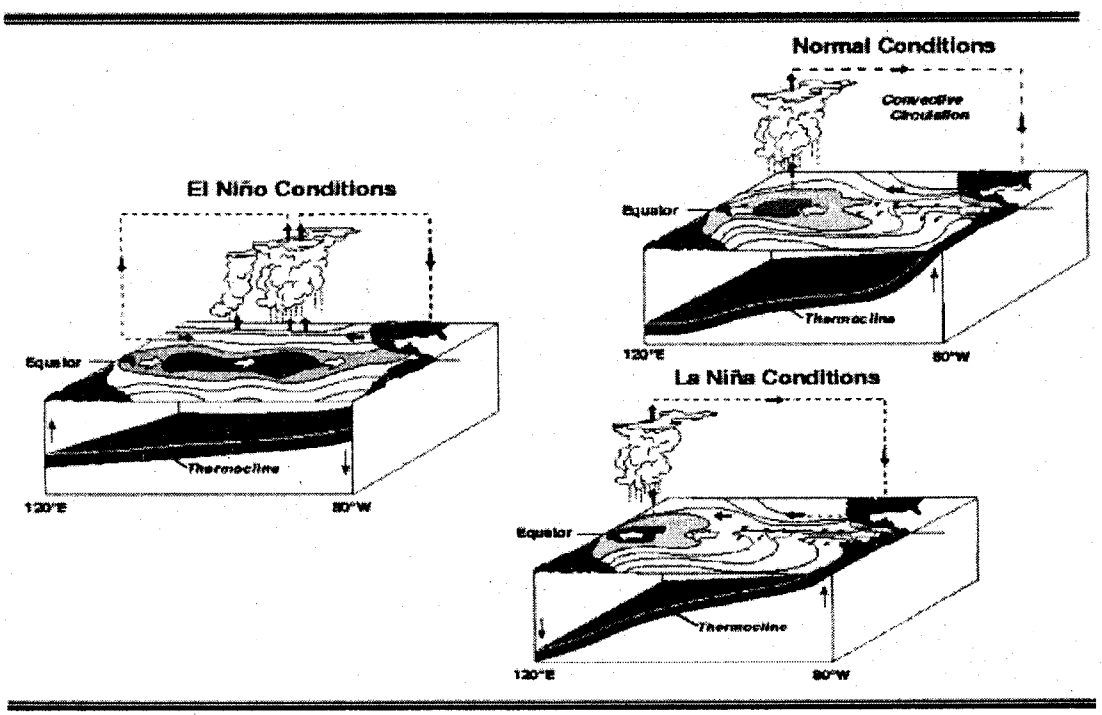


Figure-2: Southern Oscillation **during El Nino, Normal and La Nina Phases.** *Note:* The upper thin (less than 100 m) warm layer of the Pacific Ocean water is separated by a sharp boundary, called the *thermocline,* below which the water is appeciably colder.

El Nino and Indian Monsoon: In general sense, there is a close relation between El Nino, Southern oscillation and Indian Summer monsoon. An El nino in the preceeding winter is suggestive of a strong walker circulatrion and a week monsoon [ref. P. K. Das(l 988)- *The Monsoons*- NBT, New Delhi, P-31], e.g. in the year 1972. But a study conducted for the period 1875-1985 show that there were 43 years of deficient monsoon rains although there were 19 El Nino years. Again, there were 6 El Nino years when rainfall was not deficient. This indicates that there are definite relation between the Indian Summer monsoon and El Nino, but this is not the sole determining factor.

(B) Impact of ENSO on biosphere

ENSO has both good and bad impacts on the biosphere including human beings. The bad effects are, however, more severe than that of the good

effects. Some of the general impacts of ENSO phenomena can be outlined as follows:

- El Nino's storm track affects the location of jet streams, which are a major factor in producing winter weather patterns at mid-latitudes. Instead of coming ashore in the Pacific Northwest as usual, the southern jet stream hits California, carrying moisture and storms. This increases rainfall with accompanying floods, landslides, and coastal erosion in this region.
- In the Peruvian portion of the Atacama Desert it brings copius rainfall associated with violent storms. This is followed by massive floods and landslides resulting in loss of life and property.
- Eastern Australia and New Zealand suffer severe drought, while Tahiti is affected by fatal typhoons, as in 1982-83.
- El Nino is associated with coral bleaching- *en masse* death of corals and destruction of coral reefs off Columbia, Costa Rica, Panama, and the Galapagos Islands, where the loss of corals was reported to be between 50 to 97 percent.
- El Nino reduces the upwelling of cold, nutrient-rich water that sustains large fish populations, which in turn sustain abundant sea birds, whose droppings (i.e. Guano< Spanish ***hucmu***= dung) support the fertilizer industry. The fertilizer is mixed with feather and bones of birds like cormorants, pelicans, gannets, and seal; and they comprise 6 percent phophate, 9 percent nitrogen, 2 percent potassium and moisture.
- Reduction in upwelling of cold, nutrient-rich water upon which phytoplankton depends, affects fish, birds, etc. According to the World Resources Institute (1994), El Nino was a contributing factor in the collapse of the Peruvian fishing industry. From the early 1950s through 1971 the harvest increased and peaked at over 12 million tons per year. This was above the sustainable level estimated to be about 9.5 million tons. With the arrival of the 1972-73 El Nino, disaster struck. Harvests fell to 2.5 million tons. Most of this was harvested from small ponds of cold water isolated from the warm water of the El Nino.
- Agriculture of Australia, Indonesia, Mexico, the Philippines and South Africa was severely affected due to drought conditions resulted from El Nino of 1982-83.
- Human health hazard can be related to ENSO, as it increases famine, water pollution, and diseases such as malaria, dengue fever, cholera etc.

In the arid region of American South West, for example, heavy rainfall in 1982-83 was followed by rapid plant growth and increases of deer mice that transmitted Hantavirus to humans.

Key words and study guides

The discussion as above has tried to incorporate the following key words with their meaningful understanding in climatological studies among the advanced learners in geography: **Global warming, IPCC, Greenhouse gases, Enhanced greenhouse effect, Water poverty, Carbon trading, El Nino, La Nina, ENSO**

The points discussed here are only illustrative, but concise and to the point. Readers are advised to follow some of the basic literatures of climatology as given in the reference. Advanced readers may consult other books and journals available in various libraries and take note of the latest development in some of the current topics of the subject.

3.4 Questions

A. Descriptive long analytical type

1. Identify the evidences of global warming during the recent historical past.
2. Discuss the causes of recent global warming with s reference to the role of greenhouse gases.
3. Analyze the possible cause of global warming with special emphasis on global water resources.
4. Critically examine the issues related to emission and management of greenhouse gases, especially carbon dioxide.
5. Describe ENSO and its effect on climate and biosphere.

B. Short answer type

1. How is enhanced global warming caused?
2. What is the role of carbon dioxide in global warming?
3. Differentiate between El Nino and La Nina.
4. What is Southern Oscillation Index (SOI)?
5. What is carbon trading?

3.5 ❐ References and suggested further readings

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Unit-4 : ❐ Climate changes-evidences and possible causes, reconstruction of past climates. Climate changes through geological time-Quaternary ice age, Changes after Industrial Revolution, Theories of climate change.

Structure

4.1 ❐ Introduction

Since the birth of the earth some four thousand six hundred million years before present, the climate of the planet never remained the same. The earth experienced a number of alternate cooling and warming in a cyclic manner although the durations of the cycles were quite varying. Mention may be made that the elements of weather and climate are ever changing to produce different types of weather and climate systems in a spatio-temporal frame of different scales and dimensions. These changes can be of short term involving a few years, or long term including thousands of years. Sometimes the changes are of geologic time-scales involving million of years, i.e. very long term. The current interest of climate among a wide section of people in the world may be due to the contemporary global warming and its probable consequences. Besides, the causal factors of recent climate change are much related to the activities of human beings.

1. Climate changes- evidences and possible causes, reconstruction of past climates

Reconstruction of past climate, to a satisfactory level of accuracy, is necessary to ascertain the nature and dimension of change of climate. The instrumental records of climatic elements are relatively very recent (about

100-200 years only). But understanding of climate of hundreds or thousands or millions of years before the present necessitates dependence on some proxy-data (i.e. sources containing indirect information on climate like sediments, ice-core, corals and trees). These are called *climate archives*.

A. Evidences of climate change

The evidences of climate change can be classified into a number of groups, as follows:

I. ***Tectonic evidences :*** These indicators comprise information related to plate movements, continental drifts, sea-floor spreading, orogenesis, paleomagnetism etc.

II. *Geologic evidences :* These include sedimentary formations marine and lacustrine deposits, coal seams, sedimentary deposits of limestones and various evaporates (i.e. salt deposits). Among these, lacustrine deposits of fine silts and clays in alternate sequence of layers, termed as *varves*, are very important, as they remain intact for several thousands of years. Soil profiles are also important indicators of paleo-climates.

III. *Glacial evidences:* These are related to advancements of glaciers due to cooling, and their retreat due to warming of the earth atmospheric systems. The nature of glacial or periglacial deposits, and entrapped materials within ice sheets and ice cores are quite significant. Information regarding precipitation, atmospheric condition and volcanic events can be obtained from the isotopes of oxygen contained in the ice-cores of Greenland and Antarctica.

IV. *Geomorphological evidences:* Morphogenetic (i.e. origin of landforms in a particular set of environment, especially climate) association of landform features on different parts of the earth is an important indicator of the past climate, e.g. duricrusts are representing landforms of hot and humid climates, while inselbergs and pediments are formed in hot-arid and semi-arid climates, and presence of erratics indicate their glacial origin.

V. *Biological evidences:* These can be of floral and faunal origin. Among the floral evidences, pollens in sedimentary layers are very useful. These are indicative of the type of vegetation thrived in an area during the past. The study of the annual tree rings (called *dendrochronology*), are helpful in determining the dates and sequencing of paleo-climate. The

thickness of the rings, their colour and symmetry provide information about the environmental condition, especially the climate, during the last few thousand of years. Among the faunal evidences isotope analysis of microfossils of zooplanktons (e.g. *foraminiferra)* are very important.

VI. *Archeological and historical documents.* These are usually found in the form of remains of human civilizations and /or archival records like implements, clothes, utensils, paintings, literatures etc. and are very helpful in reconstruction of the past climate of the last few thousand years from now.

B. Possible causes of climate change

The causal factors of climate change in the earth-atmospheric system, commonly called *climate forcing,* are primarily of four types - (i) *Tectonic forcing,* generated by internal heat of the earth, e.g. plate tectonics, sea-floor spreading, orogenic and epeirogenic processes etc. These may be responsible for change in the distribution of land and oceans, their configuration- both horizontally and vertically, leading to change in the distribution of heat energy in the ocean-atmospheric system. Besides, change in topography may influence in changing the pattern of wind, distribution of temperature and precipitation. Volcanic eruptions associated with mountain building also inject aerosols (i.e. small suspending particles) into the atmosphere that changes the composition of air. (ii) *Earth's orbital changes,* due to the variations in earth's orbit around the sun, followed by change in receipt of amount of solar radiation. Change in the earth's geometry results in change in the relative distance between earth and the sun, and consequently there is every possibility, although on a long-term basis, that different parts of the earth use to get fluctuating insolation, (iii) *Changes in the strength of the sun-* it is related to the sunspots cycles. Although there is no physical relationship between sunspots and change in weather of the earth, lots of studies have been made on this aspect and some coincidences have been found between sunspot cycles and change in the earth's climate; and (iv) *anthropogenic forcing,* due to various human activities altering the composition of the atmosphere. Following are some of the ways through which human activities may potentially cause climate change (Goudie, 1994): emission of gases (carbon dioxide- agricultural and industrial, methane, chlorofluorocarbons, nitrous oxide, krypton 85, water vapour, miscellaneous trace gases), generation of aerosols, thermal pollution, change in albedo (addition of dust to ice caps, deforestation, over-grazing),

extension of irrigation, diversion of fresh water into seas and oceans, and alteration of ocean currents by constructing various structures.

It is worthy to note here that the causal factors of climate change works the best and becomes meaningful for a particular range of time scale. For example, continental uplift and orogenic activities range from 104 to 109 years before the present (BP), role of carbon dioxide in the air from 10 to the present (if fossil fuel combustion is taken together), volcanic dust in the stratosphere ranging between 109 to the present, but ocean-atmospheric autovariation (10 to the present) and atmospheric autovariation (101 to the present) are relatively new.

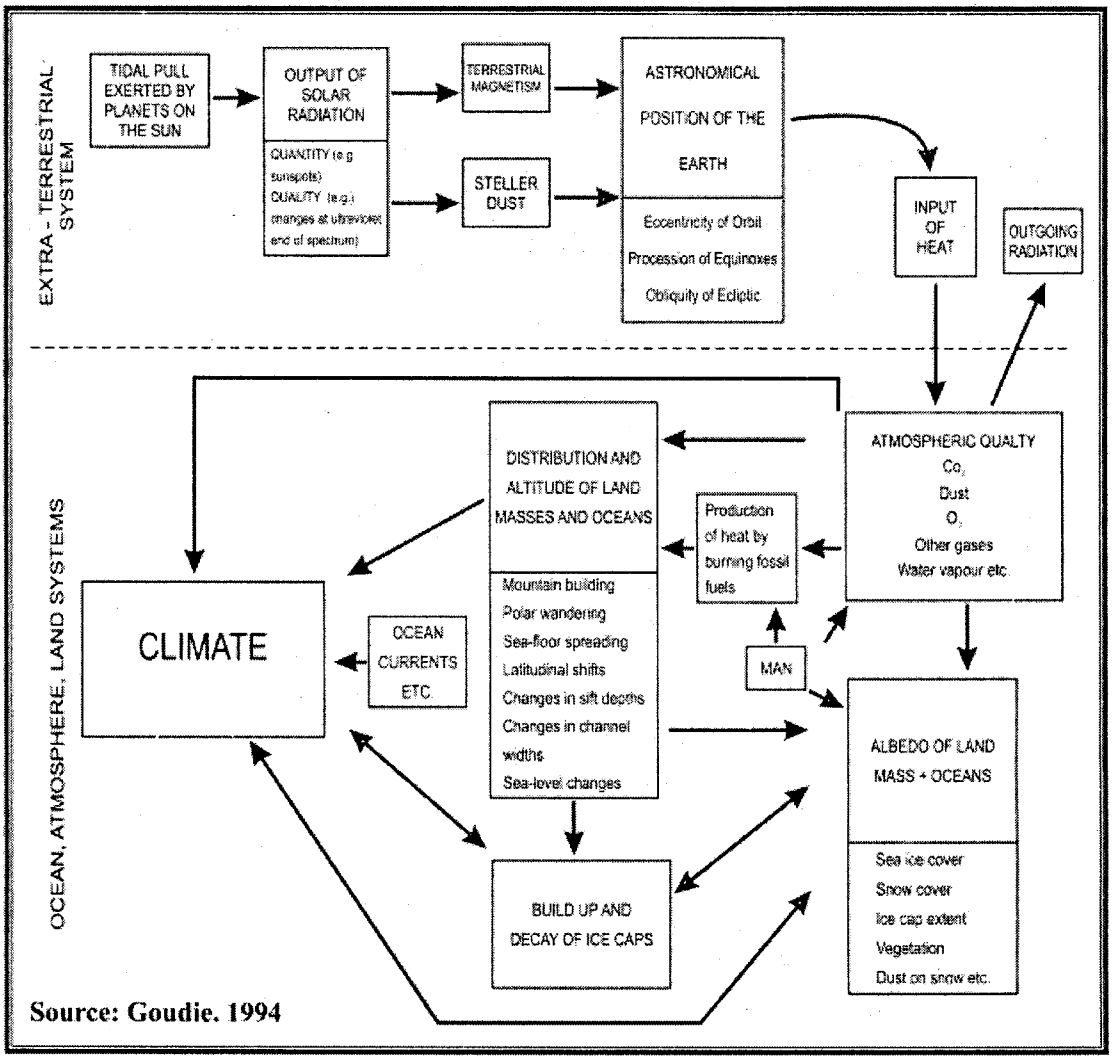


Figure-1: A schematic representation of some of the possible influences causing climate change

4. 2. ❐ Climate changes through geological time- Quaternary ice age

The earth is some 4.6 billion years old, but the study of past climate of the planet more or less covers only about 600 million years from the present. This is because most of the signatures/ evidences of past climate are not available for any reliable reconstruction of the past climate. It has already been mentioned that a relatively accurate paleo-climatic study mostly depends on palaeontology (i.e. study of fossils). Since Precambrian rocks do not have fossils, non-biological evidences like radioactivity of rocks are used to study the climate of this geologic time. Thus the more the time is recent, understanding of climate is more accurate. For example, reconstruction of climate has been possible fairly well since the Pleistocene epoch of Tertiary period.

A. Climate changes through geological time

During the geologic past the climate of earth changed a lot especially in terms of its temperature, and the causes of such change did not remain the same. The intensity of the changes also remained varied. However, it is believed that in most ofthe time during the last billions of years the earth experienced a warm type of climate (table-1). But it is to be noted that all areas ofthe earth did not have the same type of climate. Spatial variation of climate that we see today was also there in the past.

Table-1: Summary information of climates during different geological periods

Era	Period	Epoch	Date of beginning in million years before present (mbp)	Principal climatic conditions during the concerned geologic time
Cenozoic (Amen can) or Cainozoic (British)	Quaternary	Holocene (i.e. Recent)	0.01	Glacial retreat, Little Ice Age, Global warming
		Pleistocene	1.65	Pleistocene glaciations
	Tertiary	Miocene	5.5	Cool
		Pliocene	22.5	Moderate
		Oligocene	36	Moderate to warm
		Eocene	53.5	Moderate becoming warm
		Pal eocen	65	Moderate to cool
Mesozoic	Cretaceous	-	135	Moderate
	Jurassic	-	190	Warm
	Triassic	-	225	Warm
Paleozoic	Permian	-	280	First glaciated then moderate
	Carboniferous	345	First warm then glacial	
	Devonian	-	400	Moderate then warm
	Silurian	-	440	Warm
	Ordovician	-	500	Moderate to warm
	Cambrian	-	570	Cold then warm
	Precambrian		>570	Glacial

Source : Ruddiman, 2001 and others.

Some ofthe salient features ofthe earth's changing climate during the geologic past can be outlined as follows:

- During the last about 600 million years the earth's climate remained mostly warm interrupted by cold conditions.
- Three prominent glacial periods occurred, namely during Precambrian, Permian and Pleistocene.

- The duration of glacial periods remained drastically decreasing, e.g. Precambrian glaciations lasted for 950 million years, Permian lasted for some 50 million years and Pleistocene only about 18 000 years.

- The climate remained cold in most parts of the last one million years, experienced by a series of glacial and interglacial episodes resulting in advancement and retreat of ice-sheets in Europe and the North America.

The Quaternary ice age

In reference to major geologic divisions (in the Geological Time Scale) Cenozoic is the most recent era consisting of two penods, namely the Tertiary and the Quaternary. The periods are again divided into different series or epochs, e.g. the Quaternary constituting the epochs of the Pleistocene and the Holocene.

The Pleistocene *(Pleistos* means *most)* is comprised of alternating great cold and warm conditions. On the basis of faunal evidences, the start of Pleistocene is believed to be about 1.65 million years ago (Goudie, 1994). The Holocene is actually the post-glacial (sometimes called interglacial, at the end of the last Wisconsin glaciations) time of recent past in terms of geological time scale.

Dating of Quaternary climatic conditions was previously done on the basis of traditional techniques like the study of varves, geomorphological features, plant microfossils, pollens, tree-rings, and faunal remains. The modern techniques include isotope methods including Radiocarbon (C^{14}), Uranium Series (U^{234}, Th^{230}) and Potassium-argon (Pa^{231} K^{40}) isotopes found in peat, marine carbonate, coral, deep-sea organic deposits, volcanic rocks etc. Taking together such techniques can fairly delineate the time scale to the range of 0-120 000 years. On the average the Pleistocene glacial and interglacial conditions can be summarized in the following table.

TabIe-2: Approximate sequence of the Pleistocene phases (in the Northern Hemisphere)

Time (Thousand years before present)	Alpine Foreland	North America	Nature of climate
70-14	WÜRM	WISCONSINAN	Glacial
105-70	*Riss-Würm*	*Sangamon*	Interglacial
170-105	RISS	ILLINOIAN	Glacial
410-170	*Great Interglacial*	*Yarmouth*	**Interglacial**
480-410	MINDEL	KANSAN	Glacial
540-480	*Günz-Mindel*	*Aftonian*	Interglacial
600-540	GÜNZ	NEBRASKAN	Glacial

Source : Goudie, 1994

From the table it is found that, (i) about 250 thousand years of the last 600 thousand years the earth, on the average, remained cooler with advancement of glaciers, and the rest of the period under relatively warm conditions witnessing melting and retreat of the glaciers; (ii) the Great Interglacial condition prevailed for about 240 thousand years; and (iii) among the four glacial periods the two consecutive ones are separated by more or less equal time interval, but together they are interrupted by a long span of the Great Interglacial condition.

The Holocene (Holo means *complete)* epoch of the Quaternary period started some 0.01 million or 10 thousand years before the present (BP). The maximum advancement of the last glacial (Wurm or Wisconsinan) occurred at around 18 thousand years BP. Due to rise in temperature rapid melting of the ice-sheets started between 16.5 to 13 thousand years BP, and this time period is called the *period of deglaciation.* The years between this glacial maximum and the beginning of the Holocene are commonly termed as the *Late Glacial,* which were marked by different minor stadials and inter-stadials. *Stadials* are phases of lesser glaciation, and *inter-stadials* are phases of relatively greater warmth occurred during the course of a major glacial phase.

The mean sea level during the Pleistocene glacial maximum (some 18 thousand years BP) was at least 100 metre below that of the present, and the recovery of the sea level change took place around 5 thousand years BP. During this time of recovery the earth's mean temperature was at least 2.5°C

above that of the present in the mid-latitude areas favouring varied flora and fauna, and the time is called the *Climatic Optimum.*

Climate change in the historical past

Archeological evidences and historical records show that the period from 7 thousand to 5 thousand years ago was warmer than the present, and mere was general decline of temperatures during the last 5 thousand years. The distribution of artifacts of the Neolithic man shows that in those days the present Sahara desert was not a desert in true sense as it was quite habitable. Lake Chad was much bigger than that is now. According to Brooks (1949) in 5400 BC climate of Europe was moist and warm, and up to the birth of Jesus Christ the continent experienced alternating cool and warm environment, sometimes dry or moist, lasting for a varied span of years.

During the Christian era many changes in the climate occurred in Europe and adjoining areas. The following table may show the trend of climate during AD 0 and 1750 in Europe.

Table-3: Fluctuations of climate in Europe

Time (AD)	General character of climate
0	Similar to the present
100	Drier and warmer
180-350	Wetter-increased humidity and precipitation
600-700	Dry and warm- melting of valley glaciers in Alps
800-950	Heavy rainfall in Central Europe- replenishment of vailey glaciers
950-1250	Phase *of Little Climatic Optimum* or *medieval warm epoch* - warm and dry, average temperature more than about 1 to 2°C than that of the present
1250-1450	Mild winter, temperature began to decrease, great storminess
1500-1850	*Little Ice Age,* the peak during 1650-1750, extreme cold condition, surface water bodies and rivers (e.g. the Thames) periodically freezed and thawed, advancement of glaciers. The year 1816 AD being the coldest in northern Europe and the USA is known as 'the *year without summer'.*

Source: Brooks, C. E. (1949)- Climate Through the Ages. Dover Publications, New York.

3. Climate changes after Industrial Revolution

Industrial Revolution is a process of change from an agrarian, handicraft economy to one dominated by industry and machine manufacture (Encyclopedia Britannica, 2005). It started in England in the 18 Century (1760 to be precise) and witnessed many innovations and technological changes (power looms), new energy sources (coal, oil and natural gas), development of factory system, improved transport (steam engine) and communications (telegraph) etc. This led to improvement in agriculture too, through better agricultural inputs. Initially it remained confined in Britain (1760-1830), subsequently spread to Belgium, France, Germany, the USA and Japan in 19th century, and China and India in mid- 20^{th} century. The later part of the 20th century witnessed intensification of Industrial Revolution in almost all developed and developing countries, sometimes termed as second or new Industrial Revolution, with excessive mechanization, burning of fossil fuels, pollution and deterioration of environmental quality.

Instrumental records of weather elements date back for about three centuries in Europe, about two centuries in North America, and in other continents for the last 100 or 150 years. The accuracy of such measurements was definitely less. Comprehensive recording of weather elements through actual meteorological instruments started since mid-19th century for most part of the world, and the more current is the time more precise is the recordings; the more is the reliability of such data.

During the first hundred years of Industrial Revolution, climate in Europe was comprised of relatively dry and generally cold and mild winters. In the later part, the glaciers started retreating due to rise of winter temperature. According to Barry and Chorley (2002) the following features in terms of change in global temperature pattern can be identified:

(a) During AD 1860-1920 temperature increased quite irregularly with the range of 0.2 to 0.4°C;

(b) During 1921-1945 the rise of temperature was consistent with a mean value of 0.4°C; (c) During 1946-1975 there was a rise of temperature of about 0.4°C but the trend was oscillating; and (d) During 1976-1989 the rise was about 0.2°C with continuous warming trend.

The decade of 1990-2000 witnessed peak of temperature rise with

consequent heat waves in many parts of the world. It is to be noted that during the last one hundred years the average increase of temperature was about 0.6°C whereas the rate of increase was less than half (0.3°C) of this during the last one thousand years. This excessive rise is most probably caused by anthropogenic forcing in the form of extension and intensification of agriculture, deforestation, burning of fossil fuels leading to global warming due to increase of greenhouse gases in the atmosphere. Various models suggest that increase of greenhouse gases; say a doubling of carbon dioxide from the present level of about 370 ppm will result in the increase of global mean temperature by about 3.5 °C.

Annual Climate Summary 2006 of India Meteorological Department (Report produced by National Climate Centre Office, IMD, Pune) states that since 1993 both maximum and minimum temperatures are increasing, 1996 being the warmest year since 1993, and is above average (of the period 1961-90) by 0.59°C. During the last 100 years normal temperature in India has increased by 0.48°C, and in the northern parts of the country minimum temperature has increased by more than 2°C during this period *(Ref.* Global Warming Sounds Alarm Bells for India- *The Statesman,* Kolkata, dated 23. 04. 2007).

4.3 ❐ Theories/hypotheses of climate change

The process of climate change is very complicated and the potential causative factors of such change operate over a very wide range of time-scale. So it is pertinent to consider one or more of them, sometimes in combination, for a particular time span experiencing climatic fluctuation or change. However, on the basis of the causal factors, many scholars working on climate change have developed a number hypothesis (not theories in true sense), some of which are discussed below.

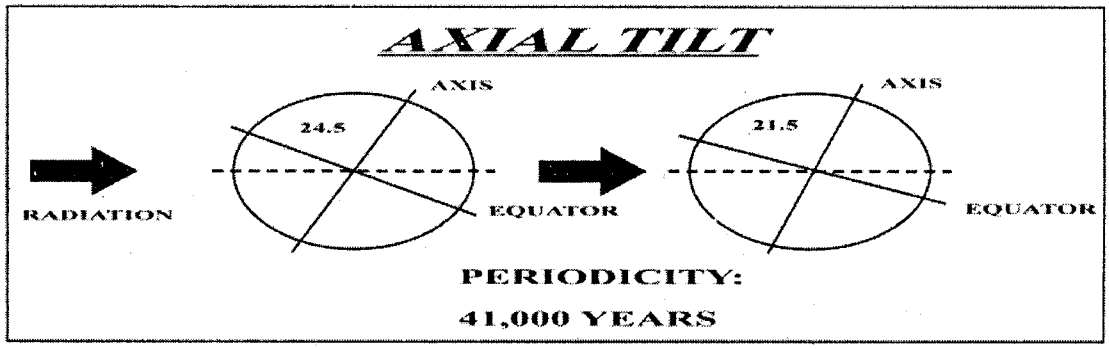
(1) ***Solar radiation hypotheses:*** It has been observed that there are changes of solar radiations both in terms of their quantity due to sunspots, and quality owing to changes in the ultraviolet range of solar spectrum. Some significant coincidence between sunspot cycles (i.e. the consequence of solar out put) and climate change has been found in short term basis, but over a longer time-scale it is yet to be established mat there is any

significant influence of change of solar output on earth's climate.

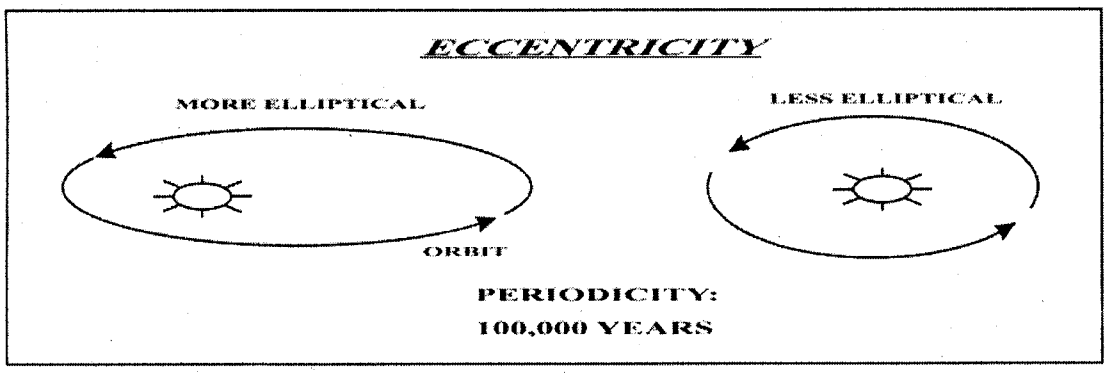
(2) *Atmospheric transparency hypothesis:* Change in the composition of the atmosphere can potentially affect the insolation. Suspended Particulate Matters (SPM) consisting of dust and salt particles, pollen, smoke and soot, volcanic dusts and ashes can reduce incoming of solar energy into the earth's surface through absorption, reflection and scattering. For example, the ash emissions from Krakatoa volcano (in 1880s) and Katmai (1912) were responsible for cutting down of 10 to 20 percent of solar energy for about two years. Various evidences have been found to suggest that the glacial periods have coincidence with volcanic eruptions. Besides, carbon dioxide is another potential gas contributing change in the atmospheric transparency throughout the geologic time, and thereby it has affected the earth's climate.

(3) *Astronomical hypotheses:* This is popularly known as Milankovitch theory after Milutin Milankovitch (1879-1958), a Yugoslav geophysicist-astronomer, who tried to explain advancement and retreat of Pleistocene ice-sheets through a mathematical model. According to him, following are the astronomical changes that can greatly influence long-term climate.

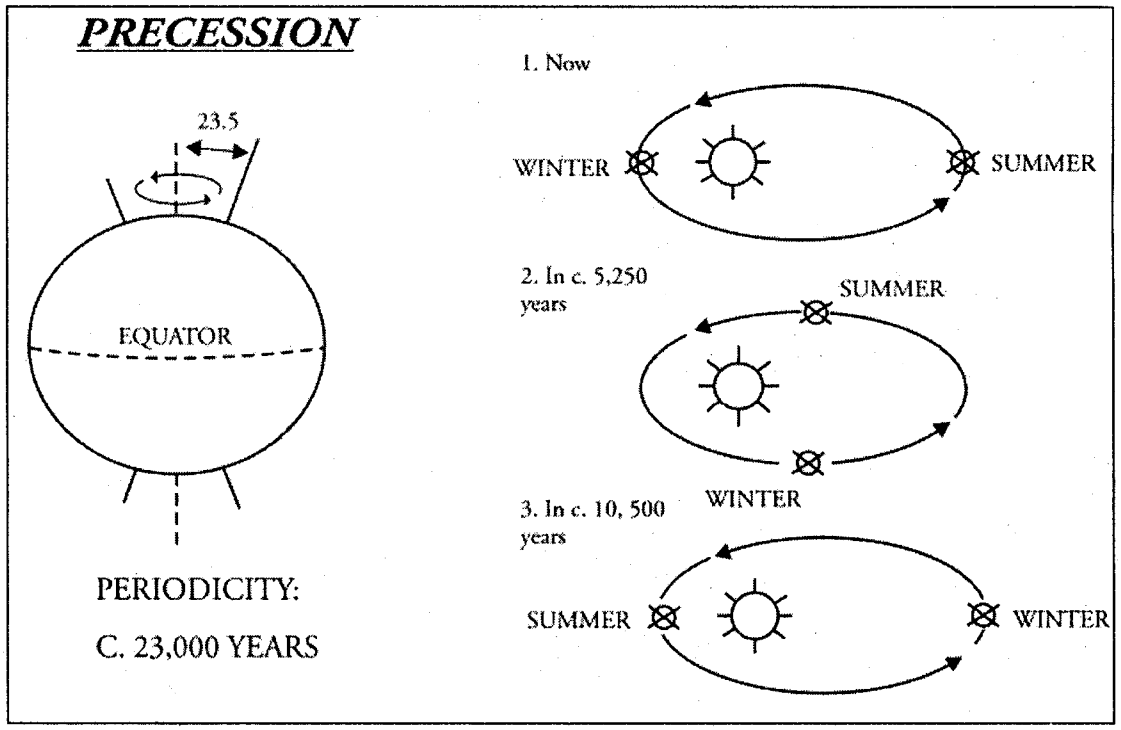
(i) Obliquity of the ecliptic-means the angle of earth's axis in relation to the plane of revolution (ecliptic). This tilt angle varies slowly between 22.1° and 24.5° during a cycle of about 41 thousand years, having a potential effect on distribution of temperature leading to changes in general circulation and seasons as well.



(ii) **Earth's orbital eccentricity**- means over time (a period of about 0.1 million years), the orbit changes from elliptical to almost circular, leading to variation in the mean distance between earth and the sun, affecting distribution of earth's temperature.



(iii) **Precession of the equinoxes**- is related to the change of the time of the year at which the earth is closest to the sun, called perihelion (Greek, *helios* = sun). The reason is that the earth wobbles like a top and swivels around its axis. Presently in Northern Hemisphere it comes in winter (about 3rd January). But about 10.5 thousand years later it will occur in July. If other conditions will remain the same, being a continental (land) hemisphere, some 10.5 thousand years later the Northern Hemisphere will experience colder (also longer due to slow movement of the earth) winter and warmer summer than they are now, since this is a 23 thousand year cycle.



Variations in the Earth's eccentricity, axial tilt, and precession comprise the three dominant cycles, collectively known as the *Milankovitch Cycles* for Milutin Milankovitch, who is generally credited with calculating their magnitude. Taken in unison, variations in these three cycles create alterations in the seasonality of solar radiation reaching the earth's surface. These times of increased or decreased solar radiation directly influence the Earth's climate system, thus influencing the advance and retreat of earth's glaciers.

(4) *Terrestrial geographic change hypotheses:* In regard to the last glaciation phases in the Pleistocene, rapid tectonic movements in the form of mountain building, e.g. the Tibetan Highlands and the Himalayas, might have profound impact on climate change. Such upliftment could enhance albedo-temperature feedback (i.e. lowering of temperature due to increase of elevation and deposition of snow cover leading to high albedo from snow surface and further lowering of temperature), and also could greatly influence the general circulation through the effect of barrier and imbalance in temperature distribution in the concerned region of the earth.

(5) *Feedback or autovariation hypotheses-* It is envisaged that the atmosphere has a tendency of internal instability to provide a built-in mechanism of change. Thus some small change may sometimes lead to long-term changes through positive feedback. For example, when total thickness of the Antarctic ice sheets was less, it permitted further accumulation of snow. But more snow deposits and increase of depth of the ice sheets led to shearing stress at their base, and due to friction heat was generated. This allowed the ice sheets to move onto the continental self areas to spread and cover more areas. Finally, extensive ice cover created a cooling effect in the Antarctic region by decreasing heat input, as a whole about 4 percent, owing to increased albedo.

(6) The Plass hypotheses- Carbon dioxide (CO_2) in the atmosphere allows short-wave radiation from the sun to enter into the earth, but it absorbs terrestrial long wave radiation, and the temperature of the earth-atmospheric system increases, which is popularly known as *"greenhouse effect'*. The Plass hypotheses suggest that due to some reasons there is a cyclical exchange of CO_2 between atmosphere and the oceans to maintain equilibrium whenever there is any excess in one of these reservoirs. When the CO_2 content of the atmosphere is reduced there is a considerable reduction of global mean temperature. Ice-core data of Antarctica support this hypotheses, as it has been found that during the last glacial maxima (about 18 to 20 thousand years ago) the level of atmospheric CO_2 was only fifty percent that of the present. It has also been found that during the last 160 thousand years there has been a positive relation between level of CO_2 and temperature. The increase and reduction of CO_2 in atmosphere-ocean reservoirs can be attributed to various processes of photosynthetic activities, ocean circulation patterns, weathering of rocks etc.

Thus, it is to be noted that given the scale and dimension of climate change in a spatio-temporal frame from the geologic past to the present, and from global to local, it is wise to apply all of these hypotheses to explain case-by-case problems of climate change. No single hypotheses can explain all aspects of climate change, as the hypotheses are still highly speculative. Furthermore, the role of human beings in modifying the climates, especially in the cotemporary world, should not be ignored. It is certainly impossible

to prognosis the future climate, but an understanding of the causal factors of climate change may help in safeguarding the human civilization from any kind of adverse effect of climate change that may become detrimental for mankind in the near future.

In conclusion, it is relevant to quote noted scientist Dr. A. P. Mitra, that 'Climate change, caused by changes in greenhouse gases, is a slow process. The lifetime of the greenhouse gases CO_2, CH_4 and N_2O are long- decades to centuries. The impacts are, therefore, not always visible on short term scales' (Science and Culture. Kolkata, Vol. 68, Nos. 9-12, *Introductory Remarks on Climate Change).*

Key words and study guides

The discussion as above has tried to incorporate the following key words with their meaningful understanding in climatological studies among the advanced learners in geography:

Climate change, Quaternary Ice Age, Pleistocene glaciations, Hypotheses of climate change, Little Ice Age, Climatic optimum, Inter-glacial and Inter-stadials, Anthropogenic **forcing, Milankovitch Cycle**

The points discussed here are only illustrative, but concise and to the point. Readers are advised to follow some of the basic literatures of climatology as given in the reference. Advanced readers may consult other books and journals available in various libraries and take note of the latest development in some of the current topics of the subject.

4.4 ❐ Questions

A. Descriptive/long analytical type

1. Discuss the evidences of climate change.
2. Classify and discuss the possible causes of climate change.
3. Give an account of climate change during historical past.
4. How is climate change related if Industrial Revolution?
5. Briefly explain the different hypotheses of climate change.

B. Short answer type

1. What is Pleistocene glaciation?
2. Write a short note on Plass hypotheses.
3. What is meant by anthropogenic forcing in relation to climate change?

4. What is Climatic Optimum?
5. Write a short note *on* Little Ice Age?

4.5 ❐ References and suggested further readings

- Barry, R. G. and Chorley, R. J. (2002)- Atmosphere, Weather and Climate; Routledge, London (8th Edition)
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GROUP B

Soil and Biogeography

Unit 1 ❑ Processes of Soil Formation, Development of Soil Profiles and Genetic & Environmental Classifications of Soils

Structure :

1.1 Processes of Soil Formation

Soils form an important part of the physical landscape of any region and they are inseparably linked with other components of physical landscape, particularly the landforms, natural vegetation and the climate. The scientific study of soils is called pedology. The term soil is generally applied to the broken rock material having particles of various sizes that lies on the surface of the earth.

In a scientific sense, the soil can be defined as the surface material which over a period of time has accumulated over the bedrock and has come to develop distinct layers or horizons. It is made up of fine mineral fragments provided by the weathering of rocks and organic matter provided by the remains of the plant and animal organisms and can support growth of plants. Many people consider soils as a static body of minerals in which the plants can grow, and their character does not change. However, the soils are dynamic in their character and continue to change in terms of their physical as well as chemical properties, under the influence of the local environmental conditions, and man's usage of them for agricultural and other purposes. It is the distinctive physical and chemical properties of the soils that enable them to support plant growth, and set them apart from the infertile substratum. The true soil is composed of both the minerals derived from the rocks and the organic matter added by the plant and animal communities which come to inhabit it

Soil Forming Processes

Although a large number of physical and chemical processes are involved in soil formation, they can be conveniently grouped under four categories :

- enrichment
- removal
- translocation
- transformation

• ***Enrichment :*** The first group includes processes of soil enrichment through addition of material to the body of soil. Enrichment itself can be inorganic or organic. Inorganic enrichment, for example, may occur through addition of sediment brought from higher to lower areas by overland flow of water. Deposition of silt during flood is another example of inorganic enrichment. Wind deposition is an important process of inorganic enrichment in some regions. Organic enrichment takes place through accumulation of humus in the **O** horizon of soil and its movement down with percolating water to **A** horizon.

• ***Removal :*** The second category of soil forming processes is concerned with removal of material from soil body. Removal of material may occur through removal of sediment from upper layers of soil by running water, winds or any other agent of erosion. Leaching is another important process responsible for removal of material from soil body. It implies removal of soluble substances from upper layers to the lower layers or the groundwater by water percolating water.

• ***Translocation :*** The third group of processes involves translocation, which involves transfer of materials within the body of soil from one horizon to the other. Translocation is achieved through two processes that operate simultaneously – eluviation and illuviation. Eluviation refers to downward transport of fine particles such as clay and colloids from upper parts of the soil leaving behind coarse grains of sand and silt forming the E horizon of soil. Illuviation refers to the accumulation of fine particles brought down normally from horizon **E** to horizon **B**. The materials thus accumulating may be clay particles, humus or sesquioxides of iron and aluminium.

Translocation of calcium carbonate is another important process in soil formation. Many soils are rich in calcium carbonate derived from parent material. In humid climates the rainwater carrying carbon dioxide acts as a mild carbonic acid and dissolves calcium carbonate and leaches it to the lower zones. This process is called decalcification. Decalcification often leads to soil acidity. In semi-arid regions or the areas experiencing a long seasonal drought. Water carries calcium carbonate dissolved in it to horizon **B**, where water penetration reaches its limit. The calcium carbonate is thus precipitated in horizon **B**. This process is called calcification. The calcium carbonate thus precipitated gets deposited in the form of grains, nodules or plates forming a hard layer called a *hardpan.*

Another process of translocation occurs in desert I areas where the drainage from the surrounding areas accumulates in local depressions. Such areas generally have a layer of groundwater, rich in salt, close to the surface. Due to a dry climate, water evaporates continuously

from the surface or slightly below the surface aid the groundwater rises under *capillary tension.* As water evaporates, salts precipitate and get deposit forming a *salic horizon* or surface layer of salts. This process is called *salinisation.*

• ***Transformation :*** The fourth group of soil forming processes involves *transformation* of materials within soil body. Formation of secondary minerals from primay minerals is examples of soil process and the process of *humification* (decomposition of organic matter to form humus) is one such process. In warm and humid climates this process may lead to complete decomposition of organic matter yielding carbon dioxide and water leaving no organic matter at all.

1.2 Development of Soil Profile

Soil profile is also an important physical character of mature soils. The soils are generally formed of fine-grained rock and organic fragments arranged in a series of horizontal strata or layers. These horizontal layers in soil are called the *soil horizons*. The *soil profile* refers to the arrangement of various layers or horizons in the soil. The layers of are usually distinguished on the basis of their colour and texture. The texture and consistency of soil varies in different horizons. The horizons in a soil usually develop through either a selective real or an accumulation of certain ions, colloids and chemical compounds. The removal or accumulation of various substances in the soil is achieved the water seeping through soil from upper to the lower layers.

Soil Horizons : A typical soil profile is likely to develop in soils which are formed under moist climates where forest forms the vegetation cover. Under such conditions two types of soil horizons : organic and inorganic, can be distinguished. The organic horizons are denoted by letter **'O'** and they overlie the mineral horizons. Two layers of organic horizons can be easily identified in most forest soils.

The upper $\mathbf{O_1}$ horizon contains decomposing organic matter that is recognisable as leaves or twigs etc. Below this lies the $\mathbf{O_a}$ horizon, containing organic matter decomposed beyond recognition. This horizon is thus a humus layer.

Below the organic horizons there exist minerogenic horizons. In all four main horizones can be identified below the organic horizons of soil. These horizons are designated by letters **A, E, B,** and **C**. Plant roots penetrate up to B horizon and thus influence the soil development only in **A, E** and **B** horizons These three upper horizons constitute what is called the solunz or soil proper. Horizon **A** is the uppermost mineral horizon and it is rich in organic matter. Due to the presence of humus it generally has a dark colour. Below this is the **E** horizon, a light coloured layer from which clay particles and oxides of iron and aluminium have been removed leaving behind grains of sand or coarse silt. Horizon **B** lies below the **E** horizon and it receives the clay particles and the oxides or iron and aluminium washed down from the overlying horizons. Accumulation of these substances makes it dense and tough. Horizon **C** lies below horizon **B** and it is generally not considered as a part of the soil. It is the regolith layer that serves as the parcent material of soil. Below this layer lies the bedrock from which the regolith develops. This bottom rock supplies bulk of the mineral content of the soil.

Complete and systematic arrangement of horizons in the form of a profile is characteristic of the soils which have developed in situ. The transported soils like the desert sands and alluvial soils generally lack this type of stratification. The process of profile development in soils is affected by a number of factors such as climate, relief and the time period for which various soil-forming processes have acted upon it. The profile of a soil therefore is an indicator of the maturity of the soil and only the mature soils show well-developed profile with clearly marked horizons. Also, the horizons are formed only in the non-transported soils like alluvium or the loess.

1.3 Pedon and Polypedon

It is obvious that the whole soil or even large areas of it can not be studied at one time. Therefore small three-dimensional bodies of soil are used. Such a unit is large enough so that the nature of its horizons can be studied and the range of its properties identified. It varies in size from about 1 to 10 m^2 and it called a ***pedon*** (rhythms with "head on" from the Greek word *pedon* meaning ground). It is a three dimensional body of soil whose lateral dimensions are large enough to permit study of horizons and of its physical and chemical composition.

Because of its very small size, a pedon can not obviously be used as a basic unit for a work table field soil classification system. However, a group of pedons, terned a ***polypedon***, closely associated in the field and similar in their properties are of sufficient size to serve as a basic classification unit, or a *soil individual*. Such a grouping approximates, what in the USA is called a *soil series*. More than 13,000 soil series have been characterized in this country. They are the basic units used in the field classification of the nation's soils.

Two extremes in the concept of soils have now been identified. One extreme is that of a natural body called a soil, characterized by a three-dimensional sampling unit (pedon), related groups of which are termed a soil series. At the other extreme is the soil, a collection of all these natural bodies that is distinct from water, soil rock and other natural parts of the earth's crust. These two extremes present opposite ends of elaborate soil classification schemes that are used to recognize knowledge of soils.

1.3.1 Pedogenic Regimes

The various soil-forming processes operate in areas of particular climate and are associated with specific vegetative and other environmental conditions. Also, a group of processes operate in conjunction and they produce soils with peculiar characteristics. Such a complex of soil forming processes, typically associated with particular types of environmental conditions and creating soils with typical characteristics can be called a pedogenic regime.

Podzolisation : The pedogenic regime of podzolization is associated with areas of cool humid climate with forest as the natural vegetation. In such areas the low temperature inhibits bacterial action and thereby accumulation of humus takes place. This pedogenic regime is associated with areas having no long dry season. Podzolisation is the typical endogenic regime of the areas of coniferous forests. These plants do not require bases and consequently they are not added by the dead plants to the soils and the upper layers of the soils lack in bases as the process of leaching

removes them very successfully. Compounds of iron and aluminium are also removed from the upper layers of the soil. The well-distributed rainfall round the year helps in maintaining high rates of leaching. Thus the bases and colouring agents such as iron and aluminium compounds are removed from the top layer of the soil. This gives a characteristic **ash gray colour** to the *soils of cool humid regions*. The major content of these soils in the horizon **A** is silica. As the colloids of minerals and the bases leaching out of **A** and **E** horizons get accumulated in horizon **B**, the latter layer shows a slightly darker colour. Since most of the bases are removed, the soils developed under the influence of podzolisation are not very fertile for the rain crops. They can, however, support dense forests of conifers as the trees can obtain all nutrients from the lower layers of the soil where they are carried through leaching. The soils developing under this pedogenic regime have a *well-developed profile with distinct horizons*. In fact the profile of the soils formed under this regime is considered as the ideal soil profile. Podzols and podzolic soils are the most important soils formed through this pedogenic regime. These soils are characteristic of the mid-latitude coniferous regions and they are acidic in reaction. In areas where the amount of rainfall is slightly lesser or where the rainfall is seasonal, the podzols are replaced by somewhat darker coloured soils.

Laterisation : The process of laterisation is associated with the regions of tropical forests. A large amount of precipitation well distributed over the year and continuously high temperature result in high levels of bacterial activity. High level of bacterial activity results in complete decomposition of organic matter and it explains the lack of humus in soils of humid tropics in spite of dense forests found in such areas. Although the rate of addition of plant litter in these regions is very high, the soils are typically poor in humus. The rate of addition of the organic matter to the soil and decomposition thereof tend to be equal. Since there is lack of humus, there will be a lack of humic acids and as a result the sesquioxides of iron get accumulated in soils in the form of nodules, red clays and hard, rock-like layers. Silica is leached out by the process of desilication. There is no development of distinct horizons and the soils are porous and firm rather than sticky and plastic. Typical soils formed through this pedogenic regime are the **laterite**. Due to excessive leaching the laterite soils tend to be low in fertility, besides being acidic to neutral in reaction. However, they support some of the most luxuriant stands of rain forests mainly because the trees can obtain the nutrients from lower layers of the soils with the help of their long roots, and the infertility of the soils is from the point of the grain crops which are shallow rooted. However, laterite soils can be used for raising a variety of crops including rice and plantation crops if manure is added frequently.

Calcification : The pedogenic regime of calcification is associated with climates in which the annual precipitation is low, and is exceeded by annual potential evaporation. This type of climate is characteristic of continental regions with a tropical wet-dry climatic regime. Due to limited precipitation leaching is not perfect and some amount of bases is found. This makes the soil alkaline in reaction. During the dry season, there is shortage of moisture on the surface and the water being drawn upwards through capillary tension brings the soluble bases to the upper layers of the soil that and get accumulated there as a result of high rate of evaporation. These soluble bases form the hard pans or the nodules in the sub-surface zone of the soil. **Grass** is the characteristic vegetation growing in such regions and since grasses use bases, they keep restoring them to the soil when they die. There is moderate to high accumulation of humus, depending on the nature of vegetation and climate. The colloids that do not get leached are found in horizon **B** in the form of nodules and

dense layers. Lack of microbial activity due to low precipitation results in occasional accumulation of humus and it is lesser in the areas of lower rainfall. The soils formed through this regime are fairly rich for grain crops, especially in areas of good seasonal moisture availability. The prairie and steppe regions have this type of soils.

1.3.2. Soil Catena

A soil catena is a sequence of different soil profiles that occur down a slope. They occur on hill slopes where the geology is uniform and there is no marked difference in climate from the top to the bottom of the slope. This makes the slopes of the Garraf Natural Park an ideal location to study such a catena, as the underlying rock type is limestone and the climate relatively constant. Milne originally defined a catena as 'a unit of mapping convenience ... a grouping of soils which while they fall wide apart in a natural system of classification on account of fundamental and morphological differences, are yet linked in their occurrence by conditions of topography and are repeated in the same relationships to each other wherever the same conditions are met with' (Milne 1935a, p. 197).

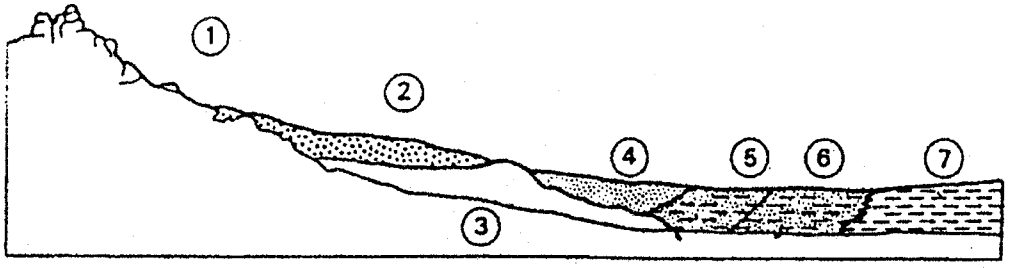
The variations in soil profile that occur down the slope are largely the result of changes in slope gradient. Soil can be eroded easily from a steep slope, but will tend to accumulate on shallower gradients. Soil water will drain freely on steep slopes, but will take much longer to drain from shallower ones. Soil drainage is relatively important in the formation of the catena. Although the limestone bedrock is permeable, the permeability is reduced by soil accumulation and the steep gradients encourage movement down slope rather than through the soil. This means that many nutrients are washed down slope, along with small particles. This has an effect on the texture and pH of the soil. This affects the properties of the soil.

During the field investigation stage, it is important to establish and understanding of the process operating within the soil.

- The depth of organic matter can be linked readily with cycling efficiency, wetness, temperature and acidity by analysing its structure.
- Red and grey colours can be used to indicate the oxidation status.
- Moderate precipitation can be sufficient to leach away any calcium carbonate which dissolves from the hard limestone fragments and thus maintain an acid soil reaction. In this acid medium the dissociation of the clay menerals can begin and is normally evidenced by the red coloration of the ferric oxide (Fe_2O_3) so released. Because of this, these soils are referred to as 'terra rossa' or 'red limestone' soils.
- Leaching processes can be deduced from accumulation lower down in the soil profile and they can also be predicted to occur from accumulations of organic matter on the top of the profile because these act as sources of organic acids.

The catena and the processes of erosion

Milne (1936a) was one of the first to include the processes of erosion as a major factor leading to the differentiation, under constant climatic conditions, of several different but related



Soils of an East African catena (after Milne 1936a)

soils usually from a common original material. A shallow dark grey loam (1) formed by weathering of the granite surfaces has worked downhill by creep and slow erosion to act, on the footslope, as the parent material on which a deeper soil (2) of the red earth group has developed. At the base of the red earth profile, where a temporary accumulation of seepage occurs in the wet season, a horizon of coarse granitic grit (3) in a black rusty ferruginous cement has formed. Occasional storm water running over the surface has gradually pared off the topsoil and the material has travelled differentially according to particle size, so that by a cumulative effect a zone of washed sand (4) has covered the footslope, with silty or clayey sand (5, 6) beyond it, and clay has accumulated on the level bottomlands (7). At all stages the erosion has been slow and non-catastrophic and the soils have borne their appropriate vegetation and been developing towards maturity.

1.3.2.1 Catenary differentiation

The differences between the soils of a catena are generally related to differences in their position and their drainage characteristics so that emphasis is placed on the difference between the freely drained upper parts of the slope and the imperfectly to poorly drained lower portions. This provides a continuum between those sites where the influence of soil moisture is at a minimum and those sites where maximum influence of soil moisture is felt. Slope steepness is one of the most important factors that causes a variation in soil moisture conditions as the steeper angles reduce the amount of water percolating through the soil and increase the removal, perhaps through accelerated erosion, of the upper portions of the soil profile. The essential feature is that soil and water can and do move downslope. For these processes to have their greatest effect the ground-surface must slope downward continuously from the crest to the base of the slope and it is incorrect to apply the term catena to landforms which lack this feature.

The main processes of catenary differentiation are surface wash, soil creep, solution and rapid mass movements. Young (1972b, 1976) has distinguished between static and dynamic causes leading to catenary differentiation. Static causes are governed by site differences alone, irrespective of the position of the site, and include effects of slope angle and the depth of the water table. Dynamic causes are brought about by the position of the site with respect to the slope.

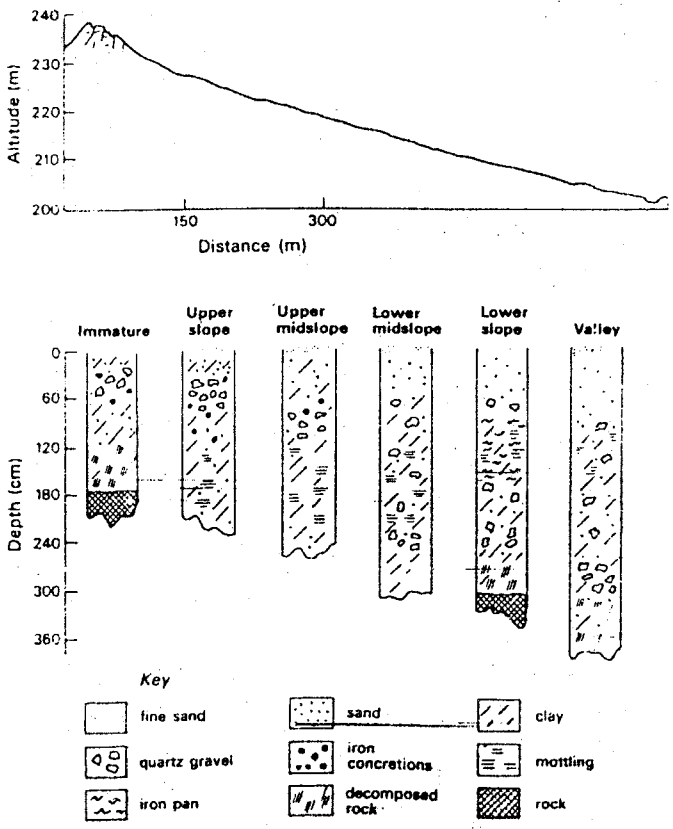
1.3.2.2 Soil changes within catenas

The result of the processes described above is to produce a series of changes in the soil properties from the upper to lower members of the catena. The variation in soil colour is one of the more obvious sequences and is typical of many West African catenas. Upland, well-drained soils

are usually reddish-brown, the colour showing the presence of non-hydrated iron oxide in the soil. The iron is well dispersed and usually partly attached to the clay fraction, thus the clay itself appears red. On the middle and lower parts of the slope, drainage is slower partly because of moisture seeping downslope from the upper soils. These soils remain moist longer and dry out less frequently and less completely ; this leads to an increasing degree of hydration of the iron. The red colour then changes to a brown or yellow one; the hydrated iron oxides are mainly limonite and goethite.

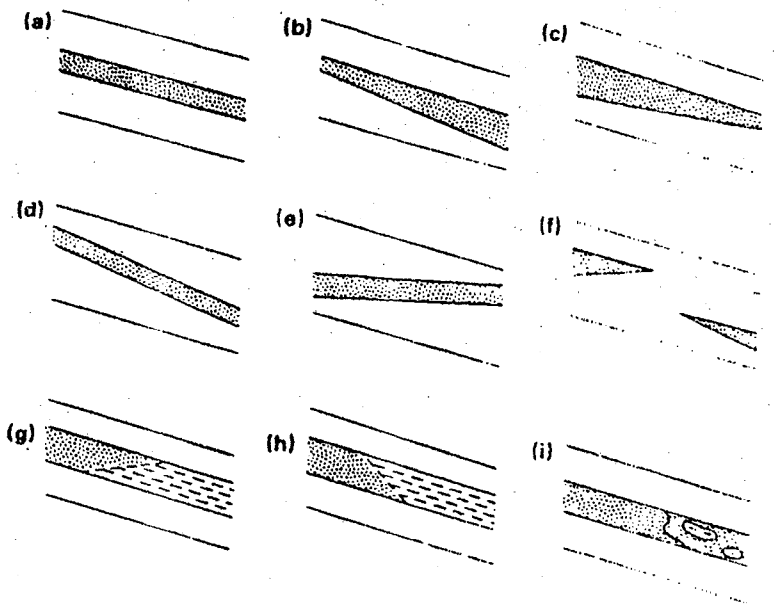
On the lowest slopes, where the drainage can be very poor and where part or all of the soil profile is waterlogged, reduction of the iron and other soil compounds takes place. Under these conditions, bacteria obtain their oxygen from the oxygen-containing compounds and these are then reduced to other compounds. These waterlogged soils are usually bluish-grey, greenish-grey or even neutral grey in colour.

Three different factors are clearly important in determining these sequences. The surface form of the slope is obviously important but so too is the form of the base of the weathered rock or regolith. The form of this weathering front is largely controlled by the type, intensity and orientation of the joints in the bedrock. This weathering front can be extremely variable and the relationship between the weathering front and the slope surface is of basic significance. To these two factors must be added the form of the water table. These three factors are connected in a highly complex way but are all of great pedogenetic and geomorphological significance.



Sequential changes in West African catena (after Nye 1954).

One of the ways of protraying catenas is by a series of soil profile diagrams representing the soil at different positions thereby allowing the changes to be seen clearly. A slight variant of this has



Possible horizon changes in a catenary sequence (from Young 1976).

been used by Williams (1968). The types of changes possible have been outlined by Young (1976). In the simplest case a single horizon remains unchanged, or it may thicken (b) or thin (c). It may also become deeper (d) or shallower (e). It sometimes ends completely and a new horizon commences (f) or it may be replaced by another horizon starting from the base (g) or top (h). The final possiblility (i) is that a horizon may undergo a gradual change in properties whilst retaining its identity and continuity.

If all the horizons are analysed in this way three common situations can be identified : first, situations in which there are no downslope changes in successions, depths or properties of horizons; secondly, there may be parts of the catena where one or more horizons undergo gradual change; and thirdly, zones where rapid changes take place leading to substantially modified horizons over short distances. If the changes observed in catenas are analysed in this manner, soil and slope processes can be related in a more meaningful way.

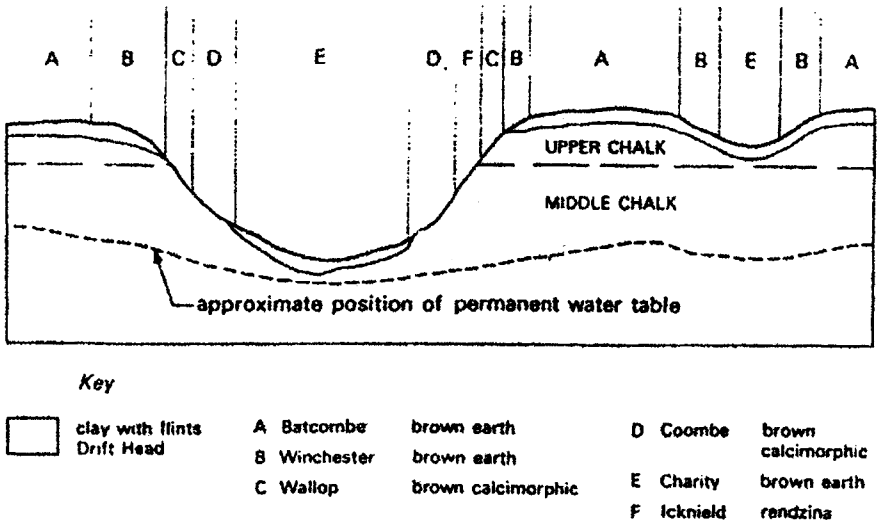
1.3.2.3 Catenas on sites of geological diversity

There has been frequent discussion as to whether catenas should be restricted to sequences on one parent material. In the United States severe limitations are placed on the degree of variation permitted in the parent rock (Watson 1965). But this is an unrealistic limitation since parent material differences in the catena can occur even though the underlying geology is uniform. The underlying rock is often only the direct parent material of some of the soils, usually the upland ones. The rest of the catena will have developed in transported materials which, although they have been initially derived from the underlying rock, are now composed of weathered and partly weathered materials

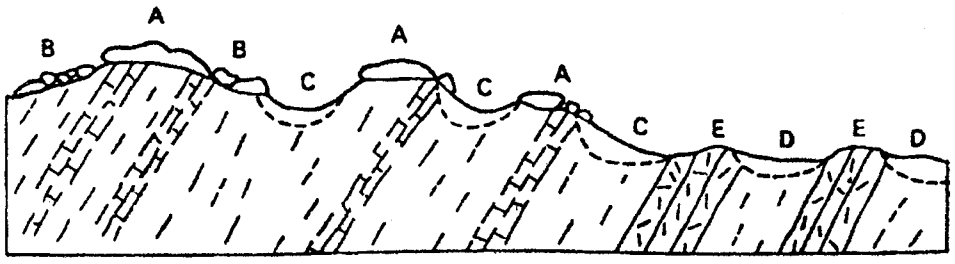
which have been transported and possibly sorted. The restriction to similar materials would mean that the soils on colluvial deposits would be placed in a separate catena from the soils on the adjacent upland. Clearly, this is unrealistic. Hole (1976), overcomes these problems by defining a catena as a group of soils developed from similar initial materials.

But this does not cover the situation where different geological formations outcrop on a single slope. Milne was aware of this problem as the following statement shows :

The first recognition of these catenary associations, it has become apparent that we have to deal with two classes of them. In one, the parent material does not vary, the topography having been modelled out of a single type of rock at both the higher and lower level .... In the other kind, the topography has been carved out of two superposed formations, so that the upper one is exposed further down the slope (Milne 1935b, p. 346).



Relationships between soils. topography and geology in the Chiltern Hills. England (after Avery 1958).



West African catena developed on alternating bands of hard and soft rock (after Ahn 1970, Pullan & De Leeuw 1964).

A certain amount of time is required before soils become sufficiently differentiated for a catenary sequence to emerge. There is often the implicit assumption that the soils have reached some sort of steady-state condition but it is notoriously difficult to decide when this condition exists especially when geomorphic processes are also involved. Time necessary to reach steady state will depend on the soil property, parent material and the kind of soil profile developing. 'A' horizon

properties form rapidly whereas 'B' horizon properties form more slowly. Thus, it has been estimated that podzols in Michigan have taken more than 3000 but less than 8000 years to form (Franzmeier & Whiteside 1963) while laterites might date from the Tertiary or early Quaternary periods.

1.3.2.4 Catenas in different climates

'On examination of the catena-climate relationships of the world, we find a contrast between extreme and non-extreme situations. Distinctive soil-slope relationships occur in the extreme situations dominated by frigid or arid conditions ..... In all the rest of the world, under non-extreme conditions, the processes of slope erosion, slope deposition and pedogenesis are almost inextricably interwoven' (Ollier 1976, p. 166).

(a) Tropical savanna catenas

Tropical savanna catenas exhibit a considerable variety of form but it is possible to classify them as catenas with rock outcrops (inselberg and pediment catenas), catenas with a hard laterite (plinthite) cap and catenas without rock outcrops. This classification, based on the work of Ollier (1959) and Moss (1968) is capable of further subdivision (Table). Although considerable variations exist, each catena is associated with a particular slope form .

(i) Inselberg and pediment catenas. This catenary type is characteristic of much of Africa and is commonly developed on granite where hillslope angles seem to be partly controlled by the basal surface of weathering. The majority of the slopes leading away from the rock residuals are sleep pediments varying from 8–10° in angle whilst the lower part of the catena may or may not possess and alluvial member depending on the often complex geomorphological history of the region.

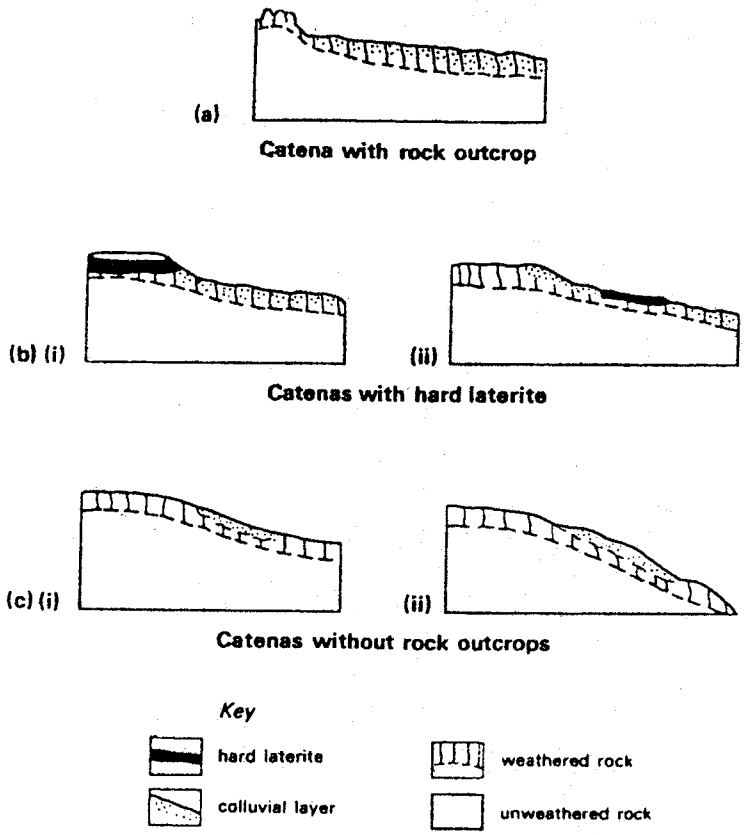
Controversy centres on whether the slope forms are fossil and the result of pedimentation under arid conditions (Birot 1960) or whether they are being actively developed at the present time (Budel 1957, Cotton 1961). Allied to this are arguments concerned with the origin of the deep layers of weathered material and the varying importance of sedentary and colluvial and wash processes (Vine et *al.* 1954, Charter 1958, Moss 1963, 1965). One such catena, in Uganda, has been described by Radwanski and Ollier (1959). This sequence can be divided into three upland and two lowland components, clearly distinguishable at the soil series level. The upper series (1), called the Buwekula Shallow, occurs as a narrow belt surrounding the rocky inselbergs. The soils

Classification of tropical savanna catenas (After Ollier 1959, Moss 1968)

(i) *Catenas with rock outcrops (inselberg and pediment)*
  (1) with extensive pre-weathering
  (2) without extensive pre-weathering

(ii) *Catenas with hard laterite*
  (1) hard laterite as an upper slope feature
    (a) with massive laterite
    (b) with concretionary or detrital fragments only
  (2) hard laterite as a lower slope feature

(iii) *Catenas without rock outcrops*
  may be subdivided on the basis of underlying geology



Basic features of tropical savanna catenas (after Moss 1968).

are shallow, compared with the other members, in that incompletely weathered rock occurs at shallow depths. The soil is essentially a loamy sand with abundant coarse angular quartz gravel and occasional fragments of feldspar. The Buwekula Red Series (2) occurs on the upper-middle and middle slopes and is usually the most extensive member. As the name suggests, it is mostly reddish in colour and of a sandy clay–loam texture. The Buwekula Brown Series (3) occurs on the low-middle and lower slopes and may be regarded as a variant of (2) in that it has been altered by drainage as influenced by topography. The changes between (1) and (2) are quite sharp whereas those between (2) and (3) are very gradual. The Buwekula Yellow-Brown (4) occurs on the slightly raised valley bottoms and valley slopes with the horizons showing evidence of the seasonal fluctuation in the water table. The Buwekula Grey (5) occurs on the valley floor and is often completely submerged in the rainy season.

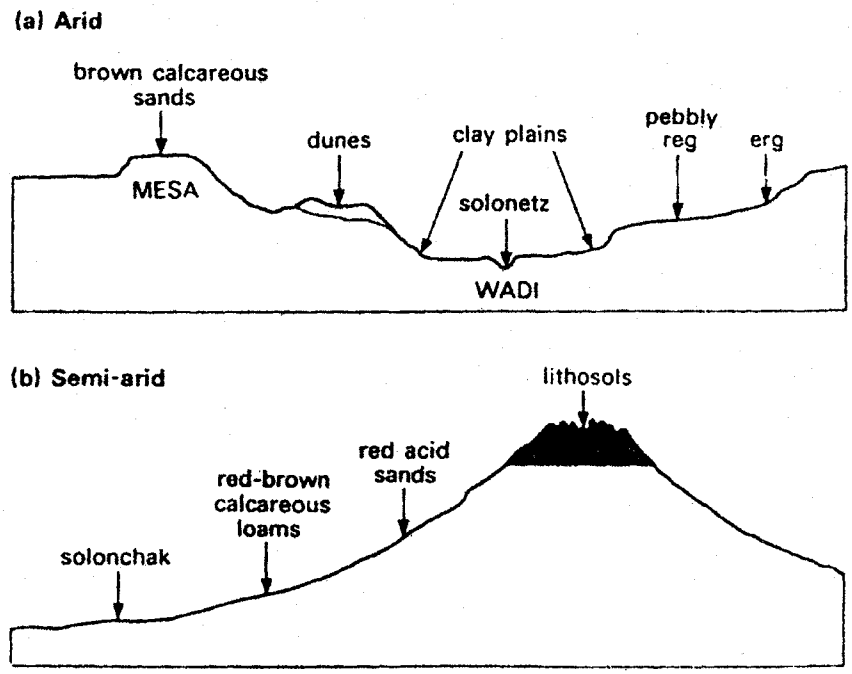
The interesting aspect of this catena is the evidence it provides not only about the processes in operation on the slope but also about the past geomorphological history of the area. Detailed mineralogical evidence has indicated that there are three parent materials involved in the catena. The Buwekula Shallow has been derived from fresh or only slightly weathered granite; the Buwekula Red and Brown from intensely pre-weathered granite; the Buwekula Red and Brown from intensely pre-weathered granite and the Yellow-Brown and Grey from alluvium derived from the pre-weathered granite. This is interpreted as providing evidence for a 'two-cycle theory' for the evolution of the landscape and pedological features (Ollier 1959).

(i) Savanna catenas with hard laterite.

(ii) Savanna catenas without rock outcrops.

(iii) Tropical rain forest catenas

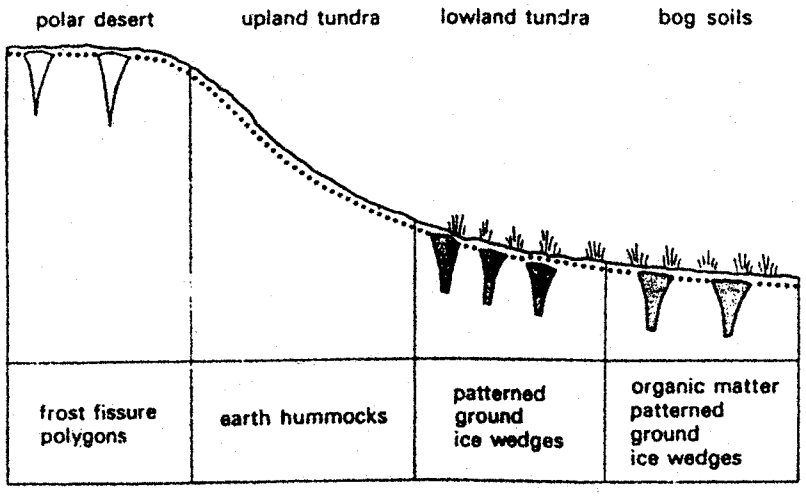
(iv) Catenas in arid and semi-arid regions



Characteristic catenas of arid semi-arid areas (from Bunting 1965).

(v) Catenas in temperate regions

(vi) Catenas of tundra regions



Soils and topography of the polar desert zone (modified from French 1971, 1976, Tedrow 1974).

It is for the recognition of the systematic relationships between soils, certain landforms and geomorphic processes that the catena concept has been and still is of the utmost importance. The classification, genesis and geography of soils in catenary association are related to the evolution and elements of the landscape. Thus, the study of catenas has shown that soils cannot be analysed in isolation. Although the concept is easiest to apply in areas with uniform geology, it has been successfull applied to areas of geological complexity.

1.4 Classification of world soils

1) Genetic classification of soils

Soils of the different areas of the world are formed under the influence of different pedogenic regimes. Hence soils vary from one place to the other, and even within short distances. The nature of soil changes according to the landform and micro-climatic conditions. Russian soil scientist V. V. Daokuchaiev made an early effort to classify soils on the basis of his study on Russian soils during 1882-1900. He emphasized that distinct types of soils develop in different areas under the impact of climate and vegetation. K. G. Glinka, the follower of Daokuchaiev expanded the concept of horizons in soil profile.. Later C.F. Marbut translated Glinka's work and developed a classfication of soils in the United States. This system with some modifications remained popular for many decades. The modifie Marbut system divides the soils into three broad groups of zonal order as follows:

- The zonal order
- The intrazonal order
- The azonal order.

The ***zonal order*** includes all those soils that have kmied in the areas of good drainage and they have well-developed horizons or profiles. These soils having developed under ideal environmental conditions and various soil forming processes have had ample opportunity to act upon these, so that the soil display the characteristics of mature soils. In general this order includes the soils which bear a impact of the local climates and vegetation on characteristics.

The ***intrazonal order*** includes the soils developed in poorly drained locations or the locations where due to the soil forming processes have not operated for a sufficiently long time due to environmental restrictions. Besides the inadequacy of soil drainage the slope of land, lack of moisture etc. can as environmental hindrances to the development of these soils. The soils developed under these do not have a complete development of profile. They have horizons but they are not very well marked. These soils may, therefore, be called as *partly mature soils*.

The ***azonal order*** includes the new soils and they are not considered to be mature soils. They are still in the process of development and no recognisable horizons are found in these soils. Generally, they represent the parent material which may be converted into mature soils if sufficient time is available for the operation of various soil forming processes. Climatic conditions such as those of very low temperature or the geomorphic restrictions such as very steep slope might have

acted as hindrances to the proper development of such soils. The transported material such as alluvium and loess are also included under this category. Some of the azonal soils may also develop into zonal soils if a sufficiently long time is allowed for the operation of various pedogenic regimes.

The soils falling under the three orders are further sub-divided into a number of sub-orders and soil groups on the basis of their characteristics in terms of colour, texture, profile, chemical properites, fertility and the location in which they are found. Table below gives a better insight into the genetic classification of soils.

Table 1 : Genetic classification of world soils

Major soil classification	Sub-order	Soil groups
Zonal order	***Suborder - I*** Light coloured podzolised soils of the forested regions	Podzol Soils, Brown Podzolic soils, Grey-Brown Podzolic soils, Red-Yellow Podzolic soils
	Suborder - II Lateritic soils of warm moist tropical and equatorial regions	Latosols : Reddish-brown Lateritic soils, Black and Dark Grey Tropical soils
	Suborder - III Soils of forest- grassland transitions. Dark coloured soils of semiarid, sub-humid and humid grasslands	Degraded Chernogems. Prairie soils, Reddish Prairie soils, Chernozem soils, Chestnut soils, Reddish Chestnut and Reddish-Brown soils
	Suborder - IV Light coloured soils of desert	Brown soils. Grey Desert soils (Sierozems) and Red Desert soils
Intrazonal order	***Suborder - I*** Hydromorphic soils of marshes. Swamps, bogs and flat uplands	Bog soils, Meadow soils, Alpine Meadow soils, Planosols
	Suborder - II Halomorphic soils of poorly drained arid regions and coastal deposits Calcimorphic soils	Saline soils, Alkali soils, Soloth, Rendzina soils
Azonal order (Lithosols)	***Suborder*** Regosols	Alluvial soils, Dry sands

2) The **Unified Soil Classification System** (or **USCS**) is a soil classification system used in engineering and geology disciplines to describe the texture and grain size of a soil. This system is termed as erivironmental classification and can be applied to most inconsolidated materials, and is represented by a two-letter symbol. Each letter is described below.

Table 2 : The Unified Soil Classification System

First and/or second letters		Second letter	
Letter	**Definition**	**Letter**	**Definition**
G	gravel	**P**	poorly graded (uniform particle sizes)
S	sand	**W**	well graded (diversified particle sizes)
M	silt	**H**	high plasticity
C	clay	**L**	low plasticity
O	organic		

Table 3

Major divisions			Group symbol	Group name
Coarse grained soils more than 50% retained on No.200 (0.075 mm) sieve	gravel > 50% of coarse fraction retained on No.4 (4.75 mm) sieve	clean gravel <5% maller than #200 Sieve	**GW**	well graded gravel, fine to coarse gravel
			GP	poorly graded gravel
		gravel with > 12% fines	**GM**	silty gravel
			GC	clayey gravel
	sand ≥ 50% of coarse fraction passes No.4 sieve	clean sand	**SW**	well graded sand, fine to coarse sand
			SP	poorly-graded sand
		sand with >12% fines	**SM**	silty sand
			SC	clayey sand
Fine grained soils More than 50% passes No.200 sieve	silt and clay liquid limit < 50	inorganic	**ML**	silt
			CL	clay
		organic	**OL**	organic silt, organic clay
	silt and clay liquid limit ≥ 50	inorganic	**MH**	Slt of hig plasticity, elastic silt
			CH	Clay of high plasticity, fat clay
		organic	**OH**	organic clay, organic silt
Highly organic soils			**Pt**	peat

3) FAO soil classification

The Food and Agriculture Organization of the United Nations (FAO) developed a supra-national classification, also called World Soil Classification, which offers useful generalizations about

soils pedogenesis in relation to the interactions with the main soil-forming factors. It was first published in form of the UNESCO Soil Map of the World (1974) (scale 1 : 5·M.). Many of the names offered in that classification are known in many countries and do have similar meanings.

Originally developed as a legend to the Soil Map of the World, the classification was applied by United Nations sponsored projects. Many countries modified this system to fit their particular needs.

The Soil Units (106) were mapped as Soil Associations, designated by the dominant soil unit:

- with soil phases (soil properties, such as saline, lithic, stony),
- with three textural classes (coarse, medium, and fine)
- three slopes classes superimposed (level to gently undulating, rolling to hilly, and steeply dissected to mountainous)

Soil Unit form 26 World Classes. The FAO soil map was a very simple classification system with units very broad, but was the first truly international system, and most soils could be accommodated on the basis of their field descriptions. The FAO soil map was intended for mapping soils at a continental scale but not at local scale.

4) Environmental classification of soils

The French classification of 1967 is being modified to give it a more environmental basis which is referred to as an environmental classification. In this classification all such terms like *hot climates*, *cold climates* tropical or mediterranean are avoided because of this inprecision as soils should be described in terms of their intrinsic properties.

1. *Soil classification is a process of synthesis*. Even though certain diagnostic horizons, particularly the argillic, spodic, natric, calcic and oxic, are described and used in classification, they are never used individually, for it is the whole of the naturally developed profile that is considered, as each horizon affects all the others in the course of its environmentally controlled development.

Division I. The role of organic matter as an integrator in classes II, III, IV, V, VI and VII will be summarised.

Class II. Slightly differentiated humic soils : very rapid insolubilisation of the abundant organomineral complexes, giving a profile uniformly coloured by humus.

Class III. Calcimagnesium soils : humification blocked at an early stage by calcium carbonate; considerable amount of slightly transformed humus incorporated in the profile; limited weathering.

Class IV. Isohumic soils : organic matter stabilised by a prolonged climatic maturation is incorporated to a considerable depth by biological processes.

Class V. Vertisols : very stable, dark coloured complexes incorporated to considerable depths by vertic movements (swelling clays – organic matter); development related to a pedoclimate with marked seasonal contrasts and impeded drainage.

Class. VI. Brunified soils : mull with rapid turnover and little thickness, resulting from insolubilisation by iron and clay, in which the iron is amorphous or slightly crystalline.

Class VII. Podzolised soils : formation of mobile organomineral complexes; processes of complexolysis and cheluviation dominant.

Division II. The three classes have in common a particular kind of sesquioxide development (strongly crystalline); each of them is defined by the degree of weathering on the one hand and the process of weathering on the other, this last factor is responsible for both qualitative and quantitative differences in the clays.

Class IX. 2 : 1 clays dominant (transformation and neoformation).

Class X. 1 : 1 clays dominant, weathering of primary materials still incomplete (neoformation dominant).

Class XI. Complete alteration of primary minerals; 1 : 1 clays exclusively neoformed (often also gibbsite present).

Division III. Particular physicochemical processes, related to local site conditions.

Class VIII. Oxidation/reduction of iron related to hydromorphic conditions.

Class XII. Involvement of the sodium ion.

Note that class I is characterised by an incomplete development of the profile as a result of either very particular climatic conditions or local conditions of site.

2. *Palaeosols as soil classes have been omitted.* It is necessary to choose between alternative uses of this term. Either the palaeosol has been modified by recent processes and it is these that are used in classification, which means that the palaeosol is considered to be a *parent material*, distinguished at the group level (polycyclic soils); or an undoubtedly old soil is involved but which is still in equilibrium with present-day climate and vegetation, so that it is not possible to consider it to be a true palaeosol.

3. *Soils that occur between classes, called intergrades*, that have been subject to several basic developmental processes, are important and several sub-classes are differentiated in terms of their intergrade characters.

Classes and subclasses

Classes. Twelve classes are differentiated and in all cases the basic criteria used are the degree of soil development and profile differentiation, the kind of weathering and clay formation, and the

basic physicochemical processes, related in the majority of cases to the nature and properties of the organomineral complexes that occur in the soil. However, the basic criteria used differ according to the general climatic conditions that control soil development and also, for certain classes, the relative importance of site conditions compared to that of the general climate.

12 classes can be split into three major divisions.

Classes and subclasses

I Slightly developed soils

(1) Slightly developed climatic soils (cryosols and desert soils)
(2) Slightly developed soils resulting from erosion.
(3) Slightly developed soils resulting from deposition (alluvial and colluvial soils).

II Desaturated humic soils with little horizon differentiation (AC profile) Rapid insolubilisation of the abundant organometal complexes (humic compounds of insolubilisation), forming a dark uniform profile.

(1) Without, or poor in, allophanes : rankers.
(2) Rich in allophanes : andosols.

III Calcimagnesian soils
Humification blocked at an early stage by calcium carbonate; slightly transformed humus incorporated in large amounts in the profile; limited amount of weathering (inheritance important).

(1) *Humus rich :* A1C – rendzinas and pararendzinas.
(2) *Humus poor :* brunified intergrade; weathered (B) well developed. Brunified calcimagnesian soils.
(3) *Very humus rich :* profile A0A1C or A1(B)C.

IV Isohumic (steppe) soils

Organic matter stablilised by long-term processes of climatic maturation, incorporated to considerable depth by biological means; dominance of 2 : 1 clays.

(1) *Saturated complex* A1Cca : chernozems, chestnut soils.
(2) *Desaturated complex,* brunified intergrades A(B)C or ABtC : brunizems.
(3) *Isohumic–fersiallitic intergrade :* reddish chestnut soils, sub-arid soils.
(4) *Arid regime :* sierozems.

V Vertisols

Soils with swelling clays : very stable, dark-coloured organomineral complexes incorporated to considerable depth by vertic movements; pedoclimate of strong seasonal contrasts.

(1) *Dark vertisols :*
little development (inherited clays);
developed (neoformed clays).

(2) *Cloured vertic soils* (intergrades or degraded) :
little sign of vertic characters;
very marked vertic characters.

VI Brunified soils with A(B)C or ABtC profiles
Humus with rapid turnover resulting from the processes of insolubilisation by iron and clay; moderate biochemical weathering : illites-vermiculites and associated hydroxides.

(1) *Brown soils with (B) horizon of weathering.*
(2) *Lessived soils with Bt of the argillic type.*
(3) *Continental or boreal lessived soils (with pseudopodzolic development).*

VII Podzolised soils
organic matter slightly transformed, forming mobile organomineral complexes : weathering by complexolysis dominants; marked differentiation of eluvial and illuvial horizons.

(1) *None or slightly hydromaorphic podzolised soils.*
(2) *Hydromorphic podzolised soils* (with water table)

VIII Hydromorphic soils
Soils with local segregation of iron by process of oxidation /reduction.

(1) Soils with marked oxidation/reduction processes (soils with water tables) : pseudogley-stagnogley-gley-peats.
(2) Processes of oxidation/reduction often reduced; hydromorphism results from the absorption of water by very clayey materials beneath a surface horizon impoverished in clays : pelosols-planosols.

IX Fersiallitic soils
Particular kinds of development of iron (rubification) : 2 : 1 clays dominant (transformation and neoformation). CEC (of clays) greater than 25 mEq/100 g.

(1) Incomplete rubification : brown fersiallitic soils.
(2) Complete rubification, saturated or almost saturated complex : red fersiallitic soils.
(3) Complex desaturated and partially degraded : acid fersiallitic soils.

X Ferruginous soils
Abundance of crystalline iron oxides (goethite or hematite); geochemical weathering still incomplete, neoformed 1 : 1 clays dominant. CEC (of clays) 15-25 mEq/100 g.

(1) Persistence of primary minerals and 2 : 1 clays in all horizons : ferruginous soils, *sensu stricto.*
(2) Complete weathering of primary minerals at least in the upper part of the profile : ferrisols.

XI Ferrallitic soils
Geochemical weathering of primary minerals complete (except for quartz); only 1 : 1 clays present; large amounts of sesquioxides : crystalline iron and aluminium oxides. CEC (of clays) less than 16mEq/100g

(1) Ferrallitic soils, *sensu stricto* : kaolinite dominant.
(2) Ferrallite : sesquioxides (gibbsite and iron oxides) dominant.
(3) Ferrallitic soils with hydromorphic segregation of iron.

XII Salsodic soils
Development controlled by the Na^+ ion which can be in two forms.

(1) Saline form : saline soils.
(2) Exchangeable form : alkaline soils.

Source : Peddagy Duchaufour

Groups and Subgroups

Degree of development, e.g. brown podzolic soils-podzolic soils-podzols. Intergrade groups, e.g. brown soils, andosolic, ochric, vertisolic.
Groups with special horizons, e.g. brown soils with fragipan, pseudolgley etc.
The time factor, e.g. eutrophic brown soil, monocyclic (on diorite) or polycyclic (terra fusca).
The effect of man, anthropic groups, e.g. anthropic brown rendzinas (of cultivation).

The criteria for the definition of groups and subgroups vary according to the class.

Model Questions

1) Define the term 'Soil' and discuss in brief the soil forming processes.
2) What is soil profile ? Identify the successive horizons present in a matured soil.
3) Describe the term Soil Catena.
4) Give an idea about the concept of pedon and popydem.
5) What is pedogenic regime ? Discuss the processes of podsolisation, laterisation and calcification.
6) Make a genetic classification of soils and describe their types.
7) Make a brief discussion on the environmental and FAO classification of soils.

Select Readings

1) Environmental Geography - Savidar Singh, (Prayag Pustak Bhawan, Allahabad)
2) The Nature and Properties of Soils - N. C Brady. (Eurasia Publishing House (Pvt.) Ltd., New Delhi)
3) An Introduction to Soil Science – E. A. Fitzpatrick. (Oliver and Boyd, Edinburgh, U.K.)

Unit 2 ❑ Soil Nutrients and Soil organisms – their Role in Determining Soil Fertility

Structure :

2.1 Soil Nutrients

The most important soil nutrients for plant growth are : Nitrogen, Phosphorous and Potassium. Each of these three nutrients plays a critical role in plant growth and development. Here is what they do and their deficiency symptoms to watch for.

Nitrogen (N) : This critical element is responsible for the healthy green foliage of the plants, as well as protein and chlorophyll development. Chlorophyll is the pigment that makes plants green and is a vital component in photosynthesis. Nitrogen moves easily in the soil and leaches out rapidly, especially from sandy soils and in high rainfall areas or irrigated gardens. Plants use lots of nitrogen during the growing season, so it's commonly the most deficient element. If you add too much nitrogen, however, plants will have dark green, leafy growth but less root development and delayed flowering and fruiting. Symptoms of nitrogen deficiency include slow growth and yellowing leaves, especially on older foliage. Animal manures, soybean meal, and cottonseed meal provide high levels of nitrogen.

Phosphorous (P) : Plants need phosphorous for strong root growth ; fruit, stem and seed development : disease resistance; and general plant vigor. Phosphorous doesn't move in the soil as easily as nitrogen does so you don't have to add it as frequently. Depending on where you live in the country, your soil may have plenty of phosphorous, but it may be unavailable to plants. Phosphorous availability depends on warm soil temperatures, pH range, and the levels of other nutrients, such as calcium and potassium in the soil. Deficiency symptoms include stunted plants with dark green foliage, reddish-purple stems or leaves, and fruits that drop early. Rock phosphate and bone meal are good sources of phosphorous.

Potassium (K) : This nutrient, sometimes called potash, is essential for vigorous growth disease resistance, fruit and vegetable flavor and development, and general plant function. Potassium breaks down slowly so you won't have to add it often. Deficiency symptoms include yellow areas

along the leaf veins and leaf edges, crinkled and rolled-up leaves, and dead twigs. Fruit trees may develop fruit with poor flavor or stunted fruits. Certain animal manures and mineral fertilizers, such as greensand, add potassium to the soil.

2.2 Soil Organisms

There are millions of microorganisms that occupy in a fistful of soil and these microorganisms, many too small to find with the naked eye, feast on organic matter like grass clippings, plant leaves and algae. When this is done, they lower the dead organic matter on the Earth's surface and discharge nutrients from the decaying organic matter for living plants to utilize.

Role of nutrients and organisms in determining soil fertility

Soil organisms are essential to crop production. In addition to their role in soilforming processes, they are important recyclers of soil nutrients. A major benefit is to break down organic materials in crop residues and release the nutrients they contain in the inorganic form so crop plants can use them.

Common microorganisms include bacteria, fungi, and algae. All are present in the soil in large numbers. For example, a single gram of soil - a 28th of an ounce - might contain 3 billion or more bacteria, a million fungi, and a quarter of a million or more algae.

Certain bacteria living in a symbiotic relationship on plant roots convert (fix) atmospheric nitrogen (N) into a form legumes such as alfalfa and soybeans can use. They play an important role in crop production by helping to supply much of the N needs of legumes and the crops that follow them. The amount of N these bacteria can fix depends on several factors - legume crop being grown, overall plant health as determined by management, soil pH, termperature, etc. The average is in the range of 35 to 45 kilograms per acre per year, but can be as high as 300 pounds.

The presence of the more highly developed organisms such as earthworms is generally indicative of a high quality soil with good structure and low in salt content. Earthworms are also excellent nutrient recyclers. Unfortunately, other higher organisms such as nematodes and insects have a detrimental effect on crop growth...even though they play a role in nutrient cycling.

Since most of these organisms have such a vital role in crop growth, one of the measures of soil quality and sustainable production is their abundance in the soil. Does the use of fertilizer nutrients - from inorganic and organic sources - have an impact on these organisms ? The answer is yes.

Research has shown that indiscriminate use of both mineral fertilizers and animal manures can result in a decline in the numbers of beneficial organisms in the soil. However, when properly applied and used, the overall impact of fertilizer nutrients is a positive one. Generally, those management decisions that optimize the efficiency of nutrient use also impact beneficial soil organisms in a positive way.

2.3 Degradation of Soil – Processes, Causes and Consequences

The cutting away of the particles of soil by natural agencies (like rain, sun, wind, currents, flowing water etc.) is called 'sail erosion'. This is the theft of the soil by natural elements and is the removal of soil particles either singly or in mass.

Factors affecting Soil Erosion

A large number of factors are responsible for inducing soil erosion, some of which are directly related to and are highly important in removing soil, while others are only indirectly related and help other factors in their erosive activity. "The heat of the sun, the rain drops, the severe blasts of the wind, the cold of the winter season, the roots of the plant, the insect life, the human life and bacterial life are all acting upon the earth's crust resulting in tremendous biological, chemical and physical changes." As a combined result, the hard rocky surface of the earth crumbles down and is shattered to pieces and ultimately powdered and displaced by wind and rain and carried and transported by these on the lower and flatter areas. This process is both destructive and constructive. Soil erosion is profoundly and directly affected by water. Quickening of the pace of erosion, owing to the changes wrought by man, has produced erosion, land forms and other conditions which are definitely abnormal gullies, dub-roil exposed by sheet erosion landslides, undercut highways, and reservoirs and channels filled with it.

Types of Soil Erosion

Usually two types of soil erosion are visible, viz., water erosion and wind erosion.

(a) Water Erosion : The *sheet*, *rill* and *gully* erosion are important. In sheet erosion, the soil is eroded as a layer from the hill slopes, bare fallow land and the cultivated lands whose plant cover has been thinned out by grazing, fire of other misuse of land. When heavy showers take place, there is more or less even removal or skimming off of soil in very thin layers. Sheet erosion merges imperceptible into *rill erosion*. In rill erosion, the run off water tends to concentrate within the streams; and the pattern resembles that of the twigs, branches and trunk of a tree. These ultimately lead to deep ravines. In gully erosion, the cutting of soil goes to immense size and volume and the entire land is turned into *badland topography*. V-shaped gullies are form : where the sub-soil is resistant; while V-shaped gullies are formed where the underlying soil is softer and easily eroded than the upper one.

The rivers in floods and the tidal waters of the sea cause considerable damage to the soil along the coast. The roaring waves rush and dash on the coast swallowing every bit of coastal lands. Coast lands are thus washed off and owing to the creeping up of the sea water into the low-lying shore lands vast strips are turned into khar lands as in Gujarat, Maharashtra and Kerala coasts. Severe erosion of the beach along the Kerala coastline is evidenced by the uprooting of coconut trees. Such type of erosion is termed *sea or shore erosion*.

(b) Wind Erosion : The actual process of wind erosion is not so spectacular but it is much more insidious, because it may not be easily noticed. Bad farming methods, failure to conserve

moisture, lack of manure and too many grazing animals all help to create a condition in which wind erosion takes place. Wind erosion is generally confined to arid and semi-arid areas, of sub-normal rainfall, high range of temperature and continual desiccation, where due to the removal of natural vegetative cover the top soil becomes extremely loose and less cohesive so as to be carried away in large quantities in times of occasional storms. The wind works as a sieve. It picks up the lighter and more fertile soil particles and lifts them to the pathways of high air currents which carry them to long distances. The coarser and less fertile soil particles skip and roil on the surface and pile un in drifts behind the obstacles.

Causes of Soil Erosion

Soil erosion is caused not due to any one single cause but a multiplicity of causes. Deforestation, destruction, and overgrazing of pastures by sheep and goat, shifting cultivation, faulty methods of cultivation, cultivation of dry crops, diversion of natural drainage courses by roads or railway embankments, ruts in roads, ditches, culverts, improperly constructed terrace outlets (along which running water is concentrated) all lead to erosion, Hence, it has rightly been said that soil erosion is essentially a manmade phenomenon.

Extent of Soil Erosion

It has been estimated that about 200 million acres of land were exposed to hazards of wind or water erosion and of lands actually under cultivation. about 100 million acres are vulnerable to soil erosion. Experts have estimated that at least 40,000 hectares of our soil is permanently lost to cultivation and a much greater area is rendered less productive every sear by the ravages of water and wind erosion.

Along most of the bigger rivers, soil erosion has led to a formation of a vast and intricate network of fissures and finger gullies and the loss of invaluable argicultural land so that soil erosion is responsible for about 1.2 lakh hectares of ravine land in Uttar Pradesh; for the man-made desert between Rajasthan and Uttar Pradesh intruding its thirsty tongue in a convex are through Ferozepur, Patiala and Agra towards Aligarh and Kasganj at the rate of about half a mile per year for the last 50 years and is encroaching upon approximately 50 sq. miles of fertile land every year and partially fil ! 3-'g the reservoirs and choking irrigation courses in the Punjab and Uttar Pradesh.

Similarly, a cattle-made desert is extending over several hundreds of square miles in the heart of the world's most fertile plain. The villages which were once surrounded by valuable fertile fields now lie in a network of useless gullies, carved out by the soft mud of the Yamuna, Chambal and other rivers by uncontrolled drainage, About 9.3 lakh hectares in Madhya Pradesh, Rajasthan and Gujarat are badly eroded by ravine erosion.

Effects of Soil Erosion

Soil erosion badly affects the run-oft and loss of soil. It leads to (i) heavy floods in rivers; (ii) lowering down of the subsoil waters level; (iii) reduction of soil fertility; (iv) silting of streams and water courses; (v) disappearance and downfall of civilizations.

2.4 Conservation of Soil

It has been rightly said that "erosion, low yields and rural poverty are all symptoms, not the primary causes of mal-adjustment between the people and soil." Like other contagious diseases, erosion need be checked at the earliest moment. For this purpose, soil conservation measures are necessary.

Conservation of the soil requires the adoption of sound land-use principles and practices by agriculture as a whole. The attainment of this objective involves the wide-spread use of physical measures of land defense and adjustment of certain economic and social forces tending to encourage exploitation of the soil.

Dr. Gorrie has suggested that conservation may be effected by improving existing plant cover, reduction of surplus cattle, proper manorial practices. Scientific farm management, contour plughing and terracing, gully plugging, canalizing small torrents by vegetational control, road drainage control and recovery of land slips and reducing fallow land.

Controlled grazing, improvement of grasslands, preventing the practice of shifting cultivation, conserving wild life, are other devises for checking the menace of soil erosion.

Wind erosion can be controlled by such measures as : (i) protection of the surface with a cover of vegetation or vegetative residues ; (ii) establishment of windbreaks and shelter belts at intervals to reduce wind velocity and soil drifting from farmsteads, gardens, etc; (iii) fixing of sand dunes by planting of trees and grasses suitable for reclamation purpose, such as, *Rohiro*, *Deshi Khejri*, *Jilayati Kheji*, *Neem*, Acacia and Eucalyptus.

Eight regional research-cum-demonstration centres have been established for the study of problems of soil and water conservation. These centres are located at Dehradun (Himalayan region), Chandigarh (Siwahk region), Kota (ravines in Rajasthan), Vasad (ravine land of Gujarat), Agra (Yamuna ravines) Bellary (black soil), Ootacamund (hilly areas), Chhatra (watershed of Losi) and Jodhpur (desert). In addition, the ***Desert Afforestation and Research Statistics*** has been set up at Jodhpur for undertaking the study of the desert problem.

The soil and water conservation programmes constitute an important activity to protect the soil resources of the country, check soil erosion and land degradation and reclaim degrader and problem lands.

Till the end of the last century, about 300 crore hectares was treated with soil conservation measures. The programmes consist of contour bunding, bench terracing, land levelling and shaping as well as improved agronomical practices on agricultural lands. On nonagricultural lands biological measures such as afforestation and grassland development are adapted. For better moisture conditions and balanced ecology, nullah plugging, farm ponds, erosion control/water harvesting structures are constructed at suitable locations.

Model Questions

1) What is soil nutrient ? Describe the importance of Nitrogen, Phosphorous and Potassium in contributing nutrients in the soil.
2) Describe the roles of soil organisms to enrich the quality of soil.
3) Describe the factors and types of soil degradation and soil erosion.
4) Write an account on the necessity and methods of soil conservation.

Select Readings

1) Environmental Geography – Savidar Singh. (Prayag Pustak Bhawan, Allahabad)
2) The Nature and Properties of Soils – N. C. Brady. (Eurasia Publishing House (Pvt.) Ltd., New Delhi)
3) An Introduction to Soil Science – E. A. Fitzpatrick. (Oliver and Boyd, Edinburgh, U.K.)

Unit – 3 ▫ Concepts of Ecology

Structure

3.1 Biogeography : A short introduction

BIOGEOGRAPHY is the scientific study of the distribution of species of plants and animals in the biosphere of the earth. Biogeography, with its scientific approaches and investigations, seeks to establish the patterns of order from the apparent orderlessness of the multiplicity of life forms present in the biosphere. In this way, biogeography is concerned with the processes and mechanisms through which both plants and animals originate, go through evolution and organize themselves into patterned assemblages and unique communities that are displayed on the earth's surface as particular distributions and affinities. At the same time, Biogeography also seeks to explain the processes that produce the variations in the patterns of distribution. The distribution of species of plants and animals may be on a local or on a global scale. Biogeography seeks to explain such distributions with reference to environmental factors, particularly climate, soil and man. In short, biogeography is the geography of organic life and is considered as one of the most important branches of geography, which concerned with the multitudinous forms of plant and animal life inhibiting the densely populated life-supporting zone of the biosphere as well as the complex biological activities which are controlled by natural environment. Biogeography is divided into two aspects – (1) phytogeography (the distribution of plants) and (2) zoogeography (the distribution of animals).

As a subject of study, geography has been defined variously as the study of spatial analysis, spatial patterns, areal distributions, location analysis, man-earth or man-environment relationships etc. In the same way, Biogeography encompasses all these aspects of study in relation to the living organisms emphasizing mainly in relation to man. Thus, biogeography studies all biotic elements constituting the environment of the earth in respect to man. Biogeography evaluates organisms to that challenge through different ways, and takes into account the effects of environmental change that can modify enough all organic relationship within a short pace of time. The students of biogeography are interested to know why in some particular areas certain species are found and not the others, and why at times the associates can turn into competitors. Biogeographers are interested to determine the precisements through which all life forms are supported by the energy and chemical resources of the planet earth. Located at an increasingly important ground of the biological and earth sciences, the recent growth area of biogeography forms a scientific thought of great significance to the future welfare of man.

In biogeography, the principal grounds of investigations are consisted of the organisms of the biosphere – plant and animal communities which, with varying degrees of concentrations, exhibit the globe with wide extensions. Thus, to be more precise, biogeography is the study of the biosphere which envelope the earth's surface and is consisted of all living-organisms – living on land, air and water.

Concept of Ecology :

Ecology, in its very simple sense, deals with the study of the relationships among organisms (1 P.H. Collin 1990, p. 57). Thus the term 'ecology' points mainly to the two components of nature : organisms and their environment. These two components are complex enough and dynamic and at the same time they are mutually reactive, interrelated and interdependent (2 Sharma p. 1). Comparative to the other sciences, Ecology is a new one which has business with the prominent roles of various principles which control and given the relationships between organisms and their environments.

Before the coinage of the term ecology, the concept and analysis of interrelations between organisms and environment was traditional in the scientific society of even eighteenth century. For example, Isodor Geofroy St. Hilare, the French Zoologist in 1989 proposed the term 'Ethology' for the scientific explanation of "the study of the relations of the organisms within the family and society in the aggregate and in the community". St. George Jackson Mivart, the famous English naturalist coined the term 'hexicology' in 1894 to deal with the "study of the relations which exist between organisms and their environment as regards the nature of the locality they frequent, the temperatures and the amounts of light which suit them, and their relations to other organisms as enemies, rivals or accidental and involuntary benefactors".

The term 'ecology' was coined by combining two Greek words – *Oikos* which means "house" or "place to live" and *logos* which means "the study of" to designate such relationships between the organisms and their environment and between the organisms themselves. Thus in its literal sense, ecology signifies the study of organisms "at home". There is a debate regarding the credit to be given to the author who first coined the term ecology and used it in literature. As stated

by Kormondy (1996) although the German biologist Ernst Haeckel is generally credited with coining the term, Hannx Reiter (1885) appears to have been the first to combine the Greek words 'oikos' and 'logos' to form the term ecology (Egerton, 1977, Kormondy, 1996). However, there is now consensus, that Haeckel gave definition and substance to the form which he used first in 1866, in the following statement published in 1870 :

> By ecology we mean the body of knowledge concerning the economy of nature – the investigation of the total relations of the animal both to its inorganic and to its organic environment; including above all, its friendly and inimical relation with those animals and plants with which it comes directly or indirectly into contact – in a word, ecology is the study of all the complex interrelations referred to by Darwin as the conditions of the struggle for existence. The science of ecology, often inaccurately, referred to as "biology" in a narrow sense, has thus far formed the principal component of what is commonly referred to as "Nature history". As is well shown by the numerous popular natural histories of both early and modern times, this subject has developed in the closest relations with systematic zoology. The ecology of animals has been dealt with quite encritically in natural history; but natural history has in any case had the merit of keeping alive a widespread interest in Zoology.

Thus, as a distinct discipline, ecology grew out of natural history early in this century as natural historians started to conglomerate their observations into a body of theory. In this context, the most vital fact to be pointed out here that it was Charles Darwin, whose concepts of the 'evolution of species' through natural selection involving interactions between biological species and habitat was the key stone of the formulations of various terms and concepts of interrelationships between organisms and their physical environment in one way or the other (Singh, 1991, Sharma, 1992).

Ecology has been defined in different ways by different ecologists. Before going to definitions, it may by carefully pointed out that although coined in 1866, the term ecology was not widely used nor recognized at the end of the nineteenth century. It first started to attract the fancy of the botanists and at the time that some zoologists, including American entomologists W.M. Wheeter, preferred 'ethology' coined by St. Hilaire (Mclntosh, 1985). The form ecology was institutionalized by 1913, with the formation of the British Ecological Society and shortly thereafter in 1915, with the formation of the Ecological Society of America. However, institutionalization of the term ecology did not necessarily mean there was concensus on what was the purview of ecology. Haeckel's definition, as noted earlier, involved the concepts of interrelationships of organisms and environment and having a strong physiological orientation, sometimes had quite different interpretations placed upon it. E. Warming (1895, 1905) employed this new science for the study of plants mainly and thus defined ecology as 'the study of organisms in relation to the environment'. American plant ecologist Frederick Clements (1905, 1916) considered ecology be the 'science of the community'. The British ecologist Charles Elton (1927) defined ecology as 'scientific natural history' concerned with the 'sociology and economics of animals', whereas the American animal ecologist Victor Shelford (1937) considered ecology as 'that branch of general physiology which deals with the organism as a whole, with its general life processes as distinguished from the more special physiology of organs'. Tailor (1936) treated ecology as 'the science of all the relations of all organisms to all their

environments'. Woodbury (1954) employed ecology as 'a science which investigates organisms in relation to their environment, and a philosophy in which the world of life is interpreted in terms of natural processes'. Thus we may consider that the science of ecology emphasized two overlapping areas of study – (a) the study of organisms in relation to their environment and (b) the evolutionary history of the organisms. These denote to the fact that ecology is found in the legion of nonliving and living structures, processes, and interrelations involved in the movement of energy and nutrients and in the regulation of population and community structure and dynamics. This means that ecology is multidisciplinary and almost boundless in its fields of concern. This fact was well stated by the British ecologist A. Macfadayen (1957) as given below :

> Ecology concerns itself with the interrelationship of living organisms, plant or animals, and their environments; these are studied with a view to discovering the principles which govern the relationships. That such principles exist is a basic assumption – and an act of faith – of the ecologist. His field of inquiry is no less wide than the totality of the living conditions of the plants and animals under observation, their systematic position, their relations to the environment and to each other, and the physical and chemical nature of their inanimate surroundings. It must be admitted that the ecologist is something of a chartered libertine. He roams at will over the legitimate preserves of the plant and animal biologist, the taxonomist, the physiologist, the behaviourist, the meteorologist, the geologist, the physicist, the chemist and even the sociologist; he poaches from all these and from other established and respected disciplines. It is indeed a major problem for the ecologist, in his own interest, to set bounds to his divagations.

The above detailed definition of ecology partly contributed to compounding the precise determination of the field of ecology during the 1960s when the term became the common place of popular use. Gradually, the usage of the term ecology was extended politically to encompass a philosophy that broadly incorporated a variety of environmental concerns in the modern environmental sciences.

Furthermore, the German ecologist Karl Friederzchs (1958) regarded ecology as 'the science of the environment'. The contemporary American ecologist, Eugene P. Odum (1959), influenced much in defining the parameters of the discipline, defined ecology as 'the study of the structure and function of nature' and later (1962) as 'the study of the structure and function of ecosystems'. F. Fraser Darling (1963) expanded the field of ecology by defining the subject as 'the science of organisms in relation to their total environment, and the interrelationships of organisms inter-specifically and between themselves'. It may be pointed out that this definiton of ecology led to the development of two approaches to the study of ecology and its divisions into two branches – (i) auticology wherein ecological relations of individual species studied in a given ecosystem and (ii) synecology wherein the plant communities in relation to their habitats are studied in a given ecosystem.

Petrids (1968) considered ecology as 'the scientific approach to the study of environmental interactions which control the welfare of living things'. R. Mishra (1967) defined ecology as 'interactions of forms, function and factors'. These three interacting elements – form, function and factors integrate together to construct the triangle of nature. The concept of ecology now has been extended to the corresponding range of phenomena, research and problems. In that connection

'ecology' has been quite logically extended as well to the field of the interaction of society and its physical environment' (Y.P. Trusov, 1983). Lastly, Krebs (1985) has defined ecology in simple modern comprehensive terms 'ecology is the scientific study of the interactions that determine the distribution and abundance of organisms'.

However, Haeckel in his definition of ecology referred to the "surrounding outer world" which are now describe as the environment of an organism' and his "organic and inorganic conditions" are the **biotic** and **abiotic** factors respectively as we call them now. **Biotic factors** are the other organisms encountered, of the same and different species. On the other hand, the **abiotic factors** are the physical and chemical conditions such as light, temperature, moisture, respiratory gases, nutriets and substrate. In fact, the recent development in the study of ecology has been the recognition of the reality that the **biotic** (= living) and **abiotic** (= non living) components of nature are not only interrelated but these components function in an orderly manner as a definite system. Thus for clear understanding of this vast nature, **structure** and **function** should be studied together.

3.2 Ecology : Its aims and scope

Ecology is a multidisciplinary field extending across the physical, biological and social sciences, and the contemporary explanation of ecology emphasizes upon ecosystems as the major unit of study. The recent problems of different nature in human society are very much related to ecology, directly or indirectly, as solutions to those problems need clear ecological knowledge. Nowadays ecology has been contributing vastly to socio-economic, political and other decision making processes of the world. There are interdependencies not only between ecology and biological sciences, but also between ecology and physical as well as social sciences. That is why it has been the common place to find references of ecology economic and social writings, journals, magazines, weeklies and even in the dailies. Indeed, ecology plays an important role in human welfare. Primary ecology is a field subject and modern ecology is concerned with the functional interdependencies between living things and their environment. Ecology plays an important role in agriculture, forestry, range management, fishery, biology, pest control and in the conservation of soil, forests, wildlife, water etc. Ecological knowledge and assistance is also needed to solve international environmental problems.

In recent times, the aims and scope of ecology have been enormously expanded with development of ecological concepts and thoughts consequent upon evergrowing interests in man-environment relationships due to increasing pressure on nature resources for sustainable development in view of rapidly increasing human population. As stated by C. C. Park (1980) 'the traditional view of ecology as the sciences of living things relation to this environment has helped to place it in a valuable strategic position from which it can make important contributions to their environmental management'. Thus ecology has not been confined only to the biological sciences but has reached the entire society and many branches of knowledge. Park (1980) also explained that ecology, to many people has become almost synonymous with conservation and the environment. This is because ecology not only studies various aspects of

plants and animals but the whole society of all biota (Friedrichs, 1958). Present day ecology emphasizes more upon the study of unity of balance of environment. Maddox (1972), thus viewd ecology as 'a state of the mind' due to its holistic nature. P. Gerondet and N. Simon (1970) proposed that ecology should not remain confined only to abstract scientific discipline but should rise above it to solve the environmental problems faced by human society. Keeping this view in mind, they have highlighted the potential contribution of ecology to ecological and environmental problems and relevance of ecological studies to social and economic stability and balance. The scope of ecology has thus been broadened manifolds. It has been extended 'from the scientific study of mutual relationships of biotic and abiotic components of whole biosphere or part thereof to the environmental problems in terms of environmental degradation and ecological crises arising out of increased human impacts on natural / ecological resources through advanced modern technologies aimed at accelerated rate of economic development to meet the demands of everincreasing population at global and regional levels' (1991). In fact, there has been prominent shift, at least from the view points of geography, in the emphasis of ecological studies in terms of man-environment relationships.

Phases of development of ecology :

The phases of development of ecology may be divided into four on the basis of its historical development in terms of aims, scope, objectives, main areas of interest and approaches to the study. These are :

First Phase : The period upto the World War-1 is considered as the first phase. This phase was actively dominated by the various attempts to define ecology with the main basis of reciprocal relationships between the organisms and their environment. Search and identification of fundamental units of vegetation, development of methods for classification of vegetation, tracing out the evolutionary history of plants and animals as influenced by Darwinian concepts of evolution of species and explanation of the relationships of plants and animals in relation to variable habitats were the important attempts of the first phase.

Second Phase : The period between the two World Wars represent the second phase in the development of ecology. The principal characteristics of the second phase was more detailed and vigorous study of relationships between vegetation characteristics and habitat conditions along with classification, survey and mapping of vegetation. Study of ecology in this phase was dominanted with the development of scientific methodologies with the help of laboratory analysis, application of quantitative techniques, branching out of the field of ecology and more close investigation into the diverse aspects of interactions between abiotic and biotic components of environment and scrutinization of ecological stability.

Third Phase : The period from the World War II to 1960 is considered as the third phase in the development of ecology. The main characteristics of this phase was the introduction of system analysis in ecological studies. On the basis of more scientific experimental analysis, through ecosystem research activities, various aspects were identified regarding the complex relationships between organisms and their physical environment. The central theme of the ecological investigations were the major ecological processes.

Fourth Phase : The period from 1960 to the present time is considered as the fourth phase with development of ecology. This phase is also known as the modern phase and is characterized by more microlevel diversification and specialization of various facets of ecology. The most excellent field of interest in ecology is this phase is the emanation of applied ecology. This modern field of ecology contemplates the role of ecology in conservation of nature and natural resources and environment management with ecological knowledges that help solving of economic, social and political problems.

At present the conceptual of ecology has been extended from solitary phenomenon to different sets of phenomena occurring at a definite time scale and occupying a definite space in the biosphere. The most important examples are – Wetland ecology, river ecology, salt-water or marine ecology, lake ecology, forest ecology, grassland ecology, agricultural ecology, industrial ecology, rural ecology, urban ecology, population ecology, social ecology, political ecology etc. (Singh 1991).

The major subdivisions of ecology has been determined with different bases. These are :

1. **Sub-division on the basis of taxonomic approaches :** Ecology at its first stage was purely associated with biological sciences – botany and zoology. As a result, plants and animals were separately studied in ecology. Thus taxonomic approach led ecology to be divided into – (a) plant ecology and (b) animal ecology. Based on different specialized investigations, each division was further subdivided into micro-level divisions – such as plant ecology into pine ecology, oak ecology and so on, and animal ecology into fish ecology, insect ecology, bacterial ecology etc.

2. **Sub-divisions on the basis of habitat of organisms :** The main purpose of dividing ecology on the basis of habitat is that in terms of physical characteristics the habitats of organisms have clear variations. Particular habitats exert definite effects on the organisms. Thus the general characteristics of biotic communities differ in different habitats. This approach actually cultivated into habital ecology. On the basis of habitats and their affiliations with the organisms inhabiting therein, sub-divided into marine ecology (salt water), fresh water ecology, estuarine ecology, island ecology, forest ecology, grassland ecology etc.

3. **Sub-divisions on the basis of levels of organization :** Ecological studies in this approach are carried out at two different levels – (i) study of ecological relationships between the species and (ii) study of ecological relationships of all the organisms present within the ecosystem. Thus, this very third approach led to the development of ecology into (a)Autecology, the study of relationships of individual species to its environment, and (b) Synecology, the study of complex interrelations of groups of organisms or the biological community. This is because the organisms such as plants, animals and micro-organisms affect each other and at the same time interact with the habitat. Therefore, the fundamental unit of study is biological community rather than individual organisms. Again, synecology is subdivided into 'population ecology' which deals with the study of interactions of individuals, that is, population of single species with each other; 'Community ecology' dealing with the study of interrelationships and interdependencies of groups of individuals of different species – plants

and animals together, 'biome ecology' deals with the interrelationsips and interactions of more than one biological communities in various stages of succession under similar climatic conditions of the concerned area and 'ecosystem ecology' that deals with the study of interactions and interrelationships of all organisms among themselves and with their environment. Thus, in simple sense, ecosystem ecology which forms the basis of studies in environmental geography and more clearly, in biogeography.

3.3 The Basic Principles and Concepts of Ecology

The principles and concepts of ecology may be explained separately on two bases – structural and functional. But, these two bases may be combined together when the ecological studies are considered at the level of ecosystem. Following are the basic principles and concepts of ecology :

(1) All living organisms and their environment are mutually reactive and affect each other in various ways. Living organisms, on the one hand, interact among themselves and affect each other and living organisms and physical environment on the other hand, are interrelated through reciprocal interactions and affect each other. The varying degrees of interactions among organisms, at both inter-and intraspecific levels are positive, negative and sometimes neutral.

(2) Ecosystem is a fundamental unit of ecological study as it comprises both biotic and abiotic components. Being a monistic concept, ecosystem brings physical environment, plants and animals together in a single framework which facilitates the study of interactions between biotic and abiotic components. Ecosystems are well structured and organized units through abiotic and biotic components. Also, ecosystems are functional units wherein the two biotic components – the autotrophs (green plants) and heterotrophs are of major significance. The autotrophic components produce food through photosynthesis (and hence are producers) and use inorganic substances. Thus they are self-feeding and provide food energy to other biological communities. The heterotrophic components use, convert and decompose organic substances which are made available from the primary produce to autotrophic components.

(3) The solar radiation is the main driving force of the ecosystem. Because ecosystem function through mainly solar radiation as energy input received by green plants and is used to produce food through the process of photosynthesis. In ecosystem, transfer of organic molecules or energy flow in unidirectional, passes through various trophic levels and is non-cyclic. This energy flow or ecosystem energetics helps in circulation of chemical nutrients within the ecosystem. As number of trophic levels increase, the energy is progressively decreased by respiration of organisms. The pattern and flow of energy in ecosystem may be explained with the help of the first and second laws of thermodynamics.

(4) The whole biosphere of the earth at the largest scale becomes an ecosystem. The abiotic and biotic components of the biospheric ecosystem are closely associated to a series of large-scale cyclic mechanisms like sedimentary cycle, hydrological cycle, chemical nutrients

cycle and unidirectional energy flow. Sediments, chemical nutrients, water and energy in biosphere are transferred with the help of these cycles.

(5) 'Sustained life on the earth is a characteristic of ecosystem, not of individual organisms or population' (D.B. Botkin and E. A. Keller, 1982).

(6) The physical and biological processes of the earth follow the principle of 'uniformitarianism'. 'Uniformitarianism' is a concept that states that same physical processes, rightly starting from the origin of planet earth and its atmosphere, and the biological processes, from the origin of first organism, that operate at present and did operate in the past, but not necessarily with constant magnitude and frequency with time, and it will continue to operate in future, but at rates that will vary as the environment be influenced by human activity (D.B. Botkin and E.A. Keller, 1982).

(7) Four 'Environmental Principles' of holistic nature of natural environment mainly affect the biological communities in a biospheric ecosystem (M.J. Holliman, 1974) –

- As all the materials are rearranged, cycled and recycled through a series of cyclic pathway in the natural environment, thus, 'nothing actually disappears when we throw it away'.
- 'All systems and problems are ultimately, if not intimately inter-related. It does not make sense to squabble over which crisis is most urgent; we can not afford the luxury of solving problems one by one. That is both obsolete and ecologically unsound anyway.'
- 'Nature has spent literally millions of years refining a stable ecosystem'.
- 'We live on a planet whose resources are finite'.

(8) Natural hazards adversely affect man in particular and biological communities in general. Severe hazards are made when biological processes are associated with physical events, i.e., after flooding of urban areas, water becomes contaminated and various kinds of diseases are frequent.

(9) The productivity of ecosystem depends upon two main parameters—(i) amount of solar radiation available to the primary producers of the green plants and (ii) the efficiency of the green plants to convert that solar energy into chemical energy. Thus, there is a positive correlation between primary productivity and solar radiation.'

(10) Chemical nutrients and organic matters circulate among various components of the biosphere through series of cycles known as 'biogeochemical cycles'. These cycles function in such a way that total mass of these matters remains almost the same and are available to biotic communities. The functioning of these biogeochemical cycles is cyclic through various simple and complex pathways though which the substances are distributed, rearranged, cycled and recycled in various phases. All living organisms require these substances as nutrients for sustenance of their lives.

(11) Ecosystems normally attain its stability through 'homoeostatic mechanisms'. All natural ecosystems posses an inbuilt self-regulating mechanism through which any change caused

by external factors in the ecosystems is counter-balanced by the responses of the ecosystems to that change is such a way that ultimately ecosystem or ecological stability is restored.

(12) Instability in ecosystem is resulted when an ecosystem becomes unable to adjust itself with environmental changes. Instability is caused when the environmental changes exceed the resistance of the capacity of the homoeostatic mechanism of the ecosystem to adjust with the changed environmental conditions.

(13) All ecosystems have a dynamic nature and they are epitomized by evolution of species. The principles and mechanisms of evolution of species by the process of 'natural selection', as postulated by Charles Darwin (1859), play vital role in species evolution as heritable variations in the populations from the basis of species evolution.

(14) The species of organisms exert all efforts for maintaining their uniformity in structure, growth, development, function and reproduction through preservation of their genetic pool. Also species are plastic and react to the variability of environment to adjust itself structurally and physiologically in the changing environment. This adjustment is achieved by the degree of plasticity set by the genetic constitution of the species. To met the challenge of changed environment, various forms of species may arise by virtue of the *ecads* (= somatic plasticity), or by the *ecotypes* (= reorganization of genes during sexual reproduction). Therefore, the species may increase their capacity of tolerance towards changing environment by developing *ecads* and *ecotypes*.

(15) The life of organisms is not only influenced by the environment, but the organisms too modify their environment as a result of their disposal, growth, reproduction, death and decomposition. Thus, the activities of the organisms change the environment. In this way, the organisms and the dynamic environment make ways for the development of various kinds of organisms through the process called succession. This process of succession continues until the development of a more or less stable community which become able to keep itself adjusted in equilibrium with the environment. The ultimate stage of community is called a 'climax'.

(16) Undisturbed and successful growth of organisms of any biome is governed by limiting factors. Because, each and every organism require various essential factors from its environment for success in growth and reproduction with a particular habitat. Deficiencies as well as the excess of substances limit the success of any organism. The minimal and maximal levels of tolerance for all ecological factors of a species vary seasonally, geographically and according to the age of the population.

(17) As an active agent of environmental change, human community modifies the ecosystem through exploitation of environmental resources. Man through removal of a host of communities reduces ecological diversity and complexity of ecosystem for various purposes.

(18) Preservation of ecological resources by maintaining the ecological diversity and ecosystem stability is the ultimate goal of ecological studies. According to J. Temborgh (1974),

'preserving diversity in a world of rapidly shrinking land resources will require a prompt and universal response on an appropriate application of ecological knowledge. Every nation should posses an inventory of biological endowment.' It should be done for the purposeful ecological and environmental management for future generation of human society to which the present society has to bear the obligation (Singh, 1991).

3.4 Concept of Ecosystem

What ecosystem means :

A. G Tansley (1935) first used the term 'ecosystem'. He defined ecosystem as 'a particular category of physical systems, consisting of organisms and inorganic components in a relatively stable equilibrium, open and of various sizes and kinds'. Tanseley further stated that the ecosystem is constituted of two major parts—biome (the whole complex of plants and animals of a particular spatial unit) and habitat (physical environment). All parts of an ecosystem—organic and inorganic, biome and habitat—may be regarded as interacting factors. In a mature ecosystem these factors are in approximate equilibrium and the whole system is maintained through their interactions.

Many authors have defined ecosystem. R.L.Lindeman (1942) stated that the term ecosystem applies to 'any system composed of physical-chemical-biological processes, within a space-time unit of any magnitude'. According to F.R.Fosberg (1963) ecosystem is 'a functioning, interacting system composed one or more living organisms and their effective environment, both physical and biological'. E.P.Odum (1971) defined ecosystem as 'Living organisms and their non-living (abiotic) environment are inseparably interrelated and interact upon each other. Any unit that includes all of the organisms (=the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycle (exchange of materials between living and non-living parts) within the system is an ecological system'. A. N. Strahler and A. H. Strahler (1976) defined ecosystem, as 'the total assemblage of components interacting with a group of organisms is known as ecological system or more simply, an ecosystem. Ecosystems have inputs of matter and energy used to build biological structure (the biomass), to produce and to maintain necessary internal energy levels. Ecosystems also do export matter and energy. An ecosystem tends to achieve a balance of the various processes and activities within it'. Therefore, as explained by P.A.Furley and W.W.Newey (1983) 'ecosystems are unities of organisms connected to one another and to their environment'. It signifies that ecosystem is the sum of all natural organisms and substances within an area. Ecosystem, according to C. C. Park (1980), can be viewed as 'a basic example of an open system in physical geography' and he stressed that 'ecosystems are regarded by many ecologists to be the basic units of ecology because they are complex, interdependent and highly organized systems, and because they are the basic building blocks of the biosphere'.

Thus, considering all the views mentioned above, ecosystem might be defined in a more simple way as a fundamental functional unit occupying spatial dimension 'spaceship earth'

characterized by total assemblage of biotic community and abiotic components and their mutual interactions within a given time unit.

The basic characteristics of an ecosystem are as below :

(1) Ecosystem occupies certain well defined area of the earth's surface (spatial dimension).

(2) Ecosystem is logically viewed in terms of time-unit (temporal dimension).

(3) Ecosystem is composed of three basic components—energy, biome (biotic components) and habitat (abiotic components).

(4) Ecosystem of any given space-time unit represents the sum total of all living organisms and physical environment.

(5) Ecosystem is structured and well organized system.

(6) Ecosystems are natural resource systems.

(7) Ecosystem is an open system characterized by continuous input and output of matter and energy.

(8) Ecosystem is mainly powered by solar energy but energy of various sorts is also significant.

(9) Ecosystem has its own productivity is the process of building organic matter based on the availability and amount of energy passing through the ecosystem. The productivity refers to the rate of growth of organic matter in an aerial unit per time-unit (Singh, 1995).

(10) Unless an ecosystem is disturbed by one or more controlling factors, it tends to function in relatively stable equilibrium.

(11) Ecosystem has scale dimension, the largest unit being the whole biosphere and small unit may be a part of a tree of even a drop of water having numerous micro organisms. Ecosystem, thus, may be divided into several orders on the basis of spatial dimension.

(12) Ecosystem is a functional unit in which the biotic, abiotic and energy components are intimately related to each other in ecosystem function through a series of large-scale cyclic mechanisms viz. energy flow, hydrological cycle, bio-geochemical cycle etc.

(13) Ecosystems develop through different sequences in terms of a particular suit of physical and chemical conditions called 'sere'. A 'sere' represents the development of a series of sequential successions starting from primary succession and ultimately culminating into the last succession in a sere as 'climax'. This is the most stable situation of an ecosystem.

(14) As the physical environment or the abiotic components and the biotic components like man, animals, plants and microorganisms are considered in a single framework for easy study of their interactions, thus ecosystem concept is monistic in nature.

Components of Ecosystem

Any ecosystem in the biosphere is composed of three major components—abiotic or physical component, biotic component and energy component.

3.5 Environment and Habitat

Etymologically the term 'environment' means the *surroundings*, external conditions influencing all organisms. The word *environment* is derived from French : *environner* or *environ* meaning, around, about, circle, to turn, or surroundings. Thus *environment* points towards the surrounding conditions, influences, or forces that influence or modify. In biogeography, the term *environment* means the whole complex of climatic, edaphic, and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival. In social geography, *environment* speaks about the aggregate of social and cultural conditions as customs, laws, language, religion, and economic and political organizations that influence the life of an individual or community. In earlier times, primitive man consisted of only the physical aspects of the planet earth and biotic communities but in course of time and advancement of society, *Homo sapiens* extended his environment through his social, economic and political functions. With such connotation, C C Park (1980) stated that 'environment refers to the sum total of conditions which surround man at a given point in space and time'.

Sometimes 'environment' is equated with 'nature' in which the physical components of the planet earth like air, water, land etc. affect and support life in the biosphere. As viewed by Andrew Goudie (1984), 'environment' has been taken as the representative of physical components of the earth wherein man is an important factor affecting the environment. Prof. K R Dikshit (1984) has defined environment more comprehensively 'as a holistic view of the world as it functions at any point of time, with a multitude of spatial elemental and socio-economic systems distinguished by quality and attributes of space and mode of behaviour of abiotic and biotic forms.' In his explanation, 'the definition (of environment) and in turn the scope, could be governed by our concern and priorities. Our immediate concern is the quality of space we live in, the air we breathe, the food we eat, the water we drink and the resources we draw from the environment to support our economy.'

Different groups of people has viewed environment in different ways through different angles. However, it may be stated precisely that 'environment is an inseparable whole and is constituted by the interacting systems of physical, biological and cultural elements interlinked individually as well as collectively in myriad ways. The physical elements of environment such as climate, landforms, soils, rocks and minerals and space determine the variable character of the human habitat, its opportunities as well as limitations. The biological elements of environment such as plants, animals, humans and micro organisms constitute the biosphere. Cultural elements—economic, social and political—are essentially man-made features, which together make cultural milieu' (Singh and Dubey, 1983).

The Structure of Environment

Environment encompasses both abiotic (nonliving) and biotic (living) components of the

planet earth as the term signifies both physical and biological concept. The environment, based on its basic structure, may be divided into **two basic types :** physical or abiotic environment and biological or abiotic environment may further be subdivided into **three broad categories**—(a) solid, (b) liquid and (c) gaseous representing the lithosphere (solid earth), the hydrosphere (water bodies) and the atmosphere respectively. Based on different convenient spatial scales, these may again be subdivided into smaller units, such as, plain environment, plateau environment, mountain environment, glacier environment, desert environment, coastal environment, maritime environment, river environment, lake environment etc. (Singh, 1991).

The biological or the biotic components of the environment is composed of *flora* (plants) and *fauna* (animals) including humans as a most important biotic factor. Accordingly, the biotic environment is logically subdivided into floral (vegetational) environment and faunal (animate) environment. All organisms of the environment function to form their social groups and organizations at various levels and in this way they form their social environment in which all organisms work to derive matter from the physical environment for their development and survival, and thus, economic environment is formed at a level. The social organization of man is most systematic because he is most intelligent, best skilled and civilized of all organisms of the biosphere. In the biotic environment, three aspects of man, such as, physical, economic and social have different characteristics and functions in the environment are more significant. 'Physical man' in its sense, is one of the organismic populations or biological community, and so he requires basic elements of the physical environment such as, space (habitat), food, air and water as is required by other biological populations and releases wastes into the ecosystem. 'Economic man' derives and utilizes required resources from the physical and biotic environments with his knowledge, skills and technology. Likewise, 'social man' forms social organizations, establishes social institutions, frames policies, formulates laws and principles to protect his interests, to safeguard his soical welfare and existence. Therefore, these may be interpreted as physical, economic and social functions of man. Of these, the economic function makes the man an environmental/geomorphic process in a sense as he transports matter and energy from one component of the ecosystem to the other. This function or activity of man does not necessarily involve change in the functioning of the ecosystem so long as the exploitative functions are in harmony or in a balance with the natural environment but when these exceed critical limit, the equilibrium or the balance of the environment/ecosystem is disturbed and several environmental and ecological problems arise that become detrimental not only to man himself but to whole of the population of the species in a given ecosystem.

The climatic conditions of the physical environment provide certain suitable habitats to the biological communities. The physical environment thus may be viewed as polar environment, temperate environment, tropical environment etc. They may further be subdivided in some conveniently smaller but specific units. Abiotic or physical and biotic environments are fused together to form biome environment such as tropical biome, temperate biome and tundra biome which are again subdivided into second and third order biomes. In biogeography the physical and the biotic environments are more important aspects and are given more weightage than the social and cultural environment.

Components of Environment

As we have discussed earlier, environment consists of three basic components—(i) physical

or abiotic components, (ii) biotic components and (iii) energy components. The physical or abiotic component includes atmospheric component, lithospheric component, and hydrospheric component. The biotic component includes plant component, animal component (including man) and micro organismic component. Energy component includes solar and geothermal energy.

Habitat

The term signifies the type of environment in which an organism lives. It may precisely be defined as 'that part of an environment in which a plant or animal lives and which offers the conditions favourable for its existence. It includes the climate, vegetation, topography, and other conditions of the area'. A specific part of the habitat, which is a very small-scale division of the environment, such as under the bark of trees, is called *micro habitat*. According to G MacDonald (2003), 'Habitat is the explicit spatial environment in which species can be found.' He cited the example that the damp surface soil beneath a rock is a habitat.

It may be mentioned with this context that *habitat* should not be confused with *niche*. The niche provides a means of characterizing and comparing the general relationship between species and environment. Therefore, different species have different niches. The geographic distribution of a species is controlled by more than one physical factor. Species in environment exist in a multidimensional space defined by all the different physical environmental factors that affect their physiological functioning and ultimately their abundance. Considering a particular plant species, its range and abundance are influenced both by growing season temperature and annual precipitation. These two gradients form the axes of a two-dimensional environmental space in which the species can be found growing. This two-dimensional representation of the environment in which the species can survive may be referred to as its *niche*. Further, it should be noted that, always there are more than two environmental variables that control the survival of an organism. Thus, 'the niche should not be considered as synonymous with the habitat of the species' (MacDonald, 2003).

3.6 Plant Ecology : Habitat Factors and Adaptation

Plant Ecology

1. **Definition**

Ecology is generally divided into plant ecology and animal ecology. Plant ecology deals with the relationships between plants and their environment. The study of the community structure of plant is known as phytosociology or plant sociology. The study of plant ecology merges with phytogeography or plant geography. This branch of knowledge deals with the distribution of the earth's surface and water and also deals with the migration of species. In scope and content, the line of distinction between plant ecology and plant geography is not so prominent. As stated by Turrill, 'plant ecology is intensive while plant geography is extensive in outlook, but both are concerned with plants and in attempt to correlate observed structure and behaviour of plants with causes, both refer to the same sum total of environmental factor though the emphasis varies.'

A large body of scientific knowledge helpful to the science of conservation of natural resources has been gained from the study of plants in their environment. The knowledge of ecology has been proved very much helpful in controlling soil erosion, flood control, reforestation, and preservation of wild animals as well as grassland vegetation. Plant ecology is directly related to silvics and silviculture and other branches of forest biology. According to the British Commonwealth Forestry Terminology (BCFT, 1953), 'silvics is the study of general characteristics and life history of forest trees and crops with particular reference to environmental factors as the basis for practice of silviculture while the silviculture is the art and science of culturing forest trees and crops.

2. Basic Concepts

Plants and their environment, along with all organisms, are mutually reactive, affecting each other in various ways. Population of vegetation and animals are interdependent through the environment and are mutually reactive.

Environment as a complex of various interrelated factors is most dynamic and works as a sieve selecting plant species for growth from so many forms one or another factor may become critical stages of the life cycle of the plant species.

Plant species puts each effort to maintain its uniformity in structure, function, reproduction, growth and development preserving its genetic pool. Plant species also is plastic and reacts to the varying environment to get it adjusted structurally and physiologically in the changing environment. This adjustment is achieved by the degree of plasticity set by the genetic constitution of the species. Plant species may increase thein capacity of tolerance towards changing environment by developing ecads and ecotypes.

The life of plants is not only influenced by the environment, but the environment itself is modified by the plants as a result of their growth, dispersal, reproduction, death, decay etc.

Environmental Factors

The general term *'environment'* signifies *'surroundings.'* Environment is a complex of a number of components such as light, temperature, soil, water, etc. which actually 'surround' organisms, of which, plants are most important. Any external condition or substance or force, that surround and affect the life of plants along with other organisms, becomes a *factor* of its environment and thus they are considered as *environmental factors* or *ecological factors* or *habitat factors*. The particular place or space, where a plant or animal or any organism lives, is its *habitat*, and it presents a particular set of environmental conditions, the environmental complex, affecting that living organism.

The habitat factors of the environmental complex are broadly divided into two groups :

i) **Direct factors,** such as, light, temperature, atmospheric humidity, soil air, soil water, soil nutrients etc. and

ii) **Indirect factors,** such as, altitude, slope aspect, wind, soil structure and texture, soil organisms, etc.

Daubenmire (1959) has classified the habitat factors of environmental complex into seven : i) Light, ii) Atmosphere, iii) Temperature, iv) Fire, v) Soil, vi) Water and, vii) Biotic factor. However, majority of the ecologists have recognized four categories of habitat factors as listed below :

Climatic or Aerial factors

i. **Light**
ii. **Temperature**
iii. **Humidity (air)**
iv. **Rainfall (precipitation)**
v. **Wind**

Topographic or Physiographic factors

i. **Altitude**
ii. **Direction of mountains or valleys**
iii. **Aspects of slopes—steepness and exposure.**

Edaphic factors : Dealing with soil formation, physical and chemical properties of soil and other related aspects.

Biotic factors : Dealing with various interactions between different life forms, such as, plants, animals, micro organisms etc.

Climatic or Aerial Factors

The meteorological influences like relative humidity of air, temperature, wind pressure, and the rate of evaporation basically determine the climate of a region. The habitat of a particular region is characterized by these climatic factors. These factors are concerned with the aerial environment of plants and other organisms. Thus they are also called the habitat factors and they include air temperature, air humidity, precipitation and other gaseous components including wind.

I.) Light Factor :

Light is most important habitat factor and it affects the *basic physiological processes* of plants like *photosynthesis, transpiration, germination, flowering* etc. Light plays important role in the composition and development of vegetation species. Light affects plant's life *directly* and *indirectly* in the following ways :

1. **Production of chlorophyll :** Light plays most important role in the formation of plastids and pigments. At the same time, light has marked effect upon the number and position of chloroplasts in plants. Except very few, like some algae and mosses, young fronds of ferns and seedlings of conifers, most of the plants need light for chlorophyll formation. The upper part of leaf receives full sunshine with large number of chloroplasts arranged in line with the direction of light. Thus the existence

of other life forms dependent on plants for food has become possible for the presence of light.

2. **Photosynthesis :** Only about 2% of the total solar energy reaching the earth is used in photosynthesis and about 10% is used in other physiological activities. A plant does not utilize all the wavelengths of light. The green parts of plants reflect green light completely. Green plants synthesize their food as carbohydrates from water and CO_2 in presence of sunlight. Energy required for this process is provided by solar radiation. The radiant energy of sun available to the plants is converted into the chemical energy by chlorophylls in this process. The chemical energy stored in food is utilized in various other biochemical activities of the plants. The rate of photosynthesis is greater in intermittent light than in the continuous light.

3. **Heating action :** Exposure of parts of plants to light raises their temperature that affects their related processes.

4. **Stomatal movement :** Light regulates opening and closing of stomata in leaves.

5. **Respiration :** Light has no direct effect on the respiratory activity in the plant body. In some particular conditions, such as, under water and in shade, light becomes a limiting factor and photosynthesis becomes insufficient for effective growth. The rate of photosynthesis under such conditions is just sufficient to meet the need of respiration. Then it is called *compensation level*. The dry weight of plants does not increase at this point. In some plants the rate of respiration is slightly decreased in intense light.

6. **Effects on the rate of transpiration :** Light affects transpiration rates indirectly through increase in temperature. Rate of transpiration affect correspondingly water absorption also. Thus intense light is always associated with dry habitats and high transpiration rates.

7. **Distribution of plants :** Duration and intensity of light in the polar areas are different from the other parts of the earth. Total amount of radiation received by the earth's surface differs with the change in latitude. Light decreases with the increase in the distance from the equator. This is one of the important causes for difference in the vegetation at poles and at other parts of the earth.

8. **Photoperiodism :** The total length of daily light period or the duration of light to which plants are exposed is called *photoperiodism*. It has pronounced effect on the growth and flowering of plants. Plants have been classified in relation to their response to photoperiods :

    (i) Long day plants—plants that bloom when the duration of light is more than 12 hours per day, i.e., spinach, radish, potato etc.

    (ii) Short day plants—plants that bloom when the duration of light is less than 12 hours per day, i.e., cosmos, tobacco, cereals etc.

(iii) Day neutral plants—plants which show little response to the length of day light, i.e., cotton, tomato, balsam etc.

9. **Overall growth and development of plants :** Plants are sometimes classified ecologically on the basis of their relative light requirements and the effects of light on their overall vegetative development :

(a) **Plants** that receive direct sunlight or plants growing best in full sunlight are called *Helliophytes*.

(b) **Plants** that grow best in lower light intensities or growing in the shades are called *Sciophytes*.

Some species *of helliophytes* grow best in full sunlight, but can grow fairly well under shade. Such plants are called *facultative sciophytes*. Similarly there are some species of *facultative helliophytes* which, although grow best at lower light intensities, but can grow well in full sunlight. Some plants, having probability of being injured by bright sunlight, develop some characteristics in themselves to minimize such effects, such as, plants of sunny habitats have vertically oriented leaf blades. Some variations in the pigments complex of leaves also take place. Vegetations, in moist climates, are generally a complex series of superimposed layers of tall trees, low trees, shrubs, and mosses etc., which are *obligate* or *facultative sciophytes*. However, following important features are evident in *helliophytes* :

1) Proper development of mechanical tissues
2) Stem with long lateral organs and short internodes
3) Weldeveloped xylem with thick rays
4) Weldeveloped palisades and weakly developed spongy tissue in the leaf
5) Numerous and profusely branched roots
6) Small intercellular spaces in the tissues
7) Low chlorophyll content
8) Thick cuticle
9) High respiration rate and rapid transpiration
10) Early appearance of flowers
11) Vigorous flowering and fruiting.

10. **Germination of seed :** Seeds in moist condition are very sensitive to light. Germination of seeds, in some cases, is retarded in light. The quantity of light needed for the stimulation of embryo varies in different seeds. The red light, in most cases, promotes germination and far-red light, inhibits germination.

11. **Movement :** Movements of plants in most cases are affected by light. The leaves, stems and roots show different responses to light. The effect of sunlight on the movement of plants is called helotrophic effect. The stems elongate towards the source of light, that is, positively phototrophic, and the roots are negatively phototrophic. The leaves grow transversely to the path of sunlight.

12. **Succession :** The role of light in plant succession is now well defined. It has been reported from some scientific observation that the light requirements of pioneers are comparatively much more than the climax species. But a group of botanists are in favour that the main factors are temperature and soil fertility and these factors, under natural conditions, modify the influences brought about by light. Most of the influences of light and temperature are interrelated in their effect on plants.

II) Temperature Factor

Temperature is the most important variable factor influenced by time, season, altitude, latitude, direction, slope, soil texture, plant cover and human activities like industrialization and urbanization. Temperature has profound effect upon all life forms by exerting its action through increasing and decreasing some vital activities like metabolism, reproduction, embryonic development and growth. Temperature affects vegetation either directly or indirectly. Directly it affects—

i) The physiological processes of plants and consequently their growth and size; and

ii) determines which species can survive in a particular region. Because, different plant species show a wide variation as regards their tolerance to temperature range and fluctuation.

1) **Effects on metabolism :** All chemical reactions in the body of organisms are controlled by temperature, as temperature regulates the activity of enzymes. Thus, all metabolic processes are influenced by temperature. It affects the rates of transpiration; photosynthesis in plants and respiration rates and other metabolic processes in implants and temperature also affect seed germination.

2) **Effects on reproduction** : Temperature affects flowering in plants through *thermoperiodism*—the response of plants to rhythmic diurnal fluctuations in temperature. Temperature is most important factor in the **phenology** of plants.

3) **Effect on growth and development :** The growth of plants is adversely affected by both extremely high and low temperature. Extremely high temperatures cause stunting and final death of plants, which is due to adverse

effects on a number of physiological processes as respiration, transpiration, protein metabolism etc. This is called heat injury. On the other hand, low temperatures bring about cold injuries like desiccation, chilling injury and freezing injury. In case of desiccation, tissues of plants are dehydrated and injured due to rapid transpiration and slow absorption during winter.

4) **Effect on germination :** Temperature stimulates the growth of seedlings. The rate of optimum temperature for germination of seeds ranges between 20°C and 27°C.

5) **Effects on photosynthesis :** The rate of absorption is retarded in low temperature. Photosynthesis is possible over a wide range of temperature. Lower range of temperature is suitable for photosynthesis for most of algae. On the other hand, some desert plants can continue their photosynthesis even at 80°C of temperature.

6) **Effect on respiration :** The rate of temperature increase with the rise of temperature up to a critical level, but the rate of respiration shows perceptible decrease in just beyond the optimum limit. Other factors remaining favourable, an increase of 10°C above the optimum limit may increase the rate of respiration double. High temperature generally favours the growth of plants, but low temperature is proved beneficial for some crop plants.

7) **Effects on plant diseases :** Temperature in combination with humidity and other factors helps in the spread of diseases in plants. High humidity and low temperature invite rust attack. Low temperature, high humidity and cloudy weather favour the damping off, seedling blight and root rot diseases in some plants like papaya, cucurbits, ginger, tobacco etc.

Ecologists have divided plants on the basis of their requirements of heat :

(a) **Megatherms :** The plants of warm habitat that need high degree of heat throughout the year for their development are called *megatherms*. These are the dominant plants of tropical rainforests.

(b) **Mesotherms :** The plants of habitat having neither very hot nor very cold condition are called *mesotherms*. The dominant vegetation of this class are tropical deciduous trees.

(c) **Microtherms :** The plants of temperate and cold habitat that require low temperature for their growth are called *microtherms*. These plants are very much vulnerable to high temperature. Besides temperate regions, these plants are also found in tropical and subtropical areas at high elevations where temperature conditions are less extreme.

(d) **Hekistotherms :** The plants of cold and alpine regions are called *hekistotherms*. These plants are unable to thrive well in hot condition and can withstand long and very severe winter.

Variation in temperature and its effects on plant distribution

Temperature shows clear spatial as well as temporal variations. Pronounced seasonal extremes and fluctuations in the temperature values are clearly evident in larger countries like India. Soil temperature is consequent upon the heat gained by the absorption of solar heat energy, and soil temperature is greatly influenced by the latitude of a particular place, that is, the distance from the equator. The temperature values are obviously maximum at the equator, decreasing gradually towards the poles. The division of the terrestrial vegetation into different zones as equatorial, tropical, coniferous, alpine etc., is based on the marked variations in temperature at different latitudes. Similarly, the height of a place from the sea level or the altitude affects temperature values of that place markedly. Besides latitude and altitude, the physiographic factors like the steepness and exposure of slopes, the direction of mountain chains, colour and composition of the surface, water content of soil, plant cover etc. greatly affect the temperature conditions. As for example, decrease in temperature with increasing altitude is experienced and thus vegetation at different altitude is different showing clear zonation. Generally mean temperature of air decreases about $10^{o}F$ for every degree of latitude north of the equator and for every 300 of altitude. In comparison to the mountaintops, sometimes the valleys and low lands remain much cooler due to sinking in of the heavier cold air.

Changes in both the altitude and latitude show more or less similar effect upon the type of major vegetations of the world. The various zones of different kinds of vegetation at increasing latitudes from equator towards poles and at increasing altitudes in mountains are more or less similar showing that increase in latitude and altitude brings about more or less similar influence upon vegetation. Thus, distinct latitudinal as well as altitudinal zonation are found in vegetations.

Temperature and rainfall commonly determine the type of vegetation at different altitudes on the mountains. In addition. besides temperature and rainfall, edaphic conditions are also important. With deviations in elevation on mountain terrains, in general, western and southern slopes register higher temperatures than do the eastern and northern slopes. There the slope angle in relation to sun governs the total amount of radiation. These differences are caused by the differences of solar radiation received, amount of rain and snowfall, relative humidity and movement of wind. Temperature at higher elevations generally decreases and rainfall increases. This factor definitely affects the development of soil and vegetation. The organic matter content of the soil at higher altitudes increases with an increase in soil nitrogen and a decrease in its pH values, mainly due to low temperature and high rainfall. As

a result, xerophytes are generally more common at lower altitudes and *chamaephytes* occur at higher altitudes.

General zonations of vegetation from lower to higher altitudes are quite evident due to prominent variations in temperature. The successive zones of vegetation from base upwards are tropical and subtropical, temperate and alpine. However, there are practically no sharp boundaries between these vegetational zones due to differences in topography, soil and geology. Thus, the effect of temperature on western as well as eastern, together with altitude and other factors becomes quite evident on vegetational zones at different altitudes.

Air Humidity

Humidity of air is one of the different forms of water in nature. Atmospheric moisture in form of invisible vapour is known as **humidity**. Humidity of air is expressed in terms of **relative humidity** values. It is 'the amount of moisture in air as percentage of the amount which the air can hold at saturation at the existing temperature'. Humidity is greatly influenced by intensity of solar radiation, temperature, altitude, wind, exposure, cover and water status of soil. High temperature increases the capacity of the air to retain moisture and cause lower relative humidity. Low temperature cause higher relative humidity by decreasing the capacity of the air for moisture. Relative humidity is measured by the instrument called **psychrometer** or by paper strip **hygrometer** or a **thermo-hydrograph**. Humidity plays an important role in the growth and development of plants. Various physiological processes like transpiration, absorption of water etc. are influenced much by atmospheric humidity. The rates of evapo-transpiration are modified by saturation deficit, temperature and wind velocity. Saturation deficit is the difference between the pressure of water vapour in the atmosphere at a given time and the maximum vapour pressure that it could contain at the same temperature. A decrease or increase in the saturation deficit causes a fall or a rise in evaporation rate respectively. Similarly temperature also affects the rate of evaporation. Dry winds decrease the amount of air moisture by removing moist air from plants and mixing it with dry air that decreases the humidity and thus increases transpiration. Humidity thus affects the life of plants in various ways. Effects of moist air on plants are more or less similar to those of reduced light intensity. Atmospheric moisture are directly used by some mosses, lichens, orchids etc. Also it plays an important role in germination of spores and subsequent life cycle of fungi.

Rainfall / Precipitation

Precipitation is the chief source soil water, which is the basis of life for plants. Water available to plants from soil comes as a result of rainfall. The interchange of water between the atmosphere and the earth's surface is called hydrological

cycle, responsible for occurrence and distribution of rainfall. Precipitation and evapo-transpiration are two important events involved in hydrological cycle.

During rainfall, water in fact directly of little or no use to plants. Plants use water only after reaching to the soil. Precipitation occurs in various forms like drizzle, rain, snow, dew and frost, sleet and hail etc. **Drizzle** involves tiny droplets of water appearing as to float in air. **Rain** is the drop of liquid water larger and heavier than drizzle. **Snow** is moisture in solid state, whereas **dew** and **frost** are formed due to condensation of moisture directly on the surfaces of objects. **Sleet** occurs in the form of small grains or pellets of ice and **hail** consists of balls or lumps of ice. Snow is injurious to plants, breaking tender branches, flowers and fruits. Sleet and hail also cause similar damage to plants. Some sedges grow in snow patches.

Rain is the most important of all the forms of precipitation just mentioned. The amount of annual rainfall greatly influences the vegetation of a particular region. The distribution of rainfall in different seasons of the year is of same importance in the regional distribution of vegetation. On high altitudes or mountains, definite vegetation zones are correlated with the distribution of rainfall. Three vertical zones are clearly distinguished—a) lower region with scanty rainfall, b) middle or the cloudy region with huge rainfall and c) the cold and dry upper region above the clouds covered with snow and ice.

Annual rainfall determines the type of vegetation in any region. Such as, in tropical belts with heavy rainfall throughout the year the main vegetations are **evergreen forests**. On the other hand, **sclerophyllous** forests are found in the areas with heavy rainfall during winter and summer. The plants there are short, stunted in height, with leathery, thick evergreen leaves. The areas with sufficient rainfall during summer and low during winter have **grasslands**. Deserts and **xerophytic** vegetation are found in the areas with little or scanty rainfall.

Wind

Wind is an important ecological factor and its major effects on plants are observed in flat plains, along seacoasts and at high altitudes in mountains. Wind is directly involved in transpiration, in causing several types of mechanical damage, and in dissemination of pollen, seeds and fruits. The velocity of wind is affected by such factors as topography, vegetation cover and geographic location with respect to seashores. Wind effects are much pronounced in plants along the seacoasts and at high altitudes on mountains. Wind brings about a number of physical, anatomical and physiological effects on plants as described below :

Physical effects :

High velocity wind may break living branches of trees and sometimes uproot them completely. However, such effects are uncommon in forests where the canopies

of individual trees at different heights reduce the velocity of wind. Therefore, forest vegetation serves as natural **windbreaks**. A windbreak is densely planted strip of tall vegetation of a considerable height, covering a strip of land wide enough, oriented at right angles to the direction of prevailing winds in order to reduce their velocity near the ground. Sometimes special trees and shrubs are planted to provide protection against winds for crop fields, orchards, buildings or livestock. Windbreaks afford such benefits to plants, as reduced rates of evaporation and transpiration, reduction of damage by breakage, lodging and abrasion, and reduction in the movement of soil by wind. Single trees or groups of trees uprooted in forests by strong winds are often known as **wind throws** or **windfalls**.

Deformation :

It is a type of wind injury to plants. Strong winds from a constant direction sometimes cause permanent alteration in the form and position of the shoots. Deformation is very common in trees growing on ridges and along coasts.

Lodging :

This type of wind injury is common in grasses as wheat, maize, sugarcane, oat etc. where violent wind cause the flattening of herbaceous plants against the ground.

Abrasion :

Crops grown on sandy soils and cold areas usually suffer with this type of damage. Particles of soil or ice carried by wind may act as strong abrasive force by which the buds and other parts of plants may be eroded away.

Erosion and deposition :

As the soil is generally eroded by strong wind, the roots of plants in the areas of thinly covered sandy soils may become exposed. On the other hand, the areas where those additional soils are deposited, become suitable for cultivation of crops.

Salt spray :

The salts of sea water are carried by strong winds along seacoasts in the vicinity of oceans. Salts sprayed in such way become injurious to some crops grown along seacoasts.

Physiological and anatomical effects

Desiccation :

Dry and strong winds increase the rate in evaporation and transpiration causing failure in the maintenance of internal water balance. As a result, plants suffer from desiccation. But in the same area, the plants having dense canopy with

crowded branches escape such wind damage. These types of plants are referred to as **cushion plants**.

Dwarfing :

Plants growing in a habitat experiencing the effects of dry winds generally suffer from dehydration and consequent loss of turgidity. Thus the organs of the trees commonly grown in seacoasts and arctic areas become dwarfed.

Compression wood :

A dense and reddish type of xylem, developed in some tree boles as a result of wind deformation, is known as **compression wood**. Formation of collenchyma is evident on the wind-deformed organs of some herbaceous plants.

Topographic or Physiographic Factors

The climate of any area is chiefly determined by the interactions of solar radiation, atmospheric temperature, air humidity and annual rainfall. Along with the latitude and altitude, each of these climatic factors is greatly influenced by the topography of the area. Light, temperature, moisture etc, vary at different heights on mountains (altitude) as well as at different distances from the equator (latitudes). Physiographic factors are those which are introduced by the structure, conformity and behaviour of the earth's surface, by topographic features such as elevation and slopes, by the geodynamic processes, such as silting and erosion and consequently by local geology. Valleys, hills, mountains etc. result from the irregularities of the earth's surface. These topographic reliefs produce local or microclimates.

Altitude :

At high altitude, the velocity of wind is high, temperature and air pressure decrease, humidity as well as intensity of light increases. Thus the climatic factors show variations and they become progressively extreme and rapid with increasing altitudes. The summits of mountains, for example, are different from the sides of mountains and narrow valleys are different from the open valleys.

Direction of Mountains and Valleys :

Mountains deflect winds into different directions and capture moisture from wind on different sides. As a result, water vapour may accumulate only in some preferred directions as clouds which pour rains after condensation. That is why we see luxuriant forests on certain sides and at a particular height, where as scanty vegetation with xeric tendencies on other sides and at lower levels. Thus outer Himalayas show frequent rains with luxuriant vegetation, while the middle and inner Himalayas are dry with poor vegetation. In fact moisture in the wind is

condensed and deposited at the outer Himalayas before it reaches the middle and inner ones. Similarly, southern side of Kulu valley is moist with rich vegetation, whereas there is very poor vegetation at lower levels of Lahul valley. Moreover, high mountains not only act as climatic barriers to air masses between neighbouring areas but also cause local air circulation giving rise to mountain winds. The most common winds in such areas are slope winds which blow down-hill during night and up-hill during the day.

Relative humidity depends upon the direction of the air—whether it comes from south or north, as well as on the habitat, for example, from a sea, or a desert or from forest area. The heating of the earth's surface is directly proportional to the angle at which solar rays arrive on the ground. Thus mountains affect the climate through rainfall and other factors which ultimately affect the type of vegetation.

Steepness of Slope :

Steepness of a mountain slope affects the amount of solar radiation received during the day, and soil characteristics primarily through its effect on rate of water flow. In the northern hemispheres, at higher altitudes, slope steepness increases the exposure of the surface to sun on the southern slopes, whereas the northern slope remain cooler. This happens because of the steep southern slopes receive the rays of the mid-day sun almost at right angles, whereas the northern slopes receive only oblique rays during morning and evening hours and sometimes none at all except for a short period during summer. This difference in solar radiation and consequent temperature values bring about temperature changes in the vegetation on the two slopes. Thus northern slopes, being protected from sun, support virgin forests with hygrophilous ground vegetation whereas the southern slopes, being heated by sun, have only xerophytic vegetation. These are due to local climatic differences on two slopes.

The steepness of slope also determines the speed of water flow which has an effect upon the soil characteristics. On the sloping sides, most of water flows down rapidly and is allowed to reach the soil. Thus loss of water as runoff increases with the increase of slope steepness. Thus sides with unequal slope steepness, in spite with similar annual rainfall may bear different vegetation. Plants are unable to establish on a steep slope, even if there is sufficient rainfall.

Moreover, steepness of slope also encourages soil erosion. With heavy rainfall on the steep slope, active soil erosion and denudation due to runoff results into disappearance of plants from that areas. Eroded hills, steep slopes and bare rock faces may produce a special habitat where a particular type of plants can grow. Clay, sand, gravel etc. eroded by water are brought down by rivers and streams and are deposited as silts at the lower reaches provide new habitats that support different kinds of plants.

Edaphic Factors :

Soil is the outermost layer of the earth's crust and is formed constantly through weathering and decomposition of rocks. It is not only the factor of the environment but also a product of the organic activities causing the biological weathering of rock. Soil may be defined as the unconsolidated top or surface layer of the earth's crust lying below any aerial vegetation and undecomposed dead organic remains and extending down to the limits to which it affects the plants growing about its surface. Beneath the soil, lie the subsoil and unweathered rocks.

The soil is one of the most important ecological factors known as **edaphic factors**. It is most important characteristic feature of the terrestrial environment. Soil is the reservoir of biogenic salts and minerals essential for the survival of living organisms. Edaphic factors are those which are dependent on the soil as such—on soil constitution, soil air, soil water, soil organisms and so forth. Soils of different places vary considerably in their structure, components and properties. These differences in the soils are often largely responsible for differences in vegetation within the same climatic region and consequently they are of great significance in the distribution of plant communities.

Soil is a layered mixture of inorganic and organic materials. The inorganic or mineral constituents of soil are derived from some parent materials, the soil forming rocks by fragmentation or breakdown through weathering. The organic constituents of soil are formed either by decomposition of dead remains of plants and animals or through metabolic activities of living organisms present in the soil. Weather of soil forming rocks is brought about by (a) physical factors like temperature, water, ice, gravity and wind, (b) chemical factors like solvent action, hydrolysis, oxidation, reduction, carbonation and hydration and (c) biological factors.

Plants depend for their anchorage, water and nutrient supply upon the soil. Even the free-floating aquatic plants that derive their nutrients dissolved in the water medium around them, there mud is important chief storage of all the nutrients made available to the water medium. Soil system is indeed is dynamic and very complex, undergoing continuous change, and the rates of such changes being influenced by a number of other factors of the environment. According to Marsden-Jones and Turrill (1944), soil may affect plants by affecting seed germination, size and erectness of the plant, vigour of the vegetative organs, woodiness of stem, depth of the root system, susceptibility to drought, frost and parasites, number of flower per plant, and the time of flowering etc. Warming (1909) emphasized the importance of soil characteristics and proposed five ecological groups of plants, as (i) oxylophytes—usually found on acid soils, (ii) halophytes—on saline soils, psammophytes—on sand, (iii) lithophytes–on rock surfaces and (iv) chasmophytes—in rock cervices.

3.7 Plant Succession and Climax Vegetation

Succession is a natural process by which various communities colonise the same area over a period of time in a definite sequence. Similarly, plant succession points out to the natural process by which different plant communities colonise the same area over a period of time through definite sequences. Communities of a everywhere are not stable but dynamic, changing more or less regularly over time. Plants as communities are also never found permanently in complete balance with their component species or with the physical environment. Environment, on the other hand, keeps itself always changing through time because of (a) variations in climatic and physiographic factors, and (b) the activities of the species of the communities themselves. These conditions bring about marked changes in the dominance of the existing plant community which is thus sooner or later replaced by another community at the same place. This process continues and successive communities develop one after another over the same area, until the terminal final community again becomes more or less stable for a period of time. This occurrence of relatively definite sequence of communities over a period of time in the same area is known as **ecological succession** (Sharma, 1993). According to Clements (1916), plant succession is 'the natural process by which the same locality becomes successively colonized by different groups of communities of plants.'

Oclum (1971) preferred to term this orderly sequential process as **ecosystem development** rather than **ecological succession**. Ecological succession, or ecosystem development as stated by Odum, may be defined in terms of the following three parameters :

(i) Succession is an orderly process of plant community development that involves changes in species structure and community processes with time, it is reasonably directional and therefore predictable.

(ii) Plant succession results from modification of the physical environment by the plant community, which means, succession is community controlled even though the physical environment determines the pattern, the rate of change, and often sets limits as to how far the development can proceed.

(iii) Succession culminates in a stabilized ecosystem in which maximum biomass and symbiotic function between organisms are maintained per unit of energy flow.

Causes of Plant Succession

As in fact, plant succession is a series of complex processes, its causes are also manifold. There are three general causes of succession :

1. **Initiating causes or initial :** The climatic as well as the biotic causes are considered as the initial or initiating causes. The climatic causes include the factors as precipitation, wind, fire, erosion and deposition etc. and the biotic causes include the various activities of the organisms. These causes produce bare spaces or destroy the existing populations of an area.

2. **Continuing causes or ecesis :** These processes include aggregation, migration, ecesis, competition and reaction etc. which successive waves of populations as a result of changes, chiefly in the edaphic features of the area.

3. **Stabilizing causes :** These causes bring about the stabilization of the community. As stated by Clements (1917), the climate of an area is the principal cause of stabilization of plants whereas other causes are of secondary importance.

Types of Succession

The basic types of plant succession may be stated as below :

1. **Primary succession :** Primary succession starts from the primitive substratum, where there was no sort of living matter in previous time. This is true for any of the basic environments like terrestrial or freshwater or marine. The first group of organisms establishing there are known as the **pioneers, primary community** or **primary colonizers**.

2. **Secondary succession :** It starts from previously built up substrata with already existing living matter. Perturbation from external forces like sudden change in climatic factors, biotic intervention, fire etc. forces the existing community to disappear. The area, thus, becomes devoid of living matter but its sub-stratum becomes built up. These types of successions are relatively more rapid.

3. **Autogenic succession :** The community, in most cases after the succession starts, modifies its own environment as a consequence of its reaction with the environment. This is known as autogenic succession.

4. **Allogenic succession :** The replacement of the existing community in some cases is largely caused by some external condition. Such course of succession is known as allogenic succession.

5. **Autotrophic succession :** This type of succession is characterized by early and continued dominance of green plants as autotrophioc organisms. It is started in a predominantly inorganic environment and the energy flow is maintained indefinitely. The inorganic matter in that environment increases gradually supported by energy flow.

6. **Heterotrophic succession :** This succession is characterized by early and continued dominance of heterotrophs like bacteria, fungi, actinomycetes, microbes and other animals. It begins in a predominantly organic environment, and there is a progressive decline in the energy content.

Some other kinds of successions based upon the nature of environment and the place where the process of succession begins are also mentioned in the ecological literature. The succession starting in the region where water is plenty like pond, lake, streams, bogs or swamps etc. is called **hydrarch** or **hydro-sere**; where water is not plenty but adequate, the succession is known as

mesarch and where moisture condition is minimum is called **xerach** or **xerosere**. Likewise, the process of succession initiated on bare rocks is called **lithosere**, succession active on sands is known as **psammosere** and plant succession active in saline soil or water is known as **halosere**.

Basic Processes of Plant Succession

The entire process of plant succession usually is accomplished through a number of sequential stages as stated below :

I. Nudation

This stage denotes the presence of a bare land surface where no form of life is present. The bare surface may develop as a result of some geomorphic causes like erosion, deposition, landslide or any catastrophic agency. The major causes of **nudation** are :

1. **Climatic :** Severe storm, frost, fire, long drought period, glaciers etc. may totally destroy the community of the area leaving the surface bare.
2. **Topographic :** The existing community of an area may disappear due to erosion of topsoil by water or wind. Similarly, plant community of an area may disappear due to volcanic activity, landslide, sand deposition and shifting of sand dunes.
3. **Biotic :** Sometimes, the whole population of an area may be destroyed by the attack of fungi, viruses, etc. which introduce diseases and epidemics. But the most powerful biotic factor is man who destroys large areas of forests for promotion of agriculture, housing and industry.

II. Invasion

The successful establishment of a species in a bare area is termed as invasion. The species invade there from other area through dispersal or migration. The whole process of invasion is completed through the following three stages :

1. **Migration / dispersal :** The seeds, spores, or other propagules of plant species reach the bare area mainly with the help of air and water.
2. **Ecesis (=establishment) :** The process of successful establishment of the species after coming to the new area and adjusting itself with the existing condition is known as ecesis. Seeds and propagules of plants germinate in new area, seedlings grow and adult plants start to reproduce. But under this harsh condition, only few of them become successful and most of them disappear. The individuals of species become established in the area as a result of ecesis.
3. **Aggregation :** The individuals of species increase in number through reproduction after ecesis and they become compact in course of time. This process is known as aggregation.

III. Competition and coaction :

Inter-specific as well as intra-specific competition mainly for nutrition and space develops in the initiated space after aggregation of a large number of species. Then the individuals of species affect each other in various ways known as coaction. Any species unable to compete with the other become eliminated. Thus, the capacity of reproduction, wide ecological amplitude etc. help much the species to withstand competition.

IV. Reaction

Reaction is the most important stage in plant succession. It is the mechanism of the environment through the influence of living organisms. Characteristic changes in temperature and light conditions, soil and water of the environment take place as consequence of reaction. These changes bring about modifications in the environment which become gradually unsuitable for the existing community and thus it replaced sooner or later by another species. The whole sequence of communities that replaces one another in the given area is called a **sere**, and various communities constituting the **sere, as seral communities, seral stages** or **developmental stages** (Sharma, 1993). The pioneers generally are more dynamic, need less nutrient and capable of consuming minerals in complex forms.

V. Climax (stabilization)

As the above-mentioned processes proceed through time, finally there occurs a stage when the final terminal community becomes more or less established for a longer period of time and the species then becomes able to maintain in equilibrium with the climate of the area. This final community is not replaced, and is known as **climax vegetation** and the stage is then known as **climax stage**.

The generalized process of succession as just described above and different plant communities appearing in the process with developing environmental complex. Each of the developmental stage is called a **seral stage**. In fact, these stages are continuous with each other, and, from beginning till the climax stage, the whole sequence is known as sere. The species, which colonise the bare area in starting of the succession process, are called pioneers.

Retrogressive succession is another type of succession in which continuous biotic influences have some degenerating effects on the process. In some cases, the development of effected communities does not occur and the process of succession instead of progressive becomes retrogressive due to destructive effects of organisms. This type of succession is called retrogressive succession. For example, change of forest community into shrubby community.

The process of succession sometimes becomes deflected in a different direction due to changes in local conditions as in soil or microclimate. As a result, the climax communities

become different from that of the presumed climax community. Some ecologists have termed this type of succession as **deflected succession.**

Hydrarch or hydrosere

Different stages in a hydrosere clearly observed in freshwater ecosystems like ponds, swamps, pools or lakes. Initiating in a pond, hydrosere begins with the colonization of some phytoplanktons forming the pioneer plant community and finally terminates into a forest as a climax community together with their chief associates of vegetation. Successive changes take place in plants as well as animal's life in a hydrosere just like other primary autotrophic successions. But changes in plants are more obvious than the animals. Thus succession of plants seems clearer. The succession of plants in a hydrosere takes place through the following stages :

1. **Phytoplankton stage :** Diatoms, some blue-green algae, bacteria etc. colonise the primitive medium of the pond as first organisms, which form the pioneer community, and they grow and multiply for a relatively brief period.

2. **Rooted submerged stage :** A soft mud rich with organic matter develops at the bottom of the pond as a result of death and decomposition of phytoplankton mixing with the silts from surrounding areas. This changed habitat tends to be a bit shallower where penetration of light becomes easy making it suitable for the growth of rooted submerged hydrophytes (i.e. *Elodea, hydrilla, myriophyllum, Potamogeton, Vallisneria* etc.). These hydrophytes bring about further build up of the substratum as a result of their death and decay. The water level then further decreases making the pond again shallower. This new habitat then replaces these plants giving way to another type of plants which are floating leaf type.

3. **Rooted floating stage :** The plants in this stage colonise the habitat with their rhizomes. All of them are rooted hydrophytes with their large leaves floating on the surface. Even, in this stage, some free floating species (i.e. *Azolla, Lemna, Wolffia, Pistia, Spirodella, Salvinia* etc.) also become associated with the rooted plants (i.e. *Aponogeton, Limnanthemum, Monochoria, Nelumbo, Nymphaea, Trapa* etc.) due to abundance of salts and other minerals. Now the water level decrease further making the pond shallower. The organic matter precipitated due to death of these plants brings about further build up of the substratum. Thus sooner or later the floating species disappear from the area.

4. **Reed-swamp stage :** Though the plants of the community in this stage are still rooted but most parts of their shoots remain exposed to air. Thus, this stage is also known as **amphibious** stage. The chief plants of this stage are of this type (i.e. *Phragmites, Sagittaria, Scirpus, Typha* etc.). They possess well developed rhizomes and constitue a dense vegetation. By now the water level becomes more reduced and the habitat sooner becomes unsuitable for the growth of these amphibious species.

5. **Seelgé-meadow stage :** In this stage, species of some Cyperaceae and Gramineae colonise the area due to successive stages decrease in water level. Then they form mat-like vegetation towards the center of the pond with the help of their multi-branched rhizomatous systems. There is much rapid loss of water due to high rate of transpiration and gradually the mud is exposed to air as a result of which nutrients like ammonia, sulphides etc. become oxidized to nitrates and sulphates. Thus mesic conditions appear in the area with the gradual disappearance of marshy vegetation.

6. **Woodland stage :** The soil of the habitat becomes drier for most part of the year by the time of disappearance of marshy vegetation. Some shrubs and trees as terrestrial plants invade into the area. Humus with rich flora and micro organisms is accumulated in the area by this time. Mineralisation of the soil favours the arrival of new tree species in the area.

7. **Forest stage :** The climax community appears in this stage. Several trees rapidly invade the woodland community. The tropical rain forests develop in the tropical climates with heavy rainfall, whereas mixed forests develop in temperate regions. Monsoon forests of tropical deciduous type develop in regions of moderate rainfall.

Lithosere / Xerosere on Rock

Xerosere originate on bare rock surfaces. The primitive or original substratum remains deficient in water lacking any organic matter and having only minerals in disintegrated state. Crustose type of lichens as pioneers colonise first in this primitive substratum and through a series of successive seral stages the succession finally terminates into a forest which constitutes the climax community. The different stages and their accompanying plant species of a lithosere appearing on a rock may be described as below.

1. **Crustose lichens stage :** The substratum colonized by the pioneers in this stage is very poor in moisture and organic matter subjected with extremes of temperature. The lichens of this stage (i.e. *Rhizocarpon, Rinodina, Lecnora* etc.) produce some acids which bring about weathering of rocks. Dead organic matters from lichens mix with the small particles of rocks, but the process is slow enough. These lichens are then replaced by foliose type of lichens.

2. **Foliose lichens stage :** This community possess large leaf-like thalli and they appear on the substratum partially built up by the crustose lichens. They can absorb and retain more water and are able to accumulate dust particles helpful for further build up of the substratum. Some humus in this are also accumulated. By this time the weathering of rocks and its mixing accumulated humus results into the development of a fine thin soil layer on rock surface and thus considerable change is brought to the habitat.

3. **Moss stage :** The thin soil layer developed on the rock surface, particularly in crevices, favours the growth of some xerophytic mosses (i.e. *Grimmia, Polytrichum, Tortula*

etc.). They compete with the lichens in course of their successful growth. There is further addition of organic matter in the soil due to their death and decay. The thickness of the soil then increases gradually.

4. **Herbs stage :** There accumulates more soil due to extensive growth of mosses and more minerals are added to it due to leaching out from overlying vegetation. This modified habitat favours the growth of some herbaceous weeds which are mainly the annuals, in turn being followed by some biennials and perennials. There is much more accumulation of humus in soil due to their growth and death and further weathering of rocks. The habitat thus changes with decreasing xeric conditions. This stage is constituted by some shallow rooted grasses, which in turn are replaced by shrubs.

5. **Shrub stage :** With increasing accumulation of soil, the habitat gradually becomes suitable for shrubs which start to invade the area. These species then overshadow the herbaceous vegetation. The soil is further enriched by this dense shrubby growth and in turn trees that make up the climax community finally replace them.

6. **Forest stage :** In this final stage, some xerophytic tree species invade the area. Then further weathering of rocks and increasing humus content of the soil favour the invasion of more trees and vegetation finally becomes mesophytic. Thus, finally there develops a forest community.

The Concept of Climax in Succession

The term climax was proposed by Clements (1916) to explain the final, terminal and more or less stabilized community in succession that is able to establish some sort of equilibrium with the environmental conditions of that area. The subject of climax has long been controversial and was reviewed from time to time by many ecologists. Clements emphasized that climax has the following three major characteristics :

1. **Unity :** Climax is a unit and an index of climate of the area. Growth forms or life of plants indicate the type of climate. But climax would not indicate the climate unless all the species are not taken as an organized unit.

2. **Stability :** The form of the climax community is more or less stable with the climate. This climax community cannot be replaced through competition by any other group of species. In a particular climatic area, there may develop climax communities only with a few characteristic dominant species.

3. **Origin and phylogenetic relations :** Climax community is to be treated equivalent to an organism, like which it takes birth, grows and develops, and becomes mature. In this organismic concept of climax community, Clements designated it as super organism. In any climatic region, the developmental stages of the climax community have their own characteristics, which reflects the type of climate. Similar to the

development of organism with changing age, climax communities have also simultaneously undergone changes with changing climate. This phylogenetic relations may be established between different climax communities of the world.

There are three popular theories about the climax concept in ecology :

I. **Monoclimax therory :** Clements emphasized upon climate as an only important factor in the stabilization of the climax community. According to this theory, all land surfaces within a given region eventually tend to be occupied by a single kind of community, that is climax. The climax is determined by the regional climate. In a given stable climate, the climax community remains stable indefinitely. However, Clements' views were criticized enough by a number of ecologists. For example, disagreeing with the concept of stability, Cowles stated that 'equilibrium state is never reached and succession infact is a variable approaching, a variable rather than a constant.'

Cooper described that all progressive as well as retrogressive changes in communities reflect succession. So, Cooper considered climax state as a stage of minimum change, rather than final state of succession. Climax should not be considered equivalent to an organism, from which it differs in several respects. Thus, community would not be considered as a unit.

In a number of cases, it has been observed that climax communities are different even in the same climate. Successional stages of different communities have every chances of difference depending upon their primary stages and habitat characteristics. The most controversial point about the climax concept has been its intimate relationship with the climate. Within an area of uniform climate, it is common to observe different types of climax communitites according to the soil, topography and other factors. In such conditions, it is hard to consider the climate as the only determining factor in climax.

II. **Polyclimax theory :** Tansley (1935) believed that climax is not controlled alone by climate as a single factor as stated by Clements, but is a result of many factors. Thus Tansley's concept on climax popularly came to be known as **polyclimax theory**. Although Clements agreed with the possible control of several factors on climax rather than climate only, but he believed that these communities, sooner or later, would develop into a climatic-climax type. Clements introduced a number of new terms in ecological literature with the purpose to accommodate those stages.

He identified the stage in succession just preceding the climax community as **subclimax**. Likewise, the community that became stabilized at any of the seral stages of succession due to effects of soil or microclimate was identified as **sereclimax**. The community which became more or less stabilized due to recurrent disturbance by biotic factor, mainly due to anthropogenic causes preventing the establishment of climatic climax community in the area was termed as **disclimax**. This is frequently observed that there may develop different climax communities at shorter distances, even in the same place

under similar climatic conditions due to differences in water and soil characteristics. With this context, Clements introduced to other types of climax community—(i) **preclimax**, the community with life forms lower than those in the expected climatic climax and (ii), **Postclimax**, a strip of community with life forms higher than those in the expected climatic climax.

A number of terms regarding climax community came into existence in ecological literature are : **anti-climax, coclimax, superclimax, conclimax, metaclimax, paraclimax, pseudoclimax, quasiclimax** etc.

Thus the term 'polyclimax theory' is the most suitable term to avoid the confusion arising from the jargons of the terms mentioned above. This is true that even under primal conditions sometimes it becomes difficult to identify large areas of uniform vegetation. That is why the polyclimax theory is more suitable which explains that the climax stage may be controlled not by the climate alone, but by any factor of the environment. With the views of Tansley, the climax stage may be named on the basis of the nature of the factor in stabilization. Thus there may develop :

1. **Edaphic climax :** Develops with controlling effects of soil, mainly on undeveloped soil.
2. **Biotic climax :** Develops with the controlling effects of biotic disturbances. It has further been categorized by some ecologists into : **anthropogenic climax** (with effects of man), **grazing climax** (with effects of grazing) and **zootic climax** (with effects of animals).
3. **Topographic climax :** Develops due to topographic factors.
4. **Fire climax :** Develops due to recurrent effects of fire.

III. **Climax-pattern hypothesis :** R.H.Whittaker (1953) proposed this concept on climax after rejecting the approach of climax classification. With the basis of community gradient analysis, Whittaker postulated that the communities developing at a particular place are in balance with all the factors of environment. Thus the vegetation in that area may not be divided into smaller basic units. In reality, different climax-types are orderly organized parallel to the environmental gradient. There exists, according to this hypothesis, only one principal community that is changed with the change in habitat factors.

3.8 Plant Communities

An assemblage of plants in a definite habitat is called a *plant community.* In an ecosystem, no plant or animal can live as isolated individual, but they live in groups or colonies. Different plants and animals colonizing in a habitat constitute a *biotic community.* Plant community points towards the solitary assemblage of plants of that habitat. Plants and animals in any

biological organization are strongly interrelated and interdependent. Plants and animals of a particular place share the same set of ecological conditions. Modern biologists, with these strong bases, prefer to use the term *biotic community* to mean the assemblage of both the plants and animals, and *plant community* for plants and *animal community* to mean animals.

Plant community or a plant association is the basic unit of vegetation. Each community consists of a set of many different *species* persisting for a considerable length of time. Each plant species in a community is represented by a large number of individuals and a group of individuals of the same species commonly known as *population* which is a part of the community. Plant community, according to Oosting, is "an aggregation of living organisms having mutual relationships among themselves and to the environment." Modern ecologists prefer to define plant community as 'uniform floristic composition.'

Community Composition

(1) ***Species diversity :*** In an area, the biotic community is a natural assemblage of a large number of plant and animal species. Practically, it is the part of a larger whole ecosystem wherein living and non-living components interact and bring about circulation, transformation and accumulation of energy and matter (Sukla & Chandel, 1991). The plants growing together in a community show unique uniformity in their behaviour. Thus vegetation is reflection of a climate and the areas separated widely but having uniform climate have similar aspects of landscape. Such a clearly distinguished area with uniform habitat conditions and supporting characteristic type of vegetation is called 'biotope'. Every species has a definite range of tolerance to the physical and biological condition of the environment of that habitat. The range of environment a species can tolerate is called its *ecological amplitude.*

(2) ***Coexistence :*** In their defined habitat, species do not live in an absolute isolation as pure stands, but they coexist in mutual adjustment. The relationships between the coexisting species may be obligatory in one direction or in both. The trees in a forest community can live just as good as without shrubs and herbs which grow under them. The relationship in this case is obligatory in one direction only. On the other hand, the relationship between plants and animals which pollinate them is obligatory in both directions. The nature of interaction between the two coexisting species generally fall within any of the following :

(a) ***Exploitation***—One species lives at the expense of another.

(b) ***Mutualism***—Two or more coexisting populations benefit from the relationship but none suffers.

(c) ***Competition***—Two populations may compete for same resources of the habitat.

(d) ***Neutralism***—Two populations may be quite independent and neither population affects the other.

(3) ***Interdependency :*** The members of a community have the ability to live under the conditions of the habitat and they are also interdependent upon one another to a large extent which is called *dependency.* For example, many of the shade-preferring herbs like thallophytes, mosses, ferns etc. found on the forest floor are dependent on forest trees to avail shadow and moist conditions.

(4) ***Species Dominance :*** In any habitat, all of the species of a community are not found in abundance or in equal number. Only a few species are abundant, either in number or in biomass, while the majority of the species are rare. The more abundant common species containing more biomass are considered to be dominants. The associated individuals are influenced by the dominant individuals. For example, tallest trees in a forest affect the under-storey plants and ground vegetation through controlling intensity of light and moisture content of air and by changing soil structure and its chemical composition. The dominance in the community may be the result of co-action between two or more species. Different communities are generally recognized and named on the basis of dominant species occurring in them.

(5) ***Stratification :*** Trees, shrubs, mosses, lichens and thallophytes of a plant community have some sort of relationships among themselves. In a forest habitat, these plants form approximately distinct strata or layers or storeys on vertical as well as horizontal plane. This is normally known as *stratification* and the individuals of different layers represent different *'life fomrs'*. Sometimes, each layer or community may include individuals of different morphological classes. For example, the top layer or canopy of forest is formed of tallest trees and lianas and so on. The stratification reaches its greatest complexity in vegetation of tropical rainforest biome wherein at least five vertical subdivisions or units of homogenous life forms and ecological relations may be identified : (i) *subterranean zone,* (ii) *forest floor,* (iii) *ground vegetation* nearly extending up to a meter or so, (iv) *understorey tree* and *shrub* layer extending to the height of one to 5 meters and (v) *tree layer* or *top storey* extending to the extent of 5 to 15 m in most of the forests, but sometimes it may extend up to 25 to 30 m in the coniferous forests and to about 40 to 50 m in rain forests and, even in *Sequoia* forest, the upper canopy may surpass 100m.

(6) ***Succession :*** It is an orderly process of community development that involves changes in species structure and community processes with time. *Succession* is the natural process by which the same locality becomes successively colonized by different groups or communities of plants (Clements, 1916). Succession is reasonably directional and thus predictable. Interacting populations of community are characterized by continuous death and replacement and usually by immigration and emigration of their individuals. Composition and shape of the community remains in varying state through this process. The changes in the community go on taking place until a complete balance is established between community and environment. This is called *succession.* A stable community at complete equilibrium state is established which is called climax community. Very little or no change in the shape of the climax community can be anticipated over a long period of time.

Plant Community Classification

In accordance with explicit viewpoints and meticulous needs plant communities are classified in a number of ways. The principal bases of classification are :

(1) Physiognomy, (2) Habitat, (3) Species composition and dominance.

Physiognomy refers to the general apprearance of plant community. On this basis, major plant communities of extensive area are classified into component communities and are named after the dominant life forms, such as forest, grassland, desert community etc. On the basis of habitat, particularly on the basis of water availability of habitats, major communities are sometimes divided into smaller segments. Five different types of compnent communities identified on such bases are: (i) Wetland community, (ii) Wet-mesic community, (iii) Mesophytic community, (iv) Dry-mesic community, and (v) Dry land community.

Clements recognized dynamic nature of community and also developed floristic classification with emphasis on succession, dominance, constancy and diagnostic species. As suggested by him, vegetation can be analyzed into the following classificatory units in a descending order.

1. **Formation.** The major unit of vegetation, as described by Clements, is formation. In a region, plant formation is a great vegetational unit determined by several dominant growth forms, i.e., the forests which are characterized by trees. 'Plant formation is a product of microclimate and is controlled and delimited by climate alone' (Shukla & Chandel, 1991). Weaver & Clements (1938) stated that plant formation occurs in a natural area of essential climatic unity. But Whittaker described that plant formation are not distinct or concrete vegetational unit determined solely by climate, but they are abstract groupings of communities of similar physiognomy and environmental relations. According to Clements (1938), formation is a complex organism and as such it arises, grows, matures and reproduces. Mature vegetational unit, which has no sign of change in its climatic region, is termed as *climax community* and changing vegetational units are termed as *seral communities.*

According to Dansereau (1958), followings are the fundamental types of formation :

(a) **Forests.** Forests are characterized by trees. The forests may be evergreen and deciduous, high or low, scrambled with epiphytes or sparse. They may harbor a dense carpet of mosses or little undergrowth. Dansereau recognized 6 types of forests—(i) tropical rain forest, (ii) temperate rain forest, (iii) tropical deciduous forest, (iv) summer-green deciduous forest, (v) needleleaf evergreen forest and (iv) evergreen hard-woods.

(b) **Woodland.** Woodland is open stand of trees, tall enough like trees growing in forest, but scattered rather than clumped.

(c) **Savanna.** Savanna contains low branched, often flat topped small trees and many other woody plants often scattered or assembled in small grooves. The intervening spaces are often occupied by seasonal grasses.

(d) **Scrub.** Essentially scrub is a continuous stand of medium sized, dense growing bushy plants separated by stripped grounds or herbaceous patches.

(e) **Prairie.** Prairie is a continuous stand of tall dense grasses with a height of more than 50 cms, usually seasonal in distribution. Besides grasses, some shrubs may be present.

(f) **Meadow.** It is uninterrupted stand of herbaceous plants, preponderance of which is graminoids. They are devoid of woody plants.

(g) **Steppe.** Steppe is a very open stand containing bunch grasses interspersed with low shrubs. Steppe and meadow or steppe and scrubs or even prairie differ each other in respect to the plant coverage.

(h) **Desert.** Desert is characterized by exceedingly low permanent coverage. The perpetual vegetation is most sparse and the transient may wrap the area in rainy season.

(i) **Tundra.** Tundra consists of very low woody vegetation, irregular shrubs and cushion plants intermingled with mosses.

(j) **Crusts.** Crusts are formed by algae, fungi, lichens on the rocky surface or soils.

2. **Association.** Each climax formation is consisted of two or more subdivisions recognized as associations. Each association is distinct by more than one dominant species atypical to it. Association is regional vegetation in the formation. It is climax of subclimate within the general climate of the formation. Every association is similar throughout its extent in physiognomy, in its ecological structure and in general floristic composition (Weaver & Clements, 1938). One example of association is Oak-Beech association. The developing counter part of association is called associes. Currently the concept of community continuum is gaining much importance than the concept of association.

3. **Faciations.** Every association is composed of two or more subunits termed as *faciations.* Again, each faciation may be dominated by two or more dominants. But total number of dominants in faciation is invariably lesser than that of *association.* Develping or seral counterpart of faciation is termed as *facies* and the local variation of the association is called *locies.*

4. **Consociation.** It signifies the singularity of the dominant species within the association. *Consociations* are smaller unit communities whose single dominants still have the life-forms characterizing the formation. Such *eca* (= vegetational units) are greatly modified by edaphic conditions. The emergent counterpart of consociation dominated by single species is called *consocies.*

5. **Societies.** Association and consociation may further be analyzed into several minor communities directly influenced by local variation of habitat. These minor communities are dominated by one or more species other than the dominants of associations and

consociations. These smaller units are termed as societies. The dominants of societies are sub-dominants of higher *econ.* Thus, society shows the dominance within dominance whose dominants are subordinate when the consociation is considered as a whole (Shukla & Chandel, 1991). Emerging societies are called *socies.* If the *socies* have got two or more invading species without apparent association, they are called *colonies.*

6. **Clans.** Generally, two or more smallest climax units are found in each society. These smallest climax units are called clans. Each clan is a small aggregation of single, very locally and overwhelmingly dominant species. The seral correspondent is the family derived from reproduction and sociable growth of single immigrant.

3.9 Environmental Impact of Deforestation

Forests cover one-third of the total land area of the world and play a significant role in ecological balance and economic development. Forests protect watersheds and natural environment. Human society receives innumerable important resources for its sustenance and development. Forests comprise the most biologically diverse, readily convertible and potentially self-regenerating natural store of biological resources (Repetto, 1991). Rich with diverse biological resources, they provide subsistence, shelter, and employment. In addition, they supply huge number of resources for the development of other sectors. Deforestation or decrease in forest area is very much resultant with the increase in desertification and increase in the scarcity in the supply of vital resources.

Impacts of deforestation are manifold. Some are direct and often known to common people while some are indirect but often extreme. In most cases, deforestation itself has been considered as a matter of 'ecological and economic concern' (ICHI), 1989). Environmentally deleterious local impacts of deforestation are erosion of soil, reduction of rainfall, increase in temperature, reduction of water holding capacity of soils, increase of frequency and severity of floods, siltation of dams, depletion of soil fertility, depletion of biodiversity etc, (Ramakrishna and Woodwell, ed., 1993) are of local and regional magnitudes. The global effects of deforestation include "irreplaceable loss of species; the conversion of potentially productive land to that with diminished capacity to support either crops, forests or people; changes in water cycle, heat balance and climate; and the emission of chemically active heat-trapping gases such as carbon dioxide, methane, nitrous oxide and carbon monoxide into the atmosphere" (Ramakrishna and Woodwell, ed., 1993). Social impacts of deforestation, which are no less important than the physical impacts, faced by the poor people directly dependent on forests are unhealthy transformation of culture and working habits, change of habitat conditions, proneness to diseases against which they have no immunity and so on (ICIHI, 1989). Many of these impacts directly affect economic output as well as human welfare in the broader sense (Eckholm, 1991).

Deforestation, though is a world phenomenon, but its extent and magnitude obviously are different in the developed and developing countries. The developed countries have stabilized

their forested area and in the last century they have increased their forestlands in some cases. The basic reason behind this lead to skewed land distribution, expanding population pressure, a relatively low level of agricultural productivity in most developing countries and, obviously, rural poverty. "The people most vulnerable to these trends are the poor of the world; their search for the basic requirements of food and fuel often forces them to hasten the destruction of their own environment" (Repetto, 1991). At present some 200 million people are living in and peripheral zones of tropical forests. Land reform is suggested as major remedial measure for protection of forest. It can release the pressure from forestlands, simultaneously on massive agriculture, rural development, and forestry projects sited in or neighboring to significant areas of tropical rain forest. Because, feasible substitute to an ecologically caustic way of life is considered very much necessary by the forest-dwellers. Some other important instruments of deforestation in tropical forests are intensive and regular grazing, collection of fuelwood at a rate that far outstrips the sustainable production from natural forests and widespread commercial logging. Similarly, the past preoccupation of forestry development planners with industrial forest management objectives is a major contributing factor of tropical deforestation. Factors of same magnitude may also be mentioned here are failure by the forestry organization to be apprehensive with rural people, and a lack of incorporation with planning in agriculture, energy, health and other sectors.

However, the principal causes of deforestation at global, regional and local levels may be sorted out as below :

(1) ***Conversion of forest lands into agricultural lands :*** Particularly in the developing countries, fast rate of population growth has resulted tremendous pressure on forest lands as it was proved necessary to clear and convert the virgin forests into agricultural lands so that extended agricultural production can support the empty stomachs of a large number of population. This unwise tendency ultimately became consequent upon large-scale destruction of most valuable tropical forests and savanna vegetations in subtropical regions. Extensive and highly productive *prairies* of North America, vast grasslands of Russian *steppes,* South American *pampas,* South African *Velds* and *Downs* of Australia have been extensively converted into agricultural lands. Now these areas have become symbolic as major granaries of the world. Extensive forest covers of the Mediterranean region have been converted into horticultural lands that support high demands of flowers in European markets. Clearance of dense and extensive forests in most countries and even in islands had the same fate; they were either thinned out or made vanished for extension of agricultural lands.

(2) ***Transformation of forests in to pastures :*** This has been most responsible for fast rate of loss of vast virgin forests in the Mediterranean and temperate forest areas particularly in North America. Besides, the forests of Africa and South America have followed the same course. Rapidly expanding dairy farming and cattle ranching for meat industries are the principal factors behind large-scale conversion of woodlands into pastures. Extensive areas of original forest covers have been transformed into

pastures for commercial cattle ranching in New England, Michigan and mountainous areas of the Western USA, extensive parts of Canada, African Savannas, Australia and Canada.

(3) ***Overgrazing :*** Moderately dense forest covers of large tracts of the tropical and sub-tropical as well as arid and semi-arid regions have been turned into degraded, if not completely destroyed, or wastelands as consequence of intense overgrazing by cattle. In the developing countries of the world, large numbers of cattle with low productive capacity of both milk and meat, have consumed completely the grass-cover even the bushes and herbaceous plants. Large herds of grazing animals do not allow fresh regeneration of grasses and plants. Thus the deforested areas are affected seriously. Partly by conversion of grasslands into agricultural lands for food grain production and partly by overgrazing, the savanna grasslands have been destroyed almost completely.

(4) ***Jhuming or Shifting Cultivation :*** Particularly in the mountainous and hilly tracts of South and Southeast Asia, shifting or *jhum* cultivation has caused widespread deforestation. In some definite parts of India, the rate of original forest cover loss is increasing every year as a consequence of this primitve destructive agricultural system.

(5) ***Lumbering :*** The most serious and major cause of wanton large-scale destruction of forest cover of most parts of the world is commercial lumbering. Modern economic activities like industrial expansion, rapid urban growth and continuous increase of human population have created ever increasing demand of timber for various purposes which has culminated into serious damage to rich natural forest covers throughout the world. Wanton and reckless felling of trees from the dawn of the twntieth century without caring for ecological and environmental consequences and without any wise and scientific plan for replenishment and regeneration of forests has depleted vast forests to such an extent that a series of serious consequences of deforestation are looming large over the human society all over the globe. Collection of fire woods and fodder by the rural poor, mainly in the developing countries, from the depleted forest covers has further degenerated the forest covers already impoverished (Singh, 1991).

In a number of developing countries like India and even in some developed capitalist countries, the powerful timber merchants and private contractors with illegal supports of the government officials have done great damange to the extensive forest covers through reckless felling of trees for their quick economic gain at the cost of the environmental degradation. Though the provision of the Forest Policy has been enforced since 1894, the National Forest Policy has been implemented since 1952 and the Union Government of India has issued the guidelines forbidding forestlands to no other category, there has been a remarkable loss of 91,70,000 hectares of good forest lands in India betwen 1972 and 1980.

Impacts of Deforestation

Impacts of deforestation are manifold. Forest is most important natural as well as biological resource; at the same time is a prime resource container. All civilizations of the world used this

resource for their development. Anchoring on the crucial part of the biosphere, it is influenced by the climate, water and soil. Similarly, these three components of our environment are modified and affected by presence, quality and extension of forests.

(1) Vegetation maintains the Oxygen-Carbon dioxide balance of the atmosphere. Thus rapid and widespread deforestation has direct impact on the lesser absorption of greenhouse gas like CO_2. In the same way, absorption of solar heat during evapotranspiration by vegetation is checked due to deforestation. Similarly, maintenance of local climatic conditions is also greatly affected.

(2) Forests have direct effects upon the reduction of the rate of surface water run-off and prevention of flash flood and soil erosion. Forests help prolonging and slowing run-off which creates safeguards against drought condition.

(3) Forests help in holding of soil through preventing rain from washing soils away. Thus, forests maintain the structure and nutrients of soil. The agricultural fields contiguous to the forests were the recipients of organic matters washed out from forest floors. They need no chemical fertilizer to replenish the soil fertility. These chances have been lost due to deforestation.

(4) Forests were the principal source supply of a variety of resources used by local people inhabited in and around the forests. The, collected and used those resources for their sustenance. People gathered fruits, roots, shoots, twigs, leaves, flowers etc. from forests. Rational hunting from forests was also a source of food for the local people. Other important resources commonly included : fodder for cattle, fuel wood and charcoal for cooking and heating, timber for household articles and construction, poles for building homes in nearby rural areas, fiber for making ropes, strings, nets and baskets, cocoons for silks, lacs for sealing materials, collection of pure honey, medicinal plants for traditional medicines. These materials are now either lessened in quantity or totally unavailable due to deforestation.

(5) A number of forest products used for consumptive purposes were also sold as a source of income to support the livelihoods of forest-dwelling people has now been almost stopped due their scarcity caused by deforestation. Deforestation has also resulted in shorter supply of minor forest produces. Widespread and wanton destruction of forests in many parts of the world and in India has caused extinction of a number of precious species of medicinal herbs and animals.

(6) Devegetization and destruction of biotic potentials like forest-lands lead to environmental degradation through desertification and dereliction of land. These problems are invited as consequences of over-grazing, over-exploitation of forests and random felling of trees. The devastating effect of deforestation in India includes soil, water and wind erosion, and an estimated cost of which being more than 16,400 crores of rupees every year (Sharma, 1993). Deforestation imposes crucial impact on the productivity of croplands in two ways—(i) erosion of soil increases multiple and in fact the soils get loose and wahsed out leading to an accentuated cycle of drought

and floods, (ii) but similarly important is the impact of the shortage of firewood and fodder. People start using cow dung and crop wastes as fuel for cooking when fire wood becomes insufficient. Thus every part of the plant gets used up slowly but surely and nothing goes back to soil consequent upon shortage of soil organic matter. This nutrient drain affects soil fertility and crop productivity over a period of time.

(7) Forests were also destroyed due to the growing demand of cities. In addition to this, local grazing animals like cattle, ships and goats not only destroy the vegetation but also pull out the roots of plants. The process of deforestation started in the Shivalik ranges after almost completion of the Himalayan slopes. The sal forests *(Shorea robusta)* of Shivalik were over-exploited for industrial use. Consequently, the foothills of Shivaliks once covered with dense forests are now facing an acute water scarcity and semi-desert conditions. Destruction of forests invites ecological imbalance.

(8) Vanishing of forests at a very fast rate from India has now created an alarming situation. Extensive and unabated deforestation and devegetization, overgrazing and mounting need for land has knocked the ecology of the third world appallingly. For example, India may immediately have more of waste than productive land. Extensive deforestation particularly during post-independence period has defectively affected weather condition facing almost each year more break than the normal weather. At the same time overgrazing has reduced the regenerative capability of the forests to an insignificant point. In India, deforestation and over-grazing have been causing terrific impact on land erosion and landslides. India, on an average, is losing about 6000 million tones of top soil per annum due to water erosion in the lack of trees. As a result, nearly 1 percent of the land surface of India is turning unproductive every year due to deforestation. In Himalayan ranges, the rainfall has declined 3 to 4 percent due to deforestation (Sharma, 1993).

FOREST CONSERVATION

Introduction

The forests, grasslands, grazing lands, croplands, wildlife of any region of the globe are interrelated and integrated. Alteration in any one of them affects surely the other and it goes on a complete chain of events affecting all the components of land system. Once the Forest Departments destroyed forests in our country to earn revenue from industrialists. This large-scale felling of trees was directly consequent upon soil erosion affecting productivity of crops. As a reaction, croplands had to be extended to marginal lands further reducing the grazing lands. Thus animals had to enter into the denuded forest floors and chances of natural regeneration came to an end. In a nutshell, for a long time, the situation was that the foresters had no interest in fuel wood or cropland, agricultural experts had no interest in animals or in grazing lands, and animal husbandry personnel had no interests in maintaining fodder banks. This situation compelled people and administration to think about conservation and management of forests. In case of

India, forest conservation activities actually followed a series of environmental movements which in one way resulted in forest conservation systems and rules.

Chipko Movement

The persistence by the administration of independent India of forest management practices antagonistic to local requirements generated dissatisfaction among the people of Garhwal Himalayas. Particularly, the precincts on the habitual use of the forest were professed by the people of the Uttarakhand as forfeiture of their inherited natural rights. The practice of selling large timber coupes to contractors, while keeping away the common people to meet their daily households needed from these forests had discontented the local villagers. Great bitterness continued to be expressed against the timber trade throughout the late 1960s. The government was identified as "trader" in 1921 owing to its selling the forest produce, the same allegory was reinvoked in the 1970s seeking deliberately to ascertain stability with the protest movements launched during pre independence period (WWFNI,ER, 1995).

The conflict in opposition to forest management was united with resistance led by Sarvodaya workers to other facets of commercialization and enduring social progress of this hill region. As a result, a large number of local inhabitants including women opposed the extensive distillation and sale of liquor. In the meantime, the demand for a separate hill state gathered impetus. The Uttarakhand Rajya Sammelan had prearranged a meeting where the organizers emphasized on the prowling of natural resource from the hills and on growing joblessness. A devastating flood occurred in the region owing to unusually heavy precipitation in 1970 and the flood ruined many houses, roads and bridges and caused extensive damage to human life, cattle and crops. Quickly the villagers perceived that there should be link between deforestation, landslides and flood. Dashauli Gram Swarajya Sangh (DGSS) led by Sarvodaya workers like Sarala Devi and the leading local activist Chandi Prasad Bhatt had organized a number of public meetings demanding replacement of contractor system with forest labour cooperatives and establishment of small scale industries (WWFNI,ER, 1995).

The DGSS had asked for an allocation of ash trees for making agricultural tools to be used by the poor villages. But the forest department refused to put up the request, whereas, a large number of ash trees were instead allotted to a timber trader. C. P. Bhatt, in protest against this injustice, suggested that the DGSS workers should embrace the trees, and, "Chipko" (to hug) was born in this way. Women and young people determined to hug trees even if the contractors' axe would slay them, and, the vow was tiled with signatures of blood. It brought first success to the agitators and the agents of the contractors were fruitless to cut down any tree in the face of "Chipko" action in June 1973.

Regardless of these protests the administration went in advance with the annual auctions of forest in November. One of the coupes planned to be assigned to the contractors was the Reni Forest in the Alakananda Valley, settled by the Bhotia community. Receiving the news of the auction, DGSS workers organized meetings where the 1970 flood was remembered, and the potential consequences of clear-felling the forest explained. When the felling were planned by the forest department for the last week of March, college students in a protest at Joshimath

on the 25th threatened to go on board on a Chipko movement unless the fallings were called off. In reaction, the forest department resoluted to artifice. On 26th March when C. P. Bhatt and men folk of Reni and neighbouring villages were absent, the contractor's men entered into the forest. In receipt of the report of the contractor's men impending towards the forest, the village Mahila Mandal leader Goura Devi swiftly mobilized other housewives and went to the forest. Notwithstanding abuses and coercion by the contractor's men, the women stopped the felling. It was the first instance in which women impulsively participated in a major way in the absence of their own men folk and DGSS activists (WWFNI,ER, 1995). The movement spread to all villages of Tehri Garhwal and Kumayun Himalayas very quickly. The door-to-door campaigns by Sarvodaya workers, Sunderlal Bahuguna's hunger strike and the mobilization of women by his wife Vimla and other ladies gave further impulsion to the movement, which sometimes also mobilized children. It evolved into an ecological movement that was intended for the preservation of the ecological stability of the major upland watersheds in North India. Eco-camps are there organized every year to educate the local people about the value of forests and afforestations are done by voluntary labour from the villagers. The movement has closed soft stone quarries and chemical industries in the fragile Alakananda catchment's ecosystem (WWNI,ER, 1995).

Appiko

Another impetus for conservation of forests in India came from the Appiko movement took place in Karnataka. The area of forest cover in Uttara Kanada district of the Karnataka State was 82% at the time of independence. Almost all of these natural tropical forests of the State were ruined just after the implementation of the policy of monoculture of alien profit-making species (teak and eucalyptus) by the forest department for feeding the plywood, paper and polyfibre industries. As a result, the forest cover was reduced to 20% only in 1983-84. Once, when the forest cover was in its maximum, the district was renowned for spices cultivation. But due to the absence of forest cover, erosion, became speedy and laterisation took place which show the way to despoilment of the microclimate for spices cultivation. The mounting denudation of the forests of the area aroused the local people dependent on the forests for survival. In 1983, the youth of Belegadde village appealed to the forest officials to call off the orders of clear-felling a tract of natural forest at Salkani. The villagers determined to resort to Chipko movement after their appeal was refused. They invited Sunderlal Bahuguna and also took the vow to guard the trees by embracing them. The forests in the Kalase village were saved by the villagers from axes of contractors in this non-violent way in 1983. The movement came to be known as *Appiko* in Kannada, launched with the three objectives of *ulisu* (to protect), *belesu* (to nurture) and *balasu* (to use wisely).

Appiko created awareness among villagers throughout the Western Ghats about the value of forest wealth. The villagers of Gerasoppo range of Honavar forest division monitored the forestry activities in 1984 and recorded the discrepancies between the forestry rules prescribed and the actual practice of felling by contractors. The discrepancy thus studied was later confirmed by scientists. The movement was popularized by the Appiko activists through mass demonstrations, traditional folk dances and street drama. They also undertook a walk from Coorg to Goa to herald the message of the movement. Thus it quickly spread to numerous forest areas of

Coorg, Dakshina Kannada and Shimoga districts. The movement ultimately become successful in stopping all departmental felling. The movement has succeeded to conserve the remaining mature tropical forests and regenerate the degraded vegetations. This model has been taken up by activists in Kerala to regenerate the barren lands. Appiko has helped forming environmental groups in Goa and assisted Save the Eastern Ghats Organization. In short, Chipko and Appiko are the principal experiences which shown the way of forest conservation in India.

Forest Conservation through National Forest Policies

The National Forest Policy, 1952 enunciated that one-third of the geographic area of India should be under forests. But deforestation in our country continued for various reasons. It had been estimated that 4.238 M.ha. of forest land was officially diverted to non-forest uses between 1951-52 and 1979-80. The Govt. of India framed the Forest (Conservation) Act, 1980 aiming to conserve forests of India.

Forest (Conservation) Act, 1980 was enacted with a view to check wholesale dereservation and diversion of forest land to non-forest purposes. The Act clearly stated that prior approval of the Central Government is a must before dereservation of any reserved forest or diversion of forest land to non-forest purposes. If diversion is permitted, compensatory afforestations is insisted upon and other appropriate conditions imposed. Compensatory afforestations be raised over equal area of non-forest land where it is available. But, where non-forest lands are not available, compensatory plantations be raised over degraded forests twice in extent to the area being diverted.

In 1988, the Forest (Conservation) Act was amended to incorporate stricter panel provisions against violators. Most important amendments were :

(i) No State Govt. or other authority may direct that any forest land may be assigned by way of lease or otherwise to any person, corporation or agency/organisation without prior approval of the Central Government.

(ii) No forest land or any portion thereof may be cleared of trees which have grown naturally in that land or portion, for the purpose of using it for reforestation without prior approval of the Central Government.

(iii) Scope of existing "non-forest purposes" has been extended to other areas as cultivation of tea, coffee, spices, rubber, palms, medicinal plants etc.

(iv) Admissible punishment to the offender of the provision of Section 2 of the Act.

Six regional offices have been established at Bangalore, Bhopal, Bhubaneswar, Lucknow, Shillong and Chandigarh for monitoring of conditions and safeguards in forest conservation matters by Dept. of Environment, Forest and Wildlife.

It would be logical to understand the historical background of the Forest Conservation Act 1980, amended in 1988 before we appreciate it. The Indian Forest Act of 1927 consolidated all the previous laws regarding forests that were passed before the 1920s. The Act made the provision for the Government and Forest Department the power to create Reserved Forests, and the right to use the Reseved Forests for Government use only. The Act also formed

Protected Forests in which the use of resources by local people was controlled. Some forests were to be controlled by the village community, and these were called Village Forests. The Act remained in force till the 1980s when it was realized that protecting forests for only timber production was not acceptable. The other values of protecting the services that forests provide and its valuable assets such as biodiversity began to overshadow the importance of their revenue earnings from timber. Therefore, a new act was a necessity which led to the framing of Forest Conservation Act, 1980 and its essential amendment in 1988.

It has been stated earlier that the first Forest Policy was enunciated in 1952. But the extent of deforestation was so great in between 1952 and 1988, that it proved essential to formulate a new policy on forests and their utilization. The earlier forest policies had focused only on revenue generation. But it became clear during the 1980s that forests must be protected for their other functions like maintenance of soils and water regimes centered around ecological concerns. In addition, it also provided for the use of goods and services of the forest for its local inhabitants.

Conservation of the forests as a natural heritage found a place in the new policy which also made conversion of forests into other uses much less possible. The new policy also includes the preservation of its biological diversity and its genetic resources. It also valued meeting the needs of local people for food, fuel and fodder. It gave priority to maintain environmental stability and ecological balance.

The 73rd and 74th Amendments to the Constitution furthered governance through panchayats. Local panchayats have been permitted to invest with the authority to manage local forest resource. Some of the States in the early 1980s already started to de-reseve some Reserved Forests to non-forest purposes. These States had to regularize encroachments and resettled 'Project Affected People' from development projects such as dams constructed in those de-reserved areas. Thus a new legislation was felt necessary. The Act made it possible to retain a greater control over the frightening level of deforestation in the country and specified penalties for offenders.

In case of Reserved Forests the penalties were such that no person is permitted to clear forest or set fire to a Reserved Forest. Trespassing and grazing of cattle in Reserved Forests were prohibited. Felling of trees, collection of timber, bark, leaves, collection of any forest products and quarrying is punishable for a term of six months or a fine up to Rs. 500 or both.

In case of Protected Forests the nature of penalties were such that a person who commits any of the offences like felling of trees, stripping the barks or leaves of trees, setting fire in the forest, collecting timber, allowing cattle to damage any tree, shall be punishable with imprisonment for a term that may extend to six month or with a fine which may extend to Rs. 500, or both.

In our country, with the purposes policies stated above, three types of situations recognized

1. ***Conservation or Reserved Forests***—are the areas where our water regimes are located, such as, Himalayas, Eastern and Western Ghats together with their catchment areas; National Parks; Sanctuaries; Biosphere Reserves; Sacred Grooves and all other ecologically fragile areas. Fuel, fodder and no other commercial exploitation is

allowed in these areas. In order to fulfil the real goal of ecodevelopment, widespread public support has been generated. Public awareness has been proved helpful in supplying goods and services to meet the needs of the local people.

2. ***Limited Production Forests***—are actually the less fertile areas at more than 1000 m. high altitude with hill-slope topography. Very cautiously, a part of the annual growth is allowed to be harvested with precaution that no tree or the slope is damaged.

3. ***Production Forests***—are the forests on plains managed for high degree of production. Scientific management and proper harvesting may cause no damage to these relatively more stable forests.

Basic Objectives

The basic objectives that should govern the National Forest Policy are the following :

Maintenance of environmental stablity through preservation and, where necessary, restoration of the ecological balance that has been adversely disturbed by serious depletion of the forests of the country.

Conserving the natural heritage of the country by preserving the remaining natural forests with the vast variety of flora and fauna, which represent the remarkable biological diversity and genetic resources of the country.

Checking soil erosion and denudation in the catchment areas of rivers, lakes and reservoirs in the interest of soil and water conservation, for mitigating floods and droughts and for the retardation of siltation of reservoirs.

Checking the extension of sand dunes in the desert areas of Rajasthan and along the coastal tracts.

Increasing substantially the forest/tree cover in the country through massive afforestation and social forestry programmes, especially on all denuded, degraded and unproductive lands.

Meeting the requirements of fuelwood, fodder, minor forest produce and small timber of the rural and tribal populations.

Increasing the productivity of forests to meet essential national needs.

Encouraging efficient utilisation of forest produce and maximising substitution of wood.

Creating a massive people's movement with the involvement of women, for achieving these objectives and to minimise pressure on existing forests.

The principal aim of Forest Policy must be to ensure environmental stability and maintenance of ecological balance including atmospheric equilibrium which are vital for sustenance of all lifeforms, human, animal and plant. The derivation of direct economic benefit must be subordinated to this principal aim.

Essentials of Forest Management

Existing forests and forest lands should be fully protected and their productivity improved. Forest and vegetal cover should be increased rapidly on hill slopes, in catchment areas of rivers, lakes and reservoirs and ocean shores and on semi-arid, and desert tracts.

Diversion of good and productive agricultural lands to forestry should be discouraged in view of the need for increased food production.

For the conservation of total biological diversity, the network of national parks, sanctuaries, biosphere reserves and other protected areas should be strengthened and extended adequately.

Provision of sufficient fodder, fuel and pasture, especially in areas adjoining forest, is necessary in order to prevent depletion of forests beyond the sustainable limit. Since fuelwood continues continues to be the predominant source of energy in rutal areas the programme of afforestation should be intensified with special emphasis on augmenting fuelwood production to meet the requirement of the rural people.

Minor forest products provide sustenance to tribal populations and to other communities residing in and around forests. Such produce should be protected, improved and their production enhanced with due regard to generation of employment and income.

Strategy

Area under forest

The national goal should be to have a minimum of one-third of the total land area of the country under forest or tree cover. In the hills and in mountainous regions, the aim should be to maintain two-thirds of the area under such cover in order to prevent erosion and land degradation and to ensure the stability of the fragile eco-system.

Afforestation, Social Forestry & Farm Forestry

A massive need-based and timebound programme of afforestation and tree planting, with particular emphasis on fuelwood and fodder development, on all degraded and denuded lands in the country, whether forest or non-forest land, is a national imperative.

It is necessary to encourage the planting of trees alongside roads, railway lines, rivers and streams and canals, and on other unutilised lands under state/corporate, institutional or private ownership. Green belts should be raised in urban/industrial areas as well as in aird tracts. Such a programme will help to check erosion and desertification as well as improve the microclimate.

Village and community lands, including those on foreshores and the environs of reservoirs, not required for other productive uses, should be taken up for the development of tree crops and fodder resources. Technical assistance and other input necessary for initiating such programmes should be provided by the Government. The revenue generated through such programmes belongs to the panchayats where the land is vested in them; in all other cases, such revenue should be

shared with the local communities in order to provide an incentive for them. The vesting in individuals of certain ownership rights over trees, particularly in the weaker sections of society (such as landless labour, small and marginal farmers, scheduled castes, tribal groups and women), could be considered, subject to appropriate regulations ; beneficiaries would be entitled to usufruct and would in turn be responsible for their security and maintenance.

Land laws should be so modified wherever necessary so as to facilitate and motivate individuals and institutions to undertake tree-planting and grow fodder plants, grasses and legumes on their own land. Wherever possible, degraded lands should be made available for this purpose either on lease or on the basis of a tree-patta scheme. Such leasing of the land should be subject to the land grant rules and land ceiling laws. Steps necessary to encourage them to do so must be taken. Appropriate regulations should govern the felling of trees on private holdings.

Management of State Forests

Schemes and projects which interfere with forests that clothe steep slopes, catchments of rivers, lakes and reservoirs, geologically unstable terrain and such other ecologically sensitive areas should be serverely restricted. Tropical rain/moist forests, particularly in areas like Arunachal Pradesh, Kerala, Andaman & Nicobar Islands, should be totally safeguarded.

No forest shall be worked without the Government having approved the management plan, which should be in a prescribed format and in keeping with the National Forest Policy. The Central Government should issue necessary guidelines to the State Government in this regard and monitor compliance.

In order to meet the growing needs for essential goods and services which the forests provide, it is necessary to enhance forest cover and productivity of the forests through the application of scientific and technical inputs. Production forestry programmes, while aiming at enhancing the forest cover in the country and meeting national needs, should also be oriented to narrowing, by the turn of the century, the increasing gap between demand and supply of fuelwood. No such programme, however, should entail clear-felling of adequately stocked natural forests. Nor should exotic species be introduced, through public or private sources, unless long-term scientific trials undertaken by specialists in ecology, forestry and agriculture have established that they are suitable and have no adverse impact on the native vegetation and environment.

Rights and Concessions

The rights and concessions, including those regarding grazing, should always remain related to the carrying capacity of forests. The capacity itself should be optimised by increased investment, silvicultural research and development of the area. Stall-feeding of cattle should be encoraged. The requirements of the community which cannot be met by the rights and concessions so determined, should be met by development of social forestry outside of reserved forests.

The holders of customary rights and concessions in forest areas should be motivated to identify themselves with the protection and development of forests from which they derive benefits.

The rights and concessions from forests should primarily be for the bonafide use of the communities living within and around forest areas, especially tribal groups.

The livelihoods of tribal and other subsistence groups living within and near forests are dependent upon forest products. The rights and concessions enjoyed by them should be fully protected. Their domestic requirements of fuelwood, fodder, minor forest produce and construction timber should be the first charge on forest produce. These and substitute materials should be made available through conveniently located depots at reasonable prices.

Similar consideration should be given to scheduled castes and the rural poor living near forests. However, the area which such consideration should cover shall be determined by the carrying capacity of the forests.

Wood is in short supply. The long-term solution for meeting the existing gap lies in increasing the productivity of forests, whilst relieving some of the existing pressures on forests in the form of demand for railway sleepers, furniture and panelling, pit props for mines, paper and paperboard and in the construction industry (particularly in the public sector), through sourcing alternative materials and utilizing wood substitutes. Similarly, in the case of domestic energy, fuelwood needs should be substituted as far as practicable by alternate sources such as bio-gas, LPG and solar energy. Fuel-efficient 'Chulhas' as a measure of conservation of fuelwood need to be popularised in rural areas.

Conversion of Forest Lands to Non-Forest Uses

Forest land or land with tree cover should not be treated merely as a resource readily available to be utilised for various projects and programmes, but as a national asset which demands to be properly safeguarded for providing sustained benefit to the entire community. Conversion of forest land for any non-forest pupose should be subject to the most careful examination by specialists from the standpoint of social and environmental costs and benefits. Construction of dams and reservoirs, mining and industrial development and expansion of agriculture should be consistent with the needs for conservation of trees and forests. Projects which involve such conversion should provide in their investment budget funds for regeneration/compensatory afforestation.

Beneficiaries who are allowed to carry out mining and quarrying in forest land and in land covered by trees should be required to repair and re-vegetate the area in accordance with established forestry practices. No mining lease should be granted to any party, private or public, without a proper mine management plan appraised from an environmental angle and enforced by adequate machinery.

Wildlife Conservation

Forest Management should take special care of the needs of wildlife conservation, and forest management plans should include prescriptions for this purpose. It is particularly essential to provide for 'corridors' linking protected areas in order to maintain genetic continuity between artificially separated sub-sections of migrant wildlife.

Tribal People and Forests

With regard to the symbiotic relationship between tribal people and forests, a primary task of all agencies responsible for forest management including forest development corporations, should be to associate the tribal prople closely in the protection, regeneration and development corporations, should be to associate the tribal people closely in the protection, regeneration and development of forests as well as to provide gainful employment to people living in and around the forest. In addition, special attention shall be given to the following:

– One of the major causes for degradation of forests is llegal cutting and removal by contractors and their labour force. In order to put an end to this practice, contractors should be replaced by institutions such as tribal cooperatives, labour cooperatives and government corporations, as early as possible.

– The protection, regeneration and optimum collection of minor forest produce along with institutional arrangements for the marketing of such produce.

– The development of forest villages on a par with revenue villages*.

– The promotion of family-oriented schemes for improving the status of the tribal beneficiaries.

– The implementation of integrated area development programmes to meet the needs of the tribal economy in and around the forest areas, including the provision of alternative sources of domestic energy on a subsidised basis, to reduce pressure on existing forest areas.

Shifting Cultivation

Shifting cultivation is affecting the environment as well as the productivity of the land adversely. Alternative avenues of income, suitably harmonised with the right landuse practices, should be devised to discorage shifting cultivation. Efforts should be made to contain such cultivation within the area already affected, by propagating improved agricultural practices. Areas already damaged by such cultivation should be rehabilitated through social forestry and energy plantations.

Damage to Forests through Encroachment, Fire and Grazing

Encroachment on forest land has increased. This trend has to be arrested and effective action taken to prevent the continuation of existing encroachment.

The incidence of forest fire in the country is high. Standing trees and fodder are destroyed on a large scale and natural regeneration annihilated by such fire. Special precautions should be taken during the fire season. Improved and modern management practices should be adopted to deal with forest fires.

Grazing in forest areas should be regulated with the involvement of the community. Special conservation areas, young plantations and regeneration areas should be fully protected. Grazing

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* The revenue village is a unit of administration in India.

and browsing in forest areas need to be controlled. Adequate grazing fees should be levied to discourage people in forest areas from maintaining large herds of non-essential livestock.

Forest-based Industries

The main considerations governing the establishment of forest-based industries and supply of raw material to them should be as follows :

– As far as possible, a forest-based industry should raise the raw material needed for meeting its own requirements, preferably by establishment of a direct relationship between the factory and the individuals who can grow the raw material by supporting the individuals with inputs including credit, constant technical advice and harvesting and transport services.

– No forest-based enterprise, except that at the village or cottage level, should be endorsed in the future unless it has been first cleared after careful scrutiny with regard to assured availability of raw material. In any case, the fuel, fodder and timber requirements of the local population should not be sacrificed for this purpose.

– Forest based industries must not only provide employment to local people on a priority basis, but also involve them fully in raising trees and raw-material.

– Natural forests serve as a gene pool resource and help to maintain ecological balance. Such forests will not, therefore be made available to industries for undertaking plantation development or any other activities.

– Farmers, particularly small and marginal farmers shall be encouraged to grow, on the marginal/degraded land available to them, wood species required by industry. These may also be grown along with fuel and fodder species on community lands not required for pasture purposes, and by the Forest Department and corporations on degraded forests, not earmarked for natural regeneration.

– The practice of supply of forest produce to industry at concessional prices should cease. Industry should be encouraged to use alternative raw materials. Import of wood and wood products should be liberalised.

– The above considerations will however, be subject to the current policy relating to land ceiling and land-laws.

Forest Extension

Forest Conservation programmes cannot succeed without the willing support and cooperation of the people. It is essential, therefore, to inculcate in the people, a direct interest in forests, their development and conservation, and to make them conscious of the value of trees, whildlife and nature in general. This can be achieved through the involvement of educational institutions, right from the primary stage. Farmers and interested people should be provided opportunities through institutions like Krishi Vigyan Kendras Trainers' Training Centres to learn agrosilvicultural and silvicultural techniques to ensure optimum use of their land and water resources. Short-term extension

courses and lectures should be organised in order to educate farmers. For this purpose, it is essential that suitable programmes are propagated through the mass media, audio-visual aids and the extension machinery.

Forestry Education

Forestry should be recognised both as a scientific discipline as well as a profession. Agriculture universities and institutions dedicated to the development of forestry education should formulate curricula and courses for imparting academic education and promoting post-graduate research and professional excellence, keeping in view the manpower needs of the country. Academic and professional qualifications in forestry should be kept in view for recruitment to the Indian Forest Service and the State Forest Service. Specialised and orientation courses for developing better management skills by in service training need to be encouraged, taking into account the latest developments in forestry and related disciplines.

Forestry Research

With the increasing recognition of the importance of forests for environmental health, energy and employment, emphasis must be laid on scientific forestry research, necessitating adequate strengthening of the research base as well as new priorities for action. Some broad priority areas of research and development needing special attention are :

i. Increasing the productivity of wood and other forest produce per unit area time by the application of modern scientific and technological methods.
ii. Revegetation of barren/marginal/waste/mined lands and watershed areas.
iii. Effective conservation and management of existing forest resourced (mainly natural forest ecosystems).
iv. Research related to social forestry for rural/tribal development.
v. Development of substitutes to replace wood and wood products.
vi. Research related to wildlife and management of national parks and sanctuaries.

Personnel Management

Government policies in personnel management for professional foresters and forest scientists should aim at enhancing their professional competence and status, as well as attracting and retaining qualified and motivated personnel, given the arduous nature of the duties they have to perform, often in remote and in hospitable places.

Forest Surveys and Data

Inadequacy of data regarding the forest resources is a matter of concern because it creates a false sense of complacency. Priority needs to be given to completing the survey of forest resources in the country along scientific lines and to updating existing information. For this purpose, the periodical collection, collation and publication of reliable data on relavant aspects of forest management need to be improved with recourse to modern technology and equipment.

Legal Support and Infrastructure Development

Appropriate legislation should be enforced, supported by adequate infrastructure, at the Centre and State levels in order to implement the Policy effectively.

Financial Support for Forestry

The objectives of this revised Policy cannot be achieved without the investment of financial and other resources on a substantial scale. Such investment is indeed fully justified considering the contribution of forests in maintaining essential ecological processes and life-support systems and in preserving genetic diversity. Forests should not be looked upon as a source of revenue. Forests are a renewable natural resource. They are a national asset to be protected and enhanced for the well-being of the people and the Nation.

3.10 Joint Forest Management

Joint Forest Management is comparatively a recent concept. It involves partnerships between the Forest Department and forest-fringe user groups on the basis of mutual trust and responsibilities with regard protection and development of forests. The user and the owner manage the resource and share the cost equally under this Joint Forest Management programme. The effective and meaningful involvement of local communities in evolving sustainable forest management systems is now being considered as a significant approach to address the longstanding problems of deforestation and land degradation in India. The linking of socio-economic incentives and forest development has been singularly instrumental in eliciting community participation.The institutional involvement in various forest protection and developmental activities has made promising impacts on the biophysical and socio-economic environment of the Joint Forest Management area. It is estimated that 10.24 million ha of forest lands in 22 states are being managed currently under the Joint Forest Management programme through 36,075 committees. The Government of India issued guidelines on 21 February 2000 for strengthening of the Joint Forest Management programme.

According to Bhagat, Joint Forest Management is a concept based on the principle of rights of local communities in forest, whereas, Raju saw it as 'a mechanism to manage the forest that is owned by the State but appropriated by local communities.' As described by Saxena, Joint Forest Management System is 'a possible way through which the interests of people and of long term sustainability are harmonized in a mutually supporting manner'. Dutta identified the programme as 'an approach involving the evolution of a very complex property rights regime to generate a sustainable interface between the Forest Department and the local community'.

Joint Forest Management, on the one hand, is seen as a major shift that has transformed government policies and attitudes from centralized to decentralized management, from revenue orientation to resource orientation and from restricting people to working with people. It is seen as an effort by the Forest Department to garner increased financial outlays and expand its

territories and spheres of jurisdiction to more and more area under the jurisdiction of the revenue department and other government development agencies. According to Burman, Joint Forest Management does not have the scope for genuine participation of the people and is a means of ensuring protection of the forest at a very low cost.

Saxena summarized the progress made with the joint forest management in the country since its inception as, "adoption of Joint Forest Management has not made any major change in the prevailing position of relation between the state and the people nor has it heralded the beginning of a new era of people's power". He further added "State governments look upon Joint Forest Management as a cost effective method of forest protection and economically rewarding activity for the people. The aim is neither to empower people nor to make committee autonomus."

The Spirit of JFM

The efforts of the communities to protect forests are either self initiated or initiated by outside agencies. The overall objective of such efforts is similar, irrespective of who initiates it, but the factors that affect community participation may vary with places and situations. Thus it is very difficult to enlist and rank various factors influencing community participation. However, it seems that villagers who are dependent on forests for their livelihoods should first like to be assured of a sustainable source of income for their daily subsistence. People with less dependence on forests may desire for their indirect benefits like recognition by others or they may join their hands to protect forests as it appeals to their genuine concern for the environment.

The JFM Issues

The philosophy of JFM lies in involving people in activities of resource generation through motivation, and eliciting their participation in forest management and the sharing of benefits through adequate institutional arrangements.

In the past decades, several issues of importance like the diversity in institutional arrangements with sharing of benefits, development of technology and silviculture practices to enhance the productivity of degraded forests, etc. following launch of JFM programme in India.

All over India, a number of NGOs have gained insights into the institutional arrangements, productivity, silviculture, marketing, sharing of benefits etc. Also they have gained considerable knowledge on the strengths and weakness, unique features, ambiguities in the manner in which the programme has evolved in different states.

Forest Management under British Rule

Natural resources have always been an integral part of the Indian economy and culture and are held in high esteem. Ancient religious, political and literary writings are testament to the fact that people have historically been considered an integral part of nature and not superior to it. However, it is difficult to generalise about historical forest management practices in India given the diversity of culture, forest types and administrative systems found in different parts of the country; indeed natural resources were formerly managed by princely states under different land tenure systems.

However, a great deal of documentation regarding forest management regimes under the British administration is available; in this section, discussion is confined to the colonial approach to forest management and its policies concerning people dependent on forests.

It is well known that many of the forests in India have, at different points in the nation's history, been managed under a set of rules and regulations developed by different communities. Even today, some of theses do-called self-initiated forest protection groups have survived or have been re-invented in response to the need of the hour to conserve community forests. Given this context, it is necessary to point out at the outset that participatory/joint forest management is not new to India; it is a re-invention of the successful forest management practices of the past.

State versus community interests

National Forest Policy, 1894

The British administration directed its forest policy towards commercial interests and the development of agriculture, which was a major source of revenue. These motives are explicitly documented in the National Forest Policy of 1894, the first formal forest policy in India. This policy stipulated that "forests which are the reservoirs of valuable timbers should be managed on commercial lines as a source of revenue to the States" and that "wherever an effective demand for culturable land exists that can only be supplied by a forest area, the land should ordinarily be relinquished without hesitation..." (Government of India 1894). According to this policy, the sole motivation by which forests were administered under British rule was the promotion of state interests.

For management purposes, the British administration divided the forests into four classes, as described in the National Forest Policy of 1894. The first class of forests were generally situated on hill slopes and were deemed essential for the protection of cultivated plains from damage caused by landslides and hill torrents. In this sense, they served a conservation role of the benefit of agriculture in the plains. The second class of forests included the vast reserves of valuable timber trees including *cedrus deodara, Shorea robusta* and *Tectona grandis*. Driven by commercial interests, forest management measures were developed to promote natural regeneration of these first two species and artificial regeneration of the third. In certain parts of northern and eastern India, however, techniques for the artificial regeneration of *Shorea robusta* were developed by means of the *taungya* system (Government of India 1976).

Using forests to meet people's needs was not a priority consideration for the British administration. People's requirements were to be met by the third class of forests - 'minor forests' that yieled only inferior timber, fuelwood or fodder - and by the fourth class of forests - 'pastures and grazing grounds' to which certain restrictions were applied. In general, the policy dictated "the constitution and preservation of forests and, to a greater or lesser degree, the regulation of rights and the restriction of privileges of users in those forest areas which may have previously been enjoyed by the inhabitants of the immediate neighbourhood" and further suggested that "the cardinal principle to be observed is that the rights and privileges of individuals ... be limited" (Government of India 1894). To conclude, people's interests were made subservient to the State's commercial interests with regard to forests during colonial rule.

Indian forest Act, 1927

Likewise, the implementation of the Indian Forest Act, 1927 by the British Administration also had an impact on those communities dependent on forests. The Indian Forest Act was drafted first in 1865, placing most forests under state ownership. It was further revised in 1878 and consolidated in 1927. Thus it is important to note that the National Forest Policy of 1894 evolved from the objectives of forest management as outlined in the (draft) Forest Act of 1865 and 1878. The Indian Forest Act, 1927 was "an Act to consolidate the law relating to forests the transit of forest produce and the duty levible on timber and other forest produce" (Government of India 1927). The text of this Act was divided into 13 chapters with a plethora of rules and regulations, penalties and procedures aimed at extending the Government's control over forests as well as diminishing the status of people's rights to forest use. To give an example, a clause from Chapter III 'Of Village Forests', Section 28(2) states that "the State Government may make rules for regulating the management of *village forests*, prescribing the conditions under which the community ... may be provided with timber or other forest produce or pasture, and the duties for the protection and improvement of such forest" (Government of India 1927). Thus, this Act facilitated the State's grip over forests and consequently communities were deprived of many of their traditional rights over forests. That is, "people's rights to use forests were extinguished and replaced by privileges" (Hobley 1996). This Act further alienated village communities from their age-old symbiotic relationship with forests.

The Indian states adopted the Forest Act of 1927 after independence in 1947. Subsequently, the Act was modified through several amendments, mostly to curtail local use of forests. Furthermore, the Indian states promulgated their own Forest Acts. For example, The Orissa (State) Forest Act, 1972 provided that no claim for shifting cultivation should be allowed in areas notified for reservation (Pathak 1994). According to Pathak (1994), in the post-independence era "forest offences as outlined in the Indian Forest Act, 1927 were re-categorised and harsher punishments were provided". Attempts to curtail local forest use by affecting changes to this Act continued until the early 1980s. However, the situation changed in the early 1980s as non-governmental organizations and people's groups resisted the measures imposed by the government. Currently, a facelift of the Indian Forest Act, 1927 is underway in the context of the present forest management regime. Since the adoption of the National Forest Policy of 1988 (discussed later), it has been proposed that all state forest laws and amendments be updated and consolidated to bring about a uniform law throughout the country.

People's resistance against the State

An analysis of the National Forest Policy, 1894 and the Indian Forests Act, 1927 suggests that the rights of people to forests under erstwhile rulers in the precolonial era were further limited. It is also evident that many of the informal forest management institutions that operated at the grassroots level collapse after the takeover of the forests by the British administration, leading to an erosion of social capital. However, in some cases people actively opposed the State take over and demonstrated against the curtailment of public rights. Two such cases of resistance by local communities in the state of West Bengal (Proffenberger 1995) and Uttaranchal (Guha 1983 ;

Ballabh and Singh 1988 ; Ballabh *et al.* 2002) are summarized here. These two cases had a remarkable impact on the Indian Forestry sector in the years that followed.

In the pre-colonial period, Mughal rulers were unable to exert political authority over forest-dependent tribal communities in the Jungle Mahals of the western Midnapore District in the state of West Bengal due to the inaccessibility of the area. Tribal communities protected their forest resources based on 'warfare and withdrawal'. The forest- and subsistence-oriented lifestyle of tribal communities, however, changed with the emergence of British colonial rule in Bengal in the late 18th century as the British administration tried to impose their authority and to extract land revenues through *zamindars*. Under a land tenure system termed *zamindari*, lands were granted to revenue farmers or rent collectors called *zamindars*, who had to pay a fixed amount annually as land revenue to the state. The British administration also encouraged *zamindars* to convert open forests into agricultural land, evidently to enhance the revenue earned. It is important to note in this context that such revenue-oriented measures were advocated well before the implementation of the (draft) Indian Forest Act, 1865 and the National Forest Policy, 1894.

The tribal communities reacted violently to the British administration in a series of armed revolts. The first of these, popularly known as the Chur Rebellion, lasted from 1767 to 1800. Later on, the British administration increased its grip over this region despite the resistance put up by tribal communities from time to time. With the passage of time, the tribal communities were marginalized and their traditional usufruct rights were restricted or eliminated. These forest-dependent communities were further affected by worsening ecological conditions resulting from conversion of forest into agricultural land and mounting pressure on forests for *Sal* (*Shorea robusta*) logs to meet the demand for railway sleepers to expand the country's railway network. Even after independence, the living conditions of tribal communities and other low caste people further deteriorated in this region. They were reduced to agricultural labourers or sharecroppers and suffered the loss of income from forest-based activities as the forests were cleared. Such conditions resulted in the Naxalite uprising in the Arabari area of Midnapore, West Bengal, in the 1970s, which further hastened the depletion of forest cover due to the inability of the Forest Department (FD) to protect the forest resource. As a result of such developments as well as the eventual prudence of Forest Department personnel, this region later became the site of the first experiments in Joint Forest Management (JFM), as discussed in Section 2.2.

Similarly, in response to stark public opposition to State efforts to nationalise and exploit forests that had long been under local control, *Van panchayats* (village forest councils) were established in the state of Uttaranchal (previously known as Uttar Pradesh Hills) during the early 20th century. Under the provisions of the Forest Act of 1878 and settlements thereafter, all land except cultivated land was brought under the control of the FD and a wide range of restrictions were imposed on grazing, lopping and collection of forest produce. However, in 1916 a group of the Indian elite organized people in Uttaranchal to challenge the State reservation of forests for the impact it was having on local livelihoods.

As a result of such protests, the Forest Grievances Committee was set up by the state to look into the matter. Realizing that further efforts to impose forest regulations were likely to be met

by stiff resistance and thus strengthen calls for independence, the committee recommended reclassification of state forests. In consequence, the status of reserved forests of low commercial value but of high livelihood value to local people was rebuked and *Van Panchayats* were instituted for their management. *Van Panchayats* were instituted on the principle of participatory forest management and gained the full legislative support of the state. This is a classic illustration of how the concept of participatory forest management originated well before the independence of India in 1947 an as an outcome of popular resistance to State management regimes. Today, the state of Uttaranchal has more than 4,800 *Van Panchayats* managing 244,800 hectares of forest area spread over six districts.

Genesis of Joint Forest Management

Continuous deforestation and the degradation of forests leading to a decline in forest cover have long been sources of concern for policy makers in India. Indeed, had there not been such large-scale deforestation and forest degradation in India, it is unlikely that any policy maker would have given serious thought to the 'participatory forest management' model. The need of the hour and the backalsh of policy failures have led to the emergence of a new institution and rational for the origin of a 'participatory forest management' model within the Indian forestry sector. This section discusses why the government commenced participatory forest management in India.

Misdirected forest policies

There are conflicting views on the reasons behind deforestation and forest degradation in India. State FD personnel hold the people living in and around the forests responsible for deforestation and forest degradation. If this is the case, the question arises as to what circumstances led local people to change their attitude given the existence of traditional symbiotic systems for forest use. The likely circumstances are addressed here in an attempt to answer this question.

The Government of India enacted the first post-independence National Forest Policy in 1952. An attempt to revise rather than entirely reconstruct the preceding forest policy, the 1952 policy did not alter the fundamental principles which underpinned the Forest Policy of 1894 (FAO Staff 1953). In fact, the 1952 policy "asserted that the fundamental concepts underlying the colonial policy were sound ; they just needed to be reoriented" (Pathak 1994). In the context of post-war reconstruction, the National Forest Policy of 1952 was required to accommodate and endorse heavy demand on forests as a number of industrial expansion and river valley and communications development schemes got underway.

The National Forest Policy of 1952 proposed a functional classification of forests into *protection forests, national forests, village forests* and *tree-lands* (Government of India 1952). This new classification was in no way divergent from that of the Indian Forest Act of 1927 except for the introduction of tree-lands as a new functional category. According to 1952 policy, tree-lands were defined as "those areas which, though outside the scope of ordinary forest management, are essential for the amelioration of the physical conditions of the country". However, this functional forest classification was never implemented and, likewise, most of the other policy statements made under the auspices of this policy were not effectively implemented. One of the reasons for

this ineffectiveness was that this policy was issued as a resolution by the government but was not adopted by the State Legislatures (Government of India 1976)

With regard to public involvement in forestry, the National Forest Policy of 1952 laid down that "it would be the duty of the forester to awaken the interest of the people in the development, extension and establishment of tree-lands wherever possible, and to make them tree-minded" (Government of India 1952). As with other policy proposals (such as 'balanced and complementary land-use', which sought to bring 60 per cent of the land area in mountainous regions and 20 per cent of the plains under forest cover), however, this was a general statement lacking any concrete definition for how this might be achieved. To be precise, the policy did not provide any strategic appraisal of how to bring about public participation in forest management. Rather, the government continued with the Bitish forest policies even after independence. Thus it can be concluded that the National Forest Policy of 1952 evolved in the shadow of past policies.

The wood-based industries benefited the most from the forests in the post-independence era in the form of state subsidized raw material. This strategy was adopted to promote the wood-based industries and to boost the country's economy as a whole. One such provision is summarized here. The paper industry was procuring bamboo at a price of 1 Indian Rupee (INR) per ton during the 1950s, whereas the prevailing market price was over INR 2,000 per ton. The state subsidy induced "profitability of forest-based industries" and resulted in the "explosive growth in industrial capacity, and a non-sustainable use of forest stocks" (Gadgil & Guha 1992). This in turn had an adverse effect on forest-dependent communities. It is needless to say that such incentives also led to the further degradation of forests.

Such circumstances in the past led to several people's movements in protest against state policy. In one case during the 1970s and 1980s, local people protested against the logging of trees for industrial use. In what became known as the *Chipko* movement (*Chipko* meaning 'embrace'), villagers hugged the trees, interposing their bodies between the trees and the contractors' axes, to prevent them from being cut. This movement began in the Himalayan state of Uttaranchal in 1973, later spreading in an organized manner to other states in India. The people's movement achieved a major victory in 1980 when the government of Uttar Pradesh placed a 15-year ban on tree felling in Himalayan forests. This movement against state policy was well highlighted by the media and led to the increasingly conservation-oriented management and utilization of forests. In another case, local people protested against the replacement of native *Sal* (*Shorea robusta*) forests by Teak (*Tectona grandis*) plantations by the Forest Development Corporation in the Singhbhum District of Bihar state in 1977 (CSE 1982). This movement, termed 'tree war', met with stiff resistance from the state administration (for details see CSE 1982).

Misdirected policies to curb deforestation in India on the other hand led to the introduction of laws regulating the felling and marketing of trees from both public and private lands. This had the opposite effect as farmers reduced the number of trees they planted on private lands fearing that they would not be able to sell the timber (Kerr 1997). Nonetheless, demand for wood remained strong and prices for timber high. Therefore pressure on government forests, with relatively open access, increased to meet the demand. As a result, India's forests suffered further depletion. Singh

(1994) defines three reasons for deforestation and the degradation of forests in India : "defective forest policy, faulty implementation of policy, and the poverty of the people".

To summarise, it could be said that, despite attempts to protect the forests, the state issued misdirected forest policies that failed to account for the fact that poor people have historically depended on forests for their needs and have few alternatives. According to Poffenberger (1995), in India "national resource management policy and development planning is based solely on an analysis of existing conditions and future need projections" without considering the "well grounded understanding of the history of environmental use patterns and the social, economic and political forces that shape them". In short, stakeholders, village communities/forest users and the Forest Department/forest owners were each respectively dealing with forests in isolation and from a different perspective. This resulted in implementation of forest policy initiatives as a means to overcome the problem, perhaps without analyzing the relationship between cause and effect. The outcome of such circumstances led to an increasingly indifferent attitude amongst local people towards the forests and the Forest Department, thus bringing about a shift in traditional symbiotic relationships between the users and the forest resource.

Thus it is true that people living in and around forests were responsible for the degradation of forests. Specifically it was not possible for the FD, even armed with strict forest protection laws, to safeguard a large component of the forests from the large number of local users, given the small total number of forestry personnel throughout the country. According to Bahuguna (2001), there are 200,000 villages in India on the fringes of forests with a total population of 350 million people. The inference is that the State can effectively protect forests in India only if people's participation in forest management is solicited. Conversely, the village communities as forest users should also shoulder the responsibility for protection and management of their forests along with the FD. Under such an arrangement the local community could harvest various forest products from their forest in a sustainable manner and with a sense of ownership. Ideally, this forest management model should have been in place long before, bearing in mind the continued significance of forests in the village economy. However, as the country emerged as an independent nation, it was perhaps the government's pre-occupation with a development model focusing on agriculture and industry, which meant that such a forest management perspective was overlooked.

The Arabari experiments in JFM

The relevance of a 'give and take' principle between the FD and the community surfaced in the early 1970s. A group of FD personnel realized the importance of peoples' participation in regeneration of degraded *Sal* (*Shorea robusta*) forests in Arabari Range of Midnapur district in the state of West Bengal. This forest rejuvenation strategy was started as an experiment and later on replicated on a large scale first in this state followed by its adoption in different parts of country. The West Bengal Forest Department issued the first government order in 1989 to involve village communities in forest protection with provision to give the people 25 per cent of the revenue earned on timber harvested from the protected forest. This successful experiment led to the development of a new forest. This successful experiment led to the development of a new forest management strategy known as 'Joint Forest Management' (JFM). The village communities involved

in the management of government forests in their vicinity under the JFM became known as forest protection committees. This is the first recorded case of 'co-management' of forests by FD and village communities in India (Yadav *et al.* 1998).

It is important to note that the forest protection committees formed in Arabari have emerged out of a persistent conflict between people and the government for control over forest resources as in the case of *Van Panchayats* in the state of Uttaranchal (discused in Section 1.2).

Another successful experiment, which began in 1975 in Sukhomajri, a village in the state of Haryana, also helped in the conceptualization of participatory forest management. This experiment was initiated as an integrated watershed development programme by the Central Soil & Water Conservation Research & Training Institute (CSWCRTI), Research Centre, Chandigarh. The emphasis was on rainwater harvesting to enhance irrigation of cultivated land in Sukhomajri, which faced a severe soil erosion problem. Forestry became an integral part of the experiment, as the various tree species were planted to protect the watershed, along with the building of water-harvesting structures for harnessing rainwater. An unwritten agreement between the CSWCRTI team and villagers was developed for protecting the catchment of the water-harvesting structures from grazing and illicit cutting in the area (Samra *et al.* 2002). This was achieved by instituting a 'Water Users' Association' subsequently renamed as 'Hill Resource Management Society' (HRMS). The entire management of this project was handed over to HRMS, which functioned on the principles of participation. Presently, the 55 HRMSs in Haryana are an integral part of the JFM programme in this state (for details see http : // www.teriin.org/case/jfm.htm). In additon, built upon this successful participatory model, watershed management is now an integral part of the ongoing JFM programme in the country under the ambit of micro-level planning.

At present, there are 63,618 forest protection committees (joint forest management committees) in India spread over 27 states managing about 14.09 million hectares of forest. This means that 22 per cent of the total forest cover of 63.73 million hectares in India is being managed under JFM. There are also a number of tree growers' cooperatives (for details see Section 2.4) and numerous self-initiated forest protection groups (SIFPGs) managing forests in India on the principle of participatory forest management. Thousands of SIFPGs, established by village communities with a "strong economic dependence on forests and where often a tradition of community resource management is still surviving", in the states of Orissa, Bihar, Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh, are protecting large areas of state forests (Sarin 1998). According to Sarin (1998), SIFPGs came up "parallel to, and often preceding state initiatives" in implementation of JFM in the country.

There is no doubt that the Arabari experiment of participatory forest management, which was later implemented in the entire country, was a success. However, the rise of the JFM concept in India cannot be viewed only in the light of the success of the Arabari experiment ; the significance of the communities (SIFPGs) that have been managing their forests on their own for a number of years must not be overlooked. Neither should the rise of JFM be viewed as the outcome of a sudden change in mind-set on the part of FD personnel, once known for their autocratic management

style. The factors leading to the evolution of participatory forest management are further discussed in the following two sections.

Failure to promote social forestry

To begin with, one of the first and foremost initiatives to enhance forest cover at a time when forests were declining and being degrading in the country was made by the National Commission on Agriculture (NCA) in 1976. The NCA was set up in 1970 by the government of India to examine comprehensively the progress of agriculture including forestry and to make recommendations for its improvement and modernization. In the case of forestry, the NCA investigated and reported that farm forestry should be accepted as an important factor affecting agricultural progress and as a source of raw material for industry (Government of India 1976).

Subsequently, the government of India launched a 'social forestry' programme, including 'farm forestry' on private lands and established 'community self-help woodlots' on community lands on a large scale during the 1970s and 1980s to reduce pressure on the government owned forests and also to incorporate people in the afforestation programme. However, according to Yadav *et al.* (1998), social forestry programmes were not successful, as they did not provide sufficient benefit to the local communities. The emphasis of this programme was more on farm forestry than establishment of community woodlots, where community woodlots are aimed at meeting the requirements of rural communities. For example, whilst the World Bank assisted social forestry programme in Uttar Pradesh overshot its farm forestry targets by 3,430 per cent, establishment of community self-help woodlots achieved only 11 per cent of the target (CSE 1985). By and large the State failed to involve people in the social forestry programme (Ballabh 1996).

These circumstances also led the State to think of changing its non-participatory approach to forest management to a more participatory one, increasingly involving local people. As such, the social forestry programme provided an opportunity for FD personnel to enter dialogue with village communities, so laying the foundations for JFM in India. There were also sound economic reasons for the initiation of participatory forest management in India. As the emphasis shifted away from imposing punitive measures as a component of the State's prerogative over forest issues, costs borne of monitoring and enforcement were reduced and the role of state Forest Departments in excluding people from forests was eased (Ballabh *et al.* 2002). These are some of the reasons (amongst others) cited for the initiation of participatory forest management by the State.

Facilitative role of NGOs

While discussing the development of participatory forest management initiatives, it is important to make reference to the active involvement of non-governmental organizations (NGOs) in promoting participatory forest management at the grassroots level. In most cases, NGOs are facilitating the village communities as well as the FD in the formation of JFM Committees. In many cases, NGOs and tree growers' cooperatives have developed their own participatory forest management models for JFM based on the policy directives of the government.

For example, the Foundation for Ecological Security (until February 2001 known as the National Tree Growers' Co-operative Federation Limited, NTGCF) is invloved in organizing tree

growers' cooperative societies at the village level to rehabilitate degraded village commons across seven states in India. Since its formation in 1988, the Foundation for Ecological Security (FES) has played a very active role in establishing and nurturing tree growers' cooperatives. The objective of a tree growers' cooperative is to motivate people to grow trees and grasses of suitable species on their own marginal agricultural lands and degraded village common lands to meet the local needs for forest produce. In addition, FES is also supporting self-initiated forest protection groups (SIFPGs). By the end of the year 2001 supported village institutions/SIFPGs in 866 villages and had afforested 13,348 hectares of degraded village common lands. For details on the functioning of tree growers' co-operatives, see Balooni & Ballabh (2000) and Balooni & Singh (2001).

During the inception of participatory forest management in India, the FD was skeptical about the involvement of NGOs. NGOs faced non-cooperation from FD for assisting village communities in undertaking community forestry programmes (Arul 1998 ; Balooni 1998 ; Saxena 1996 ; Saxena 2000). The conflicts between FD and NGSs suggested the State's reluctance to relinquish power. Similar conflicts in other countries involved in implementing community forestry programmes have also been cited (Desloges & Gauthier 1997 ; Hobley 1996 ; MacGean 1991).

Over the last decade, however, the state of affairs has changed in favour of NGOs, which may be mainly attributed to the 'change in mind set' of FD personnel towards forest management. Now, substantial rural developmental funds earmarked by the Government of India are routed through NGOs for the participatory forest management programmes. Besides, pressure from external aid agencies on the FD to involve NGOs in JFM programmes and to restructure the FD accordingly, as a condtion for aid in India, has also resulted in overcoming the problem between NGOs and the FD (Sundar 2000). However, there is also contrary view. According to Sarin (1998), JFM has gone through three phases since the late 1980s. The first phase was "led primarily by idealistic and democratic NGOs and a few liberal officers". In the second phase, "NGOs learnt from practical experience and exposure to ground realities". The present third phase is "dominated by donor funding with forest departments becoming the major implementors", whereas "NGO and community efforts ... have been pushed to the sidelines". Nevertheless, NGOs remain a major stakeholder in forest policy formulation in the country as revealed in the subsequent discussion.

Policy Trends in Joint Forest Management

Polcy directives

This section begins with a discussion of the new National Forest Policy of 1988, which is the first forest policy to emphasize the role of people's participation in forest protection and management. This policy had been conceptualized in the wake of the success of the participatory forest management scheme in the country, albeit on a small and localized scale. This section draws from the government of India's orders and guidelines on JFM. The text of the government of India's resolutions, circulars and orders concerning participatory forest management referred to in this paper, are given in Annexes 1 to 7 in chronological order at the end of this paper (also available at http : //www.rupfor.org/jfm—india.htm and http : //www.rupfor.org/jfm—moef.htm).

Creating a people's movement

National Forest Policy, 1988, the second forest policy after India's independence, has in the last decade changed the face of the Indian Forestry sector (Resolution No. 3A/86-FP, dated 7th December 1988, Ministry of Environment and Forests, Government of India. ; Annex 1). It is both conservation-and production-oriented. The basic objective of this policy is the maintenance of environmental stability through preservation of forests as a natural heritage. It also places emphasis on increasing substantially the forest/tree cover and the productivity of forests in the country to meet national needs. However, the distinctive feature of this new policy was mention of "creating a massive people's movement with the involvement of women, for achieving the above-mentioned objectives and to minimize pressure on existing forests". This is a complete departure from the previous National Forest Policy of 1952 as it envisages people's participation in the development and protection of forests. The National Forest Policy is a harbinger of 'management change', i.e. from government-managed to people-managed forests. As a follow up to the National Forest Policy of 1988, the government of India has issued orders and guidelines of JFM from time to time in the last ten years (as summarized in the following sections). This reflects the government's resolve succinctly out-lined in the National Forest Policy to create a massive people's movement and encourage participation in the management of forests.

It is also important to mention here that central control over forest lands was strengthened by transferring forestry from the State List to the Concurrent List by the 42nd Amendment of the Indian Constitution in 1976. This was followed by the enactment of the Forest (Conservation) Act in 1980, which made the central government's approval mandatory for conversion of forest land for non-forest purposes, such as "cultivation of tea, coffee, spices, rubber, palms, oil-bearing plants, horticultural crops or medicinal plants" and for "any purpose other than reafforestation". The Forest (Conservation) Act, 1980 has to some extent helped in checking the conversion of forest land for non-forest uses. This is reflected by the fact that the rate of conversion of forest land for non-forest uses fell to around 22,665 hectares per annum during 1981-1998 (ICFRE 2000), as compared to 143,000 hectares per annum before 1980 (*Press Information Bureau,* http : // pib.myiris.com/ refer/article, php3? fl = B3562&sr=8). In some ways, this Act has helped in facilitating implementation of the JFM programme on forest land, as generally encroachment takes place on land otherwise suitable for JFM management typically at the periphery of existing forests (also see Section 3.2.3).

First circular on JFM

Efforts to encourage adoption of participatory forest management in the forests of India were underway even before the adoption of the National Forest Policy of 1988 as illustrated by the case of the Arabari experiment in West Bengal (discussed in Section 2.2). However, the movement gained momentum and was formally institutionalized as a participatory forest management programme once people's participation had been incorporated into the new forest policy. In this context, the first policy directive was a JFM Circular issued by the central government for the *Involvement of Village Communities and Voluntary Agencies in Regeneration of Degraded forests* (Circular No. 6.2 1/89-F.p., dated 1st June 1990, Ministry of Environment and Forests, Government of

India ; Annex 2). This Circular provided the background and the methods required for the implementation of JFM by the state FDs with the involvement of village communities. It also envisaged the participation of voluntary organization/non-governmental organizations with a proven track record in JFM to facilitate participation by village communities in development and protection of forests with an emphasis on regeneration of degraded forests. Furthermore, the Circular highlighted management concerns such as ownnership or lease rights over forests, membership of village forest committees (also known as forest protection committees or joint forest management committees), usufruct rights of beneficiaries, and management and supervision of afforestation and protection activities. This Circular also suggested other do's and don't's for the village forest committees and voluntary agencies/NGOs and implications thereof, though only in a broad sense.

Consequently, state governments passed their own resolutions on JFM. These resolutions varied from state to state depending on the socio-economic and political scenario as well as cultural characteristics of each state. Nevertheless, the basic principle of community/people's participation as envisaged in the National Forest Policy of 1988 and the JFM Circular underlie all these state resolutions. Presently, 22 state governments have come up with their own JFM orders for implementing the JFM programme. The first JFM Circular by the government of India has been floowed by other government orders and notifications from time and time, as and when required to support its policy to facilitate JFM throughout the country. Accrodingly, many states have come up with revised JFM orders. For example, the state of Orissa's latest JFM resolution is the fifth since the first order was issued in 1988. Some of these orders and notifications are summarized below in chronological order.

Here it is important to highlight that the 73rd Amendment of the Indian Constitution in 1992 has also facilitated the implementation of JFM in the country. This amendment empowers village *panchayat* (village councils) to undertake village level planning for all developmental activities including those relating to forestry, irrigation and agriculture. This empowerment of the people at the grassroots level is popularly known as *Panchayati Raj*.

Establishment of a JFM Monitoring Cell

Realizing the importance of the ongoing JFM programme for the effective management of forests in the country, the Ministry of Environment and Forests created a 'JFM Monitoring Cell' within the Ministry in 1998, This Cell was created with the objective of monitoring the impact of JFM being carried out by state governments for the improvement and protection of forests (Office Order No. 1–13/97-FF, dated 19th August 1998, Ministry of Environment and Forests, Government of India ; Annex 3). This order also replaced the erst-while 'Forest Fire Division' with a 'Forest Protection Division'. This new division covers all the aspects of forest protection in India and also encompasses the 'JFM Monitoring Cell'.

Expansion of JFM to non-forest areas

Furthermore, the government constituted a 'Standing Committee on JFM' in 1998 to review the implementation of JFM programmes as well as existing JFM arrangements in the country (Notification No. 1–13/97-FPD, dated 6th November 1998, Ministry of Environment and Forests,

Government of India ; Annex 4). This committee comprised eminent scientists, senior Indian Forest Service Officers, and officials of funding agencies and other organizations engaged in JFM activities. The main objective of the committee was to advise the government on the operational aspects of JFM including institutional arrangements. The committee was also expected to discuss the strategies to expand JFM in non-forest areas.

In India, besides the forest land owned and managed by the State Forest Departments, there is a large area (around 76 million hectares) of non-agricultural and non-forest land, such as barren and unculturable wastelands, culturable wastelands, permanent pastures and other grazing lands. Such lands are owned *de jure* by the Revenue Department and other government departments, though in some cases they are *de facto* 'common property resources'. Though these uncultivated lands are highly degraded having suffered 'the tragedy of commons', they nonetheless hold the potential for the expansion of JFM in the country.

Sharing of experience

Given that each state in India has passed its own resolution on JFM to fit local socioeconomic, political and geographical conditions, it is vital that experiences of its implementation. - both successes and failures - be shared with one another. Thus it becomes essential to find ways and means for the sharing of experiences between various states. With this in view, the government established a committee comprising of senior forest officers from six states and a member of the JFM Cell in November 1999 (Notification No. 22–8/98-FPD, dated 12th November 1999, Ministry of Environment and Forests, Government of India ; Annex 5). This committee was also given the responsibility of preparing formats for monitoring JFM programme for systematic funding, with due regard to long-term sustainability.

Creating a JFM Network

In order to give added impetus to JFM in India, the government instituted a 'JFM Network' at the national level in February 2000 (Notification No. 22–8/98-FPD, dated 11th February 2000, Forest Protection Division, Ministry of Environment and Forests, Government of India ; Annex 6). The JFM Network "acts as a regular mechanism for consultation between various agencies engaged in JFM work" and also "obtains constant feed back from various stakeholders on the JFM programme for proper policy formulation and suitable directions to states". This Network has representatives from the Ministry of Environment and Forests, NGOs, funding agencies such as the World Bank, the Ford Foundation, the World Wide Fund for Nature, the Department for International Development of the United Kingdom, and the Overseas Economic Cooperation Fund of Japan. There are also representatives from Indian organizations - including the Society for Promotion of Wastelands Development, Tata Energy Research Institute and the Indian Institute of Forest Management - involved in various aspects of training and research.

Given the mammoth size of the ongoing JFM programme on a national level, promoting feedback and exchange and including the views and reactions of different stakeholders through the establishment of a 'JFM Network', is considered an appropriate step.

Issuing guidelines for strengthening JFM

The government has developed guidelines for strengthening the JFM programme based on past experience (Notification No. 22-8/2000-JFM (FPD), dated 21st February 2000, Ministry of Environment and Forests, Government of India ; Annex 7). Issued almost a decade after the first governmental notification of JFM in June 1990, these guidelines represent the latest JFM policy directives, and present a structured and broad framework for implementation of JFM in India.

The guidelines set forth a number of measures for strengthening JFM in India, including increased legal support for JFM Committees ; the promotion of women's participation in JFM programmes ; the extension of JFM into good forest areas ; the preparation of microplans in JFM into good forest areas ; the preparation of microplans in JFM areas ; conflict resolution ; and the official recognition of self-initiated forest protection groups (SIFPGs). The guidelines also highlight the need to plough back a minimum of 25 per cent of the revenue earned on products harvested by village communities into meeting the conservation and development needs of the forests. These suggestions have been developed on the basis of the successes and failures experienced in the implementation of JFM in various parts of the country. Some of the measures (such as the registration of all JFM Committees under the Societies Registration Act, 1860 to provide legal back up) seek to legally streamline the JFM programme across the country, Formal recognition of SIFPGs is also seen as a necessity, since, in the absence of government support, their authority is often challenged by "neighboring villages, migratory herders, commercial interests as well as FD staff" (Sarin 1998).

Guidelines to enhance the participation of women in the JFM programme and the development of a sound mechanism for conflict resolution together indicate that there remain challenges to achieving perfection of JFM in India. These policy issues and challenges are discussed in detail in Section 3.2, 'Policy issues and challenges ahead'.

JFM in afforestation schemes

Given the government's emphasis on participatory forest management, investments in afforestation under the Five Year Plans are being revamped in order to factor in "people's participation in project formulation and implementation". After the independence of India in 1947, the government launched a series of Five Year Plans with targeted budgetary allocations for the development of various sectors. The first Five Year Plan was implemented during 1951-9156. At present, the tenth Five Year Plan (2002-2007) is underway.

In a recent development, the Ministry of Environment and Forests has issued fresh operational guidelines for the formulation of a National Afforestation Programme under the tenth Five Year Plan. These guidelines seek to encourage a participatory approach to the development of forests under government sponsored afforestation schemes. Afforestation schemes operational during the ninth plan have been merged under the new National Afforestation Programme so as to "avoid multiplicity of schemes with similar objectives" and to ensure "uniformity in funding patterns and implementation mechanisms".

One of the major features of these guidelines is that all the new centrally sponsored afforestation schemes will be implemented via a two-tier system consisting of Forest Development Agencies

(FDAs) and JFM Committees to allow greater participation of the community in planning and implementation. FDAs are new institutional organizations registered under the Societies Registration Act and operational at the territorial/wildlife forest division level ; as of July 2002, 16 FDAs had been established in 21 states in India (*Times of India* quoted in Inform (2002). Other than JFM Committees, village institutions already in existence will act as the implementing agency at the grassroots level to cater for village needs. FDAs will work in tandem with JFM Committees under the terms of a Memorandum of Understanding. On the one hand, FDAs strengthen the role of existing JFM Committees, and on the other, they create new JFM Committees. In short, the purpose of the National Afforestation Programme is to make JFM a central and integral part of all the afforestation projects in the country.

Policy issues and challenges ahead

The emergence of new policy directives from time to time as summarized in the preceding section also implies that JFM is not bereft of problems. There are a number of policy issues and challenges which affect either the sustainability of existing JFM programmes or decelerate the pace of their implementation. The inception of the JFM programme in India was a daunting task for the FD, NGOs and other stakeholders. The state governments issued their own JFM resolutions to set the guidelines for their implementation. However, it was not possible to visualize at the outset the range of problems that would be confronted in each situation and at the different stages of JFM implementation.

In India, more than 60,000 JFM Committees have been established. This figures, however, does not give a good impression of the success rate and, more importantly, the sustainability of these community-based organizatons. These remain the major 'teething' problems for JFM programmes in India. The government has admitted that measures to sustain programmes beyond the project period have not yet been conceptualized (Government of India 2001a). For example, out of the total 362 tree growers' cooperatives organized by the NTGCF/FES during 1988-1996, only 79 per cent were actually functional, the rest being either non-functional or defunct (NTGCF 1996).

So what are the factors that directly or indirectly hamper the progress and sustainability of JFM programmes ? The following sections summarize important policy issues and challenges based on a review of the literature.

Equity in participation

'Equity in participation' in a JFM context refers to the participation of all stakeholders/users with an emphasis on weaker/under-privileged societal elements (such as the landless labour force, Marginal and small scale farmers, scheduled castes, tribal groups and women ; as defined in the National Forest Policy of 1988). The government is specifically targeting these under-privileged sections of society inhabiting forests and adjoinng areas under the JFM programmes and other afforestation schemes. As landless labourers and marginal and small scale farmers in rural India depend mostly on common property resources for their fuel supplies and fodder, they have a personal interest in the regeneration of degraded forests under the JFM programme. Futhermore,

forest products from commons are an important source of employment and income for the rural poor, especially where other opportunities are non-existent (Jodha 1997).

Given this context, one of the objectives of the JFM programme is to create employment for under-privileged sections of society with around 60 per cent of the expenditure incurred in JFM being paid as wages. A substantial proportion of the financial allcation of the various rural developmental programmes in India - including, for example, *Sampoorna Gramin Rojgar Yojana,* the Drought Prone Area Programme and the Desert Development Programme - is kept aside for afforstation schemes. Recently, the government has proposed to link the Greening India Programme (for details see Section 3.2.4) with the 'Food for Work' scheme to enhance forest coverr ; the food grains will form Work' Scheme to enhance forest over ; the food grains will form 50 per cent of the wages earned by workers in drought prone areas (Government of India 2001a). This programme is expected to ensure food accessibility for 100 million people and generate employment opportunites, mainly for landless labourers and women.

It is important to emphasize here that it is primarily the weaker sections of society that are involved in the plantation and protection activities in JFM. However, to what extent the weaker classes are involved in determining forest management priorities is questionable, since historically they have been kept at a distance by the more powerful elements in village politics. Here, the focus is on women, as in most cases they are the collectors and users of forest products. Moreover, women spend a great deal of time in the forests collecting forest produce and typically know more about the forest resource than men. Nonetheless, political control in forest management remains vested in men.

The government resolutions of JFM in India advocate active participation by women in the decision-making process and in determining forest management priorities. The National Forest Policy of 1988 specifically refers to the creation of "a massive people's movement with the involvement of women...." - the only non-bracketed mention of women in the document (Locke 1999). However, this policy objective is far from being accomplished, despite the fact that JFM orders issued by some state governments have made provision for the representation of women in the General Body and the Executive Committee of the JFM Committee. According to Sarin (1998), these JFM orders specify only a few institutional mechanisms for ensuring the active participation of women. Furthermore, "formal provisions or policy statements regarding women's roles or entitlements are extremely narrowly conceived within JFM at the national, state and even project level" (Locke 1999). For example, in the state of West Bengal, a woman automatically becomes a member of JFM Committee by virtue of her husband being a member, but even then the husband is regarded as the primary member (Agarwal 2001).

Agarwal (2001) has classified the participation of women in JFM into five categories : nominal participation, passive participation, consultative participation, activity-specific participation and active and interactive participation. Thus, for example, whilst women may be excluded from decision-making, they may be drawn into 'activity-specific participation', especially forest protection. In addition, there are few cases of women's participation in all-women committees in India's hill areas

(Agarwal 1997), one exception being the Parwara *Van Panchayat* in the state of Uttaranchal. Here, besides a paid guard that protects the village forest, there are also three *Mahila Van Suraksha Samitis* (MVSSs) - Woman Forest Protection Committees - involved in the protection of the village forest (Ballabh et al. 2002). The forest has been divided into three parts, with each MVSS taking care of one part. The MVSSs patrol the forest in groups of five or six members every month to check for damage incurred and the extent of encroachment. The members of all the three MVSSs meet on the twelfth day of every month to discuss their findings and take decisions for future action. Only one woman from a household can become a member of MVSS. However, all women can participate in MVSS activities.

Women's participation in JFM has been high on the government's agenda for more than 10 years but still remains "incompletely addressed" (Hobley 1996). Similarly, a fundamental problem exists with women's representation in other rural developmental activities under the ambit of village *panchayat*. The government has recently issued new JFM Guidelines for ensuring meaningful participation of women in JFM. According to these guidelines, "at least 50 per cent of members of the JFM general body should be women....and at least 33 per cent of the membership in the JFM Executive Committee/Management Committee should be filled by women members... One of the posts of office bearer, i.e. President/Vice-President/Secretary, should be filled by a woman member of the Committee"/ A recent study a woman member of the Committee". A recent study undertaken by the government suggested that the FD should recruit female staff at all levels and also increase the number of women extension officers to reach out to women more comprehensively. Nevertheless, it is difficult to speculate when the much needed and veritable participation of women in JFM in India will be ensured.

Equity in benefit sharing

Equity in the sharing of benefits derived from protected forests managed under the JFM programme is as important as equity in the participation in the JFM programme itself. This is one of the major challenges affecting the sustainability of JFM in India. In the past, prior to implementation of the JFM programme, village communities had access to forest products under different rights and regimes provided under various settlements. In most cases, village communities accessed forest products freely as an open access resource, which eventuality led to the degradation of forests in India. However, with the implementation of JFM, community access to forest products was restricted as a pre-requisite for the rejuvenation of degraded forests. Village communities waited patiently to harvest forest products from the protected areas ; clearly, 'free riding is inevitable' is not always the case. After more than a decade since the introduction of JFM in India, however, the stalled distribution of benefits from plantations has begun to spark signs of restiveness amongst users (Balooni & Ballabh 2000 ; Hobley 1996 ; Saxena 2000). Problems regarding benefit sharing have also been confronted by participatory forest management schemes in neighbouring countries, such as Nepal (Shrestha 1996) and Sri Lanka (Mackenzie 1998). In the case of India, two sets of problems can be discerned : those relating to the distribution of benefits amongst the users themselves, and those relating to the distribution of benefits between users/village communities and the FD.

Saxena (1988) and Campbell (1992) expressed apprehension at the lack of procedure for allocating benefits at the time when participatory forest programmes were first established. That is,

the current problems regarding benefit sharing constitute a fundamental policy failure, which, in explicit terms, tilts the flow of benefits derived from rehabilitated forests in favour of the FD, despite objections from village communities. Moreover, the arrangment for benefit sharing between village communities and the FD varies from state to state. With the passage of time, different states have passed their own resolutions to resolve this issue. For example, in Gujarat, the distribution of benefits derived from community plantations on government forest land between the FD and village communities was in the ratio of 3 : 1 before the state government issued a JFM resolution in March 1991. Subsequently, a second JFM resolution was issued in June 1994, enhancing the share of benefits from rehabilitated forests to village communities from 25 per cent to 50 per cent.

In overcoming this problem, it is important for policy makers to examine the history of past settlements during the colonial rule, wherein forest users were granted certain rights (Hobley 1996). These rights should not be abruptly extinguished by imposing new benefit sharing arrangements under participatory forest management, as that will determine the response of local people to JFM. The policies have also to ensure that poor families and women get equal entitlements in benefit sharing.

Acquisition of degraded lands

There are several problems faced in the acquisition of village common lands for implementation of JFM at the grassroots level. In particular, the bureaucratic hassle involved in acquisition of such land - which may last for than a year - presents a major obstacle (Balooni 1998 ; Raju 1997). Moreover, in the case of degraded non-forest lands handed over to village communities on a lease basis (for example, to a tree growers' cooperative to rehabilitate degraded village common land owned *de jure* by the revenue department), the terms and conditions as well as the period of lease vary significantly from state to stae (Mishra 1992). Even the NGOs involved in implementing the JFM programmes on degraded forest areas in the vicinity of a given village, may face bureaucratic hassle from the FD in a acquiring such land (Raju 1997).

Acquisition of degraded lands classed as a common property resource is further aggravated by the encroachment of local people onto such land (Balooni & Ballabh 2000 ; Jodha 1997 ; Iyengar 1989). Eviction following illegal encroachment onto forest land is typically contested by individuals and organizations in India on the grounds that many of these encroachments had taken place in the past and, in addition, that many of the encroachers are tribal people. Hence, the efforts of the national government in evicting on the basis of illegal encroachment have not been very successful. For example, even after the enactment of the Forest (Conservation) Act, 1980, 183,000 hectares of forest encroachments were regularized in the state of Madhya Pradesh in 1990 (ICFRE, 2000). The government of India has recently advised all states to "rehabilitate ineligible encroachers on non-forest land as per their policies". It has further counselled the states to "consider *in situ* economic rehabilitation by involving these ineligible encroachers in forestry activities through Joint Forest Management" ; for details see Government of India (2002).

The lack of demarcation and confusion over the boundaries of degraded lands suitable for JFM activities has also affected the programme (Balooni & Ballabh 2000). NGOs, the FD and the

revenue department generally prefer to allocate resources according to the administrative boundaries determined in settlement plans concluded during the 19th century. However, since this time, the ground realities of use and management of resources have changed quite considerably and as such these changes need to be incorporated for proper management of plantation areas. In addition, a negotiated settlement between different villages and between the hamlets within a single village needs to be arrived at for effective implementation of JFM (Balooni & Ballabh 2000).

Institutional finance

The government of India has recently introduced the Greening India Programme, which proposes to reforest 43 million hectares of degraded forest and non-forest lands under a watershed approach within a ten year timeframe. This includes regeneration of 15 million hectares of degraded forests under JFM. The government has proposed to set up a Green India Authority and a Green India Fund to undertake this programme. The implementation of the programme requires INR 48,000 million annually, compared to the INR 16,150 million currently available through the government's budgetary resources (Government of India 2001a). Given the limitation of budgetary resources for forestry activities, the government will have to seek funding from other sources. One such source is 'institutional finance' - a source which is yet to be tapped by forestry activities in India.

The National Bank for Agricultural and Rural Development (NABARD), an apex development bank in India, supports and promotes agriculture and rural development including tree plantations on private and community lands. NABARD provides refinance facilities to certain categories of financial institutions in respect of the loans advanced by them to ultimate beneficiaries - including individuals, forest-based industries, state forest development corporations and NGOs - for undertaking tree plantations and other development activities. However, since the inception of NABARD in 1982, its contribution to tree plantation activities has been paltry (Balooni & Singh 2003). Moreover, in recent years the amount disbursed by financial institutions to afforestation programmes, mostly for farm forestry projects, has declined considerably (Government of India 2001a). In 1998–1999, the figure was INR 90 million, as compared to INR 290.5 million in 1990-91.

Furthermore, there is almost a negligible flow of institutional credit for implementing ongoing JFM programmes. Most of the funds for JFM come from government sources and donor agencies. Mostly these funds are made available for a relatively short peirod, typically between three to five years for a particular project area. In many cases, the discontinuity of such funds affects the sustainability of the village level institutions involved in the JFM programmes. In such cases, financial institutions can provide credit to village communities to continue the JFM activities. This is one area where institutional finance can play an important role. The government already has defined an expanded role for NABARD in implementing JFM under the Green India Programme.

Given the poor performance of NABARD in disbursing institutional credit for tree plantation programmes in the past, it would be a challenging task to now increase the flow of institutional credit for JFM throughout the country. A number of factors have been identified as major constraints in financing forestry programmes in India. They include time-consuming and complicated procedures

for acquiring degraded land owned by the government, delays in the sanctioning and disbursement of bank credit, low (non-remunerative) prices for tree products, and flawed public policies and programmes (Balooni & Singh 2003). The Food and Agriculture Organization (FAO) of the United Nations and NABARD undertook a study in the state of Andhra Pradesh to assess the technical feasibility and financial viability of channeling institutional credit to JFM projects (Haque *et al.* 1998). The study revealed that the projects were all financially viable ; NABARD has already agreed to fund JFM programmes in Andhra Pradesh (Government of India 2001 a). However, a serious limitation of such joint ventures involving several stakeholders is the lack of effective coordination among them, which makes the task of replication of success stories daunting (Haque *et al.* 1998). Thus, inter-institutional cooperation is a pre-requisite for the future success of this strategy. Unless these constraints are overcome, the NABARD cannot by itself play any effective role in speeding up the funding of JFM in the country.

Mismatch between forest management objectives and silvicultural practices

From a silvicultural point of view, a recent study on JFM sponsored by the government revealed significant mismatch between the current forest management objectives and the silvicultural methods being employed (Government of India, undated). Forest management approach focusing on natural regeneration and improvement of the forest's productivity - with particular emphasis on non-wood forest products (NWFPs). However, silvicultural practices have remained unchanged over the past century, which is inappropriate given that, as already discussed, the Indian forestry sector was driven by commercial motives during the colonial period, basing production on a selection of relatively few commercial species. Hence, a great deal of effort is required in the coming years to change silvicultural practices, particularly in view of plans to expand JFM activities to good forests.

Institutional impediments

With the wide acceptance of JFM in India, the need to overcome various institutional impediments, which result in high transaction costs, is being increasingly realized. Here an analysis of institutional impediments in a broader sense is presented.

In many states in India, the institutional elements of JFM function under the ambit of a plethora of resoulutions, laws, policies and acts, which are often "conflicting, ambiguous, contradictory and lack legal validity" (Government of India, undated). That is, the JFM programme lacks legislative support even when it is basd on administrative orders (Sarin 1998). For example, the FD is vested with the responsibility of resolving conflicts within JFM Committees, disbanding a badly functioning JFM Committee, canceling membership and nominating NGOs for membership (Government of India, undated). In such circumstances, the question arises, what is the explicit role of JFM Committees ? The obvious answer is 'to protect the forest only'. The fact is that JFM activities presently derive their legal legitimacy from the resolutions issued by state governments. However, these resolutions do not have a statutory basis and therefore, are easily reversible (Hobley 1996). This creates uncertainty in the rights to tenure of the village communities involved in forest protection.

Hence, for the continued success of JFM, village communities need to be provided with enough flexibility to build institutional arrangements that are sustainable.

Furthermore, there remains a lot of variation between the JFM resolutions issued by different states. Also, JFM Committees in different states vary in nomenclature, structure and composition, and whereas they are registered with FDs in some states, in others they are registered as societies and cooperatives. In addition, in some states there is no legal back up for the SIFPGs. The arrangements for benefit sharing between JFM Committees and village communities, and the terms and conditions of forest land leased to JFM Committees also varies from state to state. As such, there is a pressing need to unify policy in at least the more important aspects of JFM structure across the country in order to achieve better coordination among the states and for efficient monitoring and evaluation.

Marketing of forest products is often effected by institutional impediments. For example, in several states, provisions of the Forest Law impose restrictions on felling, transportation and sale of timber ; in Andhra Pradesh, the Forest Produce Transit Rules of 1970 regulate the transit of forest produce into, from or within any area in the state. Under the JFM programme too, the JFM Committee has to get permission to fell and transport timber, which is often a time consuming process. On the other hand, the poor infrastructure and the lackadaisical approach to marketing of forest produce results in non-remunerative prices for the products. Marketing of forest produce in India is either fone by state agencies such as Forest Development Corporations marketing federations such as the Tribal Marketing Federation of India, or through the alternative markets controlled by middlement and intermediaries. In most cases, beneficiaries do not get a remunerative price.

Lack of appropriate marketing infrastructure for forest produce has always been a serious constraint in the Indian forestry sector, in contrast to the well-developed marketing infrastructure that exists for agricultural produce in the country. The JFM programme in India is emphasizing production of NWFPs as they provide a regular income for JFM Committees. For this system to function efficiently, however, it is necessary to make JFM Committees self-sufficient for their day-to-day operations, rather than depending on government and NGOs. It is important to note that the marketing of NWFPs varies between the states in India in terms of "market structure, marketing channels, price, scope for value added processing...depending on the nature of the products and their legal status...." (Government of India, undated). Given this context, the marketing strategies for NWFPs need to be radically revamped so as to fulfill the objectives of JFM. It would be a mistake for policy makers to watch and wait rather than to resolve this important issue, as in many states JFM is still in its infancy and marketing has not emerged as a serious constraint.

Conclusions

The policy directive issued by the government of India from time to time since the announcement of the National Forest Policy of 1988 indicate the existence of a 'learning curve' in the process of implementation of JFM in India. This means that with the passage of time, policy makers have realized the need for new policy measures for expanding JFM programmes together with the need for overcoming the constraints in their implementation.

Furthermore, the present analysis of forest policies on participatory forest management in India reveals the government of India's determination of the successful implementation and expansion of JFM throughout the country. Nonetheless, such a resolve is insufficient on its own without the collective effort of all stakeholders, encompassing governmental and non-governmental organizations. Here it is important to note that some visionary bureaucrats in India, in conjunction with strong political support, have played a positive role in the policy formulation and implementation stages of the JFM programme.

Persistent review of the National Forest Policy of 1988 is evidence of maturity in the forest policy-making process in India. Policy directives for JFM have been developed on the principle of 'analysis for policy' and are based on thorough and continuous research of relevant subject matter. This is indicative of the role played by social scientists in the development of a participatory forest management model. Their efforts have allowed the programme to mature significantly by injecting a better understanding of the sociology of participatory forest management, in turn influencing the thinking of forestry professionals (Gilmour & Fisher 1998).

Development of any successful doctrine is likely to be beset with failures also. The analysis presented in this paper has revealed that the JFM programme in India currently confronts several teething problems inherited from the past. It is also facing the range of challenges that normally crop up when an institution begins to take root. A sound forest policy is necessary in order to overcome these issues and challenges. Ensuring equity in representation and participation of the marginalized classes (such as the poor and women), equitable benefit sharing between the Forest Department and village communities and within the communities themselves, are issues which, if not addressed now, could jeopardize the future progress of participatory forest management. Now the time has also come to streamline the plethora of forest policies, rules and regulations inherited from the colonial period, as well as those formulated since independence, in view of JFM as a major forest management model. On the technical side, emphasis needs to be placed on the formulation of new and effective silvicultural practices to increase the productivity of forests managed by village communities for the enhanced harvest of NWFPs. These corrective measures will synchronize the practices with the basic philosophy and objectives of participatory forest management. To sum up, these issues and challenges to the basic philosophy and objectives of participatory forest management. To sum up, these issues and challenges to the JFM programme in India require in-depth study and analysis for their expeditious resolution.

The government also must not dilute its focus on farm forestry projects on private lands, as has been reported in a recent study (Government of India 2001 b). This is important for the development of the forestry sector in India, as JFM and farm forestry programmes are complementary to each other.

In conclusion, it seems reasonable to predict that all forests in India will eventually be managed under the principles of JFM, given the government's resolve to expand the programme to good forests, rather than keeping it confined to degraded forests only. The recent policy initiatives on participatory forest management by the government of India have set an example to be emulated by other countries in South Asia as well as other parts of the World.

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3.11 Social forestry in India

The term 'Social forestry' first used in 1973 by The National Commission on Agriculture, Government of India. It was then that India embarked upon a social forestry project with the aim of taking the pressure off the forests and making use of all unused and fallow land.

Social forestry programme

Government forest areas that are close to human settlement and have been degraded over the years due to human activities needed to be afforested. Trees were to be planted in and around agricultural fields. Plantation of trees along railway lines and roadsides, and river and canal banks were carried out. They were planted in village common land, Government wasteland and Panchayat land.

Involvement of common people

Social forestry also aims at raising plantations by the common man so as to meet the growing demand for timber, fuel wood, fodder, etc, thereby reducing the pressure on the traditional forest area. This concept of village forests to meet the needs of the rural people is not new. It has existed through the centuries all over the country but it was now given a new character.

With the introduction of this scheme the government formally recognised the local communities' rights to forest resources, and is now encouraging rural participation in the management of natural resources. Through the soical forestry scheme, the government has involved community participation, as part of a drive towards afforestation, and rehabilitating the degraded forest and common lands.

Need of social forestry

This need for a social forestry scheme was felt as India has a dominant rural population that still depends largely on fuelwood and other biomass for their cooking and heating. This demand for fuelwood will not come down but the area under forest will reduce further due to the growing population and increasing human activities. Yet the government managed the projects for five years then gave them over to the village panchayats (village council) to manage for themselves and generate products or revenue as they saw fit.

Types

Social forestry scheme can be categorized into groups; farm forestry, community forestry, extension forestry and agroforestry.

Farm forestry

At present in almost all the countries where social forestry programmes have been taken up, both commercial and non commercial farm forestry is being promoted in one form or the other. Individual farmers are being encouraged to plant trees on their own farmland to meet the domestic

needs of the family. In many areas this tradition of growing trees on the farmland already exists. Non-commercial farm forestry is the main thrust of most of the social forestry projects in the country today. It is not always necessary that the farmer grows trees for fuelwood, but very often they are interested in growing trees without any economic motive. They may want it to provide shade for the agricultural crops; as wind shelters; soil conservation or to use wasteland.

Community forestry

Another scheme taken up under the social forestry programme, is the raising of trees on community land and not on private land as in farm forestry. All these programmes aim to provide for the entire community and not for any individual. The government has the responsibility of providing seedlings, fertilizer but the community has to take responsibility of protecting the trees. Some communities manage the plantations sensibly and in a sustainable manner so that the village continues to benefit. Some others took advantage and sold the timber for a short-term individual profit. Common land being everyone's land is very easy to exploit. Over the last 20 years, large-scale planting of Eucalyptus, as a fast grwoing exotic, has occurred in India, making it a part of the drive to reforest the subcontinent, and create an adequate supply of timber for rural communities under the augur of 'social forestry'.

Extension forestry

Planting of trees on the sides of roads, canals and railways, along with planting on wastelands is known as 'extension' forestry, increasing the boundaries of forests. Under this project there has been creation of a wood lots in the village common lands, government wastelands and Panchayat lands.

Schemes for afforesting the degraded government forests that are close to villages are being carried out all over the country.

Agroforestry

In agroforestry, silvicultural practices are combined with agricultural crops like leguminous crop, along with orchard farming and live stock ranching on the same piece of land. In lay man language agroforestry could be understood as growing of forest tree along with agriculture crop on the same piece of land.

In a more scientific way agroforestry may be defined as a sustainable land use system that maintains or increases the total yield by combing food crop together with forest tree and live stock ranching on the same unit of land. using management practices that takes care of the social and culture characteristic of the local people and the economic and ecological condition of the local area.

Objectives of social forestry and environment wing

Social forestry, schemes that have been started all over the country have made a considerable difference in overall forest cover in a short time. Afforestation outside the conventional forest area for the benefit of rural and urban communities. The main objective is to :–

1. Improve the environment for protecting agriculture from adverse climatic factors,
2. Increase the supply of wood fuel for domestic use, small timber for rural housing, fodder for livestock, and minor forest produce for local industries
3. Increase the natural beauty of the landscape; create recreational forests for the benefit of rural and urban population,
4. Provide jobs for unskilled workers and
5. Land rehabilitation
6. Finally, its object is to raise the standard of living and quality of life of the rural and urban people.

Mission

- To carry out a need based and time bound programme of afforstation with special emphasis on fuel wood and fodder development on all degraded and denuded lands/forests.
- Afforestation of abandoned Jhum lands and mined areas.
- Linear strip plantation of fast growing species on sides of public roads, rivers, streams and irrigation canals.
- Afforestation on unutilized lands under State/Corporate, institutional or private ownership.
- Green belts in urban/industrial areas.
- Shelter belt (generally more extensive than the wind breaks) for the purpose of shelter from wind and sun covering areas larger than a single farm on a planned pattern.
- Farm forestry in the form of raising rows of trees on bund or boundaries of fields and individual trees in private agricultural land as well as creation of wind breaks round a farm or orchard by raising one or two lines of trees.
- Raise flowering trees and shrubs mainly to serve as recreation forests for the urban and rural population.
- Elicit people's participation involving women and young people in conservation of forests, wildlife and environment.
- Environmental awareness generation and celebration of vanamahotsava, environment day, wildlife week etc.

Agroforestry :

Definition

1) Agroforestry is any sustainable land-use system that maintains or increases total yields by combining food crops (annuals) with tree crops (perennials) and/or livestock on the same unit of land, either alternately or at the same time, using management practices that suit the social and cultural characteristics of the local people and the economic and ecological conditions of the area.

2) Agroforestry is a collective name for a Land-use system and technology whereby woody

perennials are deliberately used on the same land management unit as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence. In an agroforestry system there are both ecological and economical interactions between the various components.

Difference between Social Forestry and Agroforestry

Social forestry is defined as "Forestry outside the conventional forests which primarily aim at providing continuous flow of goods and services for the benefit of people. This definition implies that the production of forest goods for the needs of the local people is Social forestry. Thus social forestry aims at growing forests of the choice of the local population. Shah (1985) stated that Conceptually Social forestry deals with poor people to produce goods such as fuel, fodder etc. to meet the needs of the local community particularly underprivileged section.

Different Terminologies for Describing Tree Cultivation in non-forest Areas

1) **Farm Forestry :** Farm forestry is the name given to programmes which promote commercial tree growing by farmers on their own land. Farm forestry was defined by NCA (1976) as the practice of forestry in all its aspects in and the around the farms or village lands integrated with other farm operations.

2) **Extension Forestry :** It is the practice of forestry in areas devoid of tree growth and other vegetation situated in places away from the conventional forest areas with the object of increasing the area under tree growth. It includes the following.

a) **Mixed forestry**

It is the practice of forestry for raising fodder grass with scattered fodder trees, fruit trees and fuel wood trees on suitable wastelands, panchayat lands and village commons

b) **Shelterbelts**

Shelterbelt is defined as a belt of trees and or shrubs maintained for the purpose of shelter from wind, sun, snow drift, etc.

c) **Linear Strip Plantations**

These are the pantations of fast growing species on linear strips of land.

3) **Rehabilitation of Degraded forests :** The degraded area under forests needs immediate attention for ecological restoration and for meeting the socio economic needs of the communties living in and around such areas.

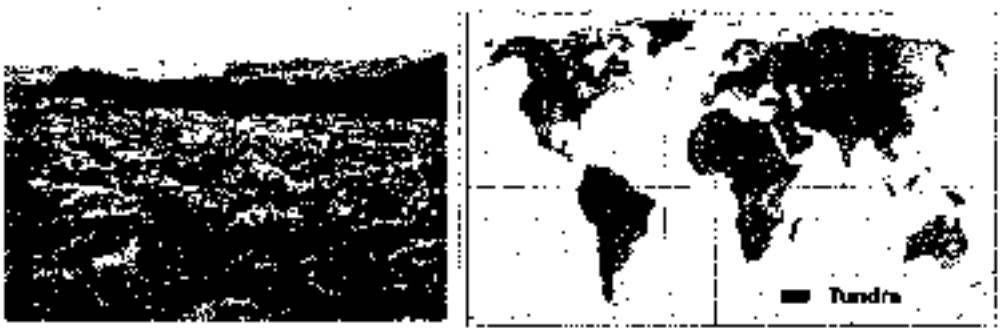
4) **Recreation Forestry :** It is the practice of forestry with the object of raising flowering trees and shrubs mainly to serve as recreation forests for the urban and rural population. This type of forestry is also known as **Aesthetic forestry** which is defined as the practice of forestry with the object of developing or maintaining a forest of high scenic value

3.12 Biomes of the world

Biomes are climatically and geographically defined areas of ecologically similar climatic conditions such as communities of plants, animals, and soil organisms, and are often referred to as ecosystems. Biomes are defined by factors such as plant structures (such as trees, shrubs, and grasses), leaf types (such as broadleaf and needleleaf), plant spacing (forest, woodland, savanna), and climate. Unlike ecozones, biomes are not defined by genetic, taxonomic, or historical similarities. Biomes are often identified with particular patterns of ecological succession and climax vegetation (quasi-equilibrium state of the local ecosystem). An ecosystem has many biotopes and a biome is a major habitat type. A major habitat type, however, is a compromise, as it has an intrinsic inhomogeneity.

Map of Biomes

(a) The Tundra



The word **tundra** derives from the Finish word for barren or treeless land. The tundra is the simplest biome in terms of species composition and food chains.

Vegetation : *Lichens*, mosses, *sedges*, *perennial forbs*, and *dwarfed shrubs*, (often *health*, but also birches and willows).

Growthforms : typical are ground-hugging and other warmth-preserving forms including :

- tussock-forming graminoids
- *mats or cushion plants*, often evergreen members of the health family
- *rosettes*
- dwarf shrubs, some of which are deciduous in habit

Climate : The high latitude conditions of Koeppen's ET climate type that impact life in this biome include

- extremely short growing season (6 to 10 weeks)
- long, cold, dark winters (6 to 10 months with mean monthly temperatures below 32° F or 0° C.)
- low precipitation (less than five inches/year) coupled with strong, drying winds. Snowfall is actually advantageous to plant and animal life as it provides an insulating layer on the ground surface.

Edaphic controls : Permafrost, not cold temperatures *per se*, is generally believed to be what prevents tree growth. Furthermore, freeze-thaw activity, a thin active layer, and solifluction during the warmer months contribute to strong controls on vegetation patterns and create a mosaic of microhabitats and plant communities.

Soil : No true soil is developed in this biome due to the edaphic factors mentioned above.

Fauna : Strategies evolved to withstand the harsh conditions of the tundra can be divided among those species that are resident and those that are migratory.

- Among the small number of bird (e.g., prarmigan) and mammal (e.g., muskox, arctic hare, arctic fox, musk ox) species that reside year-round on the tundra one commonly finds :

  Morphological adaptations

  - large, compact bodies following Bergmann's and Allen's rules
  - a thick insulating cover of feathers or fur
  - pelage and plumage that turns white in winter, brown in summer

  Physiological adaptations

  - ability to accumulate thick deposits of fat during the short growing season. Fat acts as insulation and as a store of energy for use during the winter, when animal species remain active.

  Population adaptations

  - cyclical fluctuations in population size, best seen perhaps in the lemming, a small rodent which is the major herbivore in the tundra's simple food chain. Predator

populations and plant populations respond in kind to the peaks and crashes of the herbivore populations.

- Migratory species such as waterfowl, shorebirds and caribou adapt to the tundra by avoiding the most severe conditions of winter. Each year at the end of the short growing season they move southward into the boreal forest or beyond, but return to the tundra to breed.

Aperiodic emigration from the tundra is exhibited by the snowy owl during those years that the lemming populations have crashed. Those winters see snowy owl irruptions as far south as Virginia. Most owls are found with empty stomachs and do not survive to return to the arctic.

Distribution : The tundra biome is restricted to the high latitudes of the northern hemisphere in a belt around the Arctic Ocean. Many of its species, both plant and animal, have circumpolar distribution areas.

Within the tundra biome a latitudinal zonation of communities is realized :

- **High Arctic Tundra :** eseentially confined to the islands of the Arctic Ocean and characterized by scattered lichens and mosses on care rock surfaces and perennial forbs growing in protected crannies among sharp, ice-fractured rock debris.
- **Middle Arctic Tundra :** restricted to the Arctic Coastal plain where level terrain, a thin active layer, and freeze and thaw result in *patterned ground*, or rock polygons. The sorting of particles by feeze-thaw activity results in a waterlogged center to the polygons, a microhabitat conducive to sphagnum moss and sedges; and an outer ring that is drier and provides a microhabitat favorable to forbs and some dwarf heaths.
- **Low Arctic Tundra :** the majority of the tundra lies on better drained slopes with greater depth to permafrost than is encountered on the Arctic coastal plain. Here there is a greater frequency of woody shrubs : willow, birch, and various berry-bearing members of the heath family. Along streams willows and alders may be 10 feet high. On south-facing slopes needleleaf evergreen trees (spruce and fir) are established and represent the northernmost extensions of the great boreal forest to the south. (Such areas whee two biomes interdigitate are known as *ecotones*.)

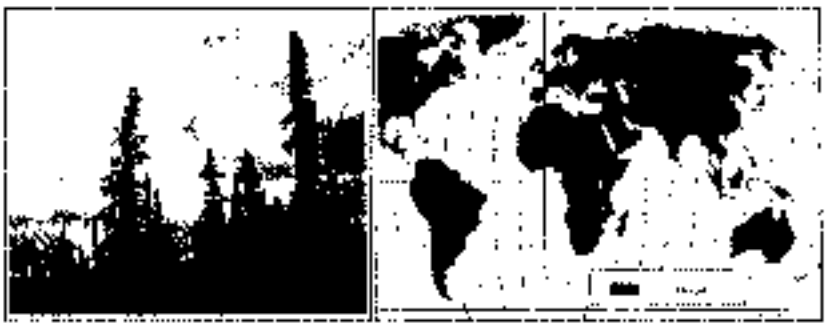
Alpine Tundra

Many tundra species can be found at high elevations in the mountains of the northern hemisphere. The *arctic-alpine lifezone* of high elevations experiences a different climate–in terms of daylength and seasons–than does the true tundra of the Arctic. However, thin soils and cold temperatures create an environment that many middle latitude trees cannot tolerate and thus alow tundra species to invade and thrive.

In the tropics, the climate of very high elevations is extremely different than that of the Arctic. Freeze-thaw, instead of following a seasonal cycle, follows a diurnal cycle. Aslo, the peaks

are isolated from the Arctic tundra. Often endemic species derived from a tropical flora or from Antarctic flora create the unique communities of tropical high mountain tops. See *Tropical Lifezones* for additional information and some photographs of the giant lobelias and groundsels of Mt. Kenya.

(b) Taiga or Boreal Forest



Introduction : The taiga or boreal forest exists as a nearly continuous belt of coniferous trees across North America and Eurasia. Overlying formerly glaciated areas and areas of patchy permafrost on both continents, the forest is mosaic of successional and subclimax plant communities sensitive to varying environmental conditions. Taiga is the Russian name for this forest which covers so much of that country. However, the term is used in North America as well.

Climate : The taiga corresponds with regions of subarctic and cold continental climate (Koeppen's Dfc, Dfd, and Dwd climate types). Long, severe winters (up to six months with mean temperatures below freezing) and short summers (50 to 100 frost-free days) are characteristic, as is a wide range of temperatures between the lows of winter and highs of summer. For example, Verkhoyansk, Russia, has recorded extremes of *minus* 90° F and *plus* 90°F. Mean annual precipitation is 15 to 20 inches, but low evaporation rates make this a humid climate.

Vegetation : Needleleaf, coniferous (gymnosperm) trees are the dominant plants of the taiga biome. A very few species in four main genera are found : the evergreen **spruce** (*Picea*), **fir** (*Abies*), and **pine** (*Pinus*), and the deciduous **larch** or **tamarack** (*Larix*). In North America, one or two species of fir and one or two species of spruce are dominant. Across Scandanavia and western Russia the Scots pine is a common component of the taiga.

Broadleaf deciduous trees and shrubs are members of early successional stages of both primary and secondary succession. Most common are alder (*Alnus*), birch (*Betula*), and aspen (*Populus*).

Growthforms : The conical or spire-shaped needleleaf trees common to the taiga are adapted to the cold and the physiological drought of winter and to the short-growing season :

- Conical shape - promotes shedding of snow and prevents loss of branches.

- Needleleaf - narrowness reduces surface area through which water may be lost (transpired), especially during winter when the frozen ground prevents plants from replenishing their water supply. The needles of boreal conifers also have thick waxy coatings–a waterproof cuticle–in which stomata are sunken and protected from drying winds.

- Evergreen habit - retention of foliage allows plants to photosynthesize as soon as temperatures permit in spring, rather than having to waste time in the short growing season merely growing leaves. [***Note:*** Deciduous larch are dominant in areas underlain by nearly continuous permafrost and having a climate even too dry and cold for the waxy needles of spruce and fir.]

- Dark color - the dark green of spruce and fir needles helps the foliage absorb maximum heat from the sun and begin photosynthesis as early as possible.

Soil : Podzolization occurs as a result of the acid soil solution produced under needleleaf trees. The main soil order associated with the taiga is **spodosol**.

Subclimaxes : Edaphic conditions result in sometimes extensive, persistent patches of vegetation other than spruce and fir.

1. **bogs (muskeg)** occur in poorly drained, glacial depressions. Sphagnum moss forms a spongy mat over ponded water. Growing on this mat are species of the tundra such as cottongrass and shrubs of the health family. Black spruce and larch ring the edge.

2. **Pine forests**, in North America dominated by the jack pine (*Pinus banksiana*), occur on sandy outwash plains and former dune areas. These are low nutrient, droughty substrates not tolerated by spruce and fir.

3. **Larch forests** claim the thin, waterlogged substrate in level areas underlain with permafrost. These forests are open with understories of shrubs, mosses and lichens. In Alaska stands of *Larix larichina* are localized phenomena, but in Siberia east of the Yenesei River the extreme continentality and nearly continuous permafrost give rise to vast areas dominated by *Larix dihurica*.

Fauna : Fur-bearing predators like the lynx (*Felis lynx*) and various members of the weasel family (e.g., wolverine, fisher, pine martin, mink, ermine, and sable) are perhaps most characteristic of the boreal forest proper. The mammalian herbivores on which they feed include the snowshoe or varying hare, red squirrel, lemmings, and voles.

Large herbivores are more closely associated with successional stages where there is more nutritious browse available and include elk or wapiti (*Cervus elaphus*, known as red deer in Europe) and moose (*Alces alces*, known as elk in Europe). The beaver (*Castor canadensis*), on which the early North American fur trade was based, is also a creature of early successional communities, indeed its dams along streams create such habitats.

Among birds, insect-eaters like the wood warblers are migratory and leave after the breeding season. Seed-eaters (e.g., finches and sparrows) and omnivores (e.g., ravens) tend to be year-round residents. During poor cone years, normal residents like the evening grosbeak, pine siskin, and red crossbill leave the taiga in winter and may be seen at bird feeders here in Virginia.

Distribution patterns within the boreal forest : The boreal is restricted to the northern hemisphere. It is circumpolar in distribution, as are many of the species which comprise it and even more of the genera. In general, plants have different species represented on North America and Eurasia; the mammals of both continents tend to be conspecific.

There are latitudinal zones within the forest. Running north to south, one finds

- the tundra/taiga ecotone
- an open coniferous forest (the section most properly called taiga)
- the characteristic closed-canopy needleleaf evergreen boreal forest; and
- a mixed needleleaf evergreen-broadleaf deciduous forest, the ecotone with the Temperate Broadleaf Deciduous Forest. In the Us, this southern ecotone is dominated by white pine (*Pinus strobus*), sugar maple (*Acer saccharum*), and American beech (*Fagus americanus*).

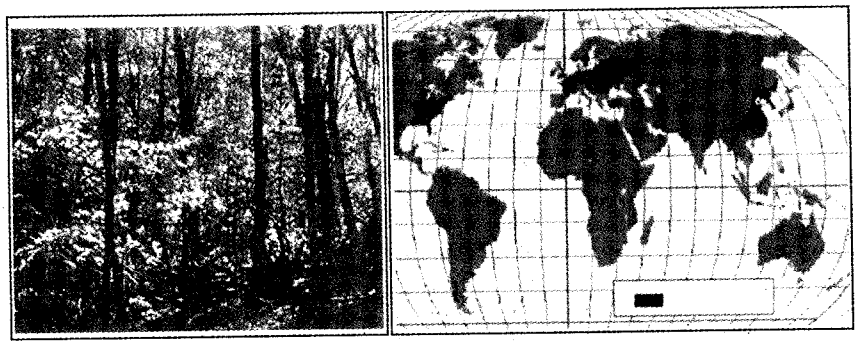
Alpine expressions of the biome : In *Merriam's Life Zones*, the Hudsonian and the Canadian zones correspond with the Boreal Forest

In North America, several variants of the boreal forest occur in the mountains of the West.

- In the Pacific Northwest, what amounts to a temperate rainforest is dominated by needleleaf species such as Douglas fir, western hemlock, and other giants. This forest type is the center of a major controversy regarding timber operations in old growth forests.
- On the windward (western) slopes of the Sierra Nevada at elevations between 4,000 and 8,000 feet, the tall western conifers are joined by the magnificent giant sequoia (*Sequoia giguntea*). The specimen named General Sherman is some 3,800 years old, 272 feet tall, and has a diameter of 37 feet. The congener of this sequoia, the redwood (*S. sempervirens*) grows along the northern California coast. Their closest relative is the Dawn Redwood, a deciduous conifer of the genus *Metasequoia* from China.
- In the Rocky Mountains, where fire is an important part of the environment, lodgepole pines (*Pinus contorta*) form nearly pure, single-aged stands. The great fire of Yellowstone National Park demonstrated once again the association of this species and its ecosystem with repeated burns.
- Along the Appalachian Mountains in eastern North America the boreal forest of eastern Canada, dominated by red spurce (*Picea rubens*) and balsam fir (*Abies balsamea*), extends southward with little change in species composition until Virginia. The southern limit of balsam fir occurs in Shenandoah National

Park; southward to the Great Smokies, on isolated mountain tops, is found Fraser fir (*A. fraseri*).

(c) Temperate Broadleaf Deciduous Forest



Introduction. The Temperate Broadleaf Deciduous Forest (TBDF)–especially in eastern North America, where is remains most intact–is known for the turning of the colors of its leaves to brilliant reds, oranges, and golds in autumn. The shortening days of fall stimulate the plants to withdraw chlorophyll from their leaves, allowing a brief but beautiful display of other pigments before the leaves are shed completely and plants enter an extended period of dormancy.

Climate : Associated with warmer continental and humid subtropical climates (Dfa, Cfa, and–in Europe, Cfb). There is an approximately 6 month growing season. The 20 to 60 inches of precipitation is distributed evenly throughout the year. The non-growing season is due to temperature-induced drought during the cold winters.

Vegetation : Many of the same genera, previously part of an **Arcto-Tertiary Geoflora**, are common to all three of the disjunct northern hemisphere expressions of this biome. Included among these genera are *Quercus* (oak), *Acer* (maple), *Fagus* (beech), *Castanea* (chestnut), *Carya* (hickory), *Ulmus* (elm), *Tilia* (basswood or linden), *Juglans* (walnut), and Liquidamber (sweet gum). Different species of these genera occur on each continent.

Structure and Growthforms : Five layers are recognized :

1. a tree stratum, 60 - 100 feet high, dominated regionally by various combinations of the genera listed above;
2. a small tree or sapling layer, with not only younger specimens of the tall trees with species limited to this layer such as (in Virginia) Allegheny serviceberry or shadbush, sourwood, dogowood, and redbud;
3. a shrub layer often with members of the health family such as rhododendron, azaleas, mountain laurel, and huckleberries,
4. an herb layer of perennial forbs that bloom primarily in early spring; and
5. a ground layer of lichens, clubmosses, and true mosses. Lichens and mosses also grow on the trunks of trees.

Lianas such as wild grape, poison ivy, and Virginia creeper climb the trees to flower and fruit high in the forest canopy

Soil : Brown forest soils (**alfisols**, in the American soil taxonomy) develop under the TBDF. Broadleaf trees tend to be nutrient-demanding and their leaves blind the major nutrient bases. Thus the litter under this forest is not as acidic as under needleleaf trees and aluminum and iron are not mobilized from the A horizon. The autumn leaf fall provides for an abundant and rich humus which begins to decay rapidly in spring just as the growing season begins. The humus content gives both A and B horizons a brown color. [Until John Deere's invention of the steel plow in the 1800s and the subsequent ability to break the prairie sod, the alfisols were considered the most fertile, most easily worked, and most easily cleared of northern hemisphere temperate zone soils. Many have been under continuous cultivation since the Neolithic.]

Ultisols replace alfisols in the southeastern US, where the older soils of unglaciated regions have been weathered to a much greater degree and are more completely leached than the younger soils to the north. Distinctive red or yellow subsoils have developed under the warmer climate. Ultisols are generally less fertile than alfisols and in the southeast were frequently further degraded under plantation and subsistence agriculture in both the colonial and post-colonial periods.

Subclimaxes : On sandy substrates, pines replace broadleaf species. Hence the New Jersey pine barrens, the pineywoods of the Deep South, and the tall (long-needled) pines of Georgia and other areas of the Atlantic Coastal Plain. On waterlogged sites in more northerly latitudes, bogs develop. In the south one finds instead pine savannas and bald cypress swamps.

Fauna : Characteristic members of the fauna are either mast-eaters (nut and acorn feeders) or omnivores. Mammals show adaptations to an arboreal life; a few hibernate during the winter months.

- North American herbivores include white-tail deer, gray squirrel, and chipmunk.
- Omnivores include raccoon, opossum, skunk, and black bear.
- Carnivores have been largely eliminated through the deliberate effort of humans but should include timber wolves, mountain lions, and bobcats. The coyote, native to the western grasslands and deserts, has recently dispersed east and taken over the niche of its departed cousin, the timber wolf.

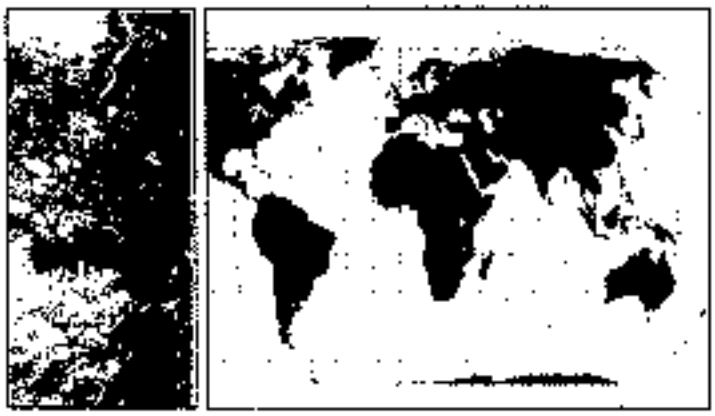
Resident bird species also tend to be seed-eaters or omnivores. Many, like the several species of woodpeckers and the chickadees, are cavity-nesters. The loud, conspicuous blue jay is a major agent in the dispersal of oaks onto abandoned farmland and pastures. Migratory species tend to be insectivorous and include many so-called neotropical migrants, including warblers, wrens, thrushes, tanagers, and hummingbirds.

Distribution : The TBDF occurs in three major, disjunct expressions in western and central Europe; eastern Asia, including Korea and Japan; and eastern North America.

- In Europe, a species-poor forest reflects widespread extinctions during the Pleistocene. Oaks, beeches, and elms dominate. Most of the forest was cleared for agriculture, with remnants surviving only in some royal hunting preserves.
- The TBDF of China is known primarily from the fossil record; intensive agriculture has caused this region to be cleared of natural vegetation for at least 4,000 years. Japan has a largely artificial forest, but in the mountains of Korea the forest is more or less intact and fall foliage is reminiscent of New England's.
- Almost all the forests of eastern North America are second growth, but they preserve the world's greatest diversity of TBDF flora and fauna. This is especially true of the unglaciated Appalachian Plateau of eastern Kentucky and Tennessee and western North Carolina and Virginia. The Great Smoky Mountains have been designated a world biosphere reserve to help protect the rich assortment of species.

Southern hemisphere expressions of the biome : Regions of humid subtropical climate occur in the southern hemisphere, but their vegetation and flora differ from that of the northern hemisphere TBDF biome. An evergreen mixed (needleleaf-broadleaf) forest characterized, in part, by Gondwanan relict gymnosperms and angiosperms occurs instead.

(d) Tropical Broadleaf Evergreen Forest : The Rainforest



Introduction. The tropical rainforest is earth's most complex biome in terms of both structure and species diversity. It occurs under optimal growing conditions: abundant precipitation and year round warmth. There is no annual rhythm to the forest; rather each species has evolved its own flowering and fruiting seasons. Sunlight is a major limiting factor. A variety of strategies have been successful in the struggle to reach light or to adapt to the low intensity of light beneath the canopy.

Climate : (Koeppen's Af and Am climate types) Mean monthly temperatures are above 64 °F, precipitation is often in excess of 100 inches a year. There is usually a brief season of reduced precipitation. In monsoonal areas, there is a real dry season, but that is more than compensated for with abundant precipitation the rest of the year.

Vegetation : A vertical stratification of three layer of trees is apparent. These layers have been identified as A, B and C layers :

- A layer: the emergents. Widely spaced trees 100 to 120 feet tall and with umbrella-shaped canopies extend above the general canopy of the forest. Since they must contend with drying winds, they tend to have small leaves and some species are deci-duos during the brief dry season.
- B layer: a closed canopy of 80 foot trees. Light is readily available at the top of this layer, but greatly reduced below it.
- C layer: a closed canopy of 60 foot trees. There is little air movement in this zone and consequently humidity is constantly high.
- Shrub/sapling layer: Less than 3 percent of the light intercepted at the top of the forest canopy passes to this layer. Arrested growth is characteristic of young trees capable of a rapid surge of growth when a gap in canopy above them opens.
- Ground layer: sparse plant growth. Less than 1 percent of the light that strikes the top of the forest penetrates to the forest floor. In such darkness few green plants grow. Moisture is also reduced by the canopy above: one third of the precipitation is intercepted before it reaches the ground.

Growthforms : Various growthforms represent strategies to reach sunlight :

1. **Epiphytes :** the so-called air plants grow on branches high in the trees, using the limbs merely for support and extracting moisture from the air and trapping the constant leaf-fall and wind-blown dust. Bromeliads (pineapple family) are especially abundant in the neotropics; the orchid family is widely distributed in all three formations of the tropical rainforest. As demonstration of the relative aridity of exposed branches in the high canopy, epiphytic cacti also occur in the Americas.
2. **Lianas :** woody vines grow rapidly up the tree trunks when there is a temporary gap in the canopy and flower and fruit in the tree tops of the A and B layers. Many are deciduous.
3. **Climbers :** green-stemmed plants such as philodendron that remain in the understory. Many climbers, including the ancestors of the domesticated yams (Africa) and sweet potatoes (South America), store nutrients in roots and tubers.
4. **Stranglers :** these plants begin life as epiphytes in the canopy and send their roots downward to the forest floor. The fig family is well represented among stranglers.
5. **Heterotrophs :** non-photosynthetic plants can live on the forest floor.
    - o **Parasites** derive their nutrients by tapping into the roots or stems of photosynthetic species. *Rafflesia arnoldi*, a root parasite of a liana, has the world's largest flower, more than three feet in diameter. It produces an odor similar to rotting flesh to attract pollinating insects.
    - o **Saprophytes** derive their nutrients from decaying organic matter. Some orchids employ this strategy common to fungi and bacteria.

Common characteristics of tropical trees. Tropical species frequently possess one or more of the following attributes not seen in trees of higher latitudes.

- **Buttresses :** many species have broad, woody flanges at the base of the trunk. Originally believed to help support the tree, now it is believed that the buttresses channel stem flow and its dissolved nutrients to the roots.
- **Large leaves** are common among trees of the C layer. Young individuals of trees destined for the B and A layers may also have large trees. When the reach the canopy new leaves will be smaller. The large leaf surface helps intercept light in the sun-dappled lower strata of the forest.
- **Drip tips** facilitate drainage of precipitation off the leaf to promote transpiration. They occur in the lower layers and among the saplings of species of the emergent layer (A layer).

Other characteristics that distinguish tropical species of trees from those of temperate forests include

- Exceptionally **thin bark**, often only 1-2 mm thick. Usually very smooth, although sometimes armed with spines or thorns.
- **Cauliflory**, the development of flowers (and hence fruits) directly from the trunk, rather than at the tips of branches.
- **Large fleshy fruits** attract birds, mammals, and even fish as dispersal agents.

Soil : Oxisols, infertile, deeply weathered and severely leached, have developed on the ancient Gondwanan shields. Rapid bacterial decay prevents the accumulation of humus. The concentration of iron and aluminum oxides by the laterization process gives the oxisols a bright red color and sometimes produces minable deposits (e.g., bauxite). On younger substrates, especially of volcanic origin, tropical soils may be quite fertile.

Subclimaxes : Distinct communities (varzea) develop on floodplains. Jungles may line rivers where sunlight penetrates all layers of the forest. Where forests have long been cleared and laterites have developed to cause season waterlogging of the substrate, tropical grasslands and palm savannas occur.

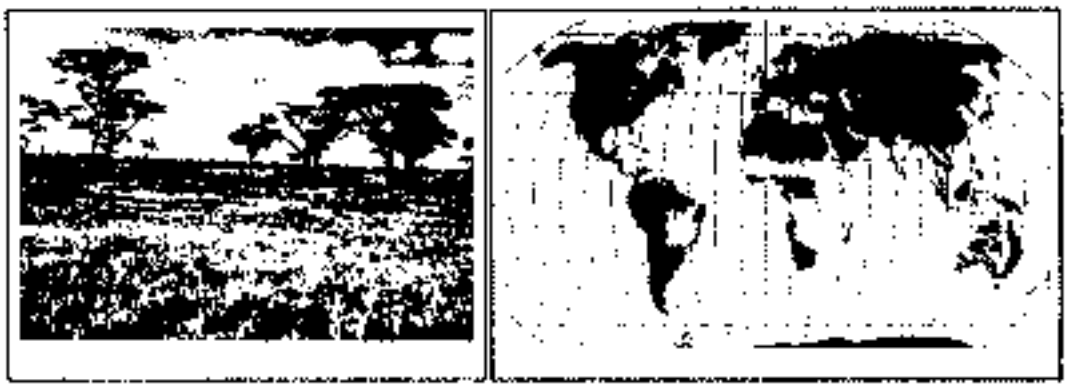
Fauna : Animal life is highly diverse. Common characteristics found among mammals and birds (and reptiles and amphibians, too) include adaptations to an arboreal life (for example, the prehensile tails of New World monkeys), bright colors and sharp patterns, loud vocalizations, and diets heavy on fruits.

Distribution of biome : The tropical rainforest is found between 10 °N and 10 ° S latitude at elevations below 3,000 feet. There are three major, disjunct formations :

- Neotropical (Amazonia into Central America)
- African (Zaire Basin with an outlier in West Africa; also eastern Madagascar)
- Indo- Malaysian (west coast of India, Assam, southeast Asia, New Guinea and Queensland, Australia.

The species composition and even genera and families are distinct in each. They also differ from species of temperate forests. Species diversity is highest in the extensive neotropical forest; second in the highly fragmented Indo-Malaysian formation; and lowest in Africa. Where 5 to a maximum of 30 species of tree share dominance in the Temperate Broadleaf Deciduous Forest, there may be 40 to

(e) Tropical Savannas



Introduction. Tropical savannas or grasslands are associated with the tropical wet and dry climate type (Koeppen's Aw), but they are not generally considered to be a climatic climax. Instead, savannas develop in regions where the climax community should be some form of seasonal forest or woodland, but edaphic conditions or disturbances prevent the establishment of those species of trees associated with the climax community. Seasonal forests of the tropics are also widespread and vary along a latitudinal/moisture gradient between the tropical broadleaf evergreen forest of the equatorial zone and the deserts of the subtropics.

The word savanna stems from an Amerind term for plains which became Hispanicized after the Spanish Conquest.

The vegetation. Savannas are characterized by a continuous cover of perennial grasses, often 3 to 6 feet tall at maturity. They may or may not also have an open canopy of drought-resistant, fire-resistant, or browse-resistant trees, or they may have an open shrub layer. Distinction is made between tree or woodland savanna, park savanna, shrub savanna and grass savanna. Furthermore, savannas may be distinguished according to the dominant taxon in the tree layer: for example, palm savannas, pine savannas, and acacia savannas.

Climate. A tropical wet and dry climate predominates in areas covered by savanna growth. Mean monthly temperatures are at or above 64° F and annual precipitation averages between 30 and 50 inches. For at least five months of the year, during the dry season, less than 4 inches a month are received. The dry season is associated with the low sun period.

Soils. Soils vary according to bedrock and edaphic conditions. In general, however, laterization is the dominant soil-forming process and low fertility oxisols can be expected.

Regional expressions.

- **East African savannas** are typically, perhaps stereotypically, acacia savannas. Many survive in the famous game parks of Kenya and Tanzania, and also those of Zimbabwe, Botswana, South Africa, and Namibia. The savannas are actually a mosaic of communities controlled (and today managed) by fire and grazing pressures.
    - The famous **Serengeti Plains** in Tanzania are a grass savanna developed on droughty but nutrient-rich volcanic sands.
- The **Ilanos** of the Orinoco basin of Venezuela and Colombia are grass savannas maintained by the annual flooding of the Orinoco and Arauca rivers and their tributaries. The long periods of standing water inhibit the growth of most trees.
- Brazil's **cerrado** is an open woodland of short-stature, twisted trees. It is species-rich, second only to the tropical rainforest in plant diversity. There are many endemic species, and severral plants have adaptations to tolerate the high aluminum content of soils resulting from laterization on the ancient Gondwanan Shield of South America.
- The **pine savannas of Belize and Honduras**, in Central America, occur on sandy soils.

Savannas as subclimaxes.

1. **Edaphic Subclimaxes.**
    - Waterlogged conditions occur when the A-horizon of lateritic soils is exposed to the atmosphere. Alternating wet and dry seasons and baking by the sun create a brick-hand layer impermeable to water. This usually red hardpan is called a laterite (from the Latin for brick). During the rainy season, there is standing water above the hardpan for several months, preventing the establishment of most tree species. During the dry season, the laterite prevents penetration of roots, also inhibiting the growth of most trees. Several species of palms do tolerate these conditions and, along with grasses, occur above laterites.
    - Droughty substrates, such as quartz or volcanic sands, also inhibit the growth of most trees. The pine savannas of Central America are examples of savanna vegetation developed on droughty, low-nutrient conditions of quartz sands; the grass savanna of the Serengeti—with its herds of large mammals–is virtually treeless.
    - Low-nutrient soils. The cerrado of Brazil occupies a broad expanse of the Brazilian Highlands that, were it not for the low-nutrient level of the heavily-leached soils, would be occupied by a seasonal forest.
2. **Fire Subclimaxes.** Two groups of plants that are pre-adapted to survive fire become dominat in areas where burning is frequent and periodic. Such fires have both natural and human origins. The savannas of South east Asia are generally considered to be man-made.
    - Palms have the advantage of being monocots : their vascular bundles are scattered throughout the stem so that scorching of the outermost layer of the trunk will not

kill the plant. (Dicot trees, on the other hand, have their vascular bundles arranged around the outer, living part of their stems where they may be easily destroyed by fire.)

- Perennial grasses have underground stems or rhizomes and so their growth nodes are protected by the soil during a ground fire. Trees and shrubs–with renewal buds above the surface–are selected against by fire and the balance tips toward the grasses.

3. **Grazing subclimax.** Large mammals such as the elephant open woodlands by debarking the trees and by knocking them over. This opens the woodland to grass invasion and attracts a variety of grazing animals, including zebras, wildbeast, and the diverse antelopes of the Ethiopian province. Grazers will both eat and trample tree seedlings, inhibiting the regrowth of the woodland. Only well-armed species of shrubs and trees can establish themselves in the clearings, leading to thickets of thorny acacias. Protected in the thicket, some acacias and other thorny trees will grow to mature specimens.
    - Overgrazing : if a grass savanna is overgrazed, patches of bare ground willbe created. The grassland will no longer carry a ground fire and invasion by trees becomes possible. The bare ground will suffer from increased evaporation and a dry microhabitat quickly develops. Well-armed, drought-resistant species like the acacias tolerate both grazing and drought, so again an acacia savanna can become established.

Fauna. The world's greatest diversity (over 40 different species) of ungulates (hoofed mammals) is found on the savannas of Africa. The antelopes are especially divers and including eland, impalas, gazelles oryx, gerenuk, and kudu. Buffalo, wildebeest, plain zebra, rhinos, giraffes, elephants, and warthogs are among other herbivores of the African savanna. Up to sixteen grazing and browsing species may coexist in the same area. They divide the resources spatially and temporally; each having its own food preferences, grazing/browsing height, time of day or year to use a given area, and different dry season refugia.

The species-rich herbivore trophic level supports a diverse set of carnivores, including cats (lions, leopards, cheetahs, servals), dogs (jackals, wild dogs), and hyenas.

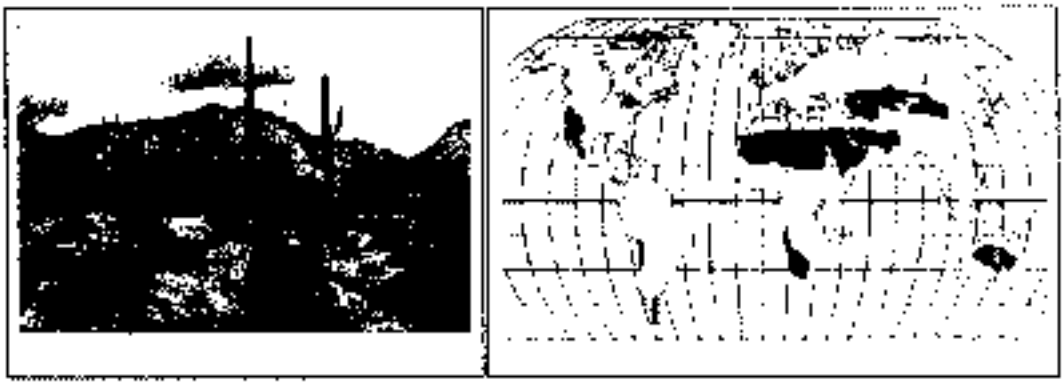
Most herbivorous mammals of the open savannas are herd animals, often organized into groups of females and their young with a single dominant male and groups of bachelor males.

In South America a distinct savanna fauna is not well-developed. The capybara, the large semi-aquatic rodent, is associated with the Ilanos, but is found elsewhere and in other vegetation types as well. Indeed, few if any neotropical mammals are restricted to the savannas. The highest diversity of mammals is found in the dry or seasonal forests. Similarly, most bird species are not restricted to savanna-type habitats.

Termites are especially abundant in the tropical savannas of the world, and their tall termitarias are conspicuous elements of the savanna landscape. These detrivores are important in soil-formation; their termitaria provide shelter for other animals; and they are the beginning of the food chain for

anteaters (endemics of the Neotropical zoogeographic province) and aardvarks and pangolins (Ethiopian endemics).

(f) Desertscrub



Introduction : Desert areas are rarely devoid of life. Instead, they abound with wonderfully adapted plants and animals that have evolved various mechanisms for tolerating or avoiding the extremes of aridity and temperature that might be encountered in their environment. Deserts develop under four distinct geographic conditions .

- Under zones of high atmospheric pressure associated with the subtropics and centered near 30° latitude. Air descending from the upper atmosphere at these latitudes causes evaporation to exceed precipitation. Much of the Sahara and the Australian desert can be associated with this phenomenon
- West coasts of continents between 20° and 30° latitude. In these latitudes, prevailing winds are easterly and prevent moist air from coming onto the west coast. Cold ocean currents also occur in these locations and moisture in the sea air condenses as fog along the shore. Some of the world's driest deserts are located right on the coast; they received most of their limited precipitation from fog. Such fog deserts include Baja California in North America, the western Sahara in northern Africa; the Atacama in South America, and the Namib in southern Africa.
- Rainshadows of high mountain ranges. When air masses are forced over mountains and downslope, they warm and their capacity for holding water vapor increases. Evaporation exceeds precipitation and an arid environment or holding water vapor increases. Evaporation exceeds precipitation and an arid environment or rainshadow is created on the leeward side. Such conditions account for some of the North American deserts (exemplified in Death Valley, CA), the Patagonian desert in Argentina; and the Peruvian desert
- Interiors of continents. Usually in combination with the rainshadow effect, distance from a major source of moist air results in dry climates in the interior of a land mass. The Great Basin desert of the US, the Australian desert, and the Gobi desert of Mongolia can all be explained in large part to their interior positions.

Climate. Arid climates (B Wh and B Wk) are those which average less than 10 inches of precipitation a year. Potential evaporation exceeds precipitation in the annual water budget.

Furthermore, rainfall is highly localized and relatively unpredictable in terms of when it will occur, although usually there are seasons of highest probability for precipitation. Annual variation in total precipitation may also be great. Temperatures are also variable. They may exceed 100° F on summer afternoons, but dip by 20-30 degrees or more at night. Winters are cool to cold: "hot deserts" rarely experience frost; "cold deserts" may have prolonged periods of below freezing temperatures and snowfall.

Vegetation. Shrubs are the dominant growthform of deserts. They may be evergreen or deciduous; typically have small leaves; and frequently have spines or thorns and/or aromatic oils. Shallow but extensive root systems procure rainwater from well beyond the canopy of the shrub whenever it does rain. These are the true **xerophytes** adapted to tolerate extreme drought. They form an open canopy and, except after rains when annuals may cover the desert floor, the ground between shrubs is bare of vegetative growth.

Water is not entirely lacking in the desert environment and several other growthforms represent strategies to reach water or to store water :

- **Phreatophytes** are plants with long taproots that may extend downward 20 to 30 feet to tap ground water supplies. Especially along intermittent streams or under dunes, underground water may be readily available. Mesquite is a good example here in North America.

  One of the world's most unusual phreatophyes in *Welwitschia mirabilis* of the Namib.

- **Succulents** store water accumulated during rains for use during the intervening dry spells. Different species store water in different parts of the plant; hence we can recognize stem succulents, leaf succulents, root succulents, and fruit succulents. Many plant families have members that evolved succulence. Most prominent among stem succulents in the Americas are the Cactaceae; in Africa succulent euphorbias have evolved shapes and sizes resembling the cacti. The agaves (Liliaceae) are examples of leaf succulents in the Americas; their role is filled by aloes (Liliaceae) in Africa. Most succulents do not tolerate freezing temperatures so they are essentially limited to the hot deserts.
- Another growthform adapted to desert conditions is the **ephemeral**. This is an especially shortlived annual forb that completes its life cycle in two-three weeks. The seeds are encased in a waterproof coating that prevents desiccation for years if necessary. These plants essentially avoid drought by occurring as seeds most of the time.
- **Perennial forbs** with underground bulbs store nutrients and water in underground tissues and also remain dormant most of the year. They can sprout rapidly after sufficient rains and replenish their underground stores.

Soils. Calcification is the dominant soil-forming process, if indeed soil forming even occurs. There is poor development of horizons, with accumulation of calcium carbonate at or near the surface. Sparse vegetative cover and tiny leaves results in little humus and soils typically have a light gray color. **Aridosols** are the dominant soil order.

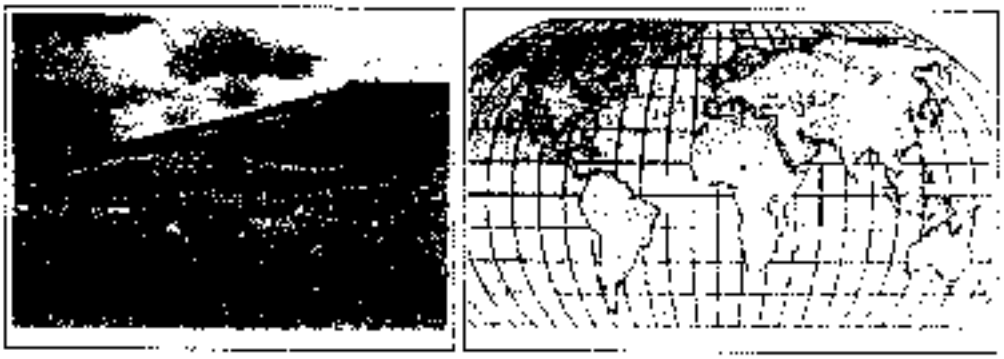
Fauna. Like the plants, the animals of the desert have evolved an array of strategies for dealing with aridity.

- **Behavioral adaptations** such as being nocturnal or crepuscular, being fossorial, and staying the shade during the heat of day are common.
- **Morphological adaptations** include those noticed by Bergmann, Allen, and Golger. The better to radiate body heat to the environment from warm-blooded animals, body sizes are small and appendages long. Pelage and plumage is light colored to reflect sunlight and help prevent the absorption of heat form the environment.
- Rarer, but important, are **physiological adaptations** such as aestivation (dormancy during summer), the absence of sweat glands, the concentration of urine, localized deposits of fat in tails or humps; and salt glands to secrete salt without loosing fluids.

Reptiles with their waterproof skin, production of uric acid instead of urine, hard-shelled eggs, and aiblity to gain body heat directly from the sun and to retreat to shade or underground to avoid heat are exceptionally well adapted to drylands and, not surprisingly, diverse there.

Many birds in the North American deserts, so fragmented by mountains offering humid habitats and permanent streams, simply fly to free water and so are not limited by the lack of open water. They maintain breeding seasons like other temperate zone birds synchronized by changing photoperiods. In Australia, where the desert geography is quite different and aridity more pervasive, bird populations synchronize their breeding readiness according to cues of rainfall, however erratic and sporadic that may be.

(g) Temperate Grasslands



Introduction. Temperate grasslands are composed of a rich mix of grasses and forbs and underlain by some of the world's most fertile soils. Since the development of the steel plow must have been converted to agricultural lands.

Climate : Semiarid, continental climates of the middle latitudes (Koeppen's BSk climate type) typically have between 10 and 20 inches of precipitation a year. Much of this falls as snow, serving as reservoir of moisture for the beginning of the growing season. Warm to hot summers are experienced, depending on latitude.

Vegetation. Perennial grasses and perennial forbs [especially Compositae (or Asteraceae, depending on the taxonomic system used) and Leguminosae--the sunflower and pea families,

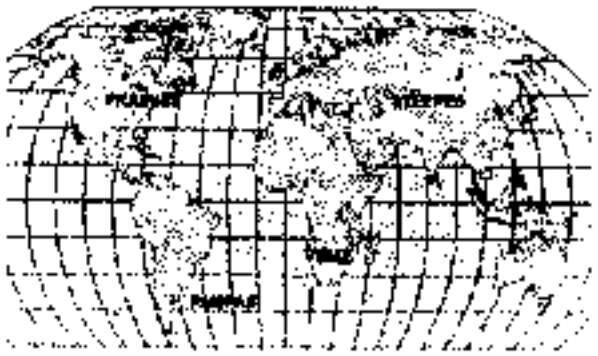
respectively] are dominant growthforms. Two or more strata of grasses (erect grasses and recumbent species) are recognized in the more humid expressions of the biome.

Grasses. Perennial grasses, with their growth buds at or just below the surface, are well-adapted to drought, fire and cold. The tiller or narrow, upright stem reduces heat-gain in the hot summers; the intricate root systems trap moisture and nutrients. Two basic types are :

- Turf-or sod-forming grasses, with rhizomes or underground stems from which new plants spring forth; associated with the more humid grasslands
- Bunch grasses, without rhizomes, that reproduce by seed; associated with the drier parts of the biome.

Major regional expressions

- North America : the **prairies** of the Central Lowlands and High Plains of the US and Canada. The Palouse Prairie of eastern Washington State, the California Grasslands, and the desert grasslands of the Southwest are also temperate grasslands.
- Eurasia : the **steppes** from Ukraine eastward through Russia and Mongolia.
- South America : the **pampas** of Argentina and Uruguay
- Africa : the **veld** in the Republic of South Africa.

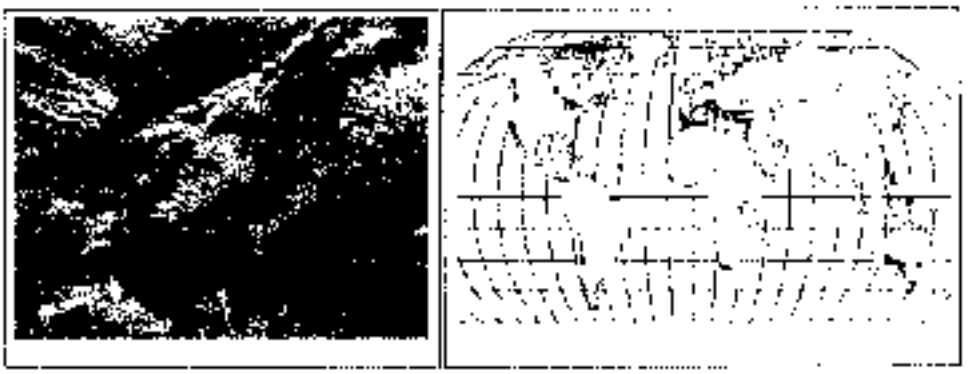


Soils. Calcification is the dominant soil-forming process in semiarid regions. Mild leaching, high organic content, and concentration of calcium carbonate in the B horizon typifies the dark brown mollisols developed under the temperate grasslands. When this process works on a loess that itself is rich in calcium the world's most fertile soils are created, the chernozems (A Russian term meaning black soil). Loess and hence chernozem underlie the eastern prairies of the US, the pampas of South America, and the steppes of Ukraine and Russia.

Fauna. The temperate grassland fauna is very low in diversity, especially in comparison with the tropical grasslands or savannas of Africa. In North America the dominant herbivores are bison *Bison bison)* and pronghorn (the sole member of the Nearctic endemic family, Antilocapridae). Rodent herbivores include the pocket gopher (another Nearctic endemic), ground squirrels, and the prairie dog. Carnivores include coyote (actually an omnivore), badger, and the federally endangered black-footed ferret, the las two members of the weasel family.

On the Russian steppes the fauna formerly included wisent (*Bison bonasus*), tarpan or wild horse, and saiga antelope, among others. Mole rats, fossorial members of one of the two mammal families endemic to the Palearctic, are conspicuous by virtue their many mounds. Polecats and other members of the weasel family are among the larger, extant carnivores.

(h) Mediterranean Shrublands



Introduction. Regions of Mediterranean-type climate occur roughly between 30° and 40° latitude on the west coasts of continents, where offshore there are cold ocean currents. Each region in which the Mediterranean shrublands and woodlands occur is island-like in character and thus there is frequently a high degree of endemism. Comparative studies of the several regional expressions of this biome reveal interesting examples of **convergent evolution** in plant families and birds (but not among reptiles or small mammals) on the different continents.

Climate : The mediterranean Climate (Cs) is unique in that the wet season coincides with the low sun or winter period. Summers are dry. Total annual precipitation ranges between 15 and 40 inches per year. Temperatures are those of the subtropics moderated by maritime influence and fogs associated with the cold ocean currents. The result is a very limited, but predictable, growing season when there is both sufficient soil moisture and adequately warm temperatures. Many plants are adapted to withstand drought.

The Vegetation. Throughout the world, the Mediterranean biome is characterized by shrubs. In most regions these shrubs are evergreen and have small, leathery (sclerophyllous) leaves with thick cuticles. Sometimes the leaves are so reduced as to appear needle-like. Many typical members of the shrub flora are aromatic (for example, sage, rosemary, thyme, and oregano) and contain highly flammable oils.

Mediterranean regions have long been impacted by humans especially through the use of fire and the grazing of livestock. The Mediterranean proper, we know from classical Greek literature, was formerly forested with live oaks, pines, cedars, wild carob and wild olive. The shrublands of California, likewise, are believed much more extensive today than before aboriginal burning and spanish livestock grazing.

Major regional expressions

- The Mediterranean proper–Europe, North Africa, and Asia Minor : around the Mediterranean Sea, which penetrates deeply into the Old World land masses, the biome reaches its maximum extent. Much of the formation is considered a subclimax developed on degraded and eroded soils and maintained in part by fire and goats. It is from this region that many culinary herbs associated with Italian cuisine originate. The shrublands are known locally as **maquis**.
- California : The **chaparral** (from the Spanish *chapa* or scrub oak) of southern California consists of two plant associations, the coastal sage and the foothills chaparral. The former is indicated by the presence of "soft" shrubs such as true sage (*Salvia* spp.). Inland, the latter is represented by a rich variety of "hard" woody shrubs that occurs in a mosaic reflecting fire history. A twenty-year cycle of fire maintains a subclimax of chamise (*Adenostoma fasciculatum*). In communities with less frequent or reguar burns, chamise gives way to ceonothus, mountain mahogany, sumac, toyon, and manzanita. Dwarfed oaks and drought-resistant, closed-cone pines also occur.

  Adaptation or preadaptation to fire is important among various plant taxa : for example,

  - o the flammable oils of chamise and other shrub species promote fire;
  - o chamise sprouts from the roots after a burn;
  - o the resin coating the cones of closed-cone pines melts in a hot fire and allows the cones to open and disperse their seeds;
  - o Perennial forbs survive as underground bulbs and sprout quickly in response to the additon of nutrients to the soil after a burn;
  - o the rosette shape of yuccas protects the inner growth bud from destruction in all but the hottest fires.

  Where fires have been prevented (and grazing also) for 50 years or more on Catalina and Santa Cruz islands (Channel Island group), an "elfin forest" of live oaks has developed. Some believe with even more prolonged suppression of fire, an oak savanna–perhaps the real climatic climax–would occur.

  California's Mediterranean region is restricted more or less to coastal areas by the surrounding mountain ranges.

- Chile : In Chile the formation is known as **matorral** (from the Spanish mata for shrub), and as in California, is confined to the coast by high mountains. The flora consists of many more deciduous species than are found in California's chaparral and many species also have thorns. Overgrazing during the Spanish colonial period has been implicated in prevalence of these thorny, deciduous shrubs.
- South Africa : The **fynbos** of the Cape region of the Republic of South Africa displays a high degree of endemism and high diversity in each family represented in the flora. (An endemic fauna is also present.) Among the more biogeographically interesting components

of the flora are the proteas, with 69 endemic species. Their closest relatives are in South America and Australia. While the protea family (Proteaceae) is very old and very primitive, the species are considered quite young. Cycads, ancient gymnosperms that look superficially like palms, are also part of this formation. Their nearest relatives are in Mexico and Australia.

Perennial forbs such as amaryllis and gladiolus are found in the fynbos, as are the succulent aloes.

- Australia : The **mallee scrub** vegetation of subtropical Australia is dominated by pungent, evergreen shrubs of the genus *Eucalyptus*, close relatives of Australian forest species. The prevailing grey-green color of the eucalypt leaves makes this vegetation appear uniform in composition, but actually dozens of families are represented. The mallee scrub occurs in two regions of southern Australia separated by arid Nullarbor Plain.

Fauna. The fauna of the various expressions of this biome are characterized by endemism that seems more a product of isolation than of peculiar adaptations to the Mediterranean environment. There is close convergence in the bird species found in California and those in Chile in terms of morphology, ecological niche, and even color and vocalization ! Approximately the same number of species is also found both regions.

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Unit-4 ❑ Means and Barriers of Global Dispersal of Animals

Structure

4.1 Concept of Dispersal

Dispersal means the spreading of individual animals into or form an area. For example, aphids breed in large numbers and spread by dispersal through various means. Organisms can respond to high-level intraspecific competition by dispersing away from the area of high population density. Even in species that are sessile for most of the life cycle, there is a mobile dispersal stage. Dispersal is often undertaken by the younger members of a population, whilst in many mammal species males disperse more than females do. Organisms avoid local unfavourable condition by moving to another location through migration. Migration, in its clear sense, is movement in space to a more favorable location. **Migration** is **directional movement,** such as the autumn flights of the swallows from Europe to Africa. In contrast, **dispersal** is **non-directional movement** away from the birth or breeding site. Dispersal may be viewed as a process evolved to avoid intraspecific and intrasibling competition.

In general, living organisms of all kinds reproduce themselves with quits astonishing rapidity and since Nature has provided them with means of dispersal they tend to enlarge their areas occupation unless some inhibiting factor of a physical or biological controls their expansion. The areal extent of plant and animal distribution is by no means unlimited, however, there lies a number of inhibiting factors:

1. The dispersal capacity of different organisms is very unequal.
2. Dispersal does not happen with equal success in all directions.
3. The constitution of the organisms may limit their movement.
4. Physical conditions may impose strict barriers to movement.
5. The organic movement may set definite limits to dispersal.

These factors check the free and unlimited distribution of animals and plants. As explained by Allee and Schmidt (1949), the possible distribution of existing species accordingly depends upon the barriers present, upon the means of dispersal at the command of the organisms in question, and on its vitality and adaptability. Thus definite patterns of distribution appear, and well-marked highways may be found by which dispersal has taken place. These highways are not common to all animals. They are conditioned by and changed according to the ecological valence and the means of dispersal, according to the classes and orders, and even to the genera and species to which the animals belong. Means and barriers of dispersal are fundamentally different for aquatic and terrestrial animals; and among the aquatic animals, in turn, the relations tend to be different for marine forms and for freshwater species.

Now it may be appreciated, from the above discussion, that the distribution of any animal species is fundamentally determined by (i) the **means** and methods of dispersal available to it and (ii) the physical and biotic obstacles or **barriers** preventing its dispersal. Because of the different groups in different ways: for instance, through some land animals can swim, usually they are limited by in their spread by stretches of water, while, conversely, water creatures are restricted by land barriers; again land animals may have their movements restricted by high mountains, flying animals may be able to surmount topographic barriers with ease—birds, in fact, are the animals least affected by barriers of any kind. Inhospitable climatic conditions, the absence of suitable supplies of food, the presence of predatory enemies or even the presence of more successful competitors, may prove to be obstacles to the movement of any particular group of animals.

Before we go into the detail of the means and barriers of animal-dispersal, it must be noted that the avenues of movement and the location of physical barriers change, albeit slowly, with the passing of geological time. The subsidence of the land surface and the consequent marine transgressions, the raising up of new mountain ranges, the advance and retreat of ice-sheets, the drying up of the interior continental seas and even changes in river courses are all events which may effect the spread of animals. The present disposition of land and sea is not the same as it was 1, 20, 50, or 100 million years ago. There is good reason to believe that land connections once existed between some areas which now lie separated from each other, as, for example, between Siberia and Alaska, between North Africa and Southern Europe, and between South-East Asia and Australia, Oscillations of land and sea have altered the shapes and patterns of the continental areas, and, as a result of such changes, the ranges of related animals, at one time continuous, may be separated while, on the other hand, areas characterized by faunas, which are only distantly allied, may become joined together.

Types of animal-disperal :

Dispersal of animals, that is, the spreading of animals from the place of their origin to other areas, may be divided into following five types.

- **Gradual dispersal :** It is peculiar in nature because it involves longer period of time but such dispersal covers larger areas and its result includes spread and distribution of animals over time.

- **Rapid dispersal :** It involves mass migration of animals from one area to the other but the animals involved in such type of dispersal are unable to colonize in the areas where they have rapidly migrated or dispersed because they are not allowed by man or by environmental conditions to settle down in new habitats. Such rapid dispersal involves certain types of animals only e.g. locusts, butterflies, several varieties of moths, dragonflies etc.
- **Seasonal dispersal :** it includes those seasonal migratory animals which leave their habitats due to seasonal weather conditions every year and migrate to those area which has favorable seasonal weather conditions. These migratory animals return again to their native places when the season becomes favorable for them. Many artic birds travel a long distance every year during the extreme cold season. Many such polar migratory birds visit India every year during the winter seasons and they return back to their native place during summer season of the same year.
- **Forced dispersal :** It occur when animals are forced to leave their native place due to sudden catastrophic events having adverse effects on animals e.g. prolonged drought, recurrent floods, forest fires, volcanic eruption etc. All such events cause scarcity of foods leading to migration of animals. Some time many animals migrate from native place because they do not find sufficient and suitable breeding places due to phenomental increase of population of animals.
- **Anthropogenic dispersal :** Man has long been involved to the dispersal of animals through various manipulative and deliberate activities. Dispersal of animals to very distant places by man has introduced diversification in the regional fauna and has caused several environmental and ecological problems. For example, the arrival of European deer and rabbits in New Zealand has resulted into rapid destruction of native natural vegetation due to grazing.

Means of Dispersal

In spite of the effective barriers to dispersal, animals as well as plants have followed a large number of long distance migratory routes for their dispersal over the globe. The common means of their dispersal are as below:

1. **Land bridges :** Like those at Suez and Panama, land bridges served and still now serve as good means of interchange of animals and plant populations. In the past, north and south Americas had land connection between them, which became later separated from each other. However, existence of such land bridges between the two continents allowed the migration of animals and plants from one continent to other.

   There are clear evidences regarding the past existence of several land bridges connecting various continents through which animals have dispersed from their places of origin to various directions. Wegener first postulated the idea and evidences of animal dispersal through land bridges of the past time in his famous theory of Continental Drift.

Wagner's hypothesis suggests a former land connection between Africa and South America. The Atlantic Ocean had grown in the upper Cretaceous period. The disintegration of East Gondwana, which started towards the end of the Paleozoic period, and the movement in a westerly direction of West Gondwana resulting from it, had a decisive effect on the formation of the Atlantic Ocean. Gondwana was a Paleozoic continent in the southern hemisphere, encompassing South America, Africa, Madagascar, Australia and India and was torn apart by continental drift.

It is not surprising therefore, that numerous *Mesozoic* animal and plant species, i.e. *Glossopteris* and *Mesosaurus* group of animal, are commonly found in all the Gondwana lands. The northern primitive continent Laurasia comprising North America, Greenland, Scandinavia and Siberia has also a common fossil record of animals and plants. Thus *Mesozoic* reptiles have a common history of evolution in these lands. It has now been studied that reptiles like *Chelonians, Mesosauria, Eosuchia, Rhynchocephalia* and *Ornithischia* underwent a common development in Gondwana land and the reptiles like *Sauropterygia* and *Therapsida* had their origin in *Laurasia.* The segregation of reptiles over different continents occurred at later stage, probably in the *Eocene* times.

It is also clear now that the *Permo-Caboniferous* age was an ice-age upon the earth. But it had its large-scale effects on South Africa, India, Australia, South America and Antarctica. These glaciated lands of the later carboniferous now occupy considerable areas on both sides of the equator. Due to the large glacial ice deposited on land it is assumed that the sea-level went down much lower than the present one; and this must have provided ample land-bridges that have provided most useful locations for the various animals and plants to migrate to other lands. Some of the past land bridges are outline below:

(i) ***Beringia :*** The Behring Straits, which are over 16 km. wide and which separate the Asian and the North America continents, are supposed to have had land connections several times in the past, chiefly in the Tertiary and Pleistocene periods. Successive marine and land deposits on the Behring-Chukchi platform containing *Sequoia* and other *taxa* show that land connections via this strait existed repeatedly during the early Tertiary. Fossil studies indicate that the Malayan tapir migrated through all the way through the west coast of Canada, the United States and Mexico. It is supposed that by the beginning of the Holocene, when man migrated to the Americas, the Beringia land bridge had closed finally.

(ii) ***Tyrrhenian Land Bridge :*** This land bridge is presumed to have existed between Italy, Corsica, Sardinia, Sicily and North Africa during the penultimate glaciations. It is indicated that in this part of the Mediterranean there were several smaller land bridges, joining the African continent with the mainland of Europe via the islands of the Mediterranean. The homogeneity of fauna in the entire Mediterranean geographical region indicates the possibility of the exist-

ence of these land bridges which must have provided routes of migration for the exchange of animals between North Africa and South Europe.

(iii) ***Archhelenis :*** This land bridge is supposed to have existed in the Mesozoic age and connected the eastern part of South America with South West Africa via Tristan de Cunha. Various fossil forms of Mesozoic fauna in the both the lands have strong similarities suggesting the probable existence of this land bridge.

(iv) ***Archatlantis :*** This land bridge is assumed to be existed in the Cretaceous age and the extensions were perhaps between Spain and Florida, connecting all the island of the North Atlantic, including the Azores, the Canaries, the Cape Verde Islands and the Antilles.

(v) ***Canaries Bridge :*** A Canaries bridge has claimed recently on the basis of geological, palaeontological and phylogenetic relationships between the eastern Canary islands and the West African tableland. But Canaries have no indigenous fauna of mammalian, and only 50 genera of land bridge are found in them and they too are of European character. Two European species of bats are also found in these islands.

(vi) ***Archiplata :*** According to some palaeontologists, a land bridge existed during the Cretaceous period between North and South America which also joined the South Pacific land bridge. A faunal exchange took place during the Tertiary between the two American.

(vii) ***Archiguina :*** This land bridge represents an assumed Cretaceous island in the region of Venezuela and the Guyanas. The distribution of numerous species of monotype genera, i.e. the parakeet, the Cotingid and the tyrant flycatcher provide ample evidence for the existence of this island. It is also indicated that the recent shifts in rainforests to these islands has also influenced the present distribution pattern of the fauna.

(viii) ***Archinotis :*** It is postulated that in the Cretaceous and in the early Tertiary times, a land bridge existed in the southern hemisphere connecting the southern part of South America with New Zealand and Australia via Antarctica and South Pacific Islands. This land connection meaningfully explains the close correlation between many animal groups distributed on both sides of the South Pacific.

(ix) ***Austro-Malayan :*** As the faunal distribution indication, the Malaya peninsula has remained the crossroads of Oriental, Palaearctic and Australian fauna in the past geological ages. The large group of Indonesian islands, of which Java and Sumatra are the largest, is anchored in the shallow sea connecting these islands with Australia. It is possible that in the Pleistocene ice age these shallow seas dried up providing a migratory route between the mainland of Asia and Australia for the land animals.

2. **Natural rafts and driftwood :** Some of the animals take long journeys upon the drifting material as ice etc. Moreover, natural rafts of vegetation in marine waters are also effective means of dispersal. Such rafts develop due to accumulation of timbers along the rivers during caving of banks on the outside of the riverbeds that are swept out to sea by the stream. These rafts carry animals like monkeys, cats, tigers, squirrels, reptiles and mollusks etc.

3. **Favouring gales :** The favouring winds disperse the aerial nektons like insects, birds, bats etc. Birds are well known to undertake long distance migratory routes.

4. **Migration :** Both the permanent movement and the seasonal migrations of animals, are important in relation to their dispersal.

5. **Anthropogenic factors :** Anthropogenic factors have also greatly altered the fauna of various continents. The primitive hunters killed most of the edible forms of animal like the taiga antelopes and wild horses of Central Asia. Some of the animal forms like cows, buffaloes, sheep, goat, pigs etc. were domesticated for human benefit. Therefore, it is true that much of the original fauna has now been altered and it is difficult to ascertain the indigenous forms in any region.

Barriers to Dispersal

Different parts of the world have their own flora and fauna which is characteristics of the environmental conditions prevailing in the particular area. Thus, we find that flora and fauna of different parts of the world do not show any uniform pattern of distribution. The difference in the pattern of distribution may to some extent be attributed to the presence of some barriers between the different parts of the world. Such barriers are responsible for this uneven distribution of not only animal life but also plants. The different kinds of barriers are as follows :

1. Climatic Barriers : Climate and the accompanying vegetation act as the greatest barrier to the dispersal of land mammals. Apes and monkeys appear to be limited by climate since they inhabit almost all the tropical regions but do not range more than 30 north and south of the equator. These animals are exclusively fruit eaters and so their distribution depends as much on vegetation as on temperature. Strikingly different are the Himalayan monkeys *(semnopithecus schistaceus)* which are found even at a 11,000 ft. leaping among fir trees loaded with snow wreaths.

Some arctic animals are bounded by the 0 C isotherms, such as the polar bear and the walrus which cannot live far beyond the limits of the frozen ocean. Elephants and rhinoceroses are today the true inhabitants of tropical climates but earlier in the post-tertiary times they roamed over the whole of the northern continents even up to the Arctic Circle. A few animals, like a tiger, can adapt various forms of climate. The tiger, once considered to be a purely tropical animal, inhabits permanently the cold plains of Manchuria and the Amur, a country of almost arctic winter climate.

2. Terrain Barriers : Hills and mountains are barriers to the animals of marshy lands and plains and vice versa. The difference of vegetation and on insect life, together with the change

of environment, often checks migration, if it is attempted. Thus the flat plains of Ganga are effectual barriers to the Himalayan fauna in reaching the mountains of central and the southern peninsula. In the great Amazonian plains many species of monkeys and quadrupeds are found on the side of the river and are unable to cross it to reach its other bank. In the lower part of the Rio Negro, two species of monkeys are found on the north bank of the river but never on the south bank where a red whiskered monkey alone is found. A few animals like camels and sheep have their hooves adapted to the sandy areas and they are unable to wolk over mountainous terrains.

3. Sea-arm Barriers : Very few animals can swim any considerable extent of a sea, although many can swim short distances well. The jaguars of South America and the bears and bison's of North America can swim considerable distance in streams. Wild pigs can swim distances of 30—40 kilometers and reach the shores many miles away. Therefore, these animals show a wider distribution on the globe. Squirrels rats and lemmings often migrate from Scandinavia in bands of thousands and pass over lakes and rivers, but they generally perish in the salt water of sea. In spite of the immense power of swimming in most of the mammals, vast expanses are effective barriers to them. They cannot undertaken intercontinental journeys swimming thousands of kilometers at one stretch. Wide arms of seas like gulfs and bays are effectual barriers to their migration.

4. Vegetation as barrier : Vegetation is a biological type of barrier that affects distribution of animals directly as well as indirectly. Plants serve as food and means of shelter for animals. Thus depending upon their selective food habits, animals remain confined to areas with vegetation of their choice. For example, primates prefer to live in tropical forests, where they feed on fruits, nuts, blossoms and tender shoots, as well as on birds and insects living there. Animals with short crowned browsing teeth need trees and shrubs, while those with long crowned grazing teeth need pastures with harsh grasses.

5. Land masses : Like extensive water bodies, landmasses also become effective physical barriers to the dispersal of marine life.

Dispersal of Animals

1. Dispersal of Birds : Birds on account of having the wings to fly for rapid dispersal even to far off places are thought to be ubiquitous, although this is not always true. Barriers as the mammals almost as strictly limit many species of birds. The different groups of avian fauna offer remarkable contrast in the extent of their range, some being the most cosmopolite of the higher animals, while others are absolutely confined to single spots on the earth's surface. The petrels and the sea-gulls are among the greatest wanderers but most of the species are confined to the Arctic and Antarctic sea. Sandpipers and plovers are also migratory birds. Great numbers of them breed in the Arctic regions and migrate as far as India, Chile, Australia, and Brazil. In striking contrast to these wide ranges we find many of the smaller perching birds like pigeons, parrots, and sparrows confined to small islands of a few square miles in extent or to single valleys or mountains.

Yet there is another group of birds which posses no power of flight, such as—the ostrich, cassowary, apteryx, kiwi and penguin. They are exactly in the same position as the mammalians as regards their dispersal. A very large number of short-wing birds, such as wrens, pitas, and toucans are perhaps worse-off, for they can fly very few miles at a time. Some birds like titlarks, cuckoos, warblers and rails sit on the ocean vessels and cross large oceans.

2. Dispersal of Reptiles and Amphibia : Reptiles and amphibians are cold-blooded animals and so their dispersal is controlled by temperature conditions. Marine reptiles like turtles and sea snakes can traverse long distances in and are, therefore found in coastal waters of all continents. Fresh-water reptiles such as crocodiles, gavials and tortoises are more confined to their native lands, as they cannot traverse long distances. These animals are mostly found in the old world.

Snakes are very sensitive to climate, becoming scarce in temperate and cold climates and entirely ceasing at 62 North latitude. They also do not ascend lofty mountains ceasing at 6000 ft. of elevation in the Alps and the Himalayas. Most of the snakes inhabit deserts and burrow under the soil to get an optimum temperature. Others are adapted to swamps and for a life in forests. Pythons are more conspicuous in thick forests where they hang the tree branches to prey upon the passing animals. The king cobra is also a native of woodlands and grasslands. Snakes swim rivers easily, but apparently have no means of passing sea, as they are very rarely found on oceanic islands.

Lizards are also essentially tropical, but they have dispersed somewhat farther north than snakes, and can ascend higher on the mountains, reaching 10,000 ft in the Himalayas. They adopt some means of crossing the oceans, as they are found to inhabit neither many islands where there are neither snakes nor any mammalian. It is probable that they had traveled to thse islands either at a mature stage on the branches and logs of floating wood or in the egg stage lying on the ice floes.

The amphibians are much less sensitive to cold than the true reptiles and they accordingly extend farther north up to tundra. Frogs are found in abundance in the arctic region. Their semi-aquatic life also gives them facilities for dispersal. They have adapted to hot as well as cold climates. Sometimes aquatic birds and waders also carry the eggs of amphibians in their feet and wings from one pond to another or from one stream to another.

Deserts and oceans are most effectual barriers to their dispersal. The salt water oceans are fatal; to them, as also to their eggs, but their distribution is fairly widespread in almost all the zoogeographical regions. It appears that the transshipment of such common species, as found in all continents, has have most commonly various forms of salamanders, toads and frogs which show special adaptations to xeric climate.

3. Dispersal of Fishes : The fact that the same species of freshwater fishes often inhabit distinct river systems and different continents prove that they have some means of dispersal over land. Alexander von Humboldt relates that many fishes from subterranean streams are sometimes

thrown up by volcanic explosions and they land in streams far apart. Another mode of dispersal may be transfer from one river basin to another by hurricanes, typhoons and whirlwinds.

A still distinct mode may be the dispersal of eggs which are carried away by aquatic birds in their webs and wings. It has been found that geese and ducks during their migrations feed on the eggs of fishes and that some of these pass through their bodies with their vitality unimpaired. Even water-beetles flying from a pond to another might occasionally carry with them some of the smaller eggs of fishes. It is also probable that fishes disperse when streams change their courses or cause floods.

Sea fishes have unlimited means of dispersal but temperature, salinity and the ocean-currents prove important barriers. Fishes like cod, herrings and salmons can only live in cold water while a variety of other fishes prefer to live in warm waters. Depth of water is the greatest barrier as the availability of food decreases with the increasing depth. Thus fishes of the Gulf of Mexico, inhabiting the shallow water, cannot cross over to the Atlantic because the ocean is very deep. Many sea fishes migrate to a limited extent for spawning in favorable situation. Herrings, the inhabitants of deep sea, come in shoals in the breeding season, while salmons quit the northern cold seas and enter the rivers, mounting upwards to the clear cold water near their sources to deposit their eggs.

But most of the fresh water fish genera are unable to migrate even to short distances because land mass is a big barrier to them. Africa and South America posse almost completely different genera of fishes and only those like Arius which are anadromous are shared in common. The head waters of the Rhine and Danube are separated by only a few kilometers and yet the fish fauna is different in both of them. Sticklebacks and eels are found in Danube while they are absent in the Rhine. Both the rivers have different species of salmons and sturgeons too. 11,000 ft. leaping among fir trees loaded with snow wreaths.

Some arctic animals are bounded by the 0 C isotherms, such as the polar bear and the walrus which cannot live far beyond the limits of the frozen ocean. Elephants and rhinoceroses are today the true inhabitants of tropical climates but earlier in the post-tertiary times they roamed over the whole of the northern continents even up to the Arctic Circle. A few animals, like a tiger, can adapt various forms of climate. The tiger, once considered to be a purely tropical animals, inhabits permanently the cold plains of Manchuria and the Amur, a country of almost arctic winter climate.

4.2. Geological Distribution of Animals

The study of the distribution of animals on the earth in zoogeography is not confined with the present distribution of animals, but it describes as well as the origin, survival, evolution and distribution of animals throughout the geological times of the earth. The earth is more than 4500 million years old and it has a long geological and organic history. The geologists, botanists, zoologists and paleontologists, using three basic principles, have pieced the reconstructed history together :

Firstly, it is now possible to determine the age of the rocks accurately by radioactive analysis and carbon dating;

Secondly, the fossils of animals found in the sedimentary rocks can be dated in relative terms of chronology;

Thirdly, the clues in the contents and texture of a rock can be deciphered in terms of past climatic conditions.

Thus the histories of landscape, climate and organisms are interlinked exhibiting evolution of life in the past ages.

The continuous adaptation of plants and animals to new environments that is evolution is not a simple straight-line story. There are many side branches to the tree where whole groups of organisms have become extinct leaving no descendents. Changes in climate and geography, due to continental drift and collision of continents on moving tectonic plates of the earth, have also had a considerable effect on the course of animal and plant evolution. The evidences from rocks and fossils reveal that the pace of evolution has sometimes been rapid and at other times very slow.

According to the views of the scientists from different disciplines that life, in its microscopic forms, originated in water soon after the warm seas appeared on the earth about 3500 million years ago. The first to evolve were bacteria followed by green algae and then the soft-bodied animal-like forms, seaweeds were the only dominant vegetation for a long time, but there were no life on land. Fossil records of these primitive plants have been found in the rocks of few places, as in Ontario where traces of multicellular algae and possibly a calcerious flagellated animals have been found and dated 1900 million years old.

Life in the Palaeozoic Era

The ***Paleozoic era*** started about 570 million years ago. With the onset of ***Cambrian age,*** life had still confined to the seas. The Cambrian period lasted for about 65 million years. The sea cover in that period was shallow extending over most parts of the continents like North America and Australia and on some parts of Europe such as Britain, Scandinavia and Russia, and also in north Asia especially Siberia. These seas were surrounded by barren lifeless land, as the rainfall was too little to produce any organism. The atmosphere in that time too had small proportions of oxygen to sustain any life.

Life in Cambrian period was confined to the seas and consisted chiefly of the algal froms of vegetation mixed with fungi, moulds, diatoms and bacteria, but several animal groups like **sponges, brachiopods, sea-snails and trilobites,** having hard skeletons, had also meanwhile evolved. The Cambrian rocks have fossils of soft-bodied animals like **jellyfishes** as well as **worms.** Trilobites were in great abundance in these times and so the Cambrian age is often called the **trilobite age.**

Life continued to remain confined to the seas in the *Ordovician age* (505 million years ago), a period that lasted for 66 million years. It was a period of alternating volcanic activity and profuse rainfall. Fossil evidences also show that the Saharan part of Africa constituted the

south pole of the earth and was covered with a mantle of snow. Besides the trilobites, which continued to exist even in this age, several new species of sea animals like **sea lily; starfishes, graptolites** and **mollusks** had evolved and lived in seas. Strange varieties of fishes, which can be said to be ancestors of modern fishes, had evolved as their remains have been found in Ordovician rocks of North America.

The ***Silurian age*** (439 million years ago) marked the beginnings of terrestrial plants. The fossil remains of such plants, which were leafless, have been found in Australia. Animal life in water was abundant, chiefly consisting of **coralreefs, sea lilies, graptolites** and giant **water scorpions** up to as much as 9 feet of length. In the ***Devonian age*** (409 m. y. ago), the earth started looking green and the atmosphere had sufficient oxygen to sustain life on land. Thus trees and ferns reaching heights of 40 feet or more called horsetails evolved in that period. The first invertebrate animals left the sea and adapted themselves to terrestrial life. These early animals were **millipedes, centipedes, mites, scorpions** and **spiders** of the class *Arthropoda.* In the oceans, a rapid evolution of vertebrate animals went on and ancestors of all modern fishes evolved. The Devonian age is known as the age of fishes when primitive sharks measuring up to 20 feet appeared. It is also said that the first amphibians came into existence towards the close of this period which lasted for 44 million years.

The succeeding ***Carboniferous*** *age* (365 m. y. ago), known as the *coal-age,* had a supra-abundance to land plants which were giant evergreen trees of ferns, club-mosses and other pteridophytes reaching heights of over 100 feet and mostly growing in the swampy areas. Primitive conifers also evolved in this period which lasted for 75 million years, the longest span of any period in the history of the earth. Therefore it is assumed that the earth was very moist and the atmosphere had almost 20 percent of oxygen in this age. Great river deltas and later vast areas of swampy forest surrounded the major landmasses. Due to constant deposition of alluvium and increased erosional activities sandstone was formed which accompanied with volcanic activities submerged vast forests that are now mined in the form of coal and petroleum. The climate over most of Europe was warm and moist as evidenced by the fossil remains of coconut and palm trees found in Britain, Greenland and France. An abundance of vegetation led the terrestrial animals to develop more profusely. Amphibious creatures continued to develop and **salamanders,** sometimes attaining the size of 15 feet, began to appear on the edges of swampy areas and lakes. The reptiles had thus begun to evolve by this time but their species were few. The insects in the form of giant **dragonflies** developed and most of them evolved wings to fly over the swamps. Fossil records also indicate that **land snails** also evolved in this period for the first time.

The ***Permian age*** (290 m. y. ago), which marked the end of ***Paleozoic era,*** is known as the age of reptiles, which were very abundant on the earth. **Dimestrdon** is the best-known animal of this period. These animals consisted of two groups, one evolving towards mammals and the other towards the **dinosaurs,** the giant reptiles. In Permian times there was a change in climatic conditions over the earth and it became drier and warmer leading to the extinction of much of the life developed in the carboniferous age. The Permian period marked the end of dominance by marine creatures, as animal and plant life on land had increased. The southern

half of Pangaea was covered with forests of small trees called **Glossopteris,** the remains of which are found in Africa, Australia and India. The Permian age, which lasted for 40 million years, had left a few animal and plant species on the earth on account of excessive warmth and dryness.

Life in the Mesozoic Era

Mesozoic is known as the era of middle life and it was a period par excellence as an age of reptiles. Towards the beginning of its first period called ***Triassic*** (250 m. y. ago) the hot, dry conditions prevailed almost everywhere, which discouraged the development of plant life. Later on with wetter conditions the growth of confiers, cycads and ferns also commenced. This period, which lasted for 45 million years, had deserts and shrub-covered mountains in most areas of the earth. The reptiles continued to dominate the earth. Carnivorous fish-shaped reptiles known as **ichthyosaurs** and the flying fishes evolved in this period. Dinosaurs were not more than six inches as there was total loss of vegetation. **Arthropods** like **flies** and **termites,** which could live in arid conditions, also evolved. The atmosphere had lower percentage of oxygen, which discouraged the survival of higher forms of life.

The succeeding age called ***Jurassic*** (205 m. y. ago) was marked by wetter conditions again. Consequently most of the land areas became swampy, having meandering rivers and lakes. This period, which lasted for 70 m. y., had predominantly mild climate, becoming sub-tropical in some areas in the latter part. Profuse rainfall was sufficient to support luxuriant vegetation of flower-like cones—the first step in the evolution of angiosperms. Seas were dominated by rapid swimmers and aquatic reptiles like **ichthyosaurs** which preyed on marine animals. On the land, reptiles increased in size and variety and many **dinosaurs,** including the giant ones like **Diplodocus** weighing 35 tonnes. Some smaller reptiles became covered with hair or feathers which was a step towards the evolution of birds and mammals. The first bird-like animal called **Archaeopteryx** which used to glide down with flappy forehands and feathers also evolved. Thus the Jurassic was an age of multitude of life-forms.

The last period of ***Mesozoic*** was *cretaceous* (135 m. y. ago) which lasted for about 69 m. y. It was a period of great orogenic activity when Pangaea, the large continent, began to break up and an arm of the sea appeared between Africa and the Ameica. The continental drift disintegrated the Gondwanaland into smaller land units now called Africa, South America, Australia, India, Madagascar and smaller islands of East Indies. The fossil remains of glossopteris and Mesosaurus in the ancient rocks of these continents support the theory of continental drift. North of the Gondwanaland was the ancient northern continent of Laurasia which consisted of two continental blocks closed off by the Tethys Sea, one of which included the northern parts of North America called Laurentia and the other was a fore-runner of Eurasia called the Angaraland. In cretaceous times, while the chelonian animals and the repitles' like Mesosauria, Eosuchia, Rhynchocephalia and Ornithischia underwent their development and segregation in Gondwana, the Sauropterygia and Therapsida had their origin in Laurasia.

Cretaceous was a period of mild climate with alternating wet and dry seasons that encouraged the growth of deciduous trees like magnolia, figs, poplars and pines. The parallel

evolution of **insects** helped in the pollination of flowering plants and their rapid dispersal. Giant reptiles like **dinosaurs** and **pterosaurs** continued to dominate over land. Some of the reptiles developed wings and they can be called as the ancestors of modern birds. A few had developed peddles for swimming. Some primitive mammals had also evolved towards the end of this period. There was sufficient oxygen in the atmosphere to sustain plants and animals but by the end of Cretaceous, the dinosaurs started becoming extinct which may be accounted for their heavy intake of food and depletion of forests. The oceans had rich aquatic life and some peculair species of **sea-urchins, mollusks, ichthyosaurs** and **plesiosaurs** had evolved in them, which soon became extinct at the end of the Cretaceous.

Life in the Cainozoic Era

The ***Cainozoic,*** which started nearly 66 million years ago is also called the modern era and is the age of the modern animals. The most characteristic feature of this era is stabilization of the present shape of the continents which have undergone few changes since then on account of the lesser volcanic activities and diastrophic movements.

Eocene (66 m. years ago), the first period of the Cainozoic era, had higher temperatures and an abundance of rainfall which made the climate tropical over most parts of the world and tropical vegetation like that of Malaya flourished even in Greeenland and England. These conditions were favorable for the growth of flowering plants which grew in abundance. Malayan type of forests existed in Greenland as the fossil records of this island reveal an abundance of palm trees. Many variety of modern animals came into existence and the ancestors of elephants, rhinoceros, horses, pigs, cows and sheep evolved. Primitive gibbons and monkeys existed in Myanmar at that time. But most of the giant reptiles had disappeared from the earth. Crocodiles and tortoises evolved at that time, as did all groups of insects that we know today. Most of the fishes which exist today had evolved by this time and some groups of mammals like early whales and sea cows had begun to adapt themselves to aquatic life. The marine reptiles had become extinct by now.

The next period was ***Oligocene*** (36.5 m. years ago) in which the warm, temperate climatic conditions continued but some parts of the earth experienced a cycle of cooler winter as the earth was becoming moister and cooler than before, which dwindled the deciduous forests and increased the grasslands and grass-eating animals. Small elephants with short trunks and tusks in both upper and lower jaws came into existence. Other herbivores like the hoofed animals—cows, buffaloes, horses, sheep, goats, camels etc. with odd numbers of toes and giant rhinoceros evolved. Quite probably a tailless primitive ape related to the ancestors of man had also evolved; otherwise the maritime biota remained the same as in the earlier period.

In ***Miocene*** age (23.5 m. years ago), the European and Asian land masses joined together and the Mediterranean became virtually a land locked sea. Mild, damp climate in Europe and North America stimulated the growth of deciduous woods—maple, oak and poplar with cedars and sequoias on higher elevations, while many of the subtropical parts of these continents were covered with grasslands. The Indian subcontinent had developed the monsoonal rhythm under which thick forests developed. Most of the mammals like elephants, horses and rhinoceros

attained the present size but the number of mammalian species dwindled on account of the rise of mountains in this period, which were barriers to free migration. During the later part of this period, probably, the ancestral man known as *Homo erectus* evolved in central Africa. Quite possibly the other species of primitive man, *Australo pithacus* also evolved at this time and the two forms co-existed. Giant sharks developed in the sea along with a variety of bony fishes in this period.

Pliocene (5 m. years ago) was the next geological period in which the continents and oceans finally attained the present shape and size and the orogenic activities subsided. The climate was much the same as today but Europe and North America were much cooler, which led to the extinction of plants like maidenhair from these continents. Tropical parts had rich grasslands that encouraged the development of forest apes in central Africa and their open-country forms spread over Asia later on. Elephants steadily increased in size and roamed over vast areas from Africa into Europe, Asia and North America. The fossil remains of these huge elephants covered with fur, called *mammoths,* have been found even in Siberia which is very cold now. Most of the birds had evolved in this period. Water-birds like ducks, pelicans, cranes etc. had developed long legs and some waders with membranes over their claws had evolved. Primitive penguins, some as tall as man, lived in Antarctica. In the oceans, giant sharks became extinct and marine life became much as it is today.

Birds are most migratory forms of faunal life and their study reveals a gradual development in the ***Cainozoic*** era that can be traced back to the Eocene times.

The gradual decline in the number of Passeriformes families and species from ***Miocene*** onwards indicates a change towards the unfavorable climate during the last 20 million years. Of the 848 recent non-Passeriformes genera, 10 are known from the Oligocene, 42 from the Miocene and 34 from the ***Pliocene.*** 245 recent genera have been established as also occurring in Pleistocene.

Life during the present age is most varied. In ***Pleistocene*** and ***Holocene*** periods marked changes took place in climatic regimes, which in turn affected topography, atmosphere, vegetation and animal life and need therefore be dealt with separately.

Life in the Pleistocene and Holocene age

The ***Pleistocene*** age started about 1.6 m. years ago and is most popularly known as the ice age on the earth when ice sheets and glaciers covered most part of Europe, northern Asia, North America, Antarctica and the Himalayas. This geological period, though the briefest in earth's history, is most fascinating for it was in that period that the geography and topography of most part of the world acquired their final outlines and their faunas and floras in their present distribution. The ***Holocene*** is the present age that started only 10,000 years ago.

The effects of the end of the ***Cainozoic*** or tertiary era and the commencement of the quaternary are marked in the entire northern hemisphere generally, by great refrigeration of climate, culminating "glacial age" or "ice age". The glacial conditions prevailed as far south as 39 N. latitude and the countries which now experience a temperate climate then had the arctic

cold of the Polar Regions, and were covered under ice sheets radiating from the higher grounds. Organic records of this period indicate extinction of certain plants and animal species or their migration to better areas which affected their distribution.**

**(Glacial Periods of Pleistocene Age)

The glacial periods occurred in several stages intercepted by inter-glacial periods which were relatively warm. On the basis of fossil records and rocks' ages the reconstruction ***Pleistocene*** age can be done as follows :

Quaternary Glacial Periods with Provisional Dates

Name of Glacial and Inter-glacial Period	years Before present	Rise/Fall of Sea-level (Mtrs)
Wurm Glacial	10,000-125,000	–10— –135
Eemian Interglacial	12,500-235,000	+7— +18
Riss Glacial	230,500-360,000	–200 or more
Great Interglacial	360,000-670,000	+32— +45
Mindel Elster Glacial	670,000-780,000	—
Interglacial *Cromerian*	780,000-900,000	+60
Gunz Glacial	900,000-1,150,000	—
Interglacial *Norwich*	1,15,000-1,370,000	+80— +100
Donau Glacial	1,370,000-1,600,000	–150

It has been estimated by carbon dating methods that the *Wurm,* which was the last glacial period, lasted for more than 100,000 years when the sea level was reduced by 10—135 meters, which exposed the shallower part of the sea to be used as land bridges for inter-continental migration of animals. This glacial period was preceded by warm *Eemian* interglacial period having a span of 1,10,000 years in which the sea level rose by 7—18 meters. *Riss* glacial period which started 3,60,000 years ago lasted for about 1,25,000 years in which the sea levels reduced by 200 meters or more prior to *Riss* was the Great Inter-Glacial Period which had longest duration of 3,10,000 years causing a rise of 32—45 meters in the sea level. The *Mindel* was the third glacial which started 7,80,000 years ago and remained for 1,10,000 years. Little is known about the fall in sea level in this age. The warm Inter-glacial period *Cromerian* which preceded it had a duration of 1,20,000 years making a rise of 60 meters in water level of seas. *Gunz,* which was the second glacial period of Quaternary, started 11,50,000 years ago and lasted for 2,50,000 years, but little can be said about the sea level fall during this age. The Norwich Inter-glacial period that preceded it, had a duration of 2,20,000 years during which water in the oceans rose by 100 meters. The *Donau* Glacial period, which was the first in the glacial age, probably started 16 lakhs years ago lasting for 2,30,000 years that caused a fall of 150 meters in the sea level.

Fossil records in India indicate that there was a sudden and widespread reduction, by extinction, of the *Siwalik* mammals. The great carnivorous, the varied races of the elephants of no less than 30 species and numerous species of angulates which were found in the Pliocene age in Northern India became extinct in the glacial age.

In some parts of the world, the existence of *'glacial man'* in the second and third glacial periods is well established. The *Australo-pithacus* of South Africa was probably born one million years ago in the Gunz glacial period. The *Pitheco-anthropus* of Java and the *sinanthropus* of China existed in the Mindel Glacial period some 600,000 years ago. The *Homo-heidelbergensis* of Germany had evolved 500,000 years before the great inter-glacial period when the climate of Europe had become warmer. The *Homo-neanderthalensis* of Prussia existed in the Wurm glacial period about 100,000 years ago.

It is believed that early man migrated from Africa to Asia and Europe, Stone tools used by man became more sophisticated and language evolved. Our own species of Homo-sapiens appeared about 2,50,000 years ago. But the alternating ice ages and warm periods accelerated the migratory habits of man and other animals to move to areas of optimum climate. It has been found that in one glacial period, the reindeer and the arctic fox lived in Southern England and in the warmer period, hippopotamuses lived in the Thames River and lions ranged as far north as Yorkshire.

In North America a large number of animals were present in the Pleistocene age that have since then become extinct. Some of these animals are elephants, bovid, reindeer, mouse, ground sloths, giant armadillos, water hogs, short-tailed bears, saber-toothed tigers, canids, giant beavers, tapirs, camels, musk ox and pronghorns.

Succeeding ice age in Europe and North America caused many plants to perish, living only hardier varieties—oak, willow, poplar, elm, hawthorn etc. to survive. In Asia, vegetation seeking warmer climates encountered no sea or mountain barriers and so more plants survived. Paleobotanists are of the view that in the interglacial periods, when the temperatures became higher and the glacier receded, temperate boreal forests developed over vast areas in Asia and America. It has also been opined that the Holocene is again an interglacial period when temperatures of the earth and the vegetation is increasing. The maximum warmth in the Holocene reached perhaps, 5000—8000 years ago and is now on the decline as the period is believed by many to be nearing its end.

4.3. Environmental Organisations and Agencies

A number of agencies and organizations throughout the world are active with different programs on environment. Their programs include the areas of forests, wildlife and other relevant issues. The main fields of such two international bodies are discussed here.

Man and Biosphere Program

In fact Man and Biosphere (MAB) program is an outcome of the important experiences gained from International Biological Programme (IBP). MAB was planned at the International

Biosphere Conference of UNESCO in 1968 after the realization that the programme requires a coordination of physical and social scientists, planners and managers vis-a-vis the local people. The programme was officially given shape by the General Conference of UNESCO at its 16th Session in 1970 but the UNESCO formally launched the program in November 1971 when the MAB International Coordinating Council held its first session and identified 13 project areas of coordinated research. The fourteenth project area was annexed in 1974.

Objectives

MAB is an interdisciplinary programme of research and training exmphasizing on ecological approach in the study of interrelationships between man and his environment. The general objectives of the program are : to develop the basis within the physical and social sciences for the rational use and conservation of the resources of the biosphere and to improve the global relationships between man and his environment; to predict the consequences of today's actions on tomorrow's world and thereby to increase man's ability to manage efficiently the natural resources of the biosphere. MAB is not a program of management, but seeks to provide the scientific knowledge and trained personnel needed to manage the natural resourfes in a rational and sustained manner.

Approach

MAB is interdisciplinary in approach, which emphasizes on the collective efforts by natural and social scientists. It is a problem-oriented programme rather than discipline oriented. This programme aims to provide scientific bases to solve the practical problems of resource management through understanding the environmental problems in the ecosystem context. Lastly, it aims to fllow a system approach to find the best possible solution under a given set of conditions. MAB, in this way, helps bringing together the planners, policy makers, managers and scientists to arrive at a rational decision on the issues of resource management.

Organisation

International Coordination Council (ICC) directs MAB at international level and in real sense the Council is inter-governmental and representative in character. ICC is constituted of 30 countries elected by the General Conference of UNESCO. It meets after every two years to review and evaluate the progress resulted through the implementation of the programme. An MAB secretariat, provided by UNESCO ensures overall coordination at international level. The entire programme is operated globally through the agencies like the National MAB Committees. Including India, MAB National Committees so far have been set up in 101 countries. Every national committee has scientists from universities and research institutions and public or private bodies' representatives concerned with environmental management. The programme is directed and supervised by these committees.

MAB cooperates closely with several other organizations viz. United Nations Environment Programme (UNEP), Food and Agricultural Organisation (FAO), World Health Organisation (WHO), International Council for Scientific Unions (ICSU), and International Union for Conservation of Nature and Natural Resources (IUCN).

MAB programme in India is serviced and funded by the department of Environment, Forest and Wildlife. The national committee, Indian National Man and the Biosphere Committee, was first constituted in 1972. It directs and supervises programme in India. The members of the committee are taken from universities and other scientific organizations and the usual term of these members is two years. This committee functions as an advisory/recommendatory body to the Department of Environment, Forest and Wildlife for the MAB programme and catalyses actions on the issues related to this programme.

Project Areas

Research activities under the MAB Programme are divided into 14 broad themses.

In India, major activities under each project are stated in brief. Project areas 1 to 7 focus on interactions of man with particular type of ecosystems (viz. mountain ecosystems, arid zones, tropical forests, fresh and saline water ecosystems etc.). Project area 1 to 8 connotes establishment of Biosphere Reserves. While project areas 9 to 14 focus on particular aspects of major processes (pollution, pesticides, urban systems, demographic changes, engineering works etc.). Each country has its own priorities for actual research activities among these 14 areas.

Project Area 1 : Ecological Efects of Increasing Human Activities on Tropical and Subtropical Forest Ecosystems :

The prime themes of this project area include :

- Base line studies in tropical forest ecosystems;
- Problems involved in natural regeneration and management of exploited tropical forest ecosystems;
- Investigations into the methods of regeneration of exploited tropical forest ecosystems which also incldues studies on agrosilviculture;
- Effects of various methods of cultivation and land use on soil structure and fertility of agro-ecosystems derived from tropical forest ecosystems;
- Investigations on other uses of tropical forest ecosystems including non-conventional uses.

Tropical forests in India covers about 58.8 M ha. and it constitutes about 9% of India's forest cover. They are the habitat of several endemic, rare and threatened plant and animal species. Further, these forests are the home of a number of tribal people and forest dwellers. At present these forests are severely damaged and threatened and a wider part of these forests are cleared. Thus, ecological management of these forests in utmost important.

Research projects on impact of grazing, silviculture and air pollution on teak forests and Savanna of Chandra Prabha Sanctuary, UP, and shifting agriculture in north-eastern area are completed. Studies on man-forest interaction in Attapady forests of Kerala, forest management in MP, jhum cultivation in north-east India, man-forest interaction on Orissa and MP, and deforestation in Kerala are in progress. Research work is also continuing on in eco-development areas of Himalayas and Western Ghats.

Project Area 2 : Ecological Effects of Different Land Uses and Management Practices on Temperate and Mediterranean Forest Landscapes :

The broad objects are :

- To identify and asses changes brought by human activities on such landscapes, and the effects of these changes on man;
- A comparative study of structure, function and dynamics of natural, modified and managed forest ecosystems and their replacement systems;
- A comparative study of interrelationship between natural and man-made forest eco-systems and scio-economic processes and the impact of changes in human population and technology ont the future viability of these systems;
- To develop ways and means of measuring quantitative and qualitative changes in the forest environment for setting up the criteria of rational use and management of forest resources.
- Ecological and socio-economic consequences of the use of introduced tree species in plantation forestry;
- Impact of tourism and other recreational activities on forest landscspes; ecological impact of forest fires, including their use in management;
- Effects of air pollution on forest ecoystems and forest influences on air quality;
- Ecological impact of free-range grazing on forest ecosystems.

Of these, the project on ecological effects of land use and management practices of forest landscapes of Srinagar mountains has been completed.

Project Area 3 : Impact of Human Activities and Land Use Practices on Grazing Lands : Savanna Grassland (from Temperate to Arid Areas)

The broad objectivies of this Project Area are to secure, quantify, synthesize, distribute and apply information from natural and social sciences research on grazing lands, in order to provde guidelines for optimal management of these lands under different climatic and socio-economic conditions and to provide more effective means to achieve optimal management of this resources.

A project on marginal lands at Rajkot in Western India was undertaken to study typical arid, semi-arid and sub-humid eco-climates. Possible means for improvement of grapzing, land productivity and human welfare are to be developed. Research work on natural and modified temperate grassland ecosystems of Western Garhwal Himalayas has also been undertaken to assess the actual and potential productivity of these lands.

Project Area 4 : Impact of Human Activities on the Dynamics of Arid and Semi-arid Zone Ecosystems with Particular Attention to the Effects of Irrigation.

The aims of this project area are general ecological improvement of arid and semi-arid regions with special emphasis on the effects of irrigation, e.g., impacts on water regime, water

logging, salinity and alkalinity, land use, soil and atmospheric conditions, flora and fauna and human populations with reference to the problems related to health, migration and socio-economic changes. Research work on impacts of human activities on sand-dune ecosystems of the desert region of India has been started at Jodhpur. Besides, another project on wind erosion in dry agricultural lands in plain districts of Tamil Nadu has been started.

Project Area 5 : Ecolocial Effects of Human Activities on the Value and Resources of Lakes, Marshes, Rivers, Deltas, Estuaries and Coastal Zones.

The principal anthropogenic activities inviting ecological impacts on aquatic systems are land use (mainly agricultural), large engineering works, industrial and domestic pollution, tourism and recreational activities, conservation and introduction of species and resource utilization especially in the Coastal Zones. Wetlands and mangroves are important elements of this project for their important ecological functions, their high productivity and serious threat of their own exploitation.

Lake Ecology : Several projects including studies on Nainital lake of Uttar Pradesh, Chilika lake of Orissa, Bharatpur and Ramgarh lakes of Rajasthan, a number of lakes in Hyderabad of Andhra Pradesh and Loktak lake of Imphal have been completed. Research work is in progress on Dal Lake including some rural lakes of Kashmir, lower lakes of Bhopal in Madhya Pradesh, Rawalsar and Renuka lakes of Himachal Pradesh and Udaipur lake of Rajasthan. The research works in these cases are based on analysis of demographic and socio-economic problems including tourism, industrial and human settlements related to stricter and function of these lakes.

Rivers : A coordinated research programme was taken for the integrated study of the river Ganga and its immediate basin. The principal areas of researh are—

- Origin, nature and extent of pollution and its effect on aquatic life, other animals and man (indicator organisms for pollution monitoring); ecological and pollution modeling;
- Sewage problems;
- Harnessing the river for agriculture, animal husbandry, fisheries, drinking and industrial water supply;
- Tidal movement—effects of ecosystem;
- Problems on human settlements on bank;
- Creating environmental awareness among people;

The river Ganga has been divided into three sectors;

Upper—Gangotri to Narora,

Middle—Narora to Bathan

Lower—Bathan to Hooghly.

Responsibility of research works of these sectors have been handed over as below :

Upper—Universities of Garhwal, Roorkee and Gurukul Kangri.

Middle—Universities of Kanpur, Banaras, Aligarh, Ranchi, Patna.

Lower—Universities of Burdwan, Kalyani, Jadavpur, BCKV and Calcutta.

Mangroves : This forest ecoystem includes detaic mangroves along the eastern coast, esturarine mangroves along the western coast and insular mangroves on the Andaman and Nicobar Islands. An All India Coordinated Project on Mangrove Research has already been developed. Studies in mangrove ecosystems of Sunderbans, Andaman Islands, Cochin backwaters are in progress.

Project Area 6 : Impact of Human Activities on Mountain Ecosystems

The chief objects are :-

- Effects of land use alternatives from conservation and restoration viewpoint (effect of shifting agriculture, over-grazing, deforestation);
- Impact of large-scale technology such as hydroelectric power and water-storage dams, extractive processes such strip mining, extraction of sand and gravel, oil and gas exploitation; roads and other communication links; buildings and other structures related to tourism etc.;
- Effects of tourism and recreation;
- Human settlements (emphasizing population migration and impact of inroads of modernization on the culture and life style of people).

Programs launched under this Project Area are :

(a) *Coordinated eco-development research-cum-field action program in the Himalayan Region.*

(i). Watershed management (Dachigam in Kashmir; Gamohar and Kotgarh areas of Sutlej catchments in HP; Gola catchements in Komaon Himalayas and Rangoon and Singtum in Sikkim).

(ii) Ecosystem studies.

(iii) Landslide hazard zonation and mitigation (Kumaon-Garhwal region).

(iv) Regeneration of the Himalayan foothills (Parandal region in J&K; other areas in HP, Punjab, Haryana and West Bengal).

(b) *Establishment of the Himalayan Institute of Environment and Development.*

The Ministry of Environment and Forests, Govt. of India, has already established the ***Govind Ballabh Pant Institute of Himalayan Environment and Development.*** The institute has already started functioning for its temporary office at Kosi, near Almora from August 1988. It consists of a chain of centers of advanced studies and field stations along the entire Himalayan belt.

(c) *Coordinated eco-development research-cum-field action program in the Western Ghats.* (covering an area of 134,000 km2 in the states of Maharastra,

Karnataka, Tamilnadu, Kerala and Union Territory of Goa). There are 49 research projects in 21 organizations under this major project.

(d) *Projet on "impact of technoogical and economic development programs on bio-cultural heritage of Gaddis and Pangawala population groups of Himachal Pradesh"* has been completed and another one on *"impact of human activities on ecosystems and vice-versa in reference to Sikkim Himalayas"* in in progress.

Project Area 7 : Ecology and Rational Use of Island Ecosystems.

The principal objective of this Project Area is to preserve the traditional life style of the natives of such areas. Emphasis is given to impact of tourism, resources exploitation and alien plants and animals on such systems. There are two such groups of islands in India : one on the eastern flank (the Andaman and Nicobar Archipelago in the Bay of Bengal), and the second on the western flank (the Lakshadweep group of islands in the Arabian sea). Already a study has been done on "value of floral resources of the Great Nicobars". A number of studies have also been undertaken.

Project Area 8 : Conservation of Natural Areas and the Genetic Material they contain.

The major areas of interests are :

- Preparation of inventory of the biomes and their genetic diversity;
- Preparation of an inventory of the rare and threatened plant and animal species;
- Protection of representative ecosystems in the form of Biosphere Reserves and National Parks, etc.;
- Studies on population dynamics on endangered/rare plant and animal species in the important natural ecosystems;
- Development of techniques for rapid multiplication of threatened and rare plant and animal species. Domesticated plants and animals and microorganisms of direct application to science, technology, medicine, agriculture are excluded for genetic diversity studies.

(a) ***Biosphere Reserves :*** In Indian region, there are about 45,000 plant and 65,000 animal species. A major step towards conservation of its flora and fauna was taken by enactment of Indian Wildlife (Protection) Act in 1972. At present there are 67 National Parks and 394 sanctuaries in India. The MAB committee of India identified a network of 13 representative ecosystems to be protected as Biosphere Reserves, out of which, four have already been declared as Biosphere Reserves.

(b) ***Conservation of endangered plant species programme on seed biology and tissue culture:*** The programme was initiated with special emphasis on medicinal plants, with the aims to conserve *in situ* and mass multiplication of plant species. Endangered species are identified on regional basis and studied are made on their gene pool conservation, artificial propagation in nature, development of tissue culture

techniques etc. An all India coordinated project is being caried with the help of two expert committees, one on tissue culture and the other on seed biology. The centers are : Garhwal University, Srinagar; Regional Research Lab., Jammu; Department of Botany, Calcutta University; Department of Botany, Delhi University; National Chemical Lab., Pune; Botanical Survey of India, Calcutta and NEHU, Shillong.

(c) ***Study of plant and animal resources :*** Research studies on biological resources in different ecological zones of India are continuing. Most among them are : cytogenetic survey of the flora of Silent Valley in Kerala; endangered and threatened species of animals and birds at Nanda Devi snactuary (UP); floral and faunal resources of biosphere Reserve area of Namdhapa Wildlife Sanctuary (Arunachal Pradesh) and of Sacred groves of Dakshin Kannada and Kodagu District in Karnataka and Bio-ecological Studies on the gray pelican and horseshoecrab.

Project Area 9 : Ecological Assessment of Pest Management and Fertilizer Use on Terrestrial and Aquatic Ecosystems.

This programme of MAB exerts special emphasis on development of ecologically safe methods for control of pests of agriculture and public health importance. The other areas of research are : bio-mangnification of pesticides through specific food chains; effects on non-target organisms; movement, cycling and degradation of pesticides within selected ecosystems; vector control and integrated pest management. The Indian Council of Agriculture Research and Agricultural Universities are doing major works of such research areas.

Project Area 10 : Effects of Major Engineering Works on Man and his Environment.

This project aims to study the impacts of major engineering works such as irrigation and hydroelectric projects. A project on long term impacts of Beas-Sutlej hydroelectric projects has been done, where the following are involved: Himachal Pradesh Agricultural University, Palampur; BSI; ZSI; Central Inland Fisheries Research Institute, Barrackpore. Another project is on the long-term environmental and ecological impacts of Idukki Hydel Project in Kerala by the Department of Environment. A project on assessment of deterioration of soil due to irrigation by Saryu Canal Project in UP is carried out to study salinity and alkalinity problems, water logging, seepage, depletion of micro-elements etc.

Project Area 11 : Ecological Aspects of Urban Systems with Particular Emphasis on Utilizations of Energy.

This area of research includes flows of matter and energy into the urban areas and pattern of their utilization; interelations between urban and rural areas; ecology of human settlements with emphasis on conceptual modeling and systems analysis.

Project Area 12 : Interactions Between Environmental Transofrmation and the Adaptive, Demographic and Genetic Structure of Human Populations.

This programme considers the interaction of humen population with his environment. An inter-sectoral study of tribals of India is in progress under this programme. The Department of Enviroment, Government of India, initiated the All India Coordinated Research Project on

Ethnobiology. About 38 million tribals of diverse ethnic groups with distinct cultural heritage live in India. This project has following objectives :

- Folklore survey and collection and identification of plants and animals used by tribals;
- Conservation of used by them;
- Impact of development and technology;
- Impact of tribal culture on vegetation and wildlfie;
- Pharmacological study on sueful chemical components of plants/animals materials used by man;
- Technology of the development of tribal communities.

The participating institutions of this programme are :

Regional Research Lab. (CSIR), Jammu Tawi; Central Drug Research institute, Lucknow; NBRI, Lucknow; BSI, Haora; ZSI, Kolkata; Birbal Sahani Institute of Paleobotany, Lucknow; Unviersity of Garhwal, Srinagar.

Project Area 13 : Perception of Environmental Quality.

The research themes mentioned below formed the basis of cooperative research between countries on different aspects of the project area :

- Perception of environmental hazards;
- Perception of the environment in isolated or peripheral ecological areas;
- Perception of National Parks and other relatively unmodified natural areas;
- Perception of typical man-made landscapes of ecological, historical and aesthetic importance;
- Perception of quality in urban environments.

Project area 14 : Research on Environmental Pollution and its Effects on the Biosphere.

The major areas of this project are;

- Analysis of pathways and transformations involved in the movement of pollutants through the ecosystems (in which a particular relevant pollutant will be emphasized);
- To identify the environmental indicators;
- Acute and long-term effects of pollutants from domestic, industrial, agricultural or other sources on biota;
- To monitor the levels of different pollutants in the environment.

A number of research projects have been sponsored on these aspects. A Unit of Genetic Toxicology has been established at Calcutta University to study (i) the chronic effects of sub-toxic doses of pollutants on human systems in relation with different modifying factors as genetic polymorphism, nutrition etc. and (ii) identify the species of vegetation genetically tolerant to various pollutants.

A project has been initiated to study the effects of SO2 and particulate matters on vegetation in the urban and industrial areas. The project was designed to focus on specific (i.e., industrial pollution) and unspecific air pollution. The organizations involved in this project ae : BHU, Varanasi; JNU, New Delhi; NBRI, Lucknow; NEERI, Nagpur; University of Calcutta; Vikram University, Ujjain and BSI, Kolkata.

The Priority Areas of MAB in India

India, for its wide diversity has been divided into the following broad geographic regions each with its predominant natural ecosystems and human sresses:

Board geographical regions	Predominant natural ecosystems	Human stresses
(i) High altitude mountains (Himalayas and NE region)	Dry evergreen (Western Himalayas) to wet evergreen forests (Eastern Himalayas); snowlines, scrub and steppes.	Forestry, cultivation, construction of roads, buildings and dams; mining, grazing, forest fires.
(ii) Mountains of Peninsular India	Southern moist deciduous, southern tropical evergreen, moist deciduous, dry deciduous, southern montane.	Forestry, cultivation, mining, developmental projects.
(iii) Indo-Gangetic Plains	Tropical deciduous forests	Population density, settlements, cultivation, irrigation.
(iv) Vihdhyan and Deccan Highlands and Plateau	Tropical deciduous forests with teak (semi-arid, west) and with *sal* (moist, east)	Forestry, mining, constructions, grazing.
(iv) Coastal Regions	Mangrove (deltaic regions), palm, savannas, moist deciduous forests.	Industrialisation, urbanization, mining.
(vii) Oceanic Islands	Tropical evergreen forests, mangroves.	Tourism.

During the period 1985-90 the MAB had focused much attention on the following areas : (i) conservation of flora and fauna. (ii) mountain ecosystem. (iii) arid and semiarid regions (iv) mangroves, wetlands and coastal areas (v) tropical forest ecosystems, particularly the tropical moist forests and (vi) environmental awareness programme.

International Biological Programme (IBP)

Human society, for a long time, has been trying to understand the environment on global basis and the success of International Geophysical Year (IGY) encouraged the ecologists to think of the biosphere as a workable ecosystem. Man is an important component as well as a factor in this ecosystem and for all his needs of food, comfort and energy he is tapping the natural resources in a rapid pace, which at a point upsets the balance of Nature. Human population is not distributed uniformly over the globe and the numerical strength is increasing at an alarming fast rate. Man has to perceive the *ecological potential* of his surroundings in order to maintain the dominance and quality of man over other animals. Ecologists all over the world realized the necessity of evaluating biological potential of the biosphere in various habitats. The International Biological Programme (IBP) and Man and Biosphere Programme (MAB) were launched on global basis in this context. A short account of IBP may now be discussed.

The IBP

The International Biological Programme is a worldwide plan of research concerned with 'the biological basis of productivity and human welfare'.

Period of start and duration

Discussions leading to initiation of BIP started in 1959 and were stimulated by the success of the International Geophysical Year (IGY). A planning committee was formed in 1962, but the programme was not formalized until July 1964, when the first General Assembly of IBP approved it. The first three years (phase I) are devoted to design and feasibility of studies. The operation program (phase 2) started formally on 1st July 1967 and was to run for five years.

The second phase of IBP came to an end in 1972 and the life of this programme was extended for further two years. The period 1973-74 formed Phase III—Synthesis and Transfer. Many countries invested substantially to this programme during this period and ample of useful information had been collected. All the data had been planed to be synthesized and published in 40 volumes. The activities were planed to be transferred to other continuing organizations like MAB and IUCN etc.

The aims and objectives of IBP

The rapidly increasing human population and wide extent of malnutrition called for greatly increased food production coupled with rational management of natural resources. This could be achieved only on the basis of scientific knowledge which were inadequte in many parts of the world. At the same time human activities are creative rapid and comprehensive changes in the environment. Thus, in terms of human welfare, the reason for the IBP lies in its promotion of basic knowledge relevant to the needs of man.

The aims of BIP were to fill in the gaps in knowledge by means of a coordinated, comprehensive approach including sufficient standardization of methods to assure comparable results. It is concentrated on problems, the solution of which will benefit form international collaboration. In order to provide an operating framework for its research the IBP was divided in to seven sections known by their initials :

The section of IBP

There are seven sections of the IBP as detailed below :-

(a) ***Productivity of Terrestrial Communities (PT).*** This includes primary productivity through green plants and secondary prodicutivity through animals feeding on plants or on each other. It also includes the breakdown of organic matter.

(b) ***Production Process (PP).*** This is concerned with the utilization of solar energy in photosynthesis and transpiration by plants and the nitrogen cycle.

(c) ***Conservation of Terrestrial Communities (CT).*** Its principal task was to provide a scientific basis for the conservation of areas and species, to assure for present and future needs an adequate supply of natural habitats. Those provided unique and rapidly disappearing opportunities for research on biological processes and also have aesthetic values.

(d) ***Productivity of freshwater Communities (PF).*** Like PT this section had branches concerned with primary and secondary producitivity. It includes the conservation of aquatic communities. On the practical side fisheries benefit from an increase of productivity, whereas water supply benefits from the reverse.

(e) ***Productivity of Marine Communities (PM).*** This section was tended to concentrate its activities of inshore waters and estuaries for there are several other international organizations dealing with the open oceans. The conservation of marine habitats was included.

(f) ***Human Adaptability (HA).*** The subjects covered include genetics, growth and physique, tolerance to heat, cold and high altitudes, working capacity and population dynamics of man.

(g) ***Use and Management of Biological Resources (UM).*** This section included the establishment of plant gene pools, biological control, growth and production of cereals and the development of new biological resources used by man.

In addition to these seven programmes there were interesectional activities concerning terminology, biometeorology, nutrition, and a programme on large herbivores. Other activities were also developed.

The Committee responsible for IBP

A Special Committee for International Biological Programme (SCIBP) is responsible for the programme to the International Council of Scientific Unions (ICSU). The international programme consists of the sum of a number of national programmes that are the responsibility of national IBP committees. These were set up by scientific organizations, such as, national academies of sciences, research councils or equivalent organizations, and most of these are members of ICSU. Thus IBP is not directly part of governments although it requires official funds to be carried through.

The Organization of IBP

The SCIBP had established seven sectional committees; each presided over by a convener. In addition it has a Bureau, constituted of the President, four Vice-Presidents and a Scientific Director, and there is a separate Finance Commiteee. The headquarters is established in London, IBP Central Office, 7 Marylbone Road, London, NW 1.

Many of the participating countries have established national committees and sub-committees that correspond in the coverage of subejcts with SCIB and in sectional committees.

Relations of IBP with other International Organizations

IBP works in close consultation with several of the spcialized Agencies of the United Nations, particularly the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Food and Agricultural Organisation (FAO), the World Health Organisation (WHO), and the World Meteorological Organnisation (WMO) and from these IBP draws financial and other supports.

As a part of the ICSU family, IBP is closely connected to the International Unions of Biological Sciences (IUBS), of Biochemistry (IUB), of Physical Sciences (IUOPS) and also to the Scientific Committees on Oceanic Research (SCOR). Beyond the ICSU family, IBP has close relations with the International Unions for the Conservation of Nature and Natural Resources (IUCN), Nutritional Sciences (IUNS), and Anthropological and Ethnological Sciences (IUAES).

Meetings and Publications of IBP

SCIB itself meets once a year and every other year it holds a GENERAL Assembly. Each of the section committee meets once or twice a year and upto a dozen technical meetings are held each year on particular themes which emerge from sectional or participates in other meetings which bear on the programme organized by the Specialized Agencies of UN, by ICSU and its Unions. Meetings of national committees and sub-committees and a good many other meetings are held on the national scale, including symposia on themes directly related IBP.

IBP News, of which three or four numbers are published each year since November 1964, is the main publication recording progress. IBP Handbooks form a separate series and consist of guides to sectional activities and methods of **research.** In addition there are publications issued by agencies other than IBP, including books, volumes of symposia results, papers in the technical and semi-technical press.

The participants of IBP

IBP provides a unique opportunity for obtaining data from a large variety of environments with a degree of comparability never previously achieved. Thus it can be of vital importance to biologists throughout the world, and its success will depend on the participation of the world's biologists. It is a programme of and for biologists.

4.4. Factors Controlling Biodiversity

Introduction

The growth, distribution and extinction of the biological diversity of the earth are the prime concerns of biogeography. The innumerable variety of living organisms of the planet earth has provided for various requirements of man over thousands of years. This diversity of living organisms formed support system utilized by all civilizations of the world for their survival, growth and development. The civilizations which used this gift of nature with due care and in sustainable way has survived, but those abused and overused has degraded or collapsed.

Attempt to classify and categorize the variability of life in nature has been an imortant purpose of science for more than a century. This has led to an understanding of its organization into communities of plants and animals. This in turn has helped in utilizing the organic assets of the earth for the gain of humankind and has been essential to the course of development. It includes better crops and the use of these life-forms as raw material for industrial development principal to higher standard of living and better health care. On the other hand, it also has produced the modern consumerist societies that inflict undesirable effects on the biological diversity upon which our development is based. The variety of life on earth is so enormous that if we use it sustainably we can continue developing new harvest from biodiversity for many generations. It can occur only if we deal with biodiversity as a valuable resource and avert the extinction of species.

Definition of Biodiversity

The term 'biodiversity' has been derived from two words 'biological diversity'. In a simple sense, biodiversity means the number of different species in a specific geographic area. Broadly, biodiversity can be defined as 'the number, variety, and variability of living organisms' (MC Donald, 2003). Biodiversity is that part of nature which includes the differences in genes among the individuals of a species along with the variety and prosperity of all the plant and animal species at different local, regional, continental and world scales and the types of ecosystems, terrestrial and aquatic, within a defined geographic area. The greater the number of species present, the greater the biodiversity. The simple appraisal of biodiversity based exclusively on the number of different species in given area, is also called 'species richness' by ecologists. In many extensive biogeographical studies, biodiversity is synonymous with species richness (Mc Donald, 2003).

Biodiversity thus deals with the degree of nature's variety in the biosphere. This variety or diversity can be observed at three levels—the genetic variability within a species (= Genetic diversity); the variety of species within a community (Species diversity); and the organization of species in an area into distinctive plant and animal communities (= Ecosystem diversity).

Genetic diversity

The large number of combinations feasible in the genes gives each individual its explicit characteristics. This is why each member of any animal or plant species differs extensively from

other individuals in its genetic makeup. Such as, each human being is very different from all others. This genetic variability is essential for a fit breeding population of a species. Variation in genetic makeup is reduced and in-breeding occurs when the number of breeding individuals in reduced. This leads to genetic anomalies and, in due course, to the extinction of that particular species. The diversity in wild species forms the 'gene pool' from which our crops and domestic animals have been developed over thousand of years. At present, the variety of nature's gift is being further exploited by using wild relatives to make new variety of more productive, disease-defiant crops and to breed better-quality domestic animals. Recent biotechnology also manipulates genes to develop better types of medicines and a range of industrial products.

Species diversity

The species diversity of a region means the number of species of plants and animals that are present therein. Species diversity is observed both in natural ecosystems and in man-altered ecosystems, such as, agricultural ecosystems. There is obvious unevenness in the distribution of species richness; some areas may be rich in species than others. Undisturbed natural tropical forests have much greater species richness than man-managed monoculture plantation forests. Natural forest ecosystems provide a large number of non-timber forest products like food, fiber, fuel, fodder, medicines, resin, gum, honey etc. Local people setting in and nearer the forests are much dependent on these products. Timber plantation forests are incapable to supply these resources essential to the relatively poor people. In the long-run, the sustainable economic proceeds from non-timber forest products of a natural forest ecosystem, is much larger than the returns from felling a forest for extraction of timber. Therefore, with all its species richness and higher biodiversity, even the commercial value of a natural forest is proved to be much higher than a monoculture plantation forest. Similarly, conventional agro-pastoral farming systems yielding multiple crops should have a relatively higher diversity of crops compared to modern intensive agricultural ecosystems. Conservation scientists of our time have been able to identify and categorize about 1.8 million of species on the surface of the earth. But, as described by them, this figure is only a fraction of what really exists. Many new species are being identified in many ecosystems. Areas rich in species diversity are called 'hotspots' of diversity. India ranks 15th among the nations exceptionally rich in species diversity (Bharucha, 2005).

Ecosystem diversity

The biosphere of the planet earth is considered as a great ecosystem. In fact the surface of the earth is composed of a large number of ecosystem mosaics with large range of diverse ecosystems each of which having their own accompaniment of unique interlinked species based on the differences in the habitat. Ecosystem diversity is usually described for a definite geographical region delineated physically or politically. Characteristic ecosystems embrace landscapes like mountains, forests, grasslands, deserts, watersheds, river basins, estuaries, etc., as well as aquatic ecosystems like rivers, lakes, and seas. Within those regions there may exist some ecoystems modified and managed by man such as grazing pastures, farmland etc.

Life, as a product of organic reactions, was perhaps initiated in the primeval seas of our planet earth, and scientists assume that life on earth originated some 3.5 billion years ago. After

having grasp on the planet, life began to diversify slowly. The preliminary unspecialized unicellular forms of life gradually evolved into complex multicellular plants and animals and followed the process of evolution through course of time with their ability to adapt with the changes occurred in environment. The geo-environmental changes in nature like continental drift, longtime fluctuations of temperature of the earth's temperature and resultant repeated glaciations, climatic changes and formation of geographical barriers forced plants and animals to be segregated with different communities which gradually led to the formation of new species over millions years. Their adaptability of life to gradual changes in their habitat and interactions with neospecies produced groups of interlinked organisms that continue to evolve together. Most important examples are food chains, energy flow in ecosystems, prey-predator relations, commensalisms, parasitism, ammensalisms etc. Interlinks among the different species of communities developed their behaviour patterns through the processes of migration, feeding patterns and breeding biology. As geological changes caused extinction of many species, their left behind empty niches in the habitat was filled in by the existing species through development of neo-species. Our planet earth has experienced a number of episodes of extinction and neo-species. Our planet earth has experienced a number of episodes of extinction and neo-species formation. Repeatedly these led to a severe decline in the number of species but the diversity of life recuperated each time by slowly escalating the number of species existing on the planet earth. Evolution being a very slow process, it took millions of years to recuperate. Eventually the planet earth was more affluent in species during the time man appeared on the scene before two million years before present. However, extinctions due to the behavior of modern man have begun to take place during the recent past that nature has had no time to evolve new species. Thus the earth is losing species more quickly than ever before.

Controlling factors of geographic distribution

Biodiversity differ greatly in its geographic distribution, it is higher in tropical regions than temperate and polar regions. Scientists have presented two main categories of controlling factors to explain the geographic differences in biodiversity. A group of biogeographers are in favour to explain the causes of these differences with the past history of species evolution and extinction. Others consider these differences as the result of modern environmental conditions and biological processes. Explanations formulated by the first group are referred to as *historical theories of biodiversity* and by the later group are referred to as *equilibrium theories of biodiversity.* In short, the historical explanations suppose that the modern patterns of biodiversity are not in the equilibrium with modern environmental conditions but as an alternative reveal the impacts of past events. On contrary, the equilibrium explanations presume that the number of species in a given area reflects the present physical and biological state of the area in question (Mac Donald, 2003).

The present distribution pattern and gradients in biodiversity throughout the globe reflect past events in the evolution and extinction of species. Theories on this aspect were developed largely to explain the existence of high species richness of the tropics compared to the lower biodiversity of the temperate and polar regions. These theories are known as **historical theories of biodiversity.** The classical historical theory focuses on the fact that the repeated glacial

periods of the Pleistocene resulted in severe disruptions of environment in polar and temperate regions. The theory sufficiently explains that the plants and animals in the higher latitudes had to face widespread extinction caused by advancing ice and cold during glaciations. Thus it would be natural to surmise that rates of evolution were too slow to produce significant adaptive radiation and rebuild species richness in the intervals between glacial periods. Thus, species diversity would have remained low at high latitudes as long as glacial and interglacial periods alternate.

Further, the classical historical theory holds that during glacial periods, the tropics did not experience significant environmental disorder. As a result, the rates of extinction have remained low than that of the high latitudes. Long period of environmental stability have allowed for the evolutionary development of a huge number of new species in the tropics and equatorial regions, which is known in biogeography as *stability-time hypothesis* (MacDonald, 2003). Evidences composed by scientists recommend that the tropical regions were not resistant to environmental changes during the glacial and nonglacial periods of the Pleistocene. Many scientists consider that tropical land areas cooled by some degrees and became much drier than present during the last glacial maximum. Evidences and records pertaining to that time, about 20,000 years ago, have been received from several sources like, fossils and sediments in deep sea cores, fossil soils, fossil pollens from lake sediments etc. It has been suggested from some of these records that dry conditions led to the fragmentation of the tropical rain forest in Africa, Southeast Asia and South America (MacDonald, 2003). But some biogeographers are of the opinion that fragmentation of the tropical rain forests during glacial episodes may essentially have promoted high diversity by allowing allopatric speciation to occur within the secluded forests rooted along river basins and humid areas. Along with that, genetic studies of modern rain forest species advocate that genetic divergence and speciation are most probable to occur along ecotones between rain forests and savannas. Thus it may be easily assumed that as rainforests in glacial periods became fragmented, areas of ecotones would have been augmented. Thus, one may criticize in the line that the historical theories explain local differences more perfectly, but it is not much fit to explain overall latitudinal gradients in biodiversity.

Equilibrium theories of biodiversity have been proposed to explain the causes responsible for differences in species richness on both small and large scales. These theories deem biodiversity in contexts of environmental gradients and niche theory. According to this theory, the areas of high species numbers reveal one of the following three conditions : (a) The areas of high biodiversity could contain large gradients of resources and offer a wide range of habitat for different species to utilize. If a region holds a larger geographical area, such as Amazon Basin in South America, which extends across a wide array of climo-edaphic conditions, can offer wide varieties of habitat ready to support a large number of different species. Similarly, a small region like the hill plateau-plain complex of Eastern Himalayas may offer a wide range of environmental setting due to its varied topography which creates diverse environments. Thus, theoretically both of these regions can sustain a large number of species because each resource gradient is wide and existing wide range of habitat can sustain different species with different ranges of tolerance and niches. (b) In both of the two regions, the range of habitat may be analogous and the lengths of resource gradients may be the same, but due to the existence of

particular niches, the extent of the distribution of individual species along the gradients may be short in one region and long in other region. Therefore, if it is assumed that competition between species precludes too much overlap along gradients and between niches, more species are accommodated along the resource gradients if each species is a specialist and has a constricted distribution. In such cases, the control of severe interspecific competition on natural selection is reflected on the development of such specialized niches. Deficiency of interspecific competition on natural selection is reflected on the development of such specialized niches. Deficiency of interspecific competition in one area may permit a few species to persevere with very large niches, while strong competition in other area may generate a huge number of specialist species with small niches. (c) The essential resources may be more profuse in one area than in another. The gradients for the low biodiversity area would be characterized by low abundances of resources, while the high species diversity area would be characterized by high abundances. Larger abundance of resources could permit either a reduction of competitive pressure allowing a greater number of generalist species to endure, or, if had been interspecific competition a significant factor, it could allow greater numbers of species with highly specialized niches to survive.

Habitat Diversity

Habitat diversity of larger numbers correlates positively with greater length of resource gradient and greater niche space available. Thus it means that species diversity is positively correlated with habitat diversity and it can be generated by differences in the physical or biological environment. As topography affects habitat diversity at both small and large scales, areas with complex topography present a greater number of habitats and wider variability of habitat types than do areas with flat topography. In case of small scale, a tract with gently rolling topography includes thin and dry cover of soils on hill tops, mesic soils on hills slopes, and wet soils on lower parts of foothills. Thus plants and animals would avail habitat which required dry, mesic and wet soil conditions. The rolling topography therefore would present more habitat diversity and would display greater speices diversity than a tract with flat topography contiguous to it. On contrary, at the large scale, mountainous regions with complex topography and different heights can include a wide range of environments extending from hot and dry low-elevation barren flats, cool and wet mid-elevation parts covered with forests and woodlands and cold high-elevation tundra. Further, the varied mountainous regions could lead to the reproductive seclusion of species populations and generate augmented rates of allopatric speciation. But it should be noted that topographic diversity does not offer a adequate clarification for overall biodiversity gradients, while it is fit to explicate local and regional differences in biodiversity. Another significant biological contributor to habitat diversity is vegetation structure, which may present both horizontal and vertical variations. Habitat diversity may be significantly influenced by the vertical structure of vegetation. Highly stratified forests, such as tropical rain forests, present differences in plant composition and microclimate in each stratum and presents a wide range of habitats for mammals, birds, reptiles, amphibians and insects. In addition to it, diverse plant species dominating in different strata afford different food sources and hence are capable of sustaining a huge animal and insect diversity.

Vast Land Areas in the Tropical Realms

The vast and continuous land areas of the tropical regions of the globe include the tropical rich biodiversity realms of Africa, South East Asia, South America and Australasia. These tropical and equatorial areas are the most significant contributors to the development and preservation of high species diversity. In the Amazonian rainforests of the equatorial zones, existence of vast areas of uninterrupted habitat allows species to have huge populations and large geographic distributions. A large population size decreases the possibility of extinction. Therefore species can survive with narrow ranges of tolerance along resource gradients if they were distributed over large areas and develop specific niches that would direct to sustainable small populations if the geographic area of the species' distribution is small. But is should be noted that 'the problem with this hypothesis is that it does not explain why the huge boreal biome has much lower species richness than smaller biomes such as the temperate deciduous forest, Mediterranean, or coastal rainforest biomes' (MacDonald, 2003). Further, it fails to explain latitudinal gradients in marine biodiversity.

Environmental Stability

The environments wherein climate is relatively stable in short time scale are capable of promoting higher biodiversity than unstable environments. To be clearer, the environments having low ranges of diuranal, seasonal, and annual variability naturally permit species to become finely adapted and to develop the most competent type and behaviour to take benefit of resources exclusive of requiring exchange that let them to survive with variability in environment. Existing resources could support more species as they become more expert and more competent in resource utilization.

The principal appeal of the climatic stability theory is that it explains both the decline in species richness at high latitudes and enhance in the size of species ranges found in those latitudes. Larger ranges observed at high latitudes are measured to be a reflection of the more generalized niches in those areas. But attention should be drawn in the line that in explaining the geographic distribution of biodiversity, the stability theory contains at least three drawbacks : (a) the answer of the question that why short-term climatic stability becomes so limiting to speciation remains unclear; (b) many areas of the earth have very stable environmental conditions while they experience low species diversity, and (c) latitudinal diversity gradients are seen in several groups of species for which there is no proof for more general niche extent or wider geographic distributions at high latitudes (MacDonald, 2003).

Disturbance

The hypothesis related to disturbance as a factor controlling biodiversity was postulated by J. H. Connell in 1978, commonly known as intermediate disturbance hypothesis. The hypothesis states that if an ecosystem stays free of interruption by disturbance, the stable homogenous environmental setting would favour some selected species but will lead to the extinction of some species to whom the steady habitat is unfavourable, or in other words, who are prone to competitive elimination by species that are favoured by the undisturbed environment. Disturbances invite physical and biological changes and spatial heterogeneity that can favour species

might not survive in a stable undisturbed system. On contrary, if disturbance occurs too frequently and severely, then it will lead to the extinction of the species sensitive to disturbance having long generation times or occur in small numbers and are prone to chance extinction.

Competition

Evolution and natural selection of species in the mid-latitude and high-latitude areas are directed by adaptation to physical stresses related to climate. On the other hand, evolution in the warm and moist tropics is thought to be directed more by interspecific competition. In areas of lower latitudes, high level of competition directs species to build up specialized niches which limit their distrubution in terms of habitat, and is directed alongside resource gradients. Then the species become competitively advanced within constricted ranges of environmental setting. Constricted habitat preferences and specialized niches reduce direct competition with other species which in turn increases the number of species able to survive locally, each species using a narrow range of microhabitats. But, it must be noted in this context that the competition theory suffers from at least two drawbacks in explaining global patterns of biodiversity : (a) there is very little persuasive proof that competition and narrow niche specialization can elucidate the diversity of tropical trees, and (b) why competition is a compelling force in the lower latitudes but not in middle and higher latitudes is yet to be explained.

Predation

Generally it is argued that the high numbers of predator and parasite species, especially in the tropics, sustain high biodiversity through maintaining prey populations low and reducing the competitive elimination of one prey sepcies by another. In turn, diminution in competition allows for more prey species to develop. This leads to the co evolution of supplementary specialist and generalist predators. According to this model, some scientists have noted that tropical forests include high numbers of diverse tree species but that most tree species occur as secluded individuals. Stands dominated by one or two speices do not arise in mature tropical lowland forests in common. This signifies that no species appears to be capable of effectively excluding others at a landscape scale. Some scientists have suggested that the spatial isolation of rainforest trees from other members of the same species may be explained with seed predation. The incapability of trees to establish close to other members of the same species keeps the populations of tree species small and discrete. This reduces competitive elimination and allows a greater number of tree species to coexist.

Productivity

Regions with high primary productivity build up high biodiversity due to the fact that vegetation in those regions produces more energy that can sustain more species at higher trophic levels. Larger amounts of accessible energy permit primary consumer species to have comparatively specialized niches in terms of food. If the number of primary consumers becomes greater, then the number of predators to be supported by the environment also becomes greater. The great number of diverse herbivorous species promotes even greater diversity of plants through the coevolution of specialized herbivores, pollinators, and seed dispersers (MacDonald, 2003). There is certainly a general correlation between primary productivity and latitudinal differences

in biodiversity at global level. There are sufficient evidences that these differences in productivity can be directly interrelated with the relative levels of plant and animal biodiversity.

4.4.1 Need for Conservation of Biodiveristy

In our contemporary society, biodiversity is a concern because of awareness of our limited knowledge of the earth's biological diversity, and at the same time it is a realization that it is being destroyed. Contemporary agricultural and forestry practices, annihilation of niches and habitats, pollution and degradation of ecosystems and the introduction of exotic species exterminating native species are the prime causes through which extinctions are now stirring at a quicker rate than ever before.

The importance of biodiversity may be explained with various angles. From *ecological viewpoints,* biodiversity focuses attention on conservation of habitat, ecosystems and the importance of all plants and animals. Maintaining biological and cultural diversity is seen as increasing the probability of survival, whereas monoculture is perceived as being vulnerable to disease and other coercion (Shiva, 1995). Tropical rainforests and coral reefs are predominantly affluent in biological diversity, thus justifying their conservation and preservation through actions such as biosphere reserves or national parks. From *scientific viewpoints,* focusing on biodiversity helps conserves genetic material for future generations to gain knowledge of about life on earth (Johnston et al, 2001).

Examining from *economic angle,* it is often conflated with corporations taking the biological resources from one part of the world to a science laboratory located elsewhere, and then patenting the new product they claim to have created via biotechnology. Occasionally it has been claimed by some experts that the development of biotechnology enchances biodiversity, but Shiva (1995) argues that biotechnology actually reduces biodiversity by introducing a common gene into many species, or by marginalizing less economically beneficial species in favour of the genetically engineered diversity.

Explaining *politically,* biodiversity is controversial because the majority of the 'biological wealth' is situated in the so-called developed countries. The Convention on Biological Diversity in 1992 actually failed to deal with the 'theft' of biological resources that developing countries allege has occurred ever since colonialism. On opposite side, developed countries have argued that biodiversity is part of the 'global commons' for the gain of the mankind, despite of where it is located (Johnston et al, 2001).

A variety of environmental services are prodivded by the global biological diversity from its species and ecosystems that are indispensable to global, regional and local levels. Production of oxygen, reduction of carbon dioxide, continuation of global hydrological cycle, and protection of soil are the most important services. Now the world acknowledges that the loss of biodiversity contributes to global climate changes. As forests are the principal mechanisms for the conversion of carbon dioxide into carbon and oxygen, thus the loss of forest cover and simultaneous increasing discharge of carbon dioxide and other gases in to the atmosphere through industriali-

zation contributes to the 'greenhouse effect'. Global warming is causing the melting of ice caps resulting in a rise in the sea-level that will eventually culminate into the submergence of the low-lying areas of the world. Further, biological diversity is crucial for preserving ecological processes like fixing and recycling of nutrients, formation of soil, circulation and freshening of air and water, global life support, maintenance of water balance within ecosystems, protection of watersheds, maintenance of continued stream and river flows, control of local flood and erosion. In addition, housing, food, clothing, energy, medicines are essential resources connected directly or indirectly to the biological diversity. It is obvious for the tribal communities who directly collect resources from forests or fisher folk who harvest fish from freshwater or marine ecosystems.

Areas rich in biodiversity are used by the biotechnologists to prospect and search for potential genetic properties in plants or animals that can be used to develop better varieties of crops for use or better livestock. For the agricultural scientists, biodiversity is the source for developing better crops; to the industrialists it is a rich storehouse from which new products could be developed; and to a pharmacist, it is the raw material from which new drugs could be branded. In the course of cautious breeding programs, genetic diversity enables scientists and farmers to selectively develop better crops and domestic animals. Previously this was done by selecting or pollinating crops synthetically to get a more productive or strain resistant to disease. But nowadays, it is progressively more being done by genetic engineering, that is, selecting genes from one plant and introducing them into another. Using the genetic material found in wild relatives of crop plants, new crop varieties are being developed through biotechnology. New species of plants and animals are being discovered regularly in the world even now. Wild species are the building blocks for the betterment of human life and their loss is a great economic loss to mankind. Till now, only a tiny proportion among the known species has been investigated for their value in terms of food or medicinal or industrial potential.

Traditional societies with a smaller population required fewer resources. They preserved their biodiversity as a life-supporting resource. But modern man has speedily depleted biodiversity up to the extent of leading to the irrecoverable loss due to extinction of numerous species. Therefore, apart from the local use of biodiversity, there is also the social aspect in which more and more resources are used by affluent societies. To a great extent, our biodiversity has been preserved by traditional societies that esteemed it as a resource and appreciated that its depletion would be a great loss to their society. The consumptive and productive value of biodiversity is closely linked to social concerns in traditional societies. 'Ecosystem people' considers biodiversity as a part of their livelihood as well as through cultural and spiritual sentiments.

Conservation of biodiversity is also needed for its ethical values. These are based on the importance of shielding all forms of life. Most religious and secular creeds consider that all forms of life have the right to exist on the earth. Man is only a small part of the earth's great family of species; plants and animals have an equal right to live and exist on our planet. The approval of the presence of biodiversity for its intrinsic value and beauty, as well as for the contribution it makes to our knowledge, ingenuity, thoughts and aesthetics are the other reasons to conserve biodiversity.

Destruction of the residual large areas of wilderness habitats at the current rate, especially in the amazing diverse theird world tropical forests and coral reefs is the most alarming threat to biodiversity. According to some estimation, human actions are likely to eliminate approximately 10 million species by the year 2050. It is believed that, thee are about 1.8 million species of plants and animals recognized to science now in the world. However, the number of species is likely to be larger by a factor of at least 10. Various species of plants and insects yet unknown to science are persistently being identified in the biodiversity hotspots of the world. But sorry to say, at the current rate of extinction, about 25% of the world's species would suffer extinction quite fast. It may come about at the rate of 10-20,000 species per year, at a 1000-10,000 faster rate than the anticipated natural rate. Human actions could well exterminate 25% of the world's species within the next 20 to 25 years. A good deal of these super extinction events are linked to human population growth, industrialization, urbanization and changes in land use patterns. Of course, a major part of these extinctions will occur in biodiversity rich areas like wetlands, tropical forests and coral reefs. An important donor to the speedy global destruction of biodiversity is the loss of wild habitats caused by rapid human population growth and short term economic gain. The loss of species occurs due to the obliteration of natural ecosystems, either for alteration to agriculture or industry, or by over-extraction of their resources, or through air, water and soil pollution.

Grasslands and forests, particularly in India, are continuously being changed to agricultural lands. Intrusion to these ecosystems has been endorsed frequently. Similarly, natural wetland ecosystems have been drained to establish corplands which resulted in loss of aquatic species. Further, natural forests in India has been deforested for timber and replanted with exotic varieties of single species. This type of plantation does not sustain the same biological diversity as a multistoried natural forest endowed with closed canopy and a rich undergrowth of vegetation.

Thus the above discussion proves the need for conservation of biodiversity as must. There is global realization that conservation of biological diversity is an urgent need. Humankind's essential natural resources are forests, wetlands, mangroves and wildlife—all being important habitats of biodiversity needs special efforts and methods of convervation. Conservation in this context may be defined as "the management for the benefit of all life including humankind of the biosphere so that it may yield sustainable benefit to the present generation while maintaining its potential to meet the needs and aspirations of the future generations." Conservation of living resources has three specific objectives: (a) to continue fundamental ecological processes and life support system; (b) to preserve biological diversity and (c) to ensure that any utilization of species and ecoystems is sustainable (Sharma, 1993).

Conservation has two main categories : ***in situ*** and ***ex situ*** conservation.

(i) ***In Situ conservation :*** The conservation of genetic resources along with their manitenance within natural ecosystem or ecosystems altered by man in whom they occur is known as in situ conservation, most ideal system for conservation of genetic resources in which efforts are aimed at preserving species in their natural environment. Conservation of this type includes a system of protected areas of different categories,

managed with various objectives to bring benefit both to the species and the society. Sanctuaries, National Parks, Biosphere Reserves, Nature Reserves, Natural Monuments, and Cultural Landscapes etc. are included in this type of conservation.

(ii) ***Ex Situ conservation :*** Conservation of biodiversity outside their habitats by perpetuating sample populations in genetic resource centers, zoos, botanical gardens, culture collections etc. or in the form of gene pools, and gamete storage for fish; germ palsm banks for seeds, cells, pollen, semen, ova etc. Plants in this type of conservationa are more willingly maintained than animals. This method of conservation is very important because, in some cases, ensuring the survival of a species may prove impossible. Reasons behind it may be that too much habitat has been destroyed or that the remaining population size is too low to sustain the species any longer.

4.5 Endangered species

An endangered species is a population of organisms which is at risk of becoming extinct because it is either few in numbers, or threatened by changing environmental or predation parameters. Also it could mean that due to deforestation there may be a lack of food and/or water. The International Union for Conservation of Nature (IUCN) has calculated the percentage of endangered species as 40 percent of all organisms based on the sample of species that have been evaluated through 2006. (Note : the IUCN groups all threatened species for their summary purposes.) Many nations have laws offering protection to conservation reliant species : for example, forbidding hunting, restricting land development or creating preserves. Only a few of the many species at risk of extinction actually make it to the lists and obtain legal protection. Many more species become extinct, or potentially will become extinct, without gaining public notice.

Conservation status

The conservation status of a species is an indicator of the likelihood of that endangered species not living. Many factors are taken into account when assessing the conservation status of a species; not simply the number remaining, but the overall increase or decrease in the population over time, breeding success rates, known threats, and so on. The IUCN Red List is the best known conservation status listing.

Internationally, 194 countries have signed an accord agreeing to create Biodiversity Action Plans to protect endangered and other threatened species. In the United States this plan is usually called a species Recovery Plan.

IUCN Red List Endangered species

Endangered species under the IUCN Red List refers to a specific category of threatened species, and may include critically endangered species.

IUCN Red List of Threatened Species uses the term *endangered species* as a specific category

of imperilment, rather than as a general term. Under the IUCN Categories and Criteria, *endangered species* is between critically endangered and vulnerabler. Also critically endangered species may also be counted as endangered species and fill all the criteria

The more general term used by the IUCN for species at risk of extinction is *threatened species*, which also includes the less-at-risk category of vulnerable species together with endangered and critically endangered. IUCN categories include :

- **Extinct :** the last remaining member of the species has died, or is presumed beyond reasonable doubt to have died. Examples : Thylacine, Dodo, Passenger Pigeon, Tyrannosaurus, Caribbean Monk Seal, Dimetrodon

- **Extinct in the wild :** captive individuals survive, but there is no free-living, natural population. Examples : Alagoas Curassow

- **Critically endangered :** faces an extremely high risk of extinction in the immediate future. Examples : Arakan forest Turtle, Ethiopian wolf, Darwin's Fox, Javan Rhino, Brazilian Merganser, Gharial

- **Endangered :** faces a very high risk of extinction in the near future. Examples : Dhole, Blue Whale, Bonobo, Giant Panda, Snow Leopard, African Wild Dog, Tiger, three species of Albatrosses, Crowned Solitary Eagle, Markhor, Orangutan

- **Vulnerable :** faces a high risk of extinction in the medium-term. Examples : Cheetah, Gaur, Lion, Sloth Bear, Wolverine, Manatee, Polar Bear, African Golden Cat

- **Conservation Dependent :** The following animal is not severely threatened, but the animal must depend on conservation programs, Examples : Spotted Hyena, blanford's fox, Leopard Shark, Black Caiman

- **Near Threatened :** may be considered threatened in the near future. Examples : Blue-billed Duck, Solitary Eagle, Small-clawed Otter, Maned Wolf, Tiger Shark.

- **Least Concern :** no immediate threat to the survival of the species. Examples : Nootka Cypress, Wood Pigeon, Harp Seal, White-tailed Mongoose

United States

Extinct Endangered Threatened Delisted

"Endangered" in relation to "threatened" under the ESA.

Under the Endangered Species Act in the United States, "endangered" is the more protected of the two categories. The Salt Creek tiger beetle (*Cicindela nevadica lincolniana*) is an example of an endangered subspecies protected under the ESA.

In the United States alone, the "number of known species threatened with extinction is ten times higher than the number protected under the Endangered Species Act" (Wilcove & Master, 2008). The US Fish and Wildlife Service as well as the National Marine Fisheries Service are held responsible for classifying and protecting endangered species, yet, adding a particular species to the list is a long, controversial process and in reality it represents only a fraction of imperiled plant and animal life (Wilcove & Master, 2008).

Some endangered species laws are controversial. Typical areas of controversy include : criteria for placing a species on the endangered species list, and criteria for removing a species from the list once its population has recovered; whether restrictions on land development constitute a "taking" of land by the government; the related question of whether private landowners should be compensated for the loss of uses of their lands; and obtaining reasonable exceptions to protection laws.

Under the Bush administration, the former policy that required federal officials to consult a wildlife expert before taking actions that could damage endangered species was lifted. Under the Obama administration, this policy has been reinstated.

Being listed as an endangered species can have negative effect since it could make a species more desirable for collectors and poachers. This effect is potentially reducible, such as in China where commercially farmed turtles may be reducing some of the pressure to poach endangered species.

Another problem with the listing species is its effect of inciting the use of the "shoot, shovel, and shut-up" method of clearing endangered species from an area of land. Some landowners currently may perceive a diminution in value for their land after finding an endangered animal on it. They have allegedly opted to silently kill and bury the animals or destroy habitat, thus removing the problem from their land, but at the same time further reducing the population of an endangered species. The effectiveness of the Endangered Species Act, which coined the term "endangered species", has been questioned by business advocacy groups and their publications, but is nevertheless widely recognized as an effective recovery tool by wildlife scientists who work with the species. Nineteen species have been delisted and recovered and 93% of listed species in the northeastern United States have a recovering or stable population.

Currently, 1,556 known species in the world have been identified as endangered, or near extinction, and are under protection by government law (Glenn, 2006, Webpage). This approximation, however, does not take into consideration the number of species threatened with endangerment that are not included under the protection of such laws as the Endangered Species Act. According to NatureServe's global conservation status, approximately thirteen percent of vertebrates (excluding marine fish), seventeen percent of vascular plants, and six to eighteen percent of fungi are considered imperiled (Wilcove & Master, 2008,). Thus, in total, between seven and eighteen percent of the United States' known animals, fungi, and plants are near extinction (Wilcove & Master, 2008). This total is substantially more than the number of species protected under the Endangered Species Act in the United States, which means numerous species are inching closer and closer toward extinction.

Question of ethics

Even in the search to learn more about these species, many ecologists do not take into consideration the impact they leave on the environment and its inhabitants. It is apparent that the "quest for ecological knowledge, which is so critical for informing efforts to understand and conserve Earth's biodiversity along with valued ecosystem goods and services, frequently raises complex ethical questions", and there is no clear way to identify and resolve these issues. Environmentalists tend to focus on the whole ecological sphere instead of the welfare of individual animals. Focusing on such a broad view tends to diminish the value of each individual creature. "Biodiversity conservation is currently a principle goal for resource management of 11.5% of the world's surface area." Large portions of life occur outside these protected areas and must be taken into consideration if the conservation of endangered species is going to be effective.

Impact on biodiversity and endangered species

In order to conserve the biodiversity of the planet, one must take into consideration the reasons why so many species are becoming endangered. "Habitat loss is the most widespread cause of species endangerment in the U.S., affecting 85% of imperiled species" (Wilcove & Master, 2008). When an animal's ecosystem is not maintained, they lose their home and are either forced to adapt to new surroundings or perish. Pollution is another factor that causes many species to become endangered, especially a large proportion of aquatic life. Also, over-exploitation, disease (Wilcove & Master, 2008), and climate change (Kotiaho et al., 2005) have led to the endangerment of several species.

However, the most important factor leading to the endangerment of the majority of wildlife in the world is the human impact on the species and their environment. "As human use of resources, energy, and space intensified over the past few centuries, the diversity of life has been substantially diminished in most parts of the world" (Ishwaran & Erdelen, 2006). Basically, as the human impact on the environment increases, the diversity of life decreases. Humans are constantly using the resources and space of other species for themselves, negatively impacting the survival rate of many creatures.

Humans also set standards for which species they think should be saved and which species they find unimportant or undesirable. For example, the coqui frog, an invasive species in Hawaii, is so common there that its "nocturnal singing" reduces the value of homes and prevents hotels from using rooms near forests. Hawaiians have proposed eliminating the frog, and several wildlife managers want to release a pathogen to kill the frogs (Minteer & Collins, 2005). The frog has decreased the value of homes and caused a loss of business for several hotels, so the Hawaiians decided it was acceptable to get rid of the group of coqui frog living near them.

Another example where the human impact affected the welfare of a species sex in the instance of non-native mute swans establishing themselves at Arrowhead Lake in Vermont. When the population of swans grew to eight birds, the Vermont Fish and Wildlife Department decided to take action. Two swans were eventually killed, angering animal welfare organizations and people

living near the lake (Minteer & Collins, 2005). The case of the Arrowhead Lake swans demonstrates what one considers the natural environment based on human assumptions. Simply because the swans were not normally living there does not mean it is not part of their natural habitat, and there is certainly no reason for them to be destroyed because of human dissatisfaction.

Yet another example of the human impact in the lives of endangered species is that of the Preble's meadow jumping mouse. Research has shown that the mouse is not taxonomically different from the Bear Lodge meadow jumping mouse and the US Fish and Wildlife Service has proposed removing the Preble's mouse from the endangered species list based on this information (Minteer & Collins, 2005).

A final example of the human impact on existing species is the issue of toe clipping in ecological research. While ecologists are doing research on different species to advance their knowledge of methods of conservation, they must take into consideration the impact they have on the wildlife they are studying. Toe clipping "has been reported to result in a number of adverse effects on the animals, including inflammation and infection of the feet and limbs" (Minteer & Collins, 2005). This example demonstrates how humans must take into consideration the well-being of the animal even before they perform research to help conserve the species. The human impact on species and their environments has many negative effects. It is important for humans to help maintain all species in the world and not deter their development.

Species maintaining importance

"Diversity of life and living systems are a necessary condition for human development" (Ishwaran & Erdelen, 2006). Many question the importance of maintaining biodiversity in today's world, where conservation efforts prove costly and time consuming. The fact is that the preservation of all species is necessary for human survival. Specis should be saved for "aesthetic and moral justifications; the importance of wild species as providers of products and services essential to human welfare; the value of particular species as indicators of environmental health or as keystone species crucial to the functioning of ecosystems; and the scientific breakthroughs that have come from the study of wild organisms" (Wilcove & Master, 2008). In other words, species serve as a source of art and entertainment, provide products such as medicine for human well-being, indicate the welfare of the overall environment and ecosystem, and provided research that resulted in scientific discoveries. An example of an "aesthetic justification" in conserving endangered species is that of the introduction of the gray wolf into Yellowstone National Park. The gray wolf has brought numerous amounts of tourists to the park and added to the biodiversity in the protected region (Wilcove & Master, 2008).

Another example, supporting the conservation of endangerd species as providers of products for human well-being, is the scrub mint. It has been found that the scrub mint contains an anti-fungal agent and a natural insecticide (Wilcove & Master, 2008). Also, the deterioration of the bald eagle and the peregrine falcon "alerted people to the potential health hazards associated with the widespread spraying of DDT and other persistent pesticides" (Wilcove & Master, 2008).

This serves as an example of how certain fish can serve as identifiers of environmental health and protect human life as well as other species. Finally, an example of species providing for scientific discoveries is the instance of the Pacific yew which "became the source of taxol, one of the most potent anticancer compounds ever discovered" (Wilcove & Master, 2008). Endangered species could prove useful to human development, maintenance of biodiversity and preservation of ecosystems.

Helping preserve endangered species

It is the goal of conservationists to create and expand upon ways to preserve endangered species and maintain biodiversity. There are several ways in which one can aid in preserving the world's species who are nearing extinction. One such way is obtaining more information on different groups of species, especially invertebrates, fungi, and marine organisms, where sufficinet data is lacking.

For example, to understand the causes of population declines and extinction an experiment was conducted on the butterfly population in Finland. In this analysis, the butterflies' endangered list classification, distribution, density, larval specificity, dispersal ability, adult habitat breadth, flight period and body size were all recorded and examined to determine the threatened state of each species. It was found that the butterflies' distribution has declined by fifty-one and a half percent, and they have a severely restricted habitat. One example of specific butterflies who have a declining distribution rate are the Frigga's Fritillary and Grizzled Skipper, who have been affected by habitat loss due to extensive draining of the bogs where they live (Kotiaho et al., 2005). This experiment proves that when we know the cause of endangerment, we can successfully create solutions for the management of biodiversity.

Another way to help preserve endangered species is to create a new professional society dedicated to ecological ethics. This could help ecologists make ethical decisions in their research and management of biodiversity. Also, creating more awareness on environmental ethics can help encourage species preservation. "Courses in ethics for students, and training programs for ecologists and biodiversity managers" all could create environmental awareness and prevent violations of ethics in research and management (Minteer & Collins, 2005). One final way in which one can conserve endangered species is through federal agency investments and protection enacted by the federal government. "Ecologists have proposed biological corridors, biosphere reserves, ecosystem management, and ecoregional planning as approaches to integrate biodiversity conservation and socioeconomic development at increasingly larger spatial scales" (Ishwaran & Erdelen, 2006).

One example of a federal mandated conservation zone is the Northwest Hawaiian Islands Marine National Monument, the largest marine protected area in the world. The monument is essential to the preservation of underwater communities and overfished regions. Only researchers working in the area are permitted to fish, no corals may be removed, and the Department of Homeland Security will enforce restrictions on vessels passing through the waters via satellite imaging. The monument will serve as a home to an estimated seven thousand species, most of which cannot be found anywhere else in the world (Raloff, 2006). This environmental monument demonstrates

the fact that it is possible to create a safe environment for endangered species, as well as maintaining some of the world's largest ecosystems.

Captive breeding programs

Captive breeding is the process of breeding rare or endangered species in human controlled environments with restricted settings, such as wildlife preserves, zoos and other conservation facilities. Captive breeding is meant to save species from going extinct. It is supposed to stabilize the population of the species so it is no longer at risk for disappearing. This technique has been used with success for many species for some time, with probably the oldest known such instances of captive mating being attributed to menageries of European and Asian rulers, a case in point being the Pere David's Deer. However, captive breeding techniques are usually difficult to implement for highly mobile species like some migratory birds (eg. cranes) and fishes (eg. Hilsa). Additionally, if the captive breeding population is too small, inbreeding may occur due to a reduced gene pool; this may lead to the population lacking immunity to diseases.

Legal private farming for profit

Whereas poaching causes substantial reductions in endangered animal populations, legal private farming for profit has the opposite effect. Legal private farming has caused substantial increases in the populations of both the southern black rhinoceros and the souther white rhinoceros. Dr. Richard Emslie, a scientific officer at the IUCN, said of such programs, "Effective law enforcement has become much easier now that the animals are largely privately owned.... We have been able to bring local communities into the conservation programmes. There are increasingly strong economic incentives attached to looking after rhinos rather than simply poaching: from eco-tourism or selling them on for a profit. So many owners are keeping them secure. The private sector has been key to helping our work. "Conservation experts view the effect of China's turtle farming on the wild turtle populations of China and South-Eastern Asia - many of which are endangered - as "poorly understood" - While they commend the gradual replacement of wild-caught turtles with farm-raised ones gradually in the marketplace (the percentage of farm-raised individuals in the "visible" trade growing from around 30% in 2000 to around 70% ca. 2007), they are concerned with the fact that a lot of wild animals are caught to provide farmers with the breeding stock. As the conservation expert Peter Paul van Dijk noted, turtle farmers often believe in the superiority of wild-caught animals as the breeding stock, which may create an incentive for turtle farmers often believe in the superiority of wild-caught animals as the breeding stock, which may create an incentive for turtle hunters to seek and catch the very last remaining wild specimens of some endangered turtle species.

4.6 Wildlife Management and Conservation

Introduction

Wildlife management is a general term for the process of keeping wild species at desirable levels which are determined by the wildlife managers. Wildlife management has become an integrated

science using disciplines such as mathematics, chemistry, biology, ecology, climatology and geography to gain the best results. Wildlife conservation aims to halt the loss in the earths biodiversity by taking into consideration ecological principles such as carrying capacity, disturbance and succession and environmental conditions such as physical geography, pedology and hydrology with the aim of balancing the needs of wildlife with the needs of people. Most wildlife is concerned with the preservation and improvement of habitats though increasingly reinstatement is being used. Techniques can include reforestation, pest control, nitrification and denitrification, irrigation, coppicing and hadge laying.

Game keeping is the management or control of wildlife for the wellbeing of game birds may include killing other animals which share the same niche or predators to maintain a high population of the more profitable species, such as pheasants introduced into woodland. In his 1933 book Game Management, Aldo Leopold, one of the pioneers of wildlife management as a science, defined it as "the art of making land produce sustained annual crops of wild game for recreational use".

Pest control is the control of real or perceived pests and can be for the benefit of wildlife, farmers, game keepers or safety reasons. In the United States, wildlife management practices are often implemented by a governmental agency to uphold a law, such as the Endangered Species and by state governments.

In the United Kingdom, wildlife management undertaken by several organizations including government bodies such as the Forestry Commission, Charities such as the RSPB and The Wildlife Trusts and privately hired gamekeepers and contractors. Legislation has also been passed to protect wildlife such as the Wildlife and Countryside Act 1981. The UK government also give farmers subsidies through the Countryside Stewardship Scheme to improve the conservation value of their farms.

History

The profession of wildlife management was established in the United States in the interwar period (1920s-1930s) by Aldo Leopold and others who sought to transcend the purely restrictive policies of the previous generation of conservationists, such as anti-hunting activist William T. Hornaday. Leopold and his close associate Herbert Stoddard, who had both been trained in scientific forestry, argued that modern science and technology could be used to restore and improve wildlife habitat and thus produce abundant "crops" of ducks, deer, and other valued wild animals.

The institutional foundations of the profession of wildlife management were established in the 1930s, when Leopold was granted the first university professorship in wildlife management (1933, University of Wisconsin, Madison), when Leopold's textbook 'Game Management' was published (1933), when The Wildlife Society was founded, when the Journal of Wildlife Management began publishing, and when the first Cooperative Wildlife Research Units were established. Conservationist planned many projects throughout the 1940s. Some of which included the harvesting of female mammals such as deer to decrease rising populations. Others included waterfowl and wetland

research. The Fish and Wildlife Management Act was put in place to urge farmers to plant food for wildlife and to provide cover for them.

Wildlife management grew after World War II with the help of the GI Bill and a postwar boom in recreational hunting. An important step in wildlife management in the United States national parks occurred after several years of public controversy regarding the forced reduction of the elk population in Yellowstone National Park. In 1963, United States Secretary of the Interior Stewart Udall appointed an advisory board to collect scientific data to inform future wildlife management. In a paper known as the Leopold Report, the committee observed that culling programs at other national parks had been ineffective, and recommended active management of Yellowstone's elk population.

Since the tumultuous 1970s, when animal rights activists and environmentalists began to challenge some aspects of wildlife management, the profession has been overshadowed by the rise of conservation biology. Although wildlife managers remain central to the implementation of the ESA and other wildlife conservation policies, Conservation biologists have shifted the focus of conservation away from wildlife management's concern with the protection and restoration of single species and toward the maintenance of ecosystems and biodiversity.

Types of wildlife management

There are two general types of wildlife management :

- Manipulative management acts on a population, either changing its numbers by direct means or influencing numbers by the indirect means of altering food supply, habitat, density of predators, or prevalence of disease. This is appropriate when a population is to be harvested, or when it slides to an unacceptably low density or increases to an unacceptably high level. Such densities are inevitably the subjective view of the land owner, and may be disputed by animal welfare interests.
- Custodial management is preventive or protective. The aim is to minimize external influences on the population and its habitat. It is appropriate in a national park where one of the stated goals is to protect ecological processes. It is also appropriate for conservation of a threatened species where the threat is of external origin rather than being intrinsic to the system.

Opposition

The control of wildlife through culling and hunting has been criticized by animal rights and animal welfare activists. Critics object to the real or perceived cruelty involved in some forms of wildlife management.

Environmentalists have also opposed hunting where they believe it is unnecessary or will negatively affect biodiversity. Critics of game keeping note that habitat manipulation and predator control are often used to maintain artifically inflated populations of valuable game animals (including introduced exotics) without regard to the ecological integrity of the habitat.

Game keepers in the UK claim to be a necessary for wildlife conservation as the amount of countryside they look after exceeds by a factor of nine the amount in nature reserves and national parks.

Management of hunting seasons

Wildlife management studies, research and lobbying by interest groups help designate times of the year when certain wildlife species can be legally hunted, allowing for surplus animals to be removed. In the United States, hunting season and bag limits are determined by guidelines set by the US Department of Interrior, Fish and Wildlife Service (USFWS) for migratory game such as waterfowl and other migratory gamebirds. The hunting season and bag limits for state regulated game species such as deer are usually determined by State Game Commissions, which are made up of representatives from various interest groups, wildlife biologists, and researchers.

Open and closed season on Deer in the UK is legislated for in the Deer act 1991 and the Deer Act (Scotland) 1996.

Open season

Open season is when wildlife is allowed to be hunted by law and is usually not during the breeding season. Hunters may be restricted by sex, age or class of animal, for instance there may be an open season for any male deer with 4 points or better on at least one side.

Limited entry

Where the number of animals taken is to be tightly controlled, managers may have a type of lottery system called limited. Many apply, few are chosen. These hunts may still have age, sex or class restrictions.

Closed season

Closed season is when wildlife is protected from hunting and is usually during its breeding season. Closed season is enforced by law, any hunting during closed season is punishable by law and termed as illegal hunting or poaching.

Wildlife Conservation :

Wildlife conservation is the science of analyzing and protecting the Earth's biological diversity, which is the variation of life forms within a given ecosystem, or for the entire Earth. Biodiversity on the Earth today consists of many millions of distinct biological species. Wildlife conservation is the process of individuals and organization to protect and preserves these species through conservation education, preservation of habitat and management of fish and wildlife. There are many wildlife conservation societies and organizations that work tirelessly to save wild lands and wildlife through international conservation and education. These groups strive to change attitudes toward nature and to protect natural areas and wild populations of plants and animals, including endangered species. They also work to promote more efficient use of the Earth's resources and energy to reduce pollution. Environmental preservation, mainly within the United States, is the strict setting

aside of natural resources to prevent damage caused by contact with humans or by human activities, such as logging, mining, hunting and fishing. This differs somewhat from conservation in that conservation allows for some degree of industrial development, within sustainable limits. In other parts of the world, preservation and conservation are often used interchangeably.

Human influence over the Earth's ecosystems has been so extensive within the last 10,000 years that scientists have difficulty estimating the total number of species lost in this era. The rates of deforestation, reef destruction, wetlands filling and other human acts are proceeding much faster than human assessment of the Earth's species. The matter of ongoing species loss is made more complex by the fact that most of the Earth's species have not been described or evaluated for endangerment. Overpopulation of humans on the Earth has been the main threat. With overpopulation comes mass agriculture, deforestation, overgrazing, slash and burn urban development, pesticide use and global warming. An endangered species is a population of an organism which is at risk of becoming extinct because it is few in numbers and/or is threatened by changing environment. Many countries have laws offering protection to these species.

Wildlife conservation societies can be local, regional, national or global. They can be private or government run and almost every country across the world has its share of environmental activism. Wildlife environmentalists fall into three different groups : Dark, Light and Bright Greens. Light Greens see protecting the environment as a personal responsibility. They do not seek fundamental political reform, but instead focus on environmentalism as a lifestyle choice. In contrast, Dark Greens believe that environmental problems are an inherent part of industrialized capitalism and they seek radical political change. Bright Greens, the most recent group to develop, believe that radical changes are needed in the economic and political operation of society in order to make it sustainable, but that better desings, new technologies and more widely distributed social innovations are the means to make those changes.

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Published by : Netaji Subhas Open University, DD-26, Sector-I, Salt Lake, Kolkata-700 064 &
Printed at : The Saraswati Printing Works, 2, Guru Prosad Chowdhury Lane, Kolkata 700 006