39TH SIR ALBERT CHARLES SEWARD MEMORIAL LECTURE

Climate changes over space and time : their repercussions on the flora and vegetation

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The changes in the climatic types from region to region over the vast expanse of the Indian sub-continent have been examined in terms of quantum of rainfall and distribution of rainy pattern : length of the dry period and season(s) of occurrence of rains. The interyearly variability introduces a further dimension in the diversity of the climate types. The vegetation pattern generated by the climatic diversity is briefly reviewed. Of particular interest is the transition from the tropical type of climate in India to the mediterranean type further westwards.

As to the climate changes through the geological ages, the impressive record of megafossils collected by the scientists of the Birbal Sahni Institute of Palaeobotany has yielded valuable evidence of the vicissitudes. For the Quaternary period, palynology has played a key role in reconstructing the climo-vegetational history. A criticism may not be out of place. Many of the reconstructions refer to climate change only in terms of rainfall amount ignoring the distribution pattern (number of dry months, season of occurrence of rains). Sometimes the botanical markers selected are not fidel indicators of climate. In the much acclaimed and frequently cited palaeopalynological study of Gurdip Singh *et al.* (1974), the taxa selected like *Artemisia, Maytenus, Mimosa, Oldenlandia, Cyperus, Syzygium cumini* are not very fidel indicators of a humid phase. If the climate of the Thar had changed to humid type in true sense of the term, the pollen of the forest species of the Aravallis should have turned up in the profile of the Sambhar Lake.

In other cases, palynologists in their enthusiasm attribute even man-induced change in the vegetation to climate. The meticulous study of Caratini *et al.* (1991) brings out a distinct change from forest vegetation to savanna type in the Western Ghats 3,500 years B.P., which incidentally pinpoints the beginning of the anthropic activity with burning of vegetation promoting the growth of grass-savanna. In yet other cases, the change in vegetation appears likely due to shifts in the course of river rather than fluctuations in rainfall (Jolly & Bonnefille, 1992).

A hypothesis has been suggested as to how the species responded or adjusted phenologically to the drift over a vast latitudinal span from 30°S to 36°N. It has also been pointed out that major deforestation can bring about a climate change in disrupting the normal rainy pattern decreasing the number of rainy days and drastically altering the micro-climates. The physical mechanisms involved have been enumerated.

Vegetation mapping has provided clues for the areas to be protected on priority basis for conservation of biodiversity and for permitting the migration of species through these protected corridors in the wake of climatic change : from the cooler zones to the warmer and from wetter to the drier. The need for the study of populations in plant taxonomy has been stressed for assessing finer changes in climate.

Key-words — Climate, Vegetation, Biodiversity, Palaeoecology.

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सारॉंश

अतीत में जलवायवी परिवर्तन : वनस्पति एवं वनस्पतिजात पर इनके प्रतिप्रभाव

वी०एम० मेहर-होमजी

भारतीय उपमहाद्वीप के विभिन्न क्षेत्रों में वर्षा की मात्रा तथा शुष्क एवं वर्षा काल के वितरण पर आधारित जलवायवी परिवर्तनों का अध्ययन किया गया है। प्रत्येक दो वर्षों के मध्य हुए उक्त परिवर्तनों से जलवायु में भी परिवर्तन होता रहता है। जलवायवी विभिन्नता के कारण विकसित वनस्पतिक-स्वरूप का भी पुनर्आकलन किया गया है। जिसमें भारत में उष्णकटिबन्धीय प्रकार की जलवायु से पुनश्च पश्चिम की ओर भूमध्यसागरीय जलवायु परिवर्तन अधिक उल्लेखनीय है।

बीरबल साहनी पुरावनस्पतिविज्ञान संस्थान के विज्ञानीयों ने विभिन्न भूवैज्ञानिक कालानुक्रमों में हुए जलवायवी परिवर्तनों के द्योतक अनेक गुरुपादपाश्मों का महत्वपूर्ण संग्रह किया है। चतुर्थक कल्प हेतु परागाणविक अध्ययन जलवायवी-वनस्पतिक इतिहास की संरचना में महत्वपूर्ण सिद्ध हुआ है। हालॉंकि आलोचना भी परे नहीं है। अधिकतर संरचनाओं में वर्षा के कारण हुए जलवायवी परिवर्तन ही प्रदर्शित

किये जाते है तथा वर्षा के वितरण के स्वरूप (शुष्क मास, वर्षा ऋतु की विद्यमानता) पर विशेष ध्यान नहीं दिया जाता। कभी-कभी अभिनिर्धारित वनस्पतिक-चिन्हक भी जलवायु के यथार्थ सूचक होने में अक्षम रहते हैं। इसी प्रकार गुरदीप सिंह आदि (1974) के बहुचर्चित पुरापरागाणविक अध्ययन के आधार पर ***आर्टीमिसिआ, साइपेरस, माइमोसा, ओल्डनलैंडिया, सिजीजियम क्युमिनाई*** नामक अभिनिर्धारित वर्गक भी नम जलवायु के यथार्थ सूचक नहीं है। अगर थार की जलवायु वास्तव में नम जलवायु में परिवर्तित हुई होती तो अरावली के वन्य वर्गकों के परागकण साम्भर झील की परिच्छेदिका में उपलब्ध होते।

अन्य उदाहरणों में परागाणुविज्ञानी उत्साहवश वनस्पति में किये गये मानव-व्युत्पादित परिवर्तनों को भी जलवायु सुनिश्चित करने में सम्मिलित कर देते है। करातिनी आदि (1991) द्वारा किये गये एक अध्ययन से 3,500 वर्ष पूर्व पश्चिमी घाट में वन्य वनस्पति से सवाना प्रकार की वनस्पति-परिवर्तन के स्पष्ट संकेत मिले हैं, इससे वनस्पति के जलाने तथा सवाना घास के विकास में मानवजातीय गतिविधियाँ प्रदर्शित होती हैं। ऐसा भी देखने में आया है कि वर्षा के कम या अधिक होने के बजाय नदी के मार्ग में परिवर्तन के कारण भी प्रायः वनस्पतिक परिवर्तन हो जाते हैं (जॉली एवं बोनीफिल, 1992)।

एक परिकल्पना भी प्रस्तावित की गई है कि 30° दक्षिण से 30° उत्तर में बृहत् अक्षांसी क्षेत्र में जलवायवी परिवर्तनों के प्रति जातियाँ कैसी प्रति-संवेदना व्यक्त करती हैं। यह भी इंगित किया गया है कि बृहत स्तर पर वनों की कटाई से वर्षाकाल की अवधि पर प्रतिकूल प्रभाव पड़ता है। इस घटना में भौतिक परिवर्तनों का भी मूल्यॉकन किया गया है।

वनस्पति-मानचित्रण से ऐसा प्रेक्षित किया गया है कि जैवविभिन्नता के परिरक्षण तथा जलवायवी परिवर्तनों के कारण जातियों के प्रवासन हेतु प्राथमिकता के आधार पर कुछ सुरक्षित क्षेत्र निर्धारित किये जाने चाहिये। इसके अतिरिक्त वर्गीकीय अध्ययन के महत्त्व पर भी बल दिया गया है।

SPATIAL VARIABILITY OF CLIMATE IN THE INDIAN SUB-CONTINENT

Before coming to the main topic of climatic change, the variety, the variability and the complexity of climate of the Indian sub-continent may be viewed briefly.

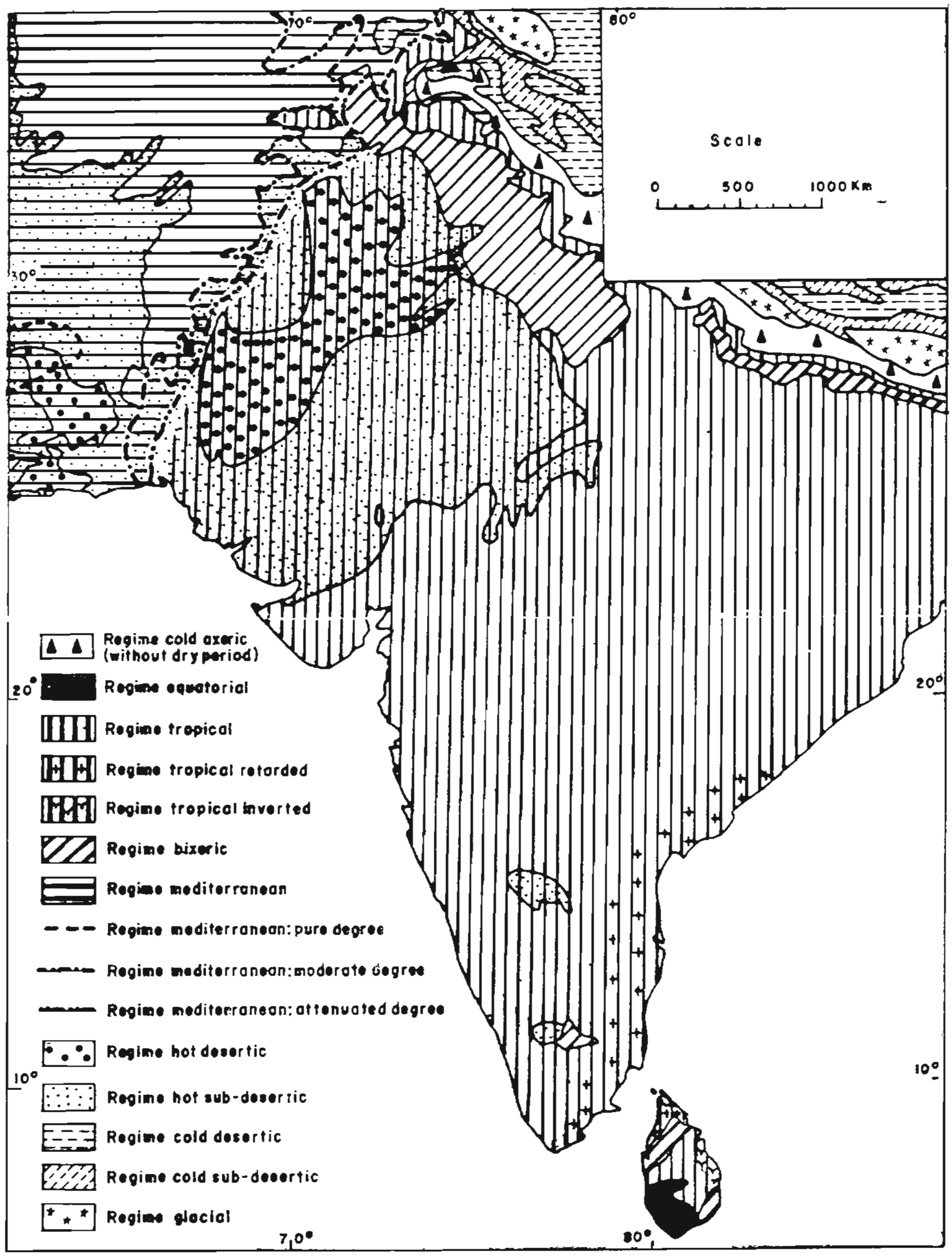
At one extreme in the south-west part of Sri Lanka prevails equatorial climate with rains almost throughout the year. At the other extreme in western Rajasthan and Sind, the climate is hot desertic with all the twelve months being dry (Text-figure 1). Between these extremes, we have a diversity of climate types ranging from average dry season of two months in the southern part of Kerala to dryness for 11 months at the periphery of the Thar. The rainfall also varies from over 10 m per annum at Cherrapunji to less than 100 mm in the Thar though both the regions are located at almost the same latitude.

The seasons of occurrence of rains introduce yet another dimension of diversity. Though the major part of the sub-continent is subject to tropical regime with the dominance of the south-west monsoon, the north-west part in Afghanistan-Pakistan remains under mediterranean regime with winter-spring precipitation. Likewise, the Coromandel-Circar coastal tract receives bulk of the rains in October-November from the so-called north-east monsoon, wherein the depressions and cyclones formed in the Bay of Bengal are the principal source of rains. The sub-Himalayan tract has two rainy seasons, one in winter-spring due to the western disturbances and another in summer due to the south-west monsoon, with two dry periods separating the two rainy seasons. Hence shows bixeric regime.

The inter-yearly variability on account of the vagaries of the monsoon disrupts the above mentioned average picture of the climate. What gets talked about mostly within the framework of variability is the total amount of rainfall due to monsoon failure and the consequent drought. The variation in the length of rainy season is a less discussed topic and the year to year fluctuations in the regime, i.e., the season(s) of occurrence of rain are seldom considered. The variations in the total yearly rainfall quantum may be so pronounced at certain stations so as to render the very definition of average climate not very meaningful. Let us take the case of Pondicherry; the annual amount may be as low as 600 mm some years, three times higher in some other years. The average of 1250 mm is seldom realized.

Similarly, there are glaring examples of variations in the length of the dry season. For example, at Kodaikanal the majority of individual years experience dryness of 1 to 4 months*. Yet on the basis of averages, the dry period does not come out because spells of droughts occur in different months in different years. At Murree, the average length of dry season is 1 month but in actual years it may vary from 0 to 5 months. Rawalpindi with 5 months of dryness on an average basis presents the range of 2 to 8 dry months and New Delhi with a range of 5 to 11 months dryness presents average of 9. In still other cases, the fluctuations involve the regime. For some stations of Kashmir and Pakistan, the average regime turns out to be of mediterranean type with winter-spring rains and summer dryness but in fact the regime varies from year to year as exemplified by the climate diagrams of Peshawar, Dera Ismail Khan and Srinagar (Text-figures 2B, 3A, 3B). No individual years matches with the average pattern nor do the individual years agree with each other so much in the rainfall regime.

*A month is empirically defined as dry when its rainfall (in mm) is less than twice its mean temperature in degree Celsius : $P \leq 2T$ Ineffective rains also refer to $P \leq 2T$

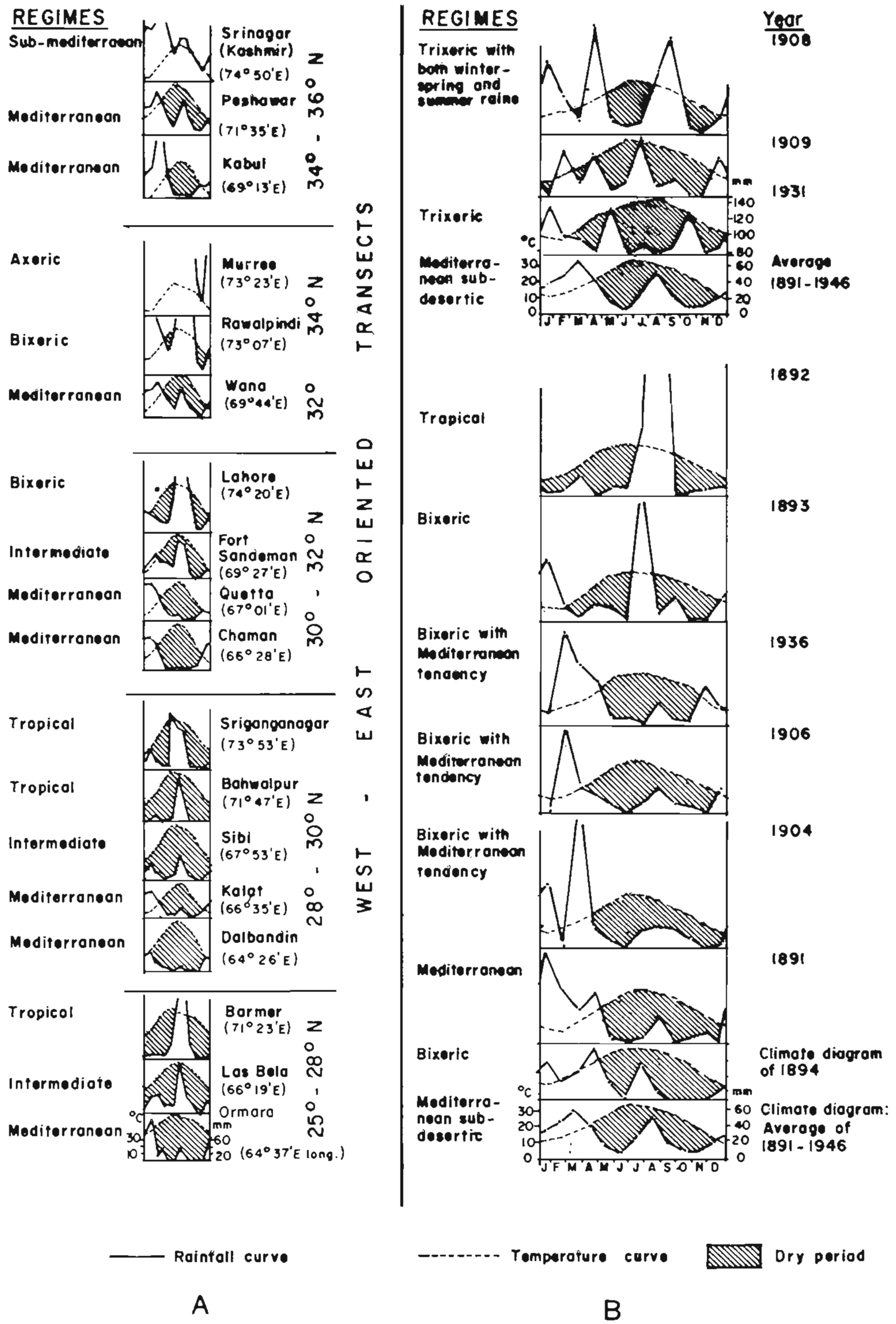


Text-figure 1—Indian region : main types of climatic regimes.

TRANSITION FROM TROPICAL CLIMATE TO MEDITERRANEAN TYPE

As seen earlier, the mediterranean type of climate is characterised by winter-spring precipitation, summer dryness and mild winter. The tropical climate on the other hand experiences rains during summer. The transition in the Indian sub-continent takes place in the north-west part which incidentally is also arid or semi-arid (Text-figure 1). In the first phase of the study on transition, the contact between the mediterranean climate and the tropical monsoon climate has been viewed across latitudinal and longitudinal belts using the long-term average climatic data as shown in Text-figure 2A.

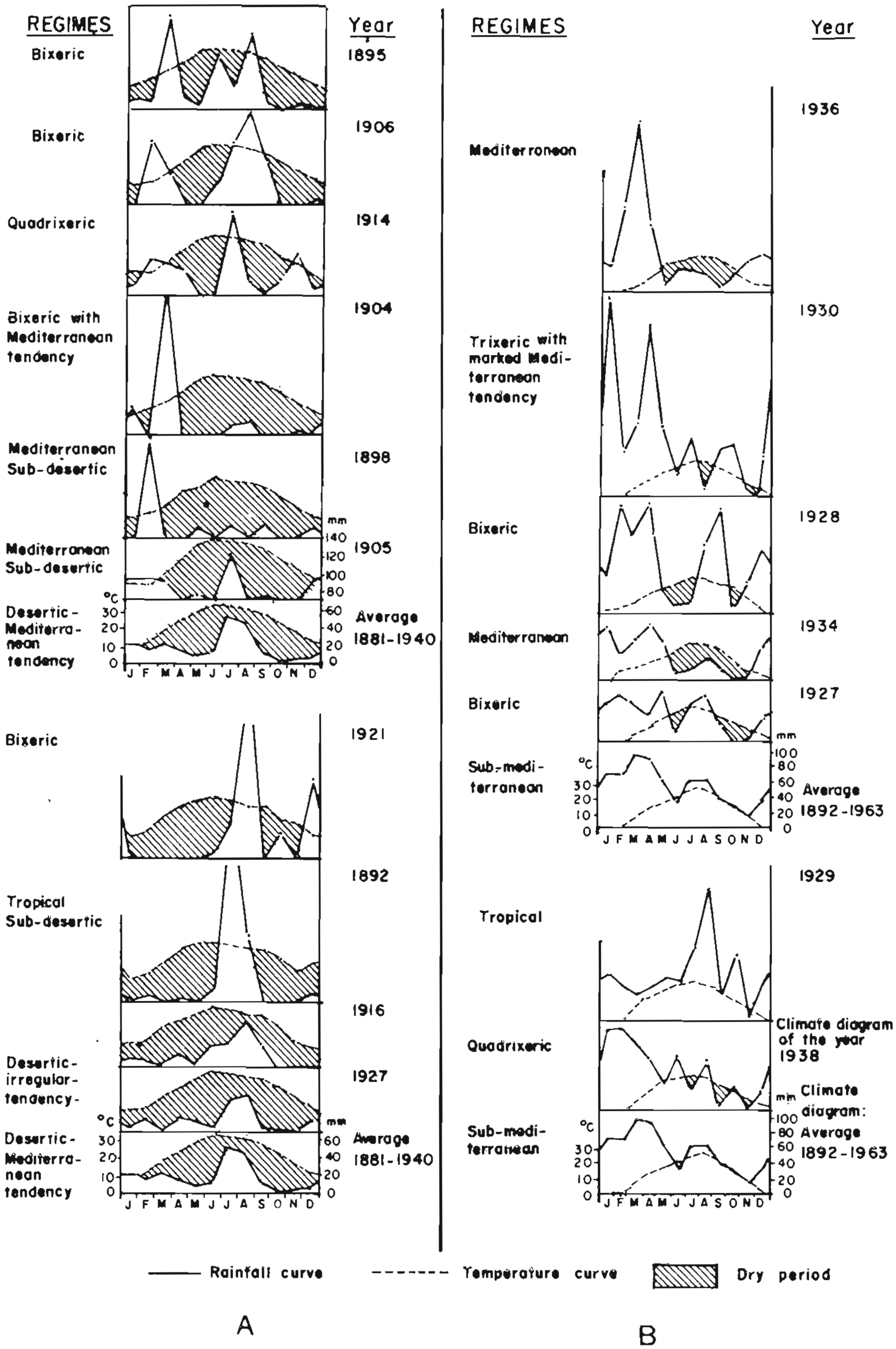
In the 25°-28° N latitudinal belt, the effective winter (January-February) rains of Ormara (64°39′E longitude) representing the mediterranean tendency gradually get reduced at the station Las Bela (66°19′E) with corresponding increase of summer (July-August) rains. Further eastwards, Barmer (71°23′E) shows a distinct peak of effective rains in July whereas the ineffective winter-spring precipitation noted at Las Bela becomes very negligible.



Text-figure 2—**A**, Climate diagrams of stations between 25 and 36 latitude North based on long term averages; **B**, Interyearly degrees variability in regimes at Peshawar

Northwards across 28°-30° latitude, marginally just effective January-February, December precipitation of Dalbandin (64°26′E) attains higher values further eastwards at Kalat (66°35′E), only to be reduced to ineffective level at more easternly located Sibi (67°53′E) where ineffective summer rains also prevail during July-August. Eastwards, the latter increase in amount at Bahawalpur (71°47′E) and become effective at Sriganganagar (73°53′E).

In the belt of 30°-32° N latitude, the western stations Chaman and Quetta repeat the mediterranean precipitation pattern of Kalat but eastwards Fort



Text-figure 3—**A**, Interyearly variability in regimes at Dera Ismail Khan; **B**, Interyearly variability in regimes of Srinagar, Kashmir.

Sandeman (69·°27′E) shows two peaks of rainfall, one of effective rains in cool season months January-February-March and the other of ineffective rains in summer months July-August. Continuing eastwards, this trend results in bixeric climate exemplified by Lahore at the longitude of 74°20′E with two rainy seasons, one in January and the other during July-August separated by two dry periods.

Between 32°-34° latitude North, Wana (69°44′E) has effective winter-spring rains and non-effective summer rains. Further eastward, Rawalpindi (73°07′E) is bixeric with two distinct rainy seasons (from January to April and from July to September) and two marked dry periods with ineffective rains; Murree at 73°23′E longitude, maintains the two minima of rains (in May and November) noticed at Rawalpindi but because of its higher elevation (2169 m), the quantity of rains it receives in its annual cycle is much more than at Rawalpindi located at a lower altitude of 510 m. In our highest latitudinal belt between 34°-36° North, Kabul in Afghanistan (69°12′E) has exclusive winter-spring precipitation; eastwards, Peshawar (71°35′E) has in addition ineffective summer rains and the winter peak of precipitation is not so marked as at Kabul. Still eastwards, Srinagar at 74°50′E represents mediterranean tendency with short dry periods in summer months, i.e. June and September.

Therefore, the transitions are of two types :

1. From mediterranean sub-desertic type* to tropical monsoon sub-desertic type in the south, passing through an intermediate desertic station with ineffective rains both in winter and summer as exemplified by the transect Ormara-Las bela-Barmer in Text-figure 2A.

   In the latitudinal belt of 28°-30°N, Dalbandin is mediterranean subdesertic, Kalat is mediterranean with dryness of 8 months, Sibi is desertic, Bahawalpur is tropical desertic and Sriganganagar tropical subdesertic.

2. However, north of 30° latitude, the mediterranean type of average climate of the western stations like Chaman, Quetta, Wana is replaced by the bixeric climate of the eastern stations Lahore and Rawalpindi through subdesertic stations of the intermediate tract like Fort Sandeman, Dera Ismail Khan, Miranshah and Peshawar. The bixeric trend of these eastern stations is decided not only by the higher latitude but also higher elevation (above 200 m) compared to the arid zone stations of the southern region like Barmer, Sukkur, Bikaner, Las Bela, Bahawalpur and Sriganganagar.

Yet further northwards approaching the latitude of 34°N, high altitude of over 2100 m at Murree, results in copious rainfall throughout the year, except in November where conditions are marginally dry.

Thus on average basis of long-term data, the spatial transition in climate regimes from east to west seems gradual. But not so if inter-annual regimes at a station are considered. According to Text-figures 2B, 3A, 3B the regimes appear to change from year to year for Peshawar, Dera Ismail Khan and Srinagar, three stations selected as examples. However, moving back and forth in time, it seems possible to arrange the individual years in a sequence to bring out the gradual change from a mediterranean type derived from average long term data to the tropical type or bixeric type through intermediary gradual changes of individual years.

*Sub-desertic : Dry period of 9 months, each with P ≤ 2T
Desertic : Dry period of 12 months.

Based on the statistics of percentage of summer rainfall and number of rainy days in summer, three following categories of mediterranean climate are recognised in the sub-continent :

1. a pure degree of mediterraneity wherein the summer rainfall is zero year after year,
2. a moderate degree of mediterraneity with up to 40 per cent of summer rainfall and rainy days, and
3. an attenuated degree of mediterraneity with up to 55 per cent of summer rains. These three categories are supported by the percentages of the mediterranean floristic elements : 27 to 40 per cent under moderate mediterraneity and 8 per cent at the eastern limit of attenuated degree of mediterraneity (Meher-Homji, 1973).

EVOLUTIONARY HISTORY OF FLORA AND VEGETATION

Thanks to the endeavours of palaeobotanists like Birbal Sahni and his successors, the evolutionary history of the Indian flora has been well established. Good literature is also available on the climatic implications of the megafossils recovered from the different geological strata. To speak about it on this occasion will be like carrying coal to New Castle. In Table 1 the salient features in the earth's history of phytogeographic relevance are summarised.

PALYNOLOGY AND QUATERNARY HISTORY

Palynology has played a key role in the reconstruction of the sequence of succeeding plants and the corresponding climates during the Quaternary. Whereas good work is being done in this direction: as an ecologist I may be permitted to bring out some of the short comings in the interpretation of the palynological data.

— In certain studies, the climate change deduced from pollen data is referred to in broad terms as humid or arid without precise indication of rainfall quantum. No reference is made to the rainfall pattern in terms of the length of the dry period or regime, i.e., season(s) of occurrence of rains.

— Changes in vegetation reflected by pollen data are frequently assigned to climate change without examining the role of anthropic factors or the physiographic changes like shifts in course of rivers.

Table 1—Geological time scale and salient features in earth's history

Group	System	Age (from to-day in millions of years)	Duration of the System (in millions of years)	Rocks and soil types	Notable events in Earth's history	Notable phytogeographic events	Facts concerning flora
	Neolithic (in India	4,500 years ago					
Quaternary	Recent (Holocene)	Began 10,000 years B. P.	0.01	Recent alluvium, sand dunes-	Last glaciation terminated 10,000 years B. P. Up-warps and down-warps; reduction of old plateau to new plateau; episodic uplift due to erosion and unloading of trap cover. Formation of black soil	Occurrence of 3 glaciations	Entry of Indo-African desert & steppe elements into India
	Pleistocene (NEOGENE)	2	2	Older alluvia and Pleistocene river terraces			
Tertiary or	Pliocene (NEOGENE)	5 million years ago	3	Rise of the Himalaya	Pliocene-deep weathering of the basaltic rocks. Shallow lagoon at conditions; formation of clayey black soils. Miocene-break up and foundering of the western segment and faulting of the west coast of India. Uplift and upwarp of laterite covered surface. Uplift maximum in Western Ghats region which formed the central axial region.	Final rise of the Himalaya in the Late Tertiary. Cooling which produced glaciation. Creation of the Western Ghats scarp. Establishment of the monsoonic rainfall pattern. Rapid erosion and retreat of W. Ghats scarp: drainage reversal.	Araucariaceae exterminated. Dessication of climate. Slow cooling resulted in extermination of tropical and subtropical flora in Europe. The Miocene flora of India indicates affinity with the flora north of the equator. The Eocene flora of India indicates affinity with the flora south of the equator. The Eocene and Miocene flora of India are different (Chowdhury, 1965)
	Miocene (NEOGENE)	26	21				
Cainozoic	Oligocene	Palaeogene	12		Palaeocene-epeirogenic uplift reflected in down-warp along the east coast where older surfaces pass below sea-level. Formation of laterite over parts of trap surface	Northward migration of India. Shifting of centre of volcanic activity. Leaving a trial behind	
	Eocene	54	16				
	Palaeocene	65 ± 2	11				
Secondary	Cretaceous	130 ± 5	65		Cretaceous-Tertiary boundary : Indian Plate passes over the Reunion hot-spot: extensive volcanism : Spread of lavas all round		
or	Jurassic	180 ± 50	50				

Group	System	Age (from to-day in millions of years)	Duration of the System (in millions of years)	Rocks and soil types	Notable events in Earth's history	Notable phytogeographic events	Facts concerning flora
					Late cretaceous : A land surface of low relief; surface covered by shallow water-shallow marine sediments along the coasts.	Separation from Africa and Madagascar	Conifers gradually decline in Cretaceous and Tertiary.
Mesozoic	Triassic	230 ±	50		Jurassic Break-up and separation from Gondwanaland. Slow northward movement of Indian segment.		Conifers represented in the Gondwana flora attain maximum development in Jurassic and beginning of Cretaceous. Gondwana flora continues till the Trias. Flowering plants appeared 160 m.y. ago.
Primary or Palaeozoic	Permian	270 ± 5	40				The great ice age. Permo-Carboniferous probably laid the foundation for the origin of the land plants. Gondwana flora appeared in the Carboniferous.
	Carboniferous	350 ± 10	80				
	Devonian	400 ± 10	50				
	Silurian	440 ± 10	40				
	Ordovician	500 ± 15	60				
	Cambrian	600 ± 20	100	Upper Vindhyan			Vascular plants existed in India since the Middle Cambrian (Ghose & Bose, 1947).
Pre-Cambrian or Proterozoic	Pre-Cambrian	1,500		Algonkian, Cuddapah, Lower Vindhyan System,			
Archaean or Azoic	Archaean	4,600		Dharwar, Aravallis, Gneiss			Life originated 3,600 million years ago.
	Earth was formed as a planet 5000 to 7000 million years ago.						

One of the better known and frequently quoted pioneering studies is that of Gurdip Singh *et al.* (1974) who reported large scale vegetational and climatic fluctuations in the present arid Thar region from the records of fossil pollen from the lakes of Rajasthan. Much acclaimed as this study is (Bryson & Swain, 1981), it does not convince an ecologist of marked changes in the climate because the taxa like *Artemisia*, *Mimosa rubicaulis*, *Oldenlandia*, *Maytenus*, *Syzygium cumini* and Cyperaceae cited as pointers of humid phases are not very fidel indicators of humidity (Vishnu-Mittre, 1974a, 1974b; Meher-Homji, 1980). If the climate had changed to humid type in the true sense of the term, pollen of some of the deciduous forest tree species of the Aravallis should have turned up in the profile of the Sambhar Lake.

Syzygium cumini even to-day grows in the core region of the Indian desert. Others like *Typha* and *Cyperus* can grow in and around the local water bodies in the arid zone.

Caratini *et al.* (1991) analysing a marine core off Karwar, near the estuary of the Kalindi River, have brought out a distinct major vegetational change in the Western Ghats of the Uttara Kannada District from forest to savanna 3,500 years B.P. which pinpoints the commencement of anthropogenic activity in the region. This investigation brings forth convincing scientific proof of the beginning of the human interference with the vegetation in the region, the case for which was earlier made out by the archaeologists. The generally accepted date of introduction of cultivation in this region is placed around 1000 B.C. after the introduction of iron (Gadgil & Subash Chandran, 1988). It is likely that the destruction of forest vegetation started with the use of fire a couple of centuries earlier when fire was an important tool in the hands of man and which resulted in profuse growth of grass-savanna. Likewise, the cultivation of paddy in the estuaries is likely a reason for the reduction in mangrove vegetation and of its pollen frequency in the marine sediment.

According to Sundara (1990) the Neolithic intruders descended from the upghat region to the downghat region in the Dakshina Kannada District in the last part of the 2nd millenium B.C. and resorted to cultivation probably by burn and slash method. Whereas, the more humid phases according to Gurdip Singh *et al.* (1974) were in Ca 8000 to 7500 B.C., Ca. 3000 to 2000 B.C. and Ca. 1400 to 1000 B.C., Van Campo (1986) from the mangrove pollen frequency of the two marine cores off the South-West Coast of India suggests a humid phase culminating around 11,000 years B.P.

In a study on a tropical marsh of Ndurumu in Burundi, Africa (Jolly & Bonnefille, 1992), samples were analysed from a swamp where the increasing level of flooding was evident. The vegetation change is solely attributed to a climate change whereas it would have been worth examining the local change in physiography or the shift in the course of the river

PHENOLOGY OF SPECIES IN RELATION TO THE NORTHWARD DRIFT OF THE INDIAN LANDMASS

Not much thought has been given to the phenological response/re-adjustment of the species to the drift of the Indian landmass over a latitudinal span of over 60°, from 30°S latitude towards the end of Cretaceous to its present position in the northern hemisphere. As is well known, the phenology is linked to the seasons and photoperiod. Not only are the seasons inversed in the two hemispheres but the temperature and day-length regimes vary with the latitude.

Then how did the species respond to these changes? Only a hypothesis may be postulated at this juncture

1 *Extinctions*—In the Mesozoic the vegetation in the Peninsula was dominated by conifers like *Podocarpus* and *Araucaria*. By Mid to Late Cretaceous commenced the decline of the gymnosperms on a large scale. They gradually made way for the increasing number of angiosperms. The probable reasons for the extermination of gymnosperms have been sought in the drastic changes in the physical geography and climatic conditions and in increasing competition with the angiosperms. Cataclysmic events like the break up of the Gondwanaland by Mid-Cretaceous, the subsequent northward drift of the Peninsula, its collision with the Asian landmass, resulting in the uplift of the Himalaya, the rise of the Western Ghats, the volcanic eruptions and outflowing of lava towards the close of the Cretaceous have been suggested for a major change in the flora of India (Ramanujam, 1976).

But changes in latitude following the continental drift could have severely affected the phenology of the species. The angiosperm genera like *Ctenolophon*, *Pentac* and *Durio* are known as fossils from India but survive elsewhere, the latter two in South-east Asia and *Ctenolophon* in tropical west Africa besides South-east Asia (Ramanujam & Rao, 1973). It would be interesting to investigate whether they were the victims of unadapted phenology

According to Muller (1970) South-east Asia has retained a more or less uniformly humid climate unlike the Indian sub-continent which experienced a major climatic change in the Tertiary. The pollen stratigraphy suggests that in this central part of the Indo-Malaysian floristic region, plant evolution has continued unperturbed by any climatic shift since the Cretaceous. Aubreville (1969) proposed that the Tertiary equator was not far from the present-day equator in South-east Asia and so the vegetation did not experience much change compared to northern Africa. It is also pertinent to note that according to Chowdhury (1965) the Miocene fossil flora differs considerably from its Eocene counterpart.

2. A gradual transition permitting phenological adjustment.

   As the drift was gradual, the position of India a little to the south of the equator, then on the equatorial line followed by a location little north of equator would have served as a transient stage for adaption as the temperature and day-length remain almost the same around the equator.

DEFORESTATION LINKED CLIMATE CHANGE

One of the raging controversies of the day is the influence of forests on the climate in general and on the rainfall in particular. Opinions vary to the extremes from no appreciable increase in precipitation (Schlich in Hill, 1916; Walker in Hill, 1916) to the onset of desertification with the disappearance of forests. Wadia (1955) pointed out that the forests in the Chinese Turkistan are not attracting rainfall but are dying out due to the general dryness of the climate. Feldman also opined that the rainfall in the forest area of U.S.S.R. does not depend on the extent of forest but Kaulin (1962) asserted that the precipitation was higher in the forest than in the neighbouring steppe. Nicholson contended that because in certain localities and under certain circumstances forests do not induce rain, it does not mean that the forests cannot induce rain. Harrington (cf. Luna, 1981), on the other hand, stated that the evidence of higher rainfall within the forest does not mean that forests increase the rainfall. Marsh (cf. Luna, 1981) reviewing the literature found evidence of decreasing precipitation consequent to forest removal.

Between these two diametrically opposite views, different percentages have been attributed to the forest-cover in augmenting the rainfall. Thus Kittredge (1948) assigned an increase of 3 per cent, 1 per cent due to the height of trees of 30 m or more, as mere objects of obstruction to air movement and 2 per cent due to the reducing effect of winds through friction of the canopy, Schubert (1937) assessed the importance at 6 per cent for Germany. Other estimates place the increase at 10 to 12 per cent in the plains and up to 25 per cent in the hills (Hursh & Connaughton, 1933).

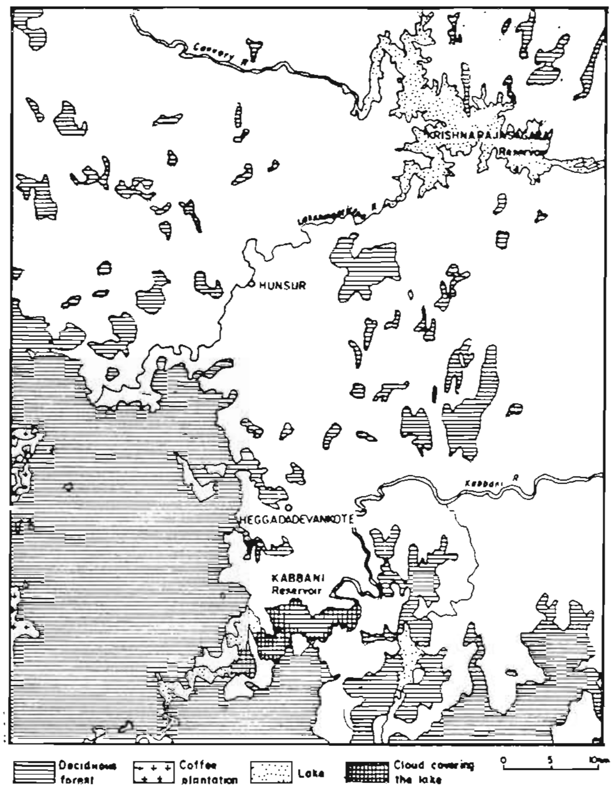
Early beliefs that forests increased rainfall has been superseded in the hydrological community by a consensus that the land-use changes had no effect of rainfall (Pereira, 1973). However, recent computer studies by meteorologists have shown significant changes in the regional climate, including rainfall due to surface changes. Dickinson (1980) explains that there is not real inconsistency between these two opinions. Hydrologists take into account small areas with limited observational data, where vegetational changes have a lesser effect on atmospheric processes than if the surface involved was larger, of the order or several hundred square kilometers. Besides rainfall of convective origin (thunderstorm) in the tropics is so much variable at any station that it becomes difficult to appreciate the moderate change in rainfall. Yet crop yields and water resources over a large area would be affected by what may appear to be a negligible change of rainfall amounting to a few per cent.

Lockwood (1980) opined that the disappearance of the tropical forests would at best modify local climates and would have a slight repercussion on the global climate but the effect would probably be swamped by those due to natural changes and through increase in carbon dioxide content of the atmosphere. The most marked changes would reflect in the hydrological cycle with increased run-off and increased tendency to droughts in view of reduced soil water storage. However, Lockwood (1980) included changes in the vegetation-cover among the factors responsible for bringing about climatic variations like solar perturbations linked to orbital variations of the earth, fluctuations in solar output, volcanic activity, tectonic movements, changes in sea-level. Replacement of forest mantle by agriculture with seasonal crops or by various constructions including hydro-electric and mining projects results in severe environmental changes.

Dickinson (1980) who has very elegantly reviewed the repercussions of tropical deforestation on climatic changes at the levels of microclimate, regional climate and global climate concludes that there would be a large modification in local microclimates. If sufficiently extensive, these micro-climatic modifications can change the climate of large regions in the vicinity of the deforested areas. If huge chunks of rain forests disappear even the global heat balance could be affected in a significant manner. According to him, the radiative effects of increase in carbon dioxide would even outweigh the effects of albedo increase, at least for a few centuries till much of the carbon dioxide released due to the absence of the tropical forests is absorbed by the oceans. Whereas the climatic change of global level brought about by the loss of forests may be of the same magnitude as the natural variations in the climate or the modification brought about by burning fuels, Dickinson (1980) warns that deforestation coupled with combustion of fossil fuels would add so much carbon dioxide to the atmosphere that it would worsen the situation at a global scale. In any case the regional changes following deforestation would be of greater magnitude than global changes and in terms of cost-benefit ratio unproportionate to the loss of forest converted for different uses. The most convincing evidence of forest generating rainfall has come from the Amazon Basin of South America, thanks to the scientific study conducted by Salati (1985) and Salati *et al.* (1979) using isotopic technique.

The historical record from India also suggests that forest has an influence on convectional type of rainfall. Nicholson (cf. Ranganathan, 1949) observed that when the Chotanagpur Plateau was densely wooded in the last century, there used to be regular afternoon convectional or instability rain during the premonsoon months which permitted tea cultivation. But once massif deforestation was carried out at the turn of the century, the convectional showers disappeared and with that the tea gardens also, inspite of the fact that there has not been much change in the total quantum of rains. Yet another example is of Udhagamandalam, popularly referred to as Ooty. One Dr Voeckler in his report entitled "Improvement of Indian Agriculture" had noted that the number of rainy days at this hill-station over the five-year period 1870-1874 (excluding the S.W. monsoon months June, July, August) was 374. Applying the same criteria, we find that after a century, the number of rainy days has come down to 271 for the 5-year period 1978-82, a decline of 28 per cent.

Text-figure 4 is taken from the False Colour Composite Thematic Mapper Satellite imagery dated 6 February, 1989. It shows a cloud over clinging to the contours of the Kabbani reservoir on the Kaveri. It is very likely that the evaporation from the lake combined with the transpiration from the neighbouring forests has led to the cloud formation over the lake. No such cloud cover is observed over the Krishnarajsagar reservoir lying further nothwards in a non-forested zone. These facts show that if the monsoon has failed, the forests can continue to generate convectional rains as the conditions during the dry summer monsoon resemble those of the premonsoon months.



Text-figure 4—Cloud cover coinciding with the contours of the Kabbani Reservoir located in a forested tract.

PROBABLE MECHANISMS INVOLVED IN FOREST-RAINFALL LINKAGES

The ascent of a moisture-bearing air mass to a height where it allows condensation of water vapour is associated with several meteorological phenomena after which various types of rainfall are named. Thus we have "convection rains" or "thunder-storms' when, due to the excessive heating of some areas (mostly in the premonsoon months—April-May), currents of air rise to great heights carrying cloud moisture. Rainfall of cyclonic or depression origin is caused by the differential heating of sea and land masses resulting in converging winds. Orographic rainfall occurs when an air mass strikes a vertical obstacle which it tries to 'climb over'

Whereas forests do not affect cyclonic or monsoon types of rainfall, they seem to influence convectional rainfall as shown by the study of Nicholson (cf. Ranganathan, 1949) for the Chotanagpur Plateau of Bihar. It may be added that the convectional rainfall could be generated by the forests at some distance and not locally. It may not be the absolute decline in monsoon rainfall that affects agriculture, flora and fauna, and water supply, but rather the lack of rains at critical stages. However, marginal may be the increase in rainfall due to forest cover, it makes a difference in sustaining agricultural crops and maintaining ecosystems.

Shukla and Mintz (1981) report that modifications in vegetation cover due to the deforestation of large-magnitude surely influence precipitation. The hypothesis is based on correlation between precipitation and evapotranspiration. The determinant factor is not only the vegetation but also the relationship between the moisture content of soil, vegetation and the solar energy necessary for transforming water into atmospheric water vapour. This is, however, an unverified computer simulation.

Charney *et al.* (1977) emphasized the role of reduced albedo (i.e., the proportion of the radiation reflected back to the atmosphere with reference to the total amount striking a surface) in inducing higher rainfall in forested areas. The albedo of deserts or barren soil is considerably greater (30-35%) than that of vegetated or forested surface (15-25%). So the actual net energy imparted to the atmosphere over a desert is less than that over green belts. The albedo depends on vegetation, which absorbs more radiation than does bare soil. Because of less evapotranspiration over bare soil, the absorbed energy heats up the air causing dry thermals.

In the case of orographic rainfall, forests act as an obstructing medium and increase the effective height of the land surface in providing an obstruction to air movement. Forests also reduce wind speed through their aerodynamically rough, undulating canopy; with the decrease in wind velocity, the air masses are forced to rise. Sud and Smith (1985) have stressed the importance of the mechanical friction effect of forests in lifting the moist air and enhancing the rainfall. Pereira (1986) maintains that the desiccation following large-scale deforestation is due to the important influence of forests on the reception of rainfall, and not on its generation. Evapotranspiration is, no doubt, important from the forest, but drought is caused less by lack of moisture in the air than by lacking a cooling mechanism to condense the water into precipitation.

An essential condition for rainfall to take place is that the warm moisture bearing air should be able to rise but deserts are the zones of large-scale descending air motion. The large amount of dust over the desert increases the subsidence rate. Deforestation through erosion increases the dust content of the atmosphere. By cutting off a good portion of shortwave solar radiation by scattering and reflection, the dust particles prevent it from reaching the ground. Another major effect of dust loading is a greater cooling and radiation divergence in the troposphere (Chakravarti, 1978). The smoke from biomass burning could also lead to reduction in rainfall. Pollen grains, debris and other parts of plants serve as condensation nuclei. Their role as seeders of crystalization is more effective than the inorganic debris like dust because the ice is formed on the inorganic debris at a much lower temperature (Glantz, 1987).

Finally, there is the role of cloud forests, mossy-forests and stunted woodlands occuring in the tropical montane belts and along coastal fog zones. This role should be emphasized in harnessing the moisture from the clouds through the mechanism of cloud or fog stripping (Stadmuller, 1986). Even a single tree or a group of trees can trap a substantial quantity of rainwater through the process called horizontal precipitation (Zadroga, 1981). The amount so trapped can vary from 7 to 18 per cent of the rainy-season precipitation and up to 100 per cent of dry-season rains (Hermann, 1970; Vogelmann, 1973; Juvik & Ekern, 1978; Vis, 1986). The destruction of such cloud forests (as in the Western Ghats of India) can diminish stream flows and ground-water recharge (Bruijnzeel, 1986).

Dickinson (1980) states that none of the numerical studies reviewed by him has treated the effect of deforestation on increasing temporal and spatial fluctuations between wet and dry conditions. However, he feels that such a change in surface conditions could in turn increase the intensity and decrease the duration of tropical rainfall, enhancing run-off even if the mean rainfall were unchanged. If the intensity increases without a change in the annual quantum of rainfall, the result is lesser number of rainy days with long spells of dryness and erratic distribution. Meher-Homji (1980a, 1980b) has shown that large-scale deforestation reflects more through a reduction in the number of rainy days than through the volume of rainfall.

Soil erosion in its turn provokes two major problems. If rainfall continues to be 'normal' but irregular, with occasional torrential falls, the consequences are the silting-up of river beds and floods; if drought years prevail in succession, not only do the streams and rivulets depending on the gradual release of water from the forest soil dry up, resulting in desertification of at least the marginally sub-humid zones, but increased dust particles in the atmosphere lead to desiccation and drought at least on the margins of the zones that are not so humid. Even the humid zones are in danger of getting progressively drier if droughts continue to recur over a series of years.

According to the UNESCO report (1978), the tropical regions which represent 40 per cent of the total earth surface, contribute about 60 per cent of the water vapour into the global water cycle. The contribution of tropical ocean area to the evaporation volume of the globe is almost 50 per cent and that of tropical land area about 10 per cent and the tropical forests, which cover about one-third of the total tropical land area, 3 per cent. Water cycling being rapid in the atmosphere with an average residence time of 9 to 10 days, the role of the tropical forest in influencing the global water cycle is thus considered to be around 3 per cent.

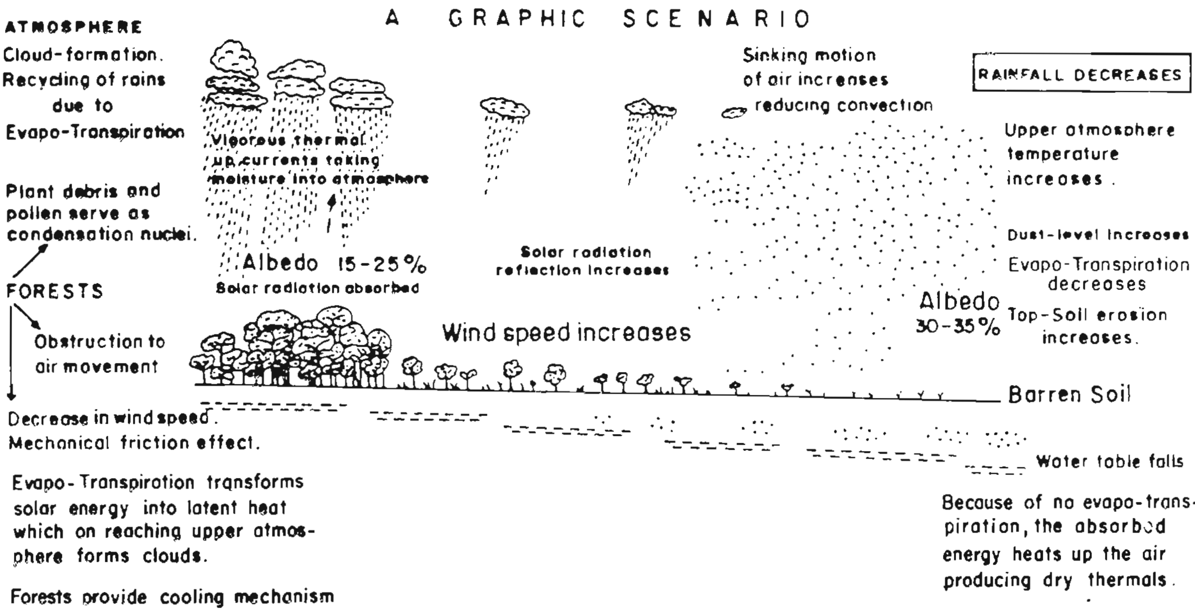
At the United Nations University Workshop on Forest-climate-hydrology held at the Commonwealth Forestry Institute, Oxford (March, 1984) it was concluded that large scale changes in vegetation induced by man of which deforestation is the most extreme example, result not only in site impoverishment but also bring about a major change in regional heat and water balances. Most local changes in precipitation, over a few tens of km due to forests are essentially caused by redistribution of precipitation and as such are edge effects. Anthropogenic increase of atmospheric carbon dioxide and the accompanying global warming will have significant effects on forests and thus on the hydrological cycle. Thus from the current evidence it would seem that changes in vegetation are more likely to have important effects on climate at regional scale. Text-figure 5 graphically depicts the physical mechanisms involved in deforestation-hydrological cycle link.

CONSERVATION OF BIODIVERSITY IN THE WAKE OF FUTURE CLIMATE CHANGE

Legris (1963) has shown as to how a drop in temperature of 6°C or an increase in rainfall by 500 mm can lead to profound changes in the vegetation types. A topic of major concern to-day is the conservation of biodiversity. The French Institute has brought out maps of vegetation of Peninsular India at the scale of 1 : 1,000,000 and of the Western Ghats at 1 : 250,000. Of the potential land area under each of these vegetation types, the percentage area still remaining under forest and under degraded vegetation like thicket, tree-savanna, shrub-savanna and scattered shrubs is presented in Table 2.

Whereas the evergreen vegetation types in the southern part of the Western Ghats and some of the deciduous forest types of the Peninsula have a fair representation of forest-cover, the situation is alarming for the vegetation types of the drier zones as they have less than 5 per cent of the potential area under forest. The same is the case with the Coromandal coastal region of Tamil Nadu and Andhra Pradesh. As the scrub-jungles of this tract are devoid of timber trees, the scrub vegetation has been practically eliminated and planted by the exotic *Eucalyptus*. However, these scrub-jungles shelter a number of economic and medicinal species like the climber *Ormocarpum sennoides*, the leaves of which are reported to be very effective in mending fractures. The leaves of the herb *Andrographis paniculata* have the property of controlling both diabetes and hypertension. The tubers of *Dioscorea* are rich in steroids but *Dioscorea* needs forest ambience for its growth. With the destruction of forests and scrub-jungles a rich source of economic resource is wiped out. Meher-Homji (1992) in his vegetation maps has indicated areas that need protection on a priority basis. As an example may be cited the case of the forests in the Western Ghats in Kozhikode District of Kerala. The narrow strip of forest is under heavy pressure from both the western and the eastern sides. The heavily populated west coast region depends on the forest for its requirement of wood whereas from the eastern side, coffee plantations are making an in-road into the forests. There is an urgent need to protect the forests in this tract otherwise there will be a discontinuity hampering the migration of large herbivores.

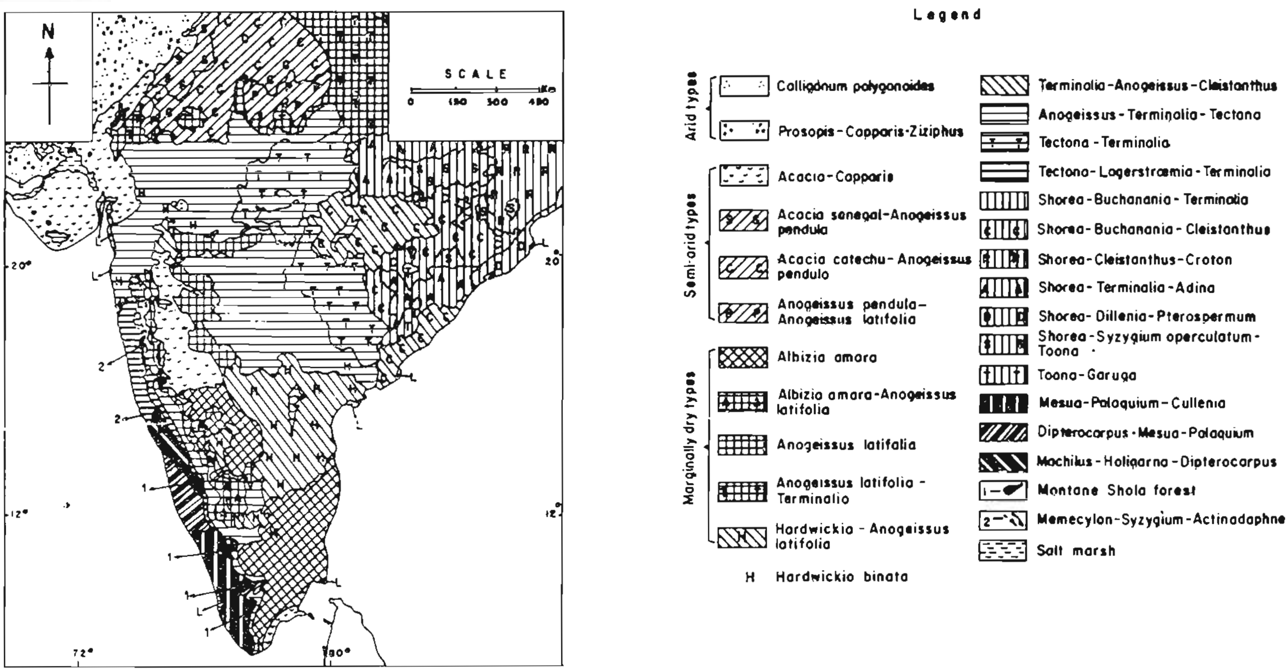
As the global climate changes, it is feared that the optimal growing range for many plants will shift, possibly at rates faster than plant populations can migrate across the landscapes. Therefore there is urgent need of conserving the remnant patches of natural vegetation so that the species migrating from cooler zones to warmer or from wetter to drier can find shelter in these vestigeal pockets after the climate change has been effected.



Text-figure 5—Repercussions of deforestation on atmospheric and soil processes : a graphic scenario.

Table 2—Potential area and percentage under forest and degraded vegetation in various vegetation types of Peninsular India

Vegetation types	Potential area (thousands ha)	Area under forest (%)	Area under degraded vegetation (%)
I. Thorny types			
1-2. *Calligonum* type and *Prosopis-Salvadora-Capparis-Ziziphus* type	30875	—	5
3. *Acacia-Capparis* type	17250	—	2
II. Deciduous types			
4 *Acacia senegal-Anogeissus pendula* type	3460	1	3
5 *Acacia catechu-Anogeissus pendula* type	15805	8	3
6 *Anogeissus pendula-A. latifolia* type	5000	2	3
7 *Acacia-Anogeissus latifolia* type	9780	—	0.3
8 *Anogeissus latifolia-Hardwickia* type	12125	12	1
9 *Anogeissus latifolia-Terminalia* type	11975	6	10
10. *Terminalia-Anogeissus latifolia-Cleistanthus* type	10375	8	20
11. *Terminalia-Anogeissus latifolia-Tectona* type	36090	5	14
12. *Tectona-Terminalia* type	17250	15	30
13. *Tectona-Terminalia-Adina-Anogeissus* type	1625	27	10
14. *Tectona-Dillenia-Lagerstroemia lanceolata-Terminalia paniculata* type	4975	18	7
15. *Shorea-Buchanania-Cleistanthus* type	8375	14	25
16. *Shorea-Cleistanthus-Croton* type	10750	7	7
17 *Shorea-Terminalia-Adina* type	19610	37	10
18. *Shorea-Dillenia-Pterospermum* type	1875	6	3
19 *Shorea-Syzygium operculatum-Toona-Symplocos* type	4950	25	42
III. Semi-evergreen types			
20 *Toona-Garuga* type	1000	17	17
21 *Bridelia-Ficus glomerata-Syzygium* type	275	41	36
IV. Evergreen types			
22-23. Shola (Montane Forest) and *Gordonia-Schefflera-Meliosma* type	500	6	19
24. *Memecylon-Actinodaphne-Syzygium* type	500	16	18
25. *Machilus-Diospyros-Holigarna* type	1250	52	—
26. *Dipterocarpus-Mesua-Palaquium* type	1950	26	34
27 *Cullenia-Mesua-Palaquium* type	2000	15	5
28. *Acacia-Albizia amara* type	15350	5	1
29 *Manilkara-Chloroxylon-Anogeissus latifolia* type	2750	0.2	5
30 *Albizia amara-Chloroxylon-Anogeissus latifolia* type	2725	0.4	0.3
31 Tropical wet evergreen type of Andaman-Nicobar	684	80	6
32. Mangroves	681	9	—



Text-figure 6—Potential area of the major vegetation types.

PLANT POPULATIONS AS INDICATORS OF FINER CLIMATE CHANGE

Finally, I would like to point out the need to develop population studies in plant taxonomy to indicate finer climate changes. Study of populations within a species may provide information whether a particular site is undergoing accentuation of aridity or not. Species are known to exhibit a number of populations. Tandon (1977) has brought out a number of populations within the grass species *Oropetium thomaeum*. It may be possible to arrange these populations along a gradient of humidity-aridity. It would be interesting to compare the present-day population of a particular site of Rajasthan with the herbarium specimens collected from the same locality a century or so ago and to note whether a trend towards xericity is indicated or not. Such an investigation may give a clue to a fine biometeorological shift or stability in the degree of aridity.

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