PART I

BIOCLIMATOLOGICAL FUNDAMENTALS

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PART I

Bioclimatological fundamentals

1 Physico-geographical survey

1.1 Geographical location and characteristics of Cuba

Cuba belongs to the West Indies and within these to the Greater Antilles as its largest and economically most important country. It lies in the middle of the Caribbean Sea, south from the Tropic of Cancer between the 74°8 and 84°58 western longitude and the northern latitude of 19°50 and 23°17. To the north a 180 km wide straight separates it from Florida and to the west a 210 km wide straight from the Mexican Yucatan peninsula. In the south the closest island is Jamaica 140 km distant and in the east it is altogether 77 km from Hispaniola (Fig. 1).

The island of Cuba itself is an elongated narrow land extending in the north-west, south-eastern direction. The aerial distance from Cabo San Antonio to Punta Maisi is 1250 km, the narrowest width between Mariel and Majana by air is 32 km. The length of the coast is about 5746 km. The area of the Republic of Cuba — including the Isle of Pines and the reefs encompassing Cuba from north and south and the smaller islands is 110 922 km^2. Of this, the island of Cuba accounts for 105 007 km^2 the Isle of Pines 2200 km^2 and the other islands and reefs altogether 3715 km^2.

1.1.1 Administrative distribution

This region falls into 6 administrative units — provinces — (Fig. 2) which are the following in the west-east direction: Pinar del Rio 13 200 km^2, La Habana including the Isle of Pines which belongs to it 7 952 km^2, Matanzas 11 340 km^2, Las Villas 18 004 km^2, Camagüey 25 335 km^2 and Oriente 35 102 km^2.

From the first of January 1977 a new administrative order has been enforced. The number of the provinces has increased to 14 (Fig. 2). Havanna the capital has become a city of provincial rank, Las Villas is distributed into three provinces (Villa Clara, Cienfuegos, Sancti Spiritus), Camagüey over two provinces (Ciego and Camagüey), Oriente over five provinces (Tunas, Holguin, Granma, Santiago, Guantanamo-Baracoa). Since our results were published according to the earlier administrative units all the topographic data reported in the book have been given according to these earlier distributions.

Fig. 1 Map of the West Indies

Fig. 2 Political map of Cuba Administrative provinces A: until 1976, B: starting from 1976

1.2 Orography of Cuba

The orography of Cuba is rather varied (Fig. 3). Along the whole length of the island we may find several isolated mountains of different height. The most important are the following:

1.2.1 Mountain ranges of Pinar del Rio province

The most significant mountain of western Cuba is the Guaniguanico Massif stretching lengthwise over the whole province of Pinar del Rio. It falls into two ranges of distinct geological ages and composition. The most ancient is the Sierra de los Organos consisting of Jurassic limestone deposited on slaty sandstone in the west; its highest peak is Pan de Azúcar of 591 m height. To its east lies the younger Sierra del Rosario highly varied in geological structure with the limestone peak Pan de Guajaibón of 692 m.

1.2.2 Hilly ranges of the Havanna and Matanzas provinces

In the province of Havanna and Matanzas two parallel low ranges stretch in the north the Havanna-Matanzas range with Pan de Matanzas of 389 m height, a little to the south with the Bejucal-Madruga-Coliseo range with Loma de Grillo (321 m).

1.2.3 Mountains of the Las Villas province

In the middle of the island in Las Villas province, several mountain regions can be found. Parallel to the north coast stretch the north Las Villas ranges comprising several low contours, the Mogotes of Caguaguas, Sierra de Purio and Sierra de Jatibonico rising to 410 m height. South of these in the middle of the province the hill region of Santa Clara does not even reach the 300 m height. Above the southern coast rises the Guamuhaya Massif or Sierra de Escambray range which is divided into two mountain regions: the western Trinidad mountains whose highest peak is Pico San Juan (1156 m) and the eastern Sancti Spiritus mountains with its summit —Loma de Banao—of 843 m height.

1.2.4 Mountain ranges of the Camagüey Province

There are altogether three low hill ranges in Camagüey Province. In the north-west la Cunagua hill or Sierra de Judas (338 m), in the northern part, the ancient denuded karstic range of Sierra de Cubitas can be found with its highest point, the Loma Tuabaquey (335 m), while in the south the disintegrated hills of Sierra de Najasa with the Cerro de Chorillo (301 m).

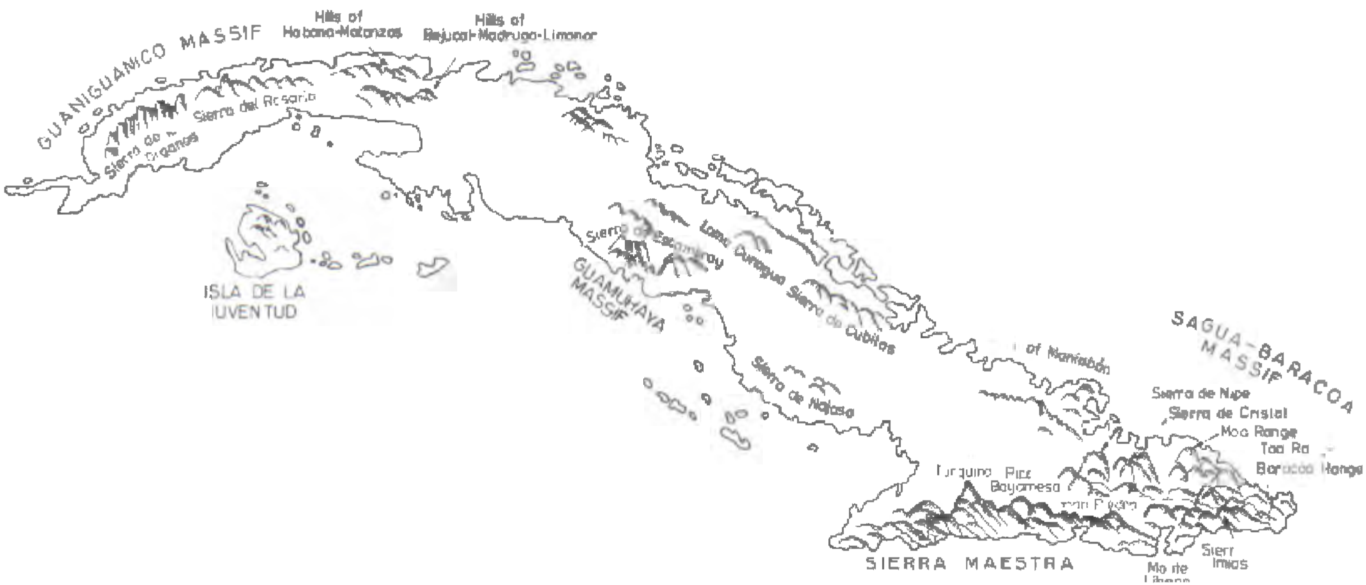


Fig. 3 The mountain ranges of Cuba

1.2.5 Mountain ranges of the Oriente Province

Oriente Province is the richest province of the Cuban mountains. The inselbergs of the Maniabon group with its varied landscape rising north from the Cauto lowland, do not even reach 300 m. The southern and north-eastern part comprises continuous montane areas: the ranges of Sierra Maestra and Sagua-Baracoa (Fig. 3).

a) Sierra Maestra is a 250 km long and 30 km wide mountain chain and the highest range of Cuba. Its western wing, the Cordillera del Turquino which stretches from Cabo Cruz to Santiago Bay — both in extent and in height — surpasses the wing extending from Santiago de Cuba to the Guanatanamo basin. In the former we find the high ridge of the Maestra range with the Turquino group (Pico Cuba 1872 m, Pico Real 1974 m and Pico Suecia of 1734 m) whose main middle peak is the highest summit of Cuba (Fig. 4), furthermore Pico Bayamesa (1730 m), Pico Marti (1722 m) and numerous peaks rising above 1500—1600 m. From here the mountain region abruptly drops towards the west and east and only at Sierra de Cobre does it rise above 1000 m. The eastern wing comprises two ridges of the Cordillera de la Gran Piedra: the Sierra de Gran Piedra range rising to 1226 m and the central range of Sierra de Santa Maria de Loreto stretching northward and rising to 500 m a.s.l.

b) The most complex mountain system is the Sagua-Baracoa Massif. The northern part consists of several serpentine block mountains separated by deep river-valleys. The most isolated is the westernmost member of the range: the Sierra de Nipe highland with the summit of La Mensura of 995 m. East of this rises Sierra de Cristal whose peak of 1231 m is the highest elevation of the range. The other three members of this mountain range Sierra de Moa with its peak El Toldo of 1139 m, Cuchillas de Toa with the 1011 m high summit of Pico Galan and Cuchillas de Baracoa produce a very complex intervowen relief system. The southern part of the mountain range comprises mainly plateau-like limestone mountains: Meseta de Guaso with its group constituted by Monte Libano, Monte Verde and Monte Cristo rising altogether 911 m above Guantanamo. South of it, lies the lower Sierra de Maquey (868 m). The most significant mountain ranges of the group are Sierra de Purial and Sierra de Imias with the summit El Gato of 1181 m and finally Meseta de Maisi with the Vista Alegre peak of 641 m.

1.2.6 Mountains of Isla de Pinos

Numerous little block hills can be found in Isla de Pinos. The oldest geologically, are the limestone ones of Sierra de Casas and Sierra de Caballos rising above Nueva Gerona. The highest is Sierra de la Canãda composed of slate and stretching over a north-west and south-east direction (310 m).

Fig. 4 The highest summit of Cuba, the Turquino-group in the Sierra Maestra (left: Pico Cuba 1862 m, middle: Pico Real 1974 m, right: Pico Suecia 1734 m; photo: A. Borhidi)

1.3 Hydrography of Cuba

The hydrography of Cuba is characterized by a large number of rivers which are short and periodically lacking water. The island has around 200 smaller or larger rivers and creeks. Of the latter they are only temporarily filled with water, during the dry winter period they dry up completely. The number of the rivers longer than 100 km is altogether 13, the longest is Rio Cauto (370 km). The most abundantly supplied with water is the river Toa in the Sagua-Baracoa range of Oriente, which with its over 77 km long stretch collects the waters of 71 tributaries and over almost the whole catchment area there is an evenly distributed precipitation of more than 2000 mm annually (Fig 5).

1.3.1 The allochthonous character of Cuban rivers

Numerous Cuban rivers are allochthonous: originating from a different geologic formation than that on which they later progress over. The Cuyaguateje originates on acidic slate and continues its route over limestone mountains. Many rivers of Oriente originate on serpentine then pass over limestone areas (Rio Nipe, Rio Naranjo, Rio del Medio, Rio Yumuri, Rio Piloto, Rio Miguel) in other cases (Rio Moa, Rio Duaba) they continue on serpentine originating from limestone.

1.3.2 Cuban still waters

The number of Cuban still waters is small. The larger ones are ocean saltwater lagunes, such as Laguna de Leche (67 km^2) and Laguna Barbacoas (19 km^2). The lakes are generally small, the largest are Ariguanabo and Laguna del Tesoro (of 9 km^2 water surface each). Of the mentioned peat bottomed lakes those of sandy and clay bottoms are more frequent. These account for the largest lake region in the Guanhacabibes peninsula in the southwest part of the Pinar del Rio Province, where more than one hundred smaller lakes are to be found. There are a large number of karst lakes of rock bottom being no more than several hundred m^2 in size which are widespread in the lowland limestone "dog-tooth" areas of the Guanhacabibes peninsula, on the southern part of Isla de Pinos and on the Zapata peninsula. Among these may be found the deepest lake of Cuba which is about 100 m in diameter and 25 m deep, Laguna San Juan.

2 General characteristics of the Cuban climate

The nature of the climate of Cuba is determined by the general atmospheric movements on the one hand and by the warm sea currents on the other. One of the branches of the warm, north-equatorial current, the so-called Cuban re-current almost entirely encircles the shores of the island its effect being reinforced by the southern equatorial current which encroaches the Caribbean Sea from the southern

Fig. 5 The watercourses of Cuba

direction. The result of these is that the climate of Cuba is much warmer and balanced — more tropical — than that of larger land masses lying in the same latitude — along the tropic. This is proved by the fact that in the areas regarded to be identical with Cuban climate — isoclimatic areas — on the continents of Asia, Africa and South America may be found between the latitudes of 8—15°.

2.1 Atmospheric currents of Cuba

The atmospheric movements of Cuba are controlled by the combined effect of the cyclone system moving the low pressured equatorial atmospheric masses and by the activity of the high-pressured air masses of different anti-cyclones. The main cyclonal activity falls to the summer rainy period more exactly from July to November. Its effects and phytogeographic significance will be discussed at length later.

2.2 Anti-cyclonal activity

The sunny dry weather is a consequence of the activity of two anti-cyclonic activities. The North Atlantic anti-cyclone developing north-east of the island makes itself felt leading to a drop in mid-summer precipitation and double peaks. It may be attributed to this that apart from the generally widespread winter dry season a summer dry period may be detected starting from the middle of the island and progressing along the northern coast eastwards which on the coasts of north Oriente may even reach 2—3 months.

2.3 Characteristics of the dry winter season

In the dry winter season—which lasts mainly from December until the end of April—the cool dry high pressured air masses developing above the North American continent stream towards Cuba creating sunny weather. If however, the activity of the air masses of the Arctic intensify, the frontal zone situated to the north, may spread above Cuba too and on the effect of the warm southern winds arising in the southern part of the Caribbean may be repressed northwards. This alternation of the cold and warm fronts occurs every 2—3 days but in contrast with the summer storms these cause showers. These sporadic winter rains therefore indicate that deviating from the typical monsoon climates (e.g. India) the dry season in Cuba is not entirely dry. The phytogeographic and ecologic significance of this climatic feature will be discussed in detail later.

3 Distribution of the temperature

3.1 Temperature maps

The temperature conditions of Cuba have not been clarified to this day. The temperature map of the yearbook of the National Observatory published in 1965—obviously due to a lack of appropriate data—completely ignores the orography isotherms virtually, as if the whole island were a plain. A major breakthrough has been provided by the temperature map published in the Atlas Nacional de Cuba (1970) which already differentiates the temperature zones according to the altitudinal belts. The temperature map presented in Fig. 6 is taken from the Atlas of Cuba (1978).

3.1.1 Distribution of annual mean temperature

The annual mean temperatures—in accordance with the moderating effect of the sea—are higher along the coasts than in the interior of the island. In this respect the island is quite even throughout. On the lowlands of West Cuba the values vary between 24 °C and 25 °C, and drop below 25 °C in the vicinity of Havanna and the valleys of Sierra de los Organos and Sierra del Rosario and the whole island of Isla de Pinos belong to this temperature range. The 25 °C isotherm is surpassed in the middle of Las Villas province in the line of Caibarien–Sancti Spiritus–Trinidad. In the east Cuban lowlands, the annual mean temperature remains between 25—26 °C with the exception of the central part of Camagüey Province between Ciego de Avila and Camagüey where in consequence of the continental effect causing greater daily fluctuation, the annual mean drops below 25 °C. The temperature rises above 26 °C only in one part of the northern coastline of Oriente (Gibara) as well as the hottest part of the island, the southern coastal region of Oriente from Manzanillo to the tip of the island at Maisi. The hottest point of Cuba lies in this part too, in the Guantanamo Bay and its environs where the annual mean reaches 27 °C.

3.1.2 Extreme values of temperature

With respect to extreme values, the situation is the reverse. As a consequence of the continental effect—even if it is only slight—the extreme values can be found along the axis of the island. With respect to the absolute maximum values the most striking are Placetas with 40 °C, Sancti Spiritus, Banes and Guantanamo (Central Baltony) with 39 °C tops, while absolute maxima of 36—37 °C are generally widespread.

The centre of the cold point of the island falls north-northeast of Sierra de Escambray and to West Cuba. The lowest values are most often found here. The absolute minimum in relation to lowlands is 3 °C (Paso Real and Zaza del Medio), 5 °C was measured in Candelaria, Santiago de las Vegas and Placetas. Frost or snow was never detected in Cuba not even on the almost 2000 m high Pico Turquino. The minimum winter temperature of Turquino was estimated at around 1 °C. In the course of my own measurements in December on the 5th, 6th and 7th 1969, I found minima of 1.5—2 °C.

3.1.3 Temperature fluctuation

Two kinds of tendencies can be detected. The temperature values grow on the one hand, from the coast towards the interior of the island, on the other hand, lengthwise along the island in a south-east direction.

As exemplified in Table 1, the tropical character of the climate in Oriente is more accentuated by the greater uniformity of higher mean temperature.

While the annual fluctuation of the monthly mean temperature was 6.4 °C in Pinar del Rio province (11 stations), in Oriente it was only 5.2 °C (14 stations). There is a tendency of uniformity in the mean temperature distribution of the mountain regions. In contrast with the tropical lowlands — where there is a slight daily temperature fluctuation that of the mountain regions is high. According to my measurements on Pico Cuba at 1750 m height the daily maximum may attain 25—30 °C on winter days too. These daily fluctuations during the course of the year appear rather uniformly and their extreme values alternate between such small intervals that the mean temperature in the annual distribution fluctuates only between 4.5—5.5 °C. The daily temperature fluctuation increasing with the height

Table 1 Comparison of the annual mean temperature and fluctuation of monthly means in Oriente and Pinar del Rio provinces

City	Annual mean temperature (°C)	Annual fluctuation of monthly means (°C)
Oriente Province		
Guantanamo	28.0	5.0
Maisi	27.8	4.8
Santiago de Cuba	27.6	5.1
Manzanillo	26.9	5.1
Cabo Cruz	26.8	4.7
Victoria de las Tunas	26.5	4.7
Pinar del Rio Province		
Pinar del Rio	24.7	6.8
Minas de Mathambre	24.9	6.6
Paso Real	24.9	6.4
Artemisa	25.4	6.5
San Juan y Martinez	25.5	6.5
Guane	25.8	6.3

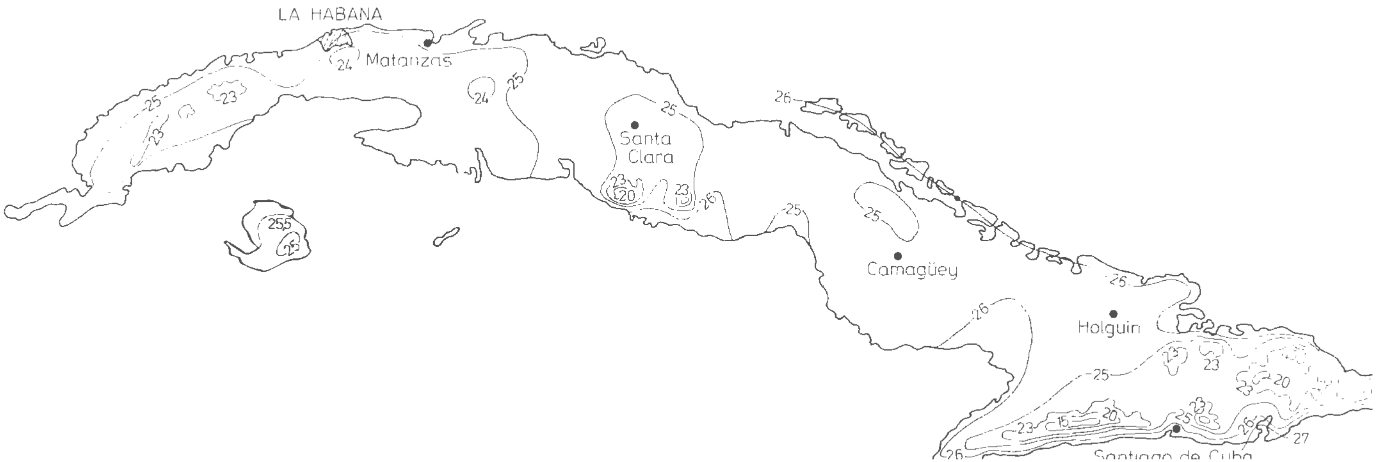


Fig. 6 The mean annual temperature in Cuba

a.s.l. and the seasonal temperature difference decreasing parallely with it is a feature observable in tropical mountain regions as Walter's (1962) measurements proved in Kilimanjaro too.

3.1.4 Physiological effect of temperature

We can hardly assess the effect of temperature on living organisms—and on the vegetation—without considering the relative moisture content. Living organisms sense and tolerate heat conditions not in terms of temperature degrees but as positive or negative thermal effects to be neutralized or physiologically to be balanced out. Depending on the relative moisture content of the air even of the same temperature, its heat generating or heat depriving activity may be quite different, and this difference could well surpass the tolerance threshold level of numerous organisms. It is a well known fact that vegetation has a much greater tolerance to dry cold weather than to wet cold one (note the polar timber line). In humid hot climate the energy loss of the vegetation by transpiration/guttation and dissimilation may be several times more that of what it has to tolerate under the same temperature but with lower humidity.

3.2 Relative atmospheric humidity

It was not possible to draw conclusions from the 3—4 observations annually carried out by sixty stations, as to the relative atmospheric humidity changes, especially not with respect to the spread, variance and extremes of the values. Several general conclusions may be drawn nevertheless.

The annual mean values of relative humidity content ranges mainly between 74—80%. Values lower than these can be experienced on the southern coastline in Sierra Maestra and Baracoa. The minimum was measured in Guantanamo on the edge of the semi-desert belt with an annual mean of 68%.

3.2.1 Vertical distribution of relative humidity

The vertical distribution of relative humidity shows a decided rise in the lower limit of the montane rainforest belt (Topes de Collantes), at 700 m the annual average was 85%, in the middle of the zone (Gran Piedra) of 1120 m the annual average was 88—90% which is above the declining point of filmy ferns characteristic of rainforests *(Hymenophyllum)*.

The vertical gradient of relative humidity appears at 100 m intervals as 1.8% probably not in even distributions.

3.2.2 Annual distribution of relative humidity

The annual distribution of atmospheric humidity on the whole, resembles that of precipitation. Its minimum in the whole area of Cuba falls to the end of the dry season to March—April while in the rainy season a double peak may be found. In western and central Cuba there is a first peak in June and a second one in October. In East Cuba however, a weaker second peak in June is followed by a vigorous main peak in October—November towards the end of the rainy season. Atmospheric humidity and the annual distribution of precipitation show a very similar variation in south-east Africa, in Tanzania, Zambia and Mozambique similar to the distribution of temperature values (Griffiths 1962, Pócs 1976, personal communication). In the North Oriente montane region on the influence of the North-Atlantic anti-cylone the maximum atmospheric humidity falls to November, December, January, the minimum to April—May. Numerous vertical gradients—obviously due to the forceful mixing effect of North Atlantic winds — up to about 600 m height cannot be demonstrated. The fact that the annual distribution pattern of atmospheric humidity significantly differs from that of the temperature, and that their minimum and maximum values fall to different seasons all contribute to a balanced thermal economy of the climate. This has an important effect on the quality of the vegetation cover which will be elaborated in detail later.

3.3 Vertical distribution of the temperature

So as to be able to construct a hypothetical sketch of the original vegetation of a cultivated land to delineate the vertical belts and within these to establish the zonal types of the soil and vegetation we had to become acquainted with the bioclimatic conditions of Cuba and to draw up its climate diagrams. The basis for this was to prepare a map reflecting the real temperature for which the vertical gradients of the temperature had to be calculated for the different montane regions.

3.3.1 Vertical temperature gradient

The vertical temperature gradient in the temperate zone is usually taken as 0.5 °C/100 m which generally agrees with the empiric values. Such calculations have not been carried out in Cuba. The gradients which can be read only with approximate exactness and estimated from it in the Atlas Nacional de Cuba (1970:35) vary unexpectedly in the different montane regions. In Sierra Maestra it is 0.65 °C, Sierra de Nipe 0.85, Sierra de Escambray 1.2 °C/100 m. Obviously these values were derived from some misprint. If they were real then the same vegetation belt should be developed in the Sierra de Escambray at a 4—500 m lower altitude than in the Sierra Maestra. In contrast with this, the vegetation belts of the two montane regions would occupy the same altitude a.s.l. which contradicts the difference in gradients.

Our investigations were carried out based on the data of the following stations: In

Table 2 Temperature gradients for three montane regions

	Sierra Maestra	Sierra de Escambray	Sierra de Nipe
J	0.9	0.9	0.6
F	0.8	0.8	0.6
M	0.8	0.8	0.6
A	0.8	0.8	0.6
M	0.8	0.8	0.6
J	0.8	0.8	0.6
J	0.8	0.8	0.7
A	0.8	0.8	0.7
S	0.8	0.8	0.8
O	0.8	0.8	0.8
N	0.8	0.8	0.7
D	0.9	0.9	0.6
annual	0.8	0.8	0.66

Sierra Maestra vertical gradients were calculated between Santiago de Cuba University (44 m) and the Gran Piedra Meteorological Station (1120 m); in Sierra de Escambray between Trinidad (35 m) and Topes de Collantes (760 m) based on 25 and 10-year registration periods and we found them completely identical. This result coincides with the parallelism of the phytogeographic zones mentioned in 5.31 in the two montane regions. With respect to Sierra de Nipe for the registration of the temperature difference between stations at Mayari (40 m) and Pinares de Mayari (650 m) only data of 10 and 5 years were available. According to our investigations the temperature gradients for the monthly and annual values in the mentioned three montane regions are to be seen in Table 2.

Due to the unfortunately small number of montane meteorological stations we could not draw graphs of the vertical gradients. Obviously the gradients are not even and they depend to a large extent on the humidity of the climate (Pócs 1974). Probably the gradient rises evenly in the Cuban montane regions to about 800 m a.s.l. while in the condensation belt (800—1600 m) it drops significantly and above this it suddenly rises again.

4 Distribution of precipitation

4.1 Derivation of data

In Cuba there are more than one hundred precipitation measuring stations with data from over 20—60 years of observations and a further 450 stations with more than 10 years of measurements. These measuring sites with a few exceptions operated in lowland coastal region in cultivation areas — largely in sugar refining centres.

With respect to montane precipitation we had no information until recently. This has changed considerably due to the fact that in 1964—65 the Instituto de los

Recursos Hidraulicos built a precipitation network station consisting of close to 3000 stations extending the observations to montane regions. The data were published in Boletin de Lluvia but not for each station but by averaging the data of several stations for four quarters of map sheets to a scale of 1:50 000. Our calculations were based partly on this published material and partly on the almost 1000 selected individual stations so as to get as far as possible, a complete and reliable picture of the precipitation pattern of Cuba.

4.1.1 Precipitation maps and their evaluation

It follows from this that although several attempts were made to construct a genuine precipitation map, only recently has this been achieved on account of the missing data. With respect to the annual precipitation amount O.L. Fassig (in Tropical Plant. Res. Foundation) prepared a map in the thirties which has been quoted by many (see Seifriz 1943; Nuñez 1959). According to this map the mean annual precipitation ranged between 750—1800 mm and the most humid part of Cuba is the western montane region of the Sierra de los Organos. The precipitation map published by Observatorio Nacional in 1965 is rather similar which lists the montane ranges of North Oriente — which have the most rainfall in Cuba — under the driest areas. A considerable advance was made in this respect with Trusov's map (1967) which indicates categories between 800—2200 mm with 100 mm isohyetes. This is the first map which has approximated correctly the regions with the most precipitation in Cuba (Sierra Maestra, Sierra de Escambray, Sagua-Baracoa) although their ranking is still not correct and the isohyetes of the Sagua-Baracoa mountain follow the orography excessively whereas in this area the valleys and the moderate slopes have the most precipitation and the tops are relatively dry.

4.2 Regional distribution of precipitation

The precipitation map drawn up by us (Fig. 7) distinguishes 8 classes between 300—3000 mm. The region with the most precipitation is the Moa-Toa-Baracoa mountain complex which is the only lowland rainforest belt. The precipitation conditions of the semi-desert cactus-scrub belt of South Oriente is reflected correctly by this map. Generally, the data of this map coincide with the borders of the different vegetation types and place numerous vegetation-ecologic questions in the right perspective. It should be noted that on account of the scaling of the map we could not indicate the density of the isohyetes according to reality. In Sierra Maestra and Sagua-Baracoa essentially higher precipitation means occur than those indicated. These have been depicted under climate diagrams on bioclimatic profiles and bioclimate maps.

It may be concluded from the geographical distribution of the annual total precipitation that:

- Precipitation increases over the whole island from the coast towards the interior of the island.

- The western Cuban lowland has a balanced 1400—1600 mm precipitation pattern, in prominent montane region 1800 mm, in fact, in places even 2000 mm.
- The annual precipitation amount along East Cuba lowland remains below that of the western part and tends to decline towards the east to 1300—700 mm.
- With a rise in altitude there is a rise in annual precipitation amount.
- In the southern rain shadow belt of the mountains, extremely dry zones develop and extremes of precipitation rise eastward. Thus in East Oriente over a 30—50 km stretch, the annual mean precipitation total ranges between 400 mm and 3000—5000 mm.

This phenomenon under similar general atmospheric conditions and orographic situations can be observed in East Jamaica and western Hispaniola (Asprey and Robbins 1953, Ciferri 1936).

4.3 Annual distribution of precipitation

For the determination of the characteristics of the climate and the quality of the vegetation it is essential to know the temporal distribution of the annual precipitation.

4.3.1 Arid and wet seasons

Cuba belongs to the belt of the zenital rains where it is characteristic for the annual distribution of precipitation that there is one summer rainy season which lasts from May to October and a dry period from November to April. This rainfall type resembles that of the monsoon climate which is typical for southern India, a large of Brazil and subequatorial regions of Africa. However, in Cuba this precipitation distribution is not caused by the monsoon winds but by the passat wind-system. The north-east coastline of Cuba falls into another rainfall distribution type where two dry and two wet periods alternate. In north East Oriente there is a transition to an opposite precipitation distribution in which the period with more rainfall lasts from September to February and there is a certain affinity to the Mediterranean precipitation distributions. Lacking suitable data, Trusov was not aware that in the montane regions of Oriente there is a third type of precipitation distribution from which a steady abundant rainfall throughout the year is characteristic. This will be elaborated when discussing the bioclimatic types of Cuba.

4.3.2 Precipitation distribution types of Trusov

According to Trusov there are eight annual precipitation distribution types in Cuba based on the position and quantity of maxima and minima. From the eight types of occurrences he established eight precipitation zones. The criteria for these zones were determined partly from agricultural practices (e.g. sugar cane harvesting regional organization) partly irrigation and erosion and flood protection aspects for which they are suited. However, there is a flaw in this classification, in that Trusov has ignored the rainfall amounts whereas this is not negligible from water management aspects either. To understand the climatic demands of terrestrial ecosystems from the point of view of the connection between climate and vegetation types and their spread Trusov's regionalization does not provide really worthwhile information.

4.4 Ecological significance of rainfall distribution

Just on account of those viewpoints mentioned, it is necessary to make some generalizations on the ecological-phytogeographical significance of the temporal precipitation distribution.

4.4.1 Amount and distribution

In determining the quality of the structural types of vegetation and terrestrial ecosystems the annual precipitation amount below a certain level is more important than the annual distribution. Above a certain threshold however, the annual distribution is decisive in contrast with the total amount. The actual threshold values are divergent in the different temperature zones and within one temperature zone they vary depending on the soil type (Walter 1951, Borhidi 1969). These aspects will be explained at length in *9.4.2–9.4.3*.

4.4.2 Extent of the rainy season

From the quality aspects of vegetation types the duration and intensity of the rainy season are essential, furthermore at this latitude whether it falls to the long-day (summer) or the short-day period. However, it is indifferent within this, what the number of rainfall maxima are or whether they fall close or distant to each other and in which month of the season they fall.

4.4.3 The length of the dry season

The duration of the dry season and the intensity of the dryness with respect to the vegetation is essential. The average precipitation amount and the minimum actually falling is the dry season in of decisive importance but as to which month these occur is irrelevant.

4.4.4 Summer or winter dryness

Which season the dry period falls in is of distinct significance for phytogeography. The short-day (winter) dryness leads to the development of quite another adaptation form than the long-day (summer) dryness. This will be discussed at length in points *9.3.2–10.3.3*.

4.4.5 More dry periods

With two dry periods the ecological effects of each period differ from quantitative and qualitative points of view, and to these the vegetation reacts in different forms of acclimatization and the ecosystems by forming nutrient chains and patterns.

4.5 Fluctuation of annual precipitation

Apart from studying the averaged amounts of precipitation it is necessary to mention the variation and extreme values of the precipitation. According to Trusov (1967) the coefficient of variance of the annual amount based on 30 years' means fell between 0.19—0.30. In areas with annual means ranging from 1400 mm to 1600 mm the precipitation amounts for certain years may vary from 600—800 mm to 2200—2500 mm. Often the "semi-desert type" of years and "rainforest type" series alternate which do not alter the basic structure of the ecosystem but it may influence the intensity and rhythm of the metabolic cycle e.g. the extent of the litter fall and the decomposition-rate of the litter and humus. In contrast with this the variability of precipitation greatly affects the functioning of the short cycle ecosystems and above all, the agricultural chances (Kool 1953, Knapp 1973).

4.6 Extreme values of precipitation

When discussing the effect of climatic elements on biologic objects it is often customary to stress the importance of extreme values and their limiting effect. The extreme values are of special significance to agricultural cultivations especially to one-year-old monocultures. Therefore certain authors consider the estimation of probability values to provide the most information on effectiveness of precipitation (Glover et al. 1954). This is even more the case since according to our observations, the extreme values of temperature or dryness or humidity are of constraining nature only in the case of "sufficiently frequent repetitions" and have a more vigorous effect on the populations of a genetic-adaptive "unit" than on polytypical systems or complex ecosystems. An outstanding extreme value may cause transient disturbance in the ecosystem which just on account of its systems nature, by means of its self-regulating mechanism, compensates during a longer or shorter time or is eliminated by regeneration. The more complex the structure of the ecosystem, the more tolerant it is to more drastic extreme values. The tropical rainforest ecosystems belong to the most complex types. The lasting disturbances of such systems may be caused by such climatic extreme event which at the same time cause the entire or partial destruction of the basic conditions of the natural ecosystem (landslides, erosion). Such climatic extremes causing long-lasting changes are the tropical cyclones and hurricanes.

5 Cyclones and their phytogeographic role

5.1 Cyclonic activity

Cyclonic activity includes western Cuba to the greatest extent. In the period ranging between 1800—1966 Havanna province had 35 hurricanes, Pinar del Rio 32, Matanzas, Las Villas, Oriente 25 each, Camagüey 20. The formation of cyclones is caused by a typical anomaly in the tropical atmosphere which is called barometric wave.

5.1.1 North Atlantic cyclones

Cyclones reaching the Caribbean region form in the southern part of the Passat belt in the northern region of the Atlantic Ocean and entering the Caribbean region following a parabola course leave in a north or north-eastern direction. The North Atlantic cyclones are most active in July, August and September. A large part of these progress along the exterior line of the Antilles or Bahamas and do not reach Cuba or once in the Caribbean region cutting it through a western direction leaves the region south from Cuba.

5.1.2 Caribbean cyclones

The other cyclones form in the southern part of the Caribbean Sea, north of Panama and Venezuela shores. The activity of these Caribbean cyclones falls to June, October and November and their trajectory in most cases reaches Cuba.

5.2 Factors causing hurricanes

Two essential elements in extremes and effects of hurricanes are wind and water. The speed of advancement of cyclones may exceed 200 km/h and may cause extraordinary strong cloud burst rains lasting for 2—3 days during which so much rain falls in the course of a day as in an average month of the rainy season (150—300 mm). In fact in the case of an extremely strong hurricane more than this. The maximum rainfall for one day was measured in 1963, in Santiago de Cuba at the time of the hurricane Flora—735 mm—which is equivalent to the total annual precipitation for an average year. During the three days of the Flora hurricane 1435 mm of precipitation was registered, more than that of many years registered at the station.

5.3 The role of hurricanes in the migration of plants

Analyzing the phytogeographic effect of hurricanes we must attribute an important role to them as migration factors in the spread of plant species, in flora migrations especially in such an isolated region as the West Indies where the connections with the continent had ceased over millions of years. The cyclones obviously had a major role in spreading the epiphytic small flowering plants *(Orchids, Bromelias)* but apart from this the translocation of very many species of the woody families with flying seeds *(Meliceae, Bignoniaceae)* to the archipelago. Hurricanes of great intensity are capable of taking complete huge trees, not only seeds, loaded by thousands of epiphytes into the atmosphere to great distances carrying out the introduction and transplantation literally.

5.3.1 Chorological types created by hurricanes

Apart from the mentioned widespread Neotropical plant species there are two chorological types (the Cuba—Antilles—South American and the Cuba–South American elements) altogether 170 species whose spread largely from the South American continent to certain parts of the West Indies or only just to Cuba may be attributed to the activity of cyclones in fact, in numerous cases they cannot be satisfactorily explained otherwise.

5.3.2 Effect of hurricanes on the vegetation

The effects of cyclones on the vegetation generally are detrimental, for the winds break up the forest along steeper slopes destroying them and the rains cause landslides and by erosion destroy the habitat for the denuded rocks thereby eliminating the ecosystem. In Cuba, the mentioned hurricane Flora, caused such destruction in several points of Sierra Maestra. I myself observed and studied its effect on the southern and western slopes of Pico Cuba.

5.3.3 The potential effect of hurricanes on succession and evolution of the flora

The surfaces derived in this way are at the same time suitable for re-settlement of pioneer vegetation for survival of species having low competitiveness, relics, in fact for the formation of new taxa within the genera having appropriate genetic and adaptive reserves. On the basic rocks which erode more readily, the landslides caused by downpours are more frequent. On these habitats mostly characteristic successional processes develop, e.g. dense pinebreak of the endemic *Pinus maestrensis* developed as first pioneer stage in the Sierra Maestra.

6 The concept and significance of bioclimatology

Bioclimatology is an interdisciplinary science derived from the coincidence of ecology and meteorology or rather climatology. Its observation material is derived on the one hand, from ecology and other field biological disciplines (phyto and zoo geography, phyto and zoo sociology) on the other, from areas of meteorology. At the same time the points in question are basically of an ecological nature with a view to solving ecological problems.

The starting point for bioclimatology is provided by the dual recognition:

a) the basis of biospheric operation is formed by the interaction and coordination of a natural trial system of climate—soil—vegetation whose prime connection is the ecological relationship of climate and vegetation,

b) the climate is a continuous and rhythmically changing system in space and time of the meteorological elements which through vectorical correlations of the different elements finally affects the biosphere through its residual, and the producing vegetation.

6.1 Goals and perspectives of bioclimatology

The goal of bioclimatology is to analyze this complex effect. It is obvious that not all meteorological elements and not all to the same extent, are responsible for their effect on the biosphere. It would be the same mistake to suppose that the structure, metabolism or productivity of systems adapted and compensated in so many directions such as a plant association or rather an ecosystem, would depend on the changes of one single factor of a climatic complex. The task of bioclimatology is to select that small complex the "functional climate" or "ecoclimate" which is significant biologically (structure *vs.* function showing a tight positive or negative correlation). Further, to work out such a model which would reflect the trend, extent, and preciseness of these small complex elements comprised of generally no more than 2—4 factors from the large complexity of numerous meteorological elements of the "holo" climate. Meher-Homji concisely refers to this as the "Bioclimate c'est le climat en fonction de la vie" (1963).

Perspective tasks of bioclimatology entail the definition of biologically important complex climatic concepts and their modelling such as humidity and aridity, oceanity, continentality or the working out of the bioclimatic model of the global vegetation types. Studies of this kind have become of increasing interest in relation to the recently started International Geosphere Biosphere Programme.

Bioclimatology in a biological sense—in biological effects and results—is concerned with recognizing the analogous climatic types (isoclimates according to Walter) and their characteristics and from this to work out a climatic system significant from a biological aspect. Classifying climatic elements purely from physical, morphological or other practical aspects often does not contain the minimal biological information as Gaussen (1954 abc) and Meher-Homji (1963) have referred to with numerous examples. I refer to this in points *4.4.1—4.4.5* in the same sense.

6.2 Bioclimatology and ecosystem research

It may be deduced from what has been said that bioclimatology is an ecological science which to this stage has been concerned with the relationship of "large-scale problems" of large systems (vegetation types, formations, large ecosystems) and its scope and importance may extend significantly in other directions.

The causal climatological investigation of primary production of ecosystems opens the area of biosystems having a smaller dimension for bioclimatology of which, Précsényi's (1972) research may be ranked among the first in the world. This present work on account of the methodological difficulties, studied the significance of certain meteorological elements. In my opinion investigation of the effect of functional element complexes of the climate may mean further progress.

6.2.1 Bioclimate and microclimate

It should be noted that the term bioclimatology is misused. Some authors use it as the synonym for microclimatology and by bioclimate they mean microclimate. Undoubtedly, in setting up microclimate areas, vegetation usually has an important role but this is not necessarily so (e.g. desert or urban microclimate). Microclimate always means climate close to the surface while bioclimatology primarily the large-scale interrelations of climate and vegetation, so mainly the ecological effect of macro- and meso-climates. Their methods and problems clearly diverge; they form strictly borderline, but well delineated areas of ecology.

6.3 Bioclimate and phytogeography

The basic concept of bioclimatology coincided with phytogeography when Humboldt observed that the plants adapt with typical adaptive so-called basic forms to the different climates which determine the general aspects or so-called formations of the vegetation.

Bioclimatology inspite of this, has been latent for almost one and a half centuries. Classification of climates and the distribution of climatic types has primarily been the job of geographers and meteorologists. The investigation of climates from a biological approach came increasingly to the foreground in the course of the nineteen forties. Mapping of vegetation and especially the demands of tropical vegetation mapping emerged at the beginning of the fifties. Since in the reconstruction of cultivated regions denuded of their degraded and original vegetation, bioclimatology has a basic task. The importance of reconstruction of vegetation has increased in connection with the tropical projects of the "Man and Biosphere Programme". In my opinion the perspectives and tasks of bioclimatology will expand in biosphere research not only in understanding the operation and productivity of ecosystems but perhaps in other spheres (e.g. ethology, human hygiene etc.) too.

7 Bioclimatologic formulae, diagrams, systems

7.1 Mathematical expression of climatic features

The complexity of the climate has made it necessary and at the same time crucial, to assess the characteristics of the climate and to recognize their analogies. Numerous investigations have been carried out to establish the characters of the climate, comparing the climate of the different regions to be able to work out such numerical formulae or graphic methods which appeared to be suitable for a comparison of the climates of different regions. Experiments aimed at determining the climatic features especially the humid and arid aspects were carried out to distinguish the climatic criteria of forest steppes and deserts since in the description of certain climates the vegetation in the regions had a rather important role. In half a century the trend of research and unfortunately its demands have been reversed. Previously, vegetation had been an indicator of climate, today we make inferences from the climate on the original quality of the already destroyed natural vegetation.

7.2 Bioclimatological formulae

To express the climatic characters mathematically, numerous empirical equations have been suggested. As examples we could mention those of Transeau (1905), Penck (1910), Lang (1915), Köppen (1918), Meyer (1926), De Martonne (1926), Emberger (1930), Perrin (1931), Thornthwaite (1931), Rosenkrantz (1936), Gorczynski (1943), Selyaninov (1948), Thornthwaite (1948), Mangenot (1951), Capot-Rey (1951), Gaussen and Bagnouls (1952), Hiernaux (1955). The majority of the formulae and indices created by the authors listed here are critically discussed by Meher-Homji (1963).

Of these the most widely known and used in America are the humidity and aridity indices and the general moisture index of Thornthwaite developed on the basis of his potential evapotranspiration concept. These indices, however, have been criticised by many tropical ecologists (Bagnouls and Gaussen 1957, Gentilli 1953, Barucha and Shanbag 1957, Aubréville 1965b, Chen-Chiang Chen 1957). The xerothermic index of Gaussen and Bagnouls (1952) should be mentioned from which the rather widely used ombrothermic diagram (Bagnouls and Gaussen 1952) and the Walter's climatic diagram (1955) were developed.

7.3 Graphic methods for description of the climatic features

Graphic description of the climatic character apart from being a means of comparison was meant to be illustrative. Taylor's (1915) hysterograph is widely used, e.g. by Richards *et al.* (1940), Vidal (1961), Aubréville (1966b) etc. Chaptal's (1933) polygonal star diagram and Szántó's (1940, 1949) indices of oceanity, continentality and climatic bonity worked out on graphical bases, have not been extensively used. Azzi's (1954) thermopluviometric diagram created wider interest which is used in agricultural evaluation effectivity of agricultural land use.

7.4 Climate diagram of Gaussen and Walter

Bagnouls and Gaussen's (1953) ombrothermic diagram was derived from the illustration of the monthly values of the xerothermic index where the months are depicted on the horizontal axis and the temperature and precipitation values on the vertical one in the ratio of 1:2. In this coordinate system by plotting the monthly mean temperature and precipitation values we get a temperature and precipitation curve which reflects the kind of climate, its warm, cold, humid and arid seasons, their length and intensity.

The ombrothermic diagram was improved by Walter (1955) on the basis of the T:P = 1:3 relation of Selyaninov's hydrothermic index incorporating in the diagram the sub-arid province already distinguished by Gaussen ($2T < P < T$) further the winter, frosty and frost-free periods with several ingenious graphic solutions and with the numerical depiction of the different extreme and mean values — a universal most illustrative climatic diagram was developed which can be used all over the world.

7.4.1 Advantages of the Gaussen–Walter's diagram

The advantages of this type of climate diagram over all the earlier and later formulae or diagrams are the following:

- Maximal information efficacy with minimal information (the lowest number and most readily available climatic elements) provides maximal bioclimate information.
- It shows the whole annual course of temperature and precipitation and beyond that it gives a most illustrative picture of the kind of climate.
- Its universal applicability is not constrained to certain climate zones or continents.
- As a consequence of this it serves as an objective source of comparison for estimating analogous climates or isoclimates.
- It provides an opportunity for working out a general climate system or climate classification with a biological approach.
- It may be a basis for further refinement of graphic or numerical methods for solving special spatial problems (Borhidi 1961, 1969).

7.5 Thornthwaite and Mather's climate diagram

Thornthwaite and Mather's (1955) graphic illustration experiment is worth mentioning which aims to express the arid season more exactly in that, instead of the T curve of the ombrothermic diagram it uses real (AE) and potential evapotranspiration (PE) values. In this case the area between PE and AE curves indicates the arid period, the phase between precipitation curves and AE curve the water utilization by the soil.

This rather logically conceived diagram which was further developed according to ecological viewpoints by Major (1963) — is wrought with numerous uncertainties. Such as:

a) The lack of an equation by which it would be possible, from the little data of PE, to estimate the whole global surface;

b) Uncertainty in the estimation of soil water capacity. At first Thornthwaite calculated that the soils generally are able to store 100 mm of precipitation, then later estimated the average storing capacity of soils at 300 mm. According to Major the water capacity of soils cannot be estimated over 100 mm, Russel and Hurlbut claim that in the USA it can be an average of 90 mm but it strongly depends on the quality of the soil;

c) The number of those registering stations is small which have all the measuring data necessary for estimation of AE and PE and this fact restricts the spread of this method.

7.6 Classification of the bioclimates

To establish and express the characteristics of climate as well as to compare objectively the climatic types it is aimed to set up a uniformly conceived climate classification.

7.6.1 Climate system of Köppen

The most well known to this day is the Köppen's climate system which was first published in 1918 and which appeared in a more detailed edition (Köppen and Geiger 1936) too. This climate classification is based on the annual and monthly mean values of temperature and precipitation and it considers the native vegetation to be the most exact expression of climatic effect. It recognizes that the efficiency of precipitation depends on the temperature. Its advantage is, namely, that it is flexible and that certain provinces are marked by letters and certain climatic types by letter formulae. This makes the climatic classification readily available for scrutiny and most manageable. It is a pity that the majority of ecologists apply the Köppen climate types automatically and only few have striven to further develop it from a bioclimatologic approach as Zólyomi (1958) did.

7.6.2 The Köppen–Trewartha climatic system

The Köppen system was updated by Trewartha (1954) with several alterations and in this version it has spread rapidly throughout America — as Trewartha says — on account of its didactive advantages. It appears however, that the Trewartha type of alteration — which proved to be useful with respect to North American climate classification — has been employed less in Europe than the original classification.

7.6.3 Thornthwaite's climate systems

Two climate classifications were created by Thornthwaite. The first (1931) is based on thermal efficiency and on the complex registering numbers of precipitation efficiency and it sets as its criterion of climate elements—that is criteria for limiting climatic areas—the plants and quality of the vegetation.

The second Thornthwaite's system of climate introduced the potential evapotranspiration (PE) concept. The climatic limits were drawn on the basis of the relation of potential evapotranspiration to precipitation, both data were derived from meteorological measurements. So in this system the vegetation is considered as the main diagnostic feature of the climatic types, but their limits were drawn exclusively on the basis of climatic data.

7.6.4 Ecological gaps in climate systems

Looking at it from the ecologist's viewpoint the main flaw in the mentioned climate systems is that the natural vegetation is considered as the criterion of climate—but without adequate knowledge of the vegetation types. All the mentioned categories of the climate system are somewhat over-generalized at least compared to the demands of plant ecologists and phytogeographers and this lack becomes more obvious as our knowledge of vegetation increases. It is generally known now, that in Köppen's–Thornthwaite's and Trewartha's savannah climate the zonal vegetation is tropical deciduous or dry forest, whereas the savannas are in reality edaphic or anthropic in this climate belt. On the other hand, if the climatologist tries to isolate the system from the vegetation as a phenetic starting point its categories easily become virtual. In the climate as a continuous accumulation of phenomena we may only draw limits of practical value if those are connected with some objectives segregated into phenetically different kinds of qualities.

The most suitable objective of this kind is the series of large zonal ecosystems in energy balance with the climate or the zonal vegetation representing them phenetically. The climate systems of practical adaptation have to incorporate this principle even if the climatic categoriės and zonal vegetation types do not coincide, their relationship sometimes is complex and apparently inconsistent. We will return to a discussion of the latter.

7.6.5 Importance of the bioclimatic system

It follows from the criticism of the mentioned climate systems that the demands of the ecologist could best be met by the climatic classification of a bioclimatological conception. Naturally the ombrothermic diagrams demand this too. It is unfortunate that in the othervise outstanding "Klimadiagram-Weltatlas" of Walter and Lieth (1964—68) the climate diagrams have been classified according to the Köppen system of categories, thereby, disregarding the conclusions of an ecological concept in the diagrams. According to our experience from the vegetation research aspects and demands of vegetation mapping, the most suitable climatic classification — at least in the tropical and subtropical belt — is the Gaussen bioclimatic system which has been published with Borhidi's original supplementation.

7.6.6 Gaussen's bioclimatic system

I Warm and moderately warm climates. The temperature curve throughout the year is above the horizontal axis.

1 Thermo-heremic or warm desert climatic belts: the number of dry months is 12. It is subdivided into the following regions:

1 *a* There is no rain all the year: real hot desert (e.g. Central Sahara, deserts of Egypt, South African deserts, Atacama desert).

1 *b* Rainy days in the "winter" short day period, transition to the Mediterranean climate (e.g. North Sahara, Arabian deserts).

1 *c* Rainy days in the summer, long daylight period; transition towards the monsoon and passat climates (South Sahara, Indian deserts, Mexican deserts)

1 *d* Rainy days with irregular distribution (e.g. Californian and Australian deserts).

2 Thermo-hemieremic or warm semi-desert climatic belt: the number of dry months is 9–11. The subregions are the following:

2 *a* The long daytime, summer period is dry: it occurs in the semi-desert belts bordering on the Mediterranean climatic areas (e.g. North Africa, Middle-East, California and South Australia.

2 *b* The short daytime "winter" season is dry: semi-desert in contact with tropical regions (e.g. South Sahara, South African, Indian, Mexican, North Australian semi-deserts)

2 *c* The dry period is not bound to a certain season or several dry seasons exist. They are mainly conditioned mesoclimatically in rain shadow belts or coastal semi-deserts (e.g. the Greater Antilles, Ethiopia).

3 Xerotheric warm climatic belt. The summer is dry, the temperature of the coldest month is above 0 °C. It may be distributed into two groups:

3 *M* Xerotheric Mediterranean or dry summer Mediterranean climates. The mean temperature of the coldest month ranges between 0–15 °C. It is widespread in southern Europe, North and South Africa, South and West Australia furthermore in California and certain parts of South America (Argentine, Chile). Its subtypes:

3 *a M* Long dry Mediterranean climate with 7–8 dry months

3 *b M* Dry Mediterranean climate with 5–6 dry months

3 *c M* Moderately dry Mediterranean climate with 3–4 dry months

3 *d M* Submediterranean climate with 1–2 dry months

3 *T* Xerotherotropical or summer dry tropical climates. The mean temperature of the coldest month is above 15 °C. The climatic types previously not discussed; for further explanation see point *I. 7.6.7.* Its subtypes:

3 *a T* Long summer dry tropical climate with 7–8 dry months.
3 *b T* Summer dry tropical climate with 3–4 dry months.
3 *c T* Moderately dry summer dry tropical climate with 3–4 dry months.
3 *d T* Subhumid summer dry tropical climate with 1–2 dry months.

4 Xerochimenic or winter dry tropical and subtropical belts. The climate is divided into a longer or shorter winter dry season and a rainy summer. It is a rather distributed tropical climate type. It is dominant on the latitudes 5–25° forming a more or less wide belt over all continents. It divides into two subgroups and several subtypes:

4 *Th* Thermoxerochimenic or winter dry hot climate: The mean temperature of the coldest month is above 15 °C. The subtypes according to the length of the dry period:

4 *a Th* Long dry subtype: the number of dry months is 7–8,
4 *b Th* Dry subtype: the number of dry months 5–6.
4 *c Th* Moderately dry subtype: the number of dry months 3–4.
4 *d Th* Subhumid subtype: number of dry months 1–2: transition towards the hot humid rainforest climate of the equatorial belt.

4 *Mes* Mesoxerochimenic or winter dry, moderately warm tropical and subtropical climates. The mean temperature of the coldest month is below 15 °C. It is widespread on the intermediate zone between the tropical and subtropical belts and in the central middle ranges and highlands lying inside the tropical continents (e.g. India, central and south China, Paraguay, north Argentine, Mexico).

The subtypes are similar to the previous ones:
4 *a Mes* long dry subtype; the number of dry months is 7–8;
4 *b Mes* dry subtype; number of dry months is 5–6;
4 *c Mes* moderately dry subtype; the number of dry months is 3—4;
4 *d Mes* subhumid subtype; the number of dry months is 1–2; transition towards the subtropical humid rainforest climate or to the tropical montane rainforest climate.

5 Bixeric or tropical climates with two dry periods: the year falls into four seasons, one winter and one summer dry period and two transitional rainy seasons. Usually the winter dry period is longer. It is a climate much less extensive compared to 4 and of importance forming in the coastal regions and montane rain shadow areas within the monsoon and passat climate belts. This occurs in north and east Mexico, east Africa, southern slopes of the Himalayas and in east Australia. Its subgroups and subtypes:

5 *Th* Thermobixeric or two dry seasonal tropical climates; the mean temperature of the coldest month is above 15 °C

5 *a Th* Long dry subtype, the number of months of the two dry periods is 7–8; transition towards the semi-desert climate (2 *c*);
5 *b Th* Dry subtype; the number of dry months is altogether 5–6;
5 *c Th* Moderately dry subtype; the number of dry months is 3–4;
5 *d Th* Subhumid subtype; with 1–2 dry months is a transition towards the tropical moist rain climate.

5 *Mes* Mesobixeric or subtropical climates with two dry seasons. The mean temperature of the coldest month is below 1 °C.

5 *a Mes* Very dry subtype; the number of dry months is altogether 7–8.

5 *b Mes* Dry subtype; with 5–6 dry months;

5 *c Mes* Moderately dry subtype with 3–4 dry months;

5 *d Mes* Subhumid subtype; with altogether 1–2 months of dry weather, transition to subtropical rainforests and humid moderate climates (7).

6 Thermaxeric or hot humid equatorial climatic belt. The number of dry months is zero. Climatic belt forming mainly in the basins and low montane regions in the vicinity of the equator; on the effect of warm sea currents it may develop further from the equator too (e.g. Central America, West Indies, Madagascar, North Vietnam, South-East Africa). Its subtypes:

6 *a* Euthermaxeric or hot humid lowland climate. The mean temperature of the coldest month is above 20 °C (valleys of the rivers Amazonas and Congo, Indonesia, Central America). Belt of tropical lowland rainforests.

6 *b* Hypothermaxeric or montane tropical rainforest climate. The coldest month ranges between 15–20 °C. Climate of tropical ranges and highlands between 1000–2500 m.

7 Mesaxeric or wet subtropical and humid moderate climatic belt: the number of dry months is zero. In contrast with the previous climatic belt the mean temperature of the coldest month is below 15 °C. Mainly warm temperate lowlands, subtropical montane regions and the high montane belts of the tropical ranges belong to this climate (e.g. South-east China and south Japan, New Zealand, south-east Australia, western Europe, the Pacific coasts of North America, Uruguay, East Argentina, south Chile, the southern slopes of the Himalayas, a large part of the Andes. Its subtypes:

7 *a* Eumesaxeric or subtropical humid climatic belt: the coldest month ranges between 10–15 °C. In subtropic and oceanic warm moderate lowlands, low and middle ranges and/or in the montane rainforest belt of tropical mountains, between 2000–3000 m.

7 *b* Hypomesaxeric or humid temperate and wet subtropical montane climate. The mean temperature of the coldest month ranges between 0–10 °C. In the tropical highlands this is the climate of the subalpine belt.

II Cold and moderately cold climates. The temperature curve assumed negative values in certain periods of the year.

8 Psychroeremic or cold desert climatic belt: the number of dry months 11–12. The highland deserts of Central Asia belong here (Tibet, Gobi). Its sub regions are the following:

8 *a* Precipitation may not occur for years

8 *b* There is no snow accumulation

8 *c* Small amount of snow

9 Psychrohemieremic or cold semi-desert climatic belt: The number of dry months is 9–10. Its occurrence in the temperate highlands and in their continental basins in rain shadow areas (Central Asian highlands and the Aralo-Caspian region, South Andes and the semi-deserts of the North American Great Basin).

10 Xerotheric cold or steppe climate belt: number of dry months 1–8. The subtypes are the following: Generally it is widespread in the internal part of the temperate continents, and in the higher montane belts of the Mediterranean and subtropic ranges. Its sub division is as follows:

10 *a* Long dry subtype 7–8 dry months, salt desert belt: thorny puna vegetation in the Andes, in the Atlas, the belt of sphaerical thorn bushes.

10 *b* Dry subtype with 5–6 dry months; dwarf shrub deserts, belt of *Artemisia* grasslands; in the Andes the belt of dry punas;

10 *c* Moderately dry subtype with 3–4 dry months, belt of dwarf grass steppes; in the Andes the belt of wet punas and alpine pastures;

10 *d* Slightly dry subtype with 1–2 dry months; subcontinental climate often with a submediterranean character. Belt of tall grass steppes and prairies; in the Andes, climate of the paramo belt.

11 Psychroaxeric or wet cold climatic belt: number of dry months: 0. The most widespread climatic belt which includes the Eurasian pine forests and tundras and the upper regions of the temperate highlands. Only the Andes and the alpine belt of the New Zealand mountains of the southern hemisphere belong here. According to the extent of the frosty period and the intensity of temperature fluctuation the following subdivisions may be discerned:

11 *a* Strongly cold subtype with more than 8 frosty months.

11 *b* Cold subtype with 7–8 frosty months. Further variations: oceanic (Oc) continental (Ct) hypercontinental (Hct) montane (Mt). Vegetation: subarctic needle-leaved forest belt.

11 *c* Moderately cold subtype with 4–6 frosty months. Vegetation: taiga belt. Variations similar to the previous: Oc, Ct, Hct and Mt.

11 *d* Slightly cold subtype with less than 4 frosty months. Continental broad-leaved forests and pine broad-leaved mixed forests.

III Ice climate — the tempereature curve throughout the year is negative.

12 Cryomeric or frost climate belt: the number of frosty months: 12. No plant life.

7.6.7 New classification of xerotheric climates

It became necessary to have a new classification of xerotheric climates because on the border of the north-east montane region of Cuba, at the northern margin and in the coastal region of Moa and Baracoa mountains we registered a climatic type which could not be identified in the Gaussen's bioclimatic system, in fact in other climatic systems either. This climatic type which I referred to previously, indicates a

Mediterranean—summer dry—feature in its precipitation while its temperature conditions unequivocally indicate a tropical climate. Accordingly we distinguish it as a xerotheric tropical or summer dry tropical climate type. Very similar climatic types are known in south India and the eastern coastal regions and the surrounding mountain slopes of Sri Lanka (Ceylon) (Meher-Homji 1963); furthermore in east Africa, Mauritius and Sao Thome, eastern slopes of the mountain regions of central Vietnam (Pócs, personal communication) but it is expected that this climatic type will be registered along the eastern coastline of Australia, in the mountains of East Mexico and other West Indian islands. It is more likely to occur where the bixeric climate comes in contact with montane wet tropical climate but as a consequence of the effect opposing the monsoon and/or passat wind system, the winter dry period disappears, while the dry summer period remains in a transitional area between the two climates. The formation of similar conditions can be expected mainly in the lower montane regions along the eastern tropical coastline of the continents and islands.

7.6.8 Bioclimatic map of the world

The phytogeographic geobotanical aspects of Gaussen's bioclimatic classification are discussed in detail by Meher-Homji (1963). In the same work a world bioclimate map of Bagnouls and Meher-Homiji is published in the scale of 1:50 million. Although this map contains some striking inaccuracies, of the climatological maps which have appeared so far, it fits the zonal vegetation type distribution best.

8 Cuban bioclimatology

The Cuban bioclimatic types were analyzed on 217 representative ombrothermic climate diagrams which had been selected from those of more than 1000 stations. From these we established the bioclimatic types of Cuba and their distribution (Borhidi 1974) which was illustrated on a map (See: Fig. 23). Further 11 bioclimate and vegetation profiles were prepared on the most characteristic regions of Cuba from geomorphological and geobotanical points of view demonstrating the rela-tionship of the relief to the bioclimate and vegetation over the whole length of the island.

We should note that the registering station names are repeated in some cases on the diagrams. The cause for this is, that the individual meteorological stations are indicated with the settlement name of the mapsheet of 1:50 000 scale and a serial number after it. So for example between Moa 756 and Moa 1290 there is a distance of 40 km, a 1000 m high ridge, and a difference of 400 m in altitude and consequently their bioclimates are entirely different.

Furthermore numerous stations—mainly in the montane regions—have only a precipitation data series; the corresponding temperature values were estimated from the data under point *3.3.1* with the help of appropriate temperature gradients. We should stress that the character and variability of the Cuban climate and the distribution of its types can be found correctly for the first time in this work. On

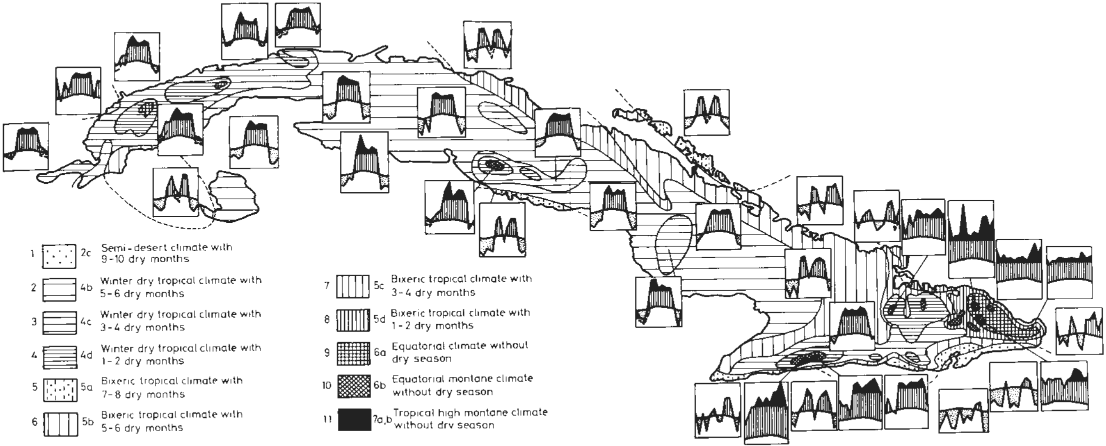


Fig. 23 The bioclimatic map of Cuba. (Borhidi 1974)

Köppen's climate map the whole island belongs to the savannah climate. According to Bagnouls and Meher-Homji's map it uniformly belongs to the thermaxeric tropical rainforest climate. Trewartha's map is less erroneous, because it lists West Cuba under the savannah climate, central and east Cuba under the tropical arid steppe belt. The least inaccuracy is contained in the Walter's "Klimadiagram Weltatlas" based on data from not more than 4 or 5 Cuban station.

8.1 Cuban bioclimate types

Taking the Gaussen's type of bioclimatic system discussed in the previous chapter as the basis, we can distinguish the following bioclimatic types:

8.1.1 Semi-desert climate

Thermohemieremic hot semi-desert climate without a characteristic rainfall distribution (**2 *c subtype***). It is the climate which prevails along the southern coastline of Oriente Province from Guantanamo basin to Punta Caleta which forms in the rain shadow of Sierra del Purial, Sierra de Imias and Cuchillas de Baracoa (Fig. 8.). The annual average temperature is 27—28 °C, the mean annual precipitation varies between 350—500 mm in a rather sporadic distribution. It is striking, that not a single month is completely free from precipitation, at the same time, a peak in May and October-November can be observed from which it follows that in the west the autumn peak may fall out and in the east the spring one. The prevailing vegetation on the sandy soils is a cactus scrub, in the rocky karstic surfaces it is a loose thorny thicket or a shrub forest. An analogous climate to this can be found in Africa, Somalia and in Asia, likewise in the rain shadow of the south Indian Tamil desert.

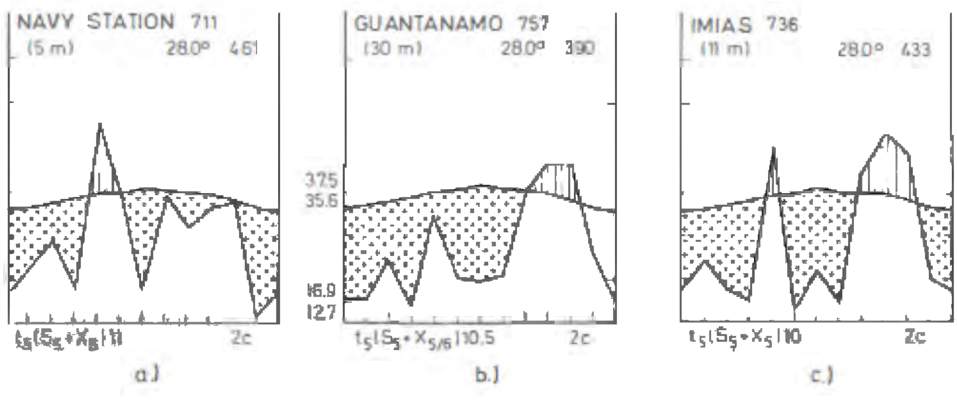


Fig. 8 Diagrams of the semi-desert climate (2c) in South-east-Oriente: a) Navy Station of Guantanamo 711: b) Guantanamo 757 and c) Imias 736

8.1.2 Xerotherotropic or summer dry tropical climate

This appears in the north eastern part of Oriente province, the climate type occurring in the northern margin and coastal belt of the Moa and Baracoa ranges. The dry season generally lasts from April to the end of August which in certain areas and in certain years has been cut into two by a slight rain peak in May. Not in frequently there is a slight February dry period. The annual precipitation ranges between 950—1500 mm. In these areas in Cuba on limestone evergreen shrub woodlands evergreen microphyllous or semi-deciduous forests, on the latosols pine forests prevail while in east Africa or South-East Asia dry evergreen forests and semi-deciduous forests can be found.

Subtypes

3 *b* *T* Summer dry tropical climate with 5—6 dry months. Medium subtype (Fig. 9). In the north-east coastline of Oriente and eastern peak cover smaller areas, the climate type has annual precipitation of 900—1000 mm and is intensively arid over longer period. The zonal vegetation comprises serpentine evergreen shrub woodlands, latosol pine forests, limestone semi-deciduous forests, perhaps deciduous dry forest.

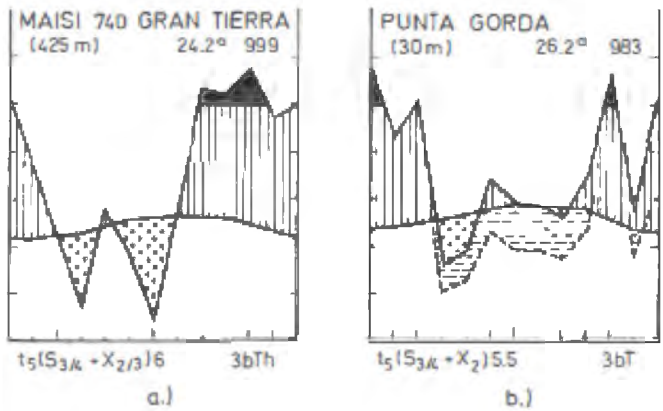
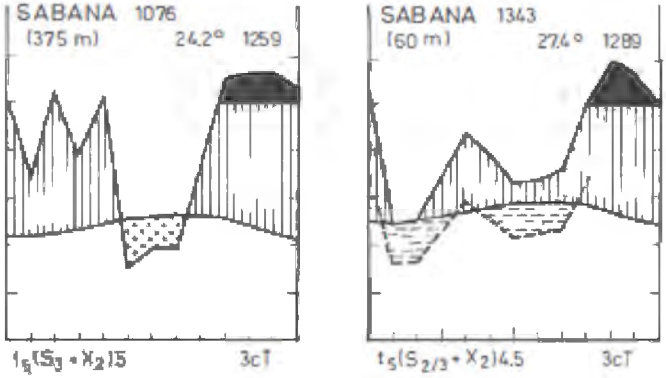


Fig. 9 Diagrams of the xerotherotropical climate, medium subtype (3bT) with 5—6 dry months, in north-east-Oriente: a) Gran Tierra—Maisi 740 and b) Punta Gorda

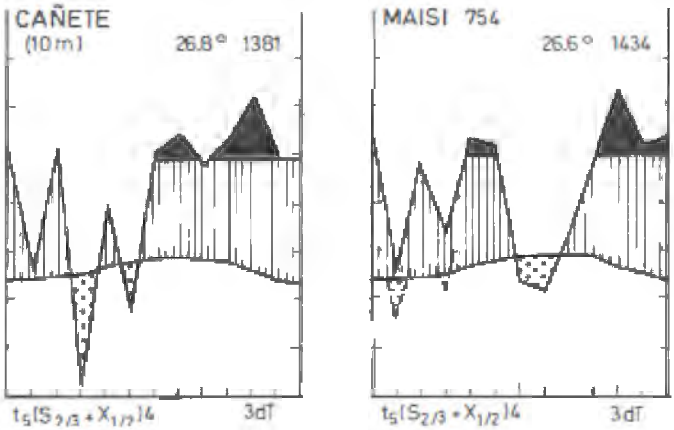
3 *c* *T* Summer dry tropical climate with 3—4 dry months. Moderate subtype (Fig. 10). It is to be found between Baracoa and Maisi over a small region of the Yumuri delta. The annual precipitation ranges between 1100 and 1300 mm. Zonal vegetation is a semi-deciduous forest.

3 *d* *T* Summer dry tropical climate with 1—2 dry months. Subhumid subtype (Fig. 11). It occurs in small patches alternating with the previous types. The zonal vegetation is seasonal evergreen forest.



a.) b.)

Fig. 10 Diagrams of the xerotherotropical climate, moderate subtype (3cT) with 3—4 dry months, in north-east-Oriente: a) Sabana 1076 and b) Sabana 1343



a.) b.)

Fig. 11 Diagrams of xerotherotropical climate, subhumid subtype (3dT), with 1—2 dry months, in North-east-Oriente: a) Cañete and b) Maisi 754

8.1.3 Xerochimenic winter dry tropical climate

It is the most common climate in Cuba; it prevails for the most part from West and Central Cuba from Cabo San Antonio to the Cauto lowland as well as Isla de Pinos, in fact, within the montane regions of Oriente, in Sierra Maestra, Sierra de Nipe, and Sierra de Cristal for the most part with the exception of higher belts. The annual mean temperature varied between 20—27 °C, the annual mean precipitation is between 800—1800 mm, it may rise exceptionally to 2200 mm. A characteristic feature of precipitation distribution in Cuba is that due to the effect of the sea, the dry season is also moderately rainy similar to other areas of the Caribbean region (Mexico, Venezuela) and is not extremely arid as in the classical regions of

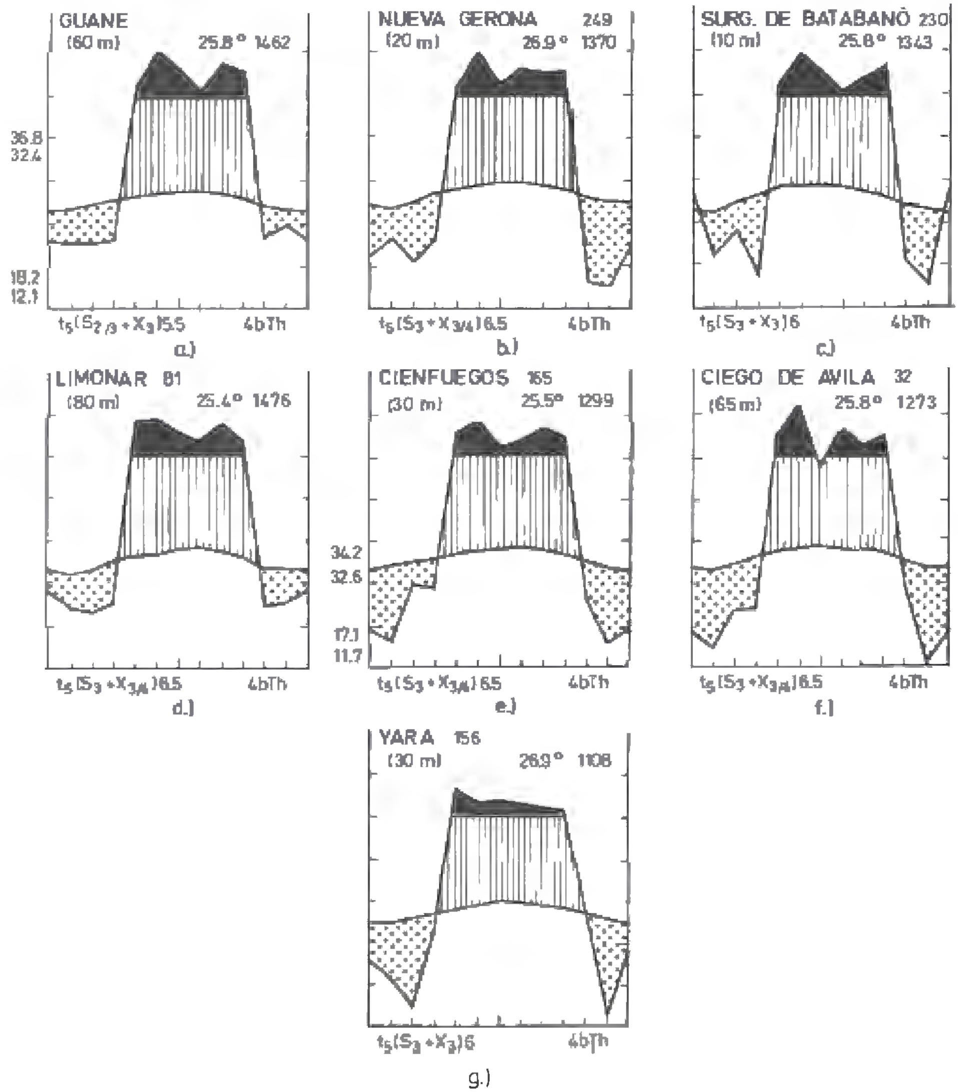


Fig. 12 Diagrams of the xerochimenic tropical climate, medium subtype (4bTh) with 5—6 dry months in the provinces: a) Pinar del Rio (Guane); b) Isle of Pines (Nueva Gerona 249); c) Habana (Surgidero de Batabanó 230); d) Matanzas (Limonar 81); e) Las Villas (Cienfuegos 165); f) Camagüey (Ciego de Avila 32) and g) Oriente (Yara 156)

monsoon climates (East Africa, India). Probably this is one of the reasons why the deciduous tropical forests are missing from the zonal vegetation of the island. The other reason may be that the driest subtype of this climate (4 a) does not occur in Cuba. This climatic belt — with the exception of the mountains — includes mostly agricultural areas and cultivated lands, extensive savannas with palms and it may be attributed to this that the view has emerged among geographers and climatologists as among pedologists that in Cuba there is a savanna climate. We shall return to this question later at greater depth. The xerochimenic climatic belt according to the length of dry seasons is divided into the following.

Subtypes

4 *b Th* Winter dry tropical climate 5—6 dry months. Medium subtype (Fig. 12).

This includes the southern part of the Guanahacabibes peninsula and almost the whole of Isla de Pinos, furthermore, the southern coastal region of Pinar del Rio and Habana provinces, the whole Matanzas province, Camagüey and West Oriente, the lowland and colline regions of the provinces Las Villas, with the exception of the northern coastal region. The annual average temperature is 24.5—27 °C, the annual precipitation is 750—1700 mm. The zonal vegetation is semi-deciduous tropical forest and on exceptionally good soils, seasonal evergreen forest. For sugar cane production it is a very appropriate climate.

4 *c Th* Winter dry tropical climate with 3—4 dry months. Temperate subtype (Fig. 13). This climatic type is to be found in West Cuba and in the lower altitudes of the mountains, so the western part of the Guanahacabibes peninsula and the central and northern part of the Pinar del Rio and Habana provinces belong here with the exception of the hilly regions; in Las Villas, the Santa Clara-hills, the Escambray mountains to about 500 m and the eastern part of the Sierra de Jatibonico, south-west part of Camagüey, and in the Oriente Sierra Maestra to about 600—800 m; Valle Central as well as Sierra de Nipe and Sierra de Cristal. The mean annual temperature ranges between 20—26.5 °C, the annual precipitation of 900—1900 mm, in certain montane regions 2100—2300 mm. The zonal vegetation is semi-deciduous forest or seasonal evergreen forest.

4 *d Th* Winter dry tropical climate with 1—2 dry months. Subhumid subtype (Fig. 14). It is a climate which dominates primarily in the middle ranges and surroundings, e.g. in the Sierra de los Organos and Sierra del Rosario, the western part of the Habana-Matanzas hills the serpentine areas of Campo Florido, the "mogotes" of Jaruco, both members of Sierra de Guamuhaya, upwards from 500 m; in Oriente province Sierra Maestra between 800—1400 m (such as the Turquino-Bayamesa group, the Loma del Gato in the Sierra del Cobre and the Gran Piedra) as well as Sierra de Nipe and Sierra de Cristal to 600—700 m. The annual mean temperature is 18—25 (to 26) °C the annual rainfall is 1100—2400 mm. The zonal vegetation types are seasonal evergreen forests, dry submontane and montane rainforests, wet montane rainforests.

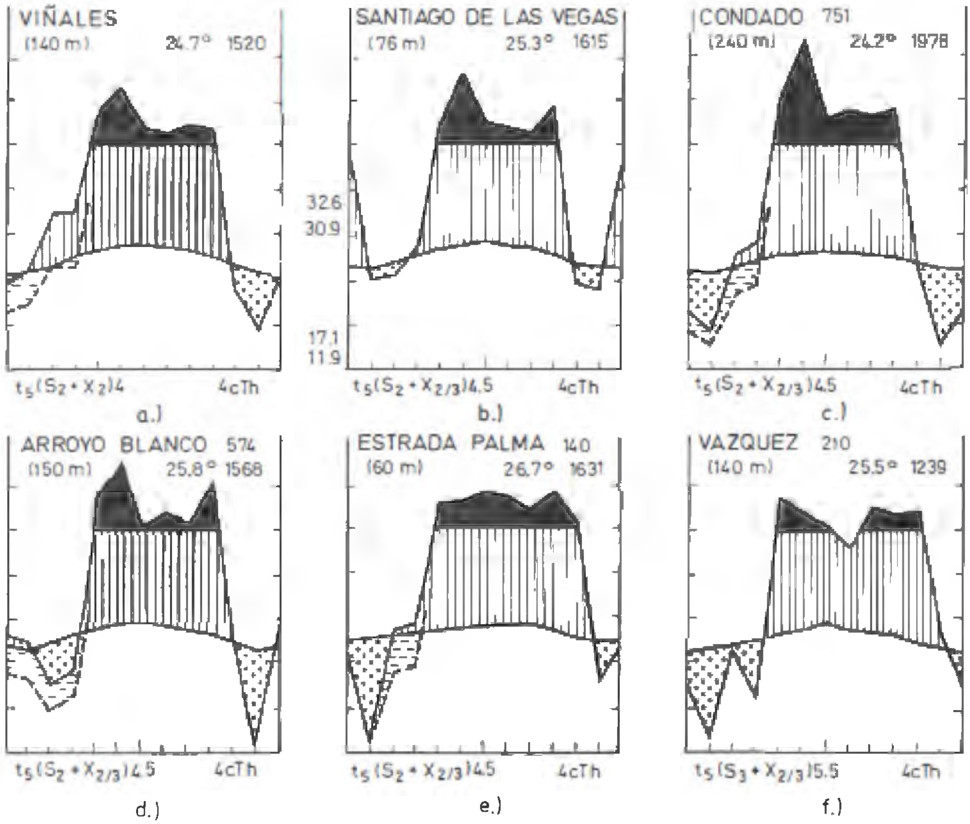


Fig. 13 Diagrams of the xerochimenic climate, moderate subtype (4cTh) with 3—4 dry months in the provinces: a) Pinar del Rio (Viñales); b) Habana (Santiago de Las Vegas); c) Las Villas (Condado 751); d) Camagüey (Arroyo Blanco 574) and e—f) Oriente (Estrada Palma 140 and Vazquez 210)

8.1.4 Thermobixeric tropical climate, with two dry periods

This climatic type is represented over a relatively large area in Cuba especially if we consider that this climatic type compared to the whole area of the earth is the least widespread. The northern coastline of Central and East Cuba belong here, the northern and eastern part of Cauto lowland; along the southern coastline, the eastern part of the isthmus of Guanahacabibes with the south-western part of Isla de Pinos, furthermore the foothill regions of the Sierra de Escambray and of the Oriente mountain ranges. This climate along the northern coastlines comes about macroclimatically as a consequence of the intensified activity of the west Atlantic anti-cyclone in summer, while on the southern coasts it forms mesoclimatically in the rain shadow of the mountains. The vegetation adapts to the two dry periods in different ways in many respects more than to the winter dry monsoon and passat climates. Besides this, the time span of the arid period has to be evaluated differently than in the case of one dry season climate. Both aspects are discussed in

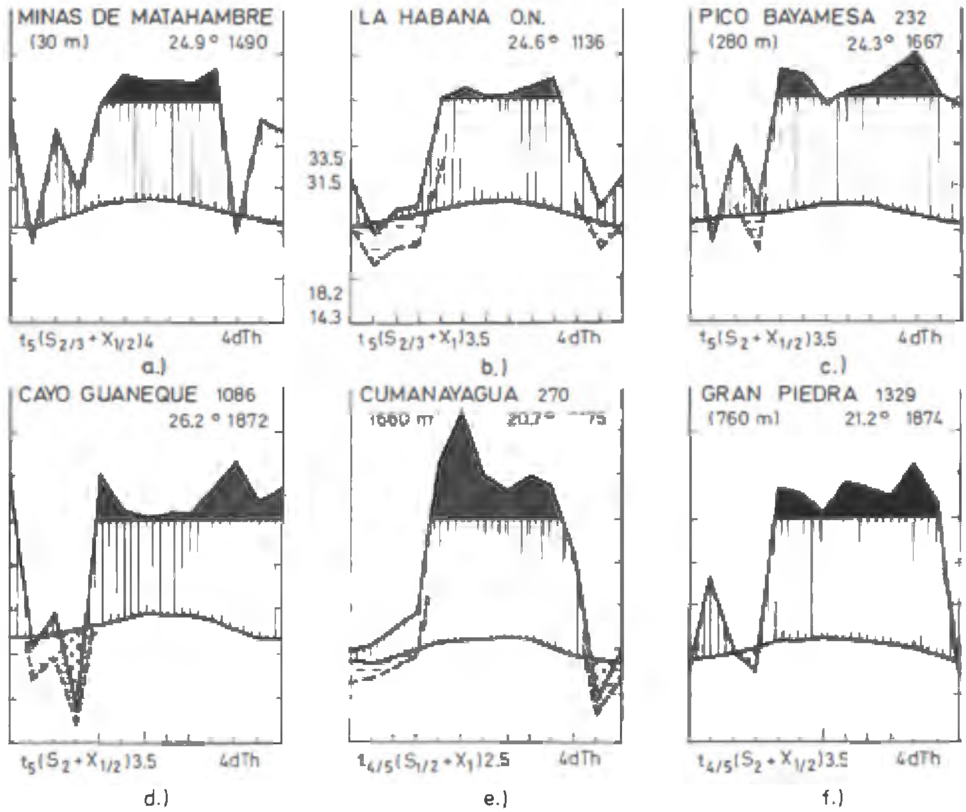


Fig. 14 Diagrams of the xerochimenic climate, subhumid subtype (4dTh) with 1—2 dry months in the lowland—colline belt of the provinces: a) Pinar del Rio (Minas de Matahambre); b) Habana (National Observatory of Habana) and c—d) Oriente (Pico Bayamesa 232 and Cayo Guaneque 1086) and in the submontane belt of e) Las Villas (Cumanayagua 270) and f) Oriente (Gran Piedra 1329)

depth in *9. 1.* The annual mean temperature ranges between 24.5—27.5 °C, the annual precipitation varies on an average between 550—1800 mm. On the basis of the total length of dry periods the following can be distinguished:

Subtypes

5 a Th Extremely dry bixeric climate with 7—8 dry months. Accentuated subtype (Fig. 15).

It formed on the south coastal region of Las Villas province in the rain shadow of Escambray mountains, on the north Camagüey islands, further on, the southern slopes of Sierra Maestra and in the Guanatanamo basin and east of it on the southern promontories of Sierra de Puriales. The latter two areas are in transition towards the semi-desert belt. In these areas the annual mean temperature is between 25.5—28.0 °C, the annual precipitation average is between 550—750 mm.

The zonal vegetation is small-leaved semi-evergreen or evergreen thorny shrub woodlands and succulent rich deciduous dry forests.

5 b Th Dry bixeric climate with 5—6 dry months. Medium subtype (Fig. 16).

This occurs in the eastern part of the isthmus of Guanahacabibes, in western Cuba, and in the south western part of Isla de Pinos, further in the northern part of Camagüey and Oriente provinces, in the eastern and southern part of Cauto lowland progressing on the southern slopes of the montane regions of Oriente and turning northwards on the plain of Maisi forming a connecting ring to Baracoa. In fact it may be found further to the west in many little isolated patches (e.g. Cayo Mambi, these are not depicted on the map on account of the scale). The annual average mean temperature ranges between 24.5—27.5 °C, the annual precipitation is 740—1150 mm. In the zones in transition towards the passat winter dry climate — mainly in West and Central Cuba — in summer, instead of the dry period, only a semi-arid one occurs. In other cases especially in the regions in contact with the wet montane climate — the winter dry period passes towards spring, in fact it may

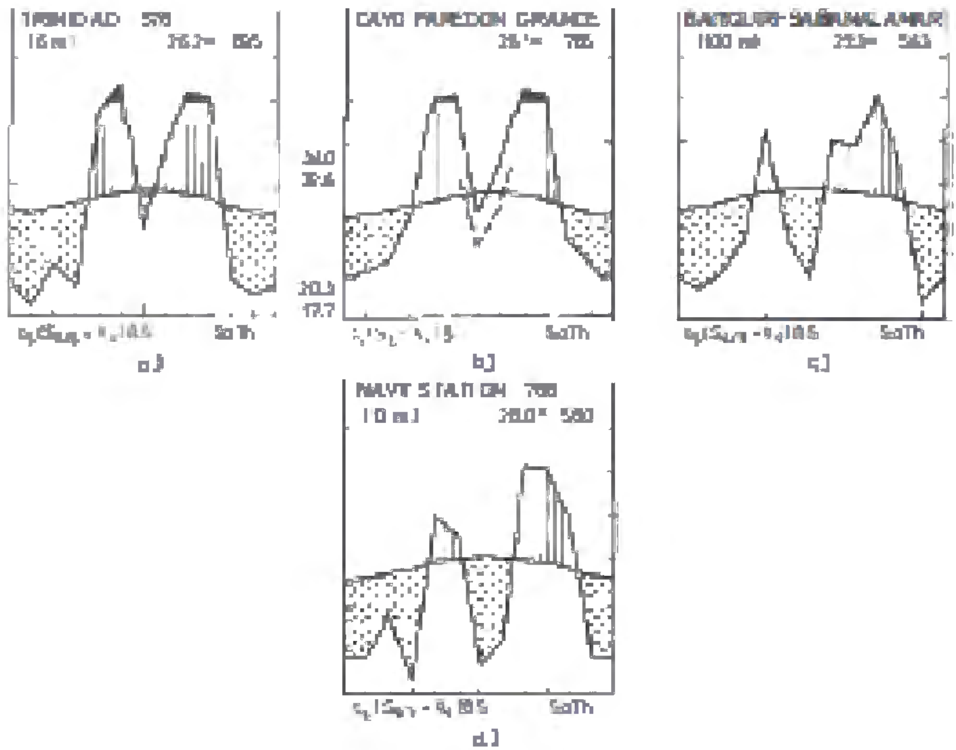


Fig. 15 Diagrams of the bixeric tropical climate, extreme subtype (5aTh) with 7—8 dry months, in the provinces: a) Las Villas (Trinidad 578); b) Camagüey (Cayo Paredon Grande) and c—d) South-east-Oriente (Baitiquiri-Sabanalamar and Navy Station of Guantanamo 788)

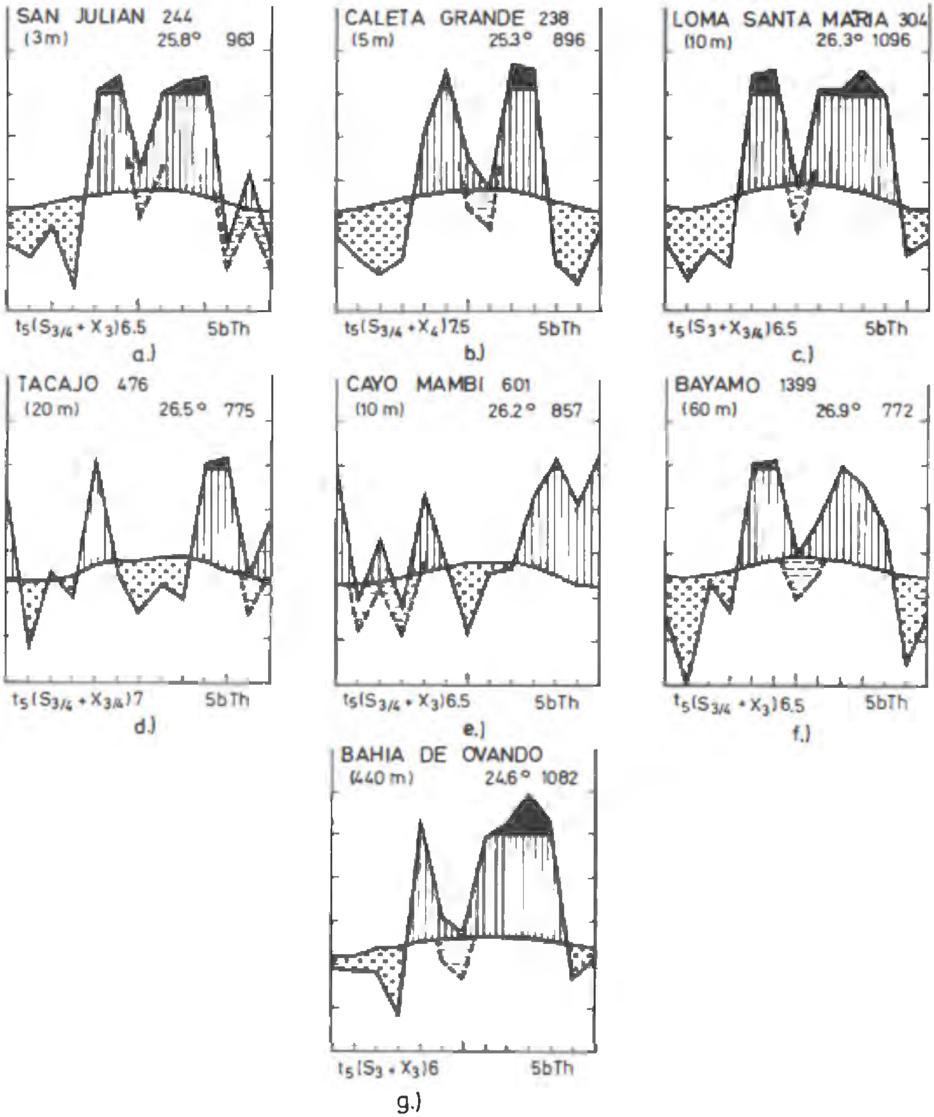


Fig. 16 Diagrams of the bixeric tropical climate, medium subtype (5bTh) with 5–6 dry months, in the provinces: a) Pinar del Rio (San Julian 244); b) Isle of Pines (Caleta Grande 238); c) Camagüey (Loma Santa Maria 304) and d–g) Oriente (Tacajo 476, Cayo Mambi 601, Bayamo 1399 and Bahia de Ovando)

merge with the summer one as a consequence of which a precipitation distribution similar to that of the Mediterranean climate is formed. Zonal vegetation types: small-leaved dry evergreen shrub woodland or forest, microphyllous semi-deciduous forest.

5 c Th Moderately dry bixeric climate with 3—4 dry months. Moderate subtype (Fig. 17).

This occurs in Las Villas province and the northern shores of West Camagüey, in Oriente, in the eastern part of the Mariabon group, further in Sierra de Nipe and in the northern promontory of Sierra de Cristal, in fact, in smaller patches in the northern and southern ridges of the montane regions of Moa and Baracoa. In the

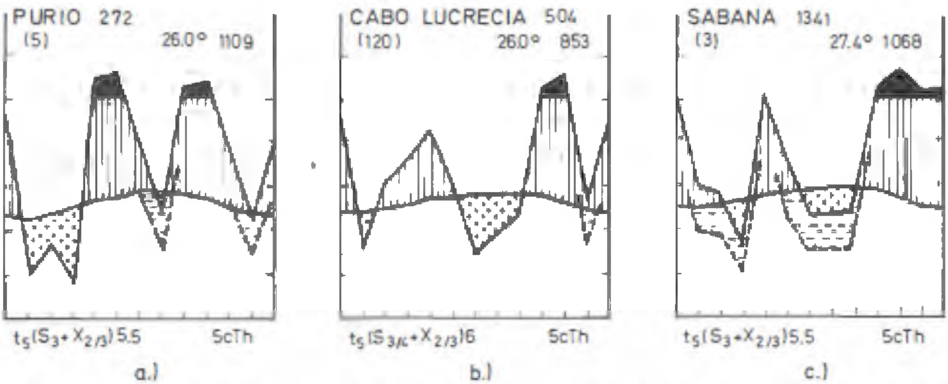


Fig. 17 Diagrams of the bixeric tropical climate, moderate subtype (5cTh) with 3—4 dry months, in the provinces: a) Las Villas (Purio 272) and b—c) Oriente (Cabo Lucrecia 504 and Sabana 1341)

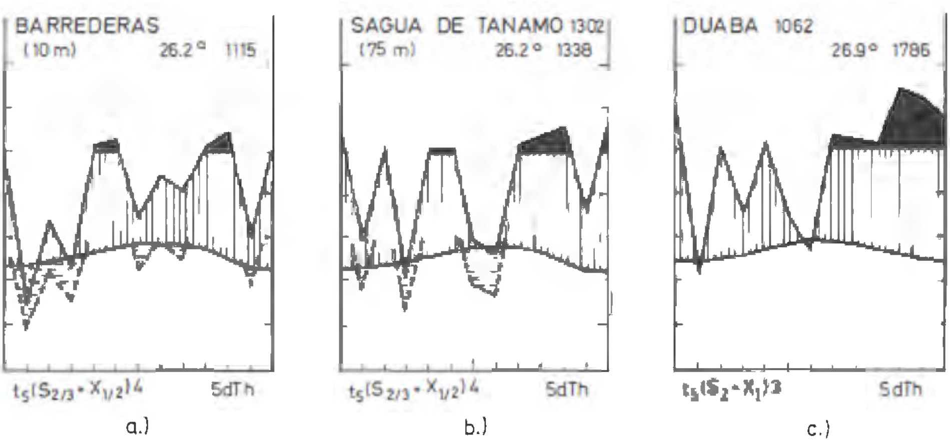


Fig. 18 Diagrams of the bixeric tropical climate, subhumid subtype (5dTh) with 1—2 dry months in Oriente (a), Barrederas b), Sagua de Tánamo 1302 and c), Duaba 1062)

latter sites it occurs as a version in transition towards the xerotherotropic climate **(3 *bT*, 3 *cT*)** (Fig. 49). The annual mean temperature ranges between 23—27.5 °C, the annual precipitation is 850—1350 mm. The zonal vegetation is semi-deciduous forest, seasonal evergreen tropical forest and dry evergreen forest.

5 d Th Subhumid bixeric climate with 1—2 dry months. Subhumid subtype (Fig. 18).

This occurs exclusively in the north-east coastal region of Oriente at the border of the Moa—Toa—Baracoa ranges. Annual average temperature varies between 23—27 °C, annual precipitation average is between 110—1800 mm. Zonal vegetation: semi-evergreen forest, seasonal evergreen forest, submontane rainforest.

8.1.5 Axeric, tropical climates wet throughout the year

In Cuba, in relatively small areas appear axeric, moist tropical climates too. These are the following:

6 *a* Euthermaxeric — equatorial climate, hot and wet throughout the year (Fig. 19).

Climate type without a dry period occurring in the middle ranges up to 500—600 m. This occurs in two smaller patches in West Cuba on the eastern parts of the Sierra de los Organos and Sierra del Rosario. More extensively it can be found in the eastern part of Oriente province in the Moa—Toa—Baracoa ranges. The annual mean temperature is 23—27.5 °C, the annual rainfall ranges between 1600—3200 mm, exceptionally to 5000 mm. The zonal vegetation type: submontane tropical rainforest.

6 *b* Hypothermaxeric climate or wet subequatorial climate or subtropic and tropical submontane climate without dry season (Fig. 20).

This climate type in Cuba occurs only in the montane belt generally between 600—1400 m altitude, e.g. in Sierra de Escambray, in the central part of Sierra Maestra and in the plateaus of Sierra de Nipe and Loma Mensura on the main ridge of Sierra del Cristal, in Moa, on the highplain of Cupeyal, on the Palenque, Pico Galáno, and in the plateaus of El Toldo and Alto de la Iberia in fact, in smaller local patches probably at Sierra del Puriales and in the area of Cuchillas de Baracoa. The annual mean temperature ranges between 18.5—23 °C, the mean temperature of the coldest month ranges between 15—20 °C, the annual rainfall is between 1400—2200 mm in fairly even distribution. The zonal vegetation: montane rainforest, on lateritic soil dry montane rainforest.

8.1.6 Tropical montane climate, wet throughout the year

At appropriate altitudinal belts of the tropical highlands a climate develops which resembles the oceanic warm temperate climate. It is characteristic that the daily fluctuation of the temperature essentially surpasses the seasonal one. This montane belt is appropriately coined in the highlands of Latin American, 'Tierra templada' that is temperate belt. In Cuba its two climatic subtypes can be found:

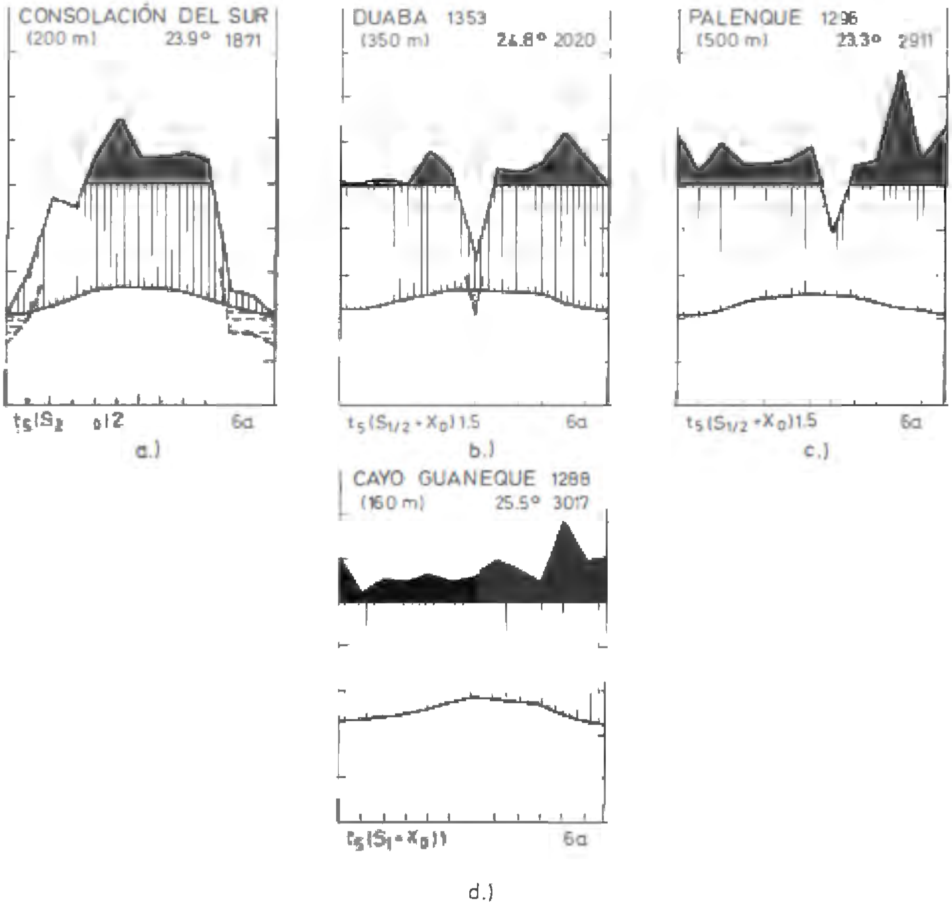


Fig. 19 Diagrams of the euthermaxeric — humid tropical climate without dry season (6a) in the provinces: a) Pinar del Rio (Consolación del Sur) and b—d), Oriente (Duaba 1353, Palenque 1296 and Cayo Guaneque 1288)

Subtypes

7 *a* Eumesaxeric, or wet warm temperate climate or tropical montane wet climate (Fig. 21). In Cuba, it develops only in the central part of Sierra Maestra at 1200—1800 m height. The annual mean temperature ranges between 10—15 °C, that of the coldest month is above 10 °C; the annual precipitation is above 2000 mm. Zonal vegetation is montane rainforest, elfin forest or mossy forest.

7 *b* Hypomesaxeric, or wet cool temperate climate, or wet tropical high montane climate (Fig. 22) This occurs exclusively in the Turquino group above 1800 m. The annual mean temperature is between 10—12 °C, the mean temperature of the

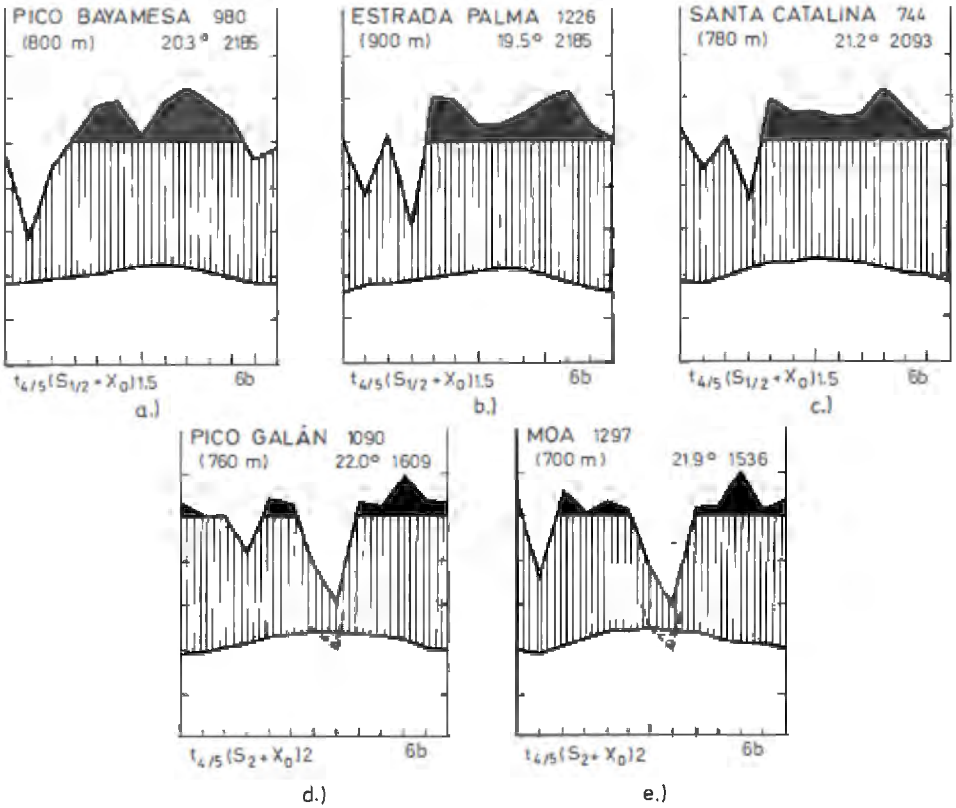


Fig. 20 Diagrams of the hypothermaxeric — submontane humid tropical — climate without dry season (6b) in the mountain ranges of Oriente province a) Pico Bayamesa 980 b), Estrada Palma 1226 c), Santa Catalina 744 d), Pico Galán 1090 and e) Moa 1297

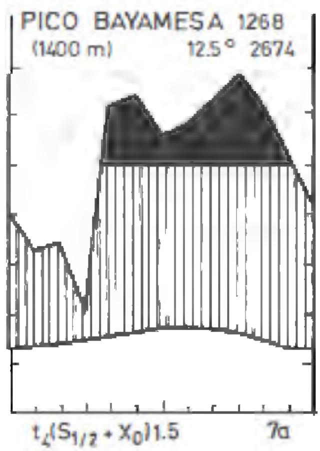


Fig. 21 Diagram of the eumesaxeric — montane humid tropical — climate without dry season (7a) on the summits of the Sierra Maestra range (Pico Bayamesa 1268)

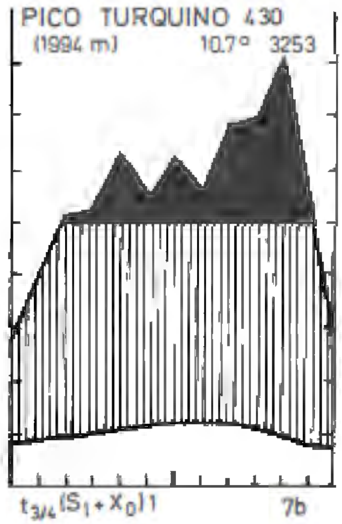


Fig. 22 Diagram of the hypomesaxeric—high montane tropical humid—climate without dry season (7b) on the highest summit of the Sierra Maestra range (Pico Turquino 430)

coldest month is between 0—10 °C. Theoretically early morning frosts are possible but they have not been observed in Cuba. The annual rainfall is above 2500 mm. Zonal vegetation type; cloud or elfin forest, evergreen subalpine shrub woodland.

8.2 Bioclimatic map of Cuba

The geographical distribution of the bioclimatic types can best be achieved on bioclimatic maps and on different vertical profiles. The bioclimatic map based on the above mentioned research (Fig. 23) may be considered to be the first attempt to give a realistic appraisal of the bioclimate of Cuba in the given scale (Borhidi 1974).

8.2.1 Bioclimatic types based on a geographical approach

It may be clearly discerned from the bioclimatic map of Cuba that in this country — including Isla de Pinos — there is largely a winter dry passat climate represented with dry and moderately dry subtypes ***4 b Th*** and ***4 c Th*** which is mostly characteristic of the lowlands of Matanzas and Camagüey provinces. The most uniform is the climate of the Matanzas province where only one of 13 climatic types of Cuba occur. Two factors create a variability already described in this climatic uniformity:

a) The anti-cyclone effect of the west Atlantic, which creates the bixeric climate of the northern shores, in fact it is responsible for the xerotheric climate of the Moa-Baracoa shores.

b) The mountains which on account of their height cause tropical rainforest climates ***6 a, 6 b*** and wet montane temperate climates ***7 a, 7 b*** on the other hand by their shading effect they have a decisive role in creating the extremely dry climates **2 *c*, 5 *a***.

As a consequence of the special geomorphology of the region and the varied soils, the zonal vegetation can be found only in small patches and in their place edaphically determined azonal or subclimax rocky forest and paraclimax pine woodlands prevail, as well as, edaphic and secondary savannas.

8.2.2 Bioclimatic and orographic diversity

The climatic variability of Cuba, in connection with the conditions of the relief, is best shown by three fairly remote and isolated areas: (1) western Cuba and the province of Pinar del Rio (in the Sierra de los Organos and Sierra del Rosario region), (2) central Cuba in the province of Las Villas (along the Sierra de Escambray) and (3) eastern Cuba, in the eastern part of Oriente (the areas of Sierra Maestra and the Sagua-Baracoa Massif). In addition to the geohistorical and petrographical factors, this climatic variability is also significant in affecting the development of high floristic abundance and diverse vegetation. Of these three regions, the Sagua-Baracoa Massif has the most varied climate; 13 climatic types of the 15 in Cuba occur here. Within the 56 km distance between Imias and Cañete, seven climatic types are found (see bioclimatic profile Fig. 34) and the semi-desert belt and the submontane rainforests are only 15 km apart. It is noted that this climatic and vegetational diversity is not unique in the Antilles. Similar phenomena are reported from eastern Jamaica (Asprey and Robbins 1953) and western Hispaniola (Ciferri 1936) under similar atmospheric and orographic conditions.

The dry period of passat climates is absent only from the mountainous areas, showing the particular mesoclimatic significance of the mountains. Consequently there is no tropical rainforest climate in the plains of Cuba, and rainforests occur as

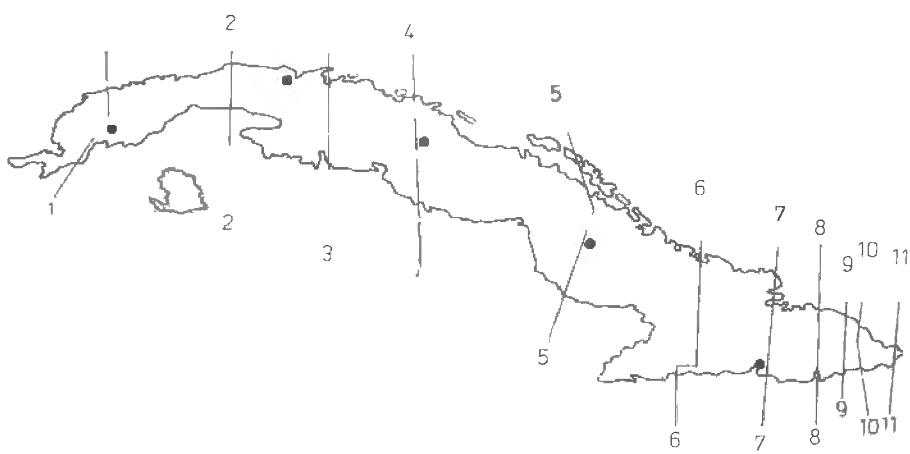


Fig. 24 Geographic localization of the complex bioclimate and vegetation transects in Cuba

zonal vegetation types of the submontane, montane and cloudy regions at various elevations above-sea-level. Upon the influence of mountains, too, the dry period of seasonal climates is longer in the southern slopes and extremely dry mesoclimatic zones develop, resulting in sclerophyllous and thorn shrubwoods and semi-desert vegetation with cacti.

8.3 The bioclimatic and vegetation profiles of Cuba

These profiles provide a good illustration of the spatial alterations of bioclimate and their relationships with relief and vegetation types. 11 bioclimatic and vegetation profiles have been prepared for Cuba. These are selected to represent all the regions of Cuba which have characteristic relief and vegetation (Fig. 24).

8.3.1 Bioclimatic and vegetation transect through the province of Pinar del Rio

The transect gives the climate and vegetation of Pinar del Rio, from Sierra de los Organos towards the Guanahacabibes Peninsula in the southwest. It is typical that due to the cold winter fronts the dry winter season is shortened, or divided into two short and weak periods by the more rain y January. This is in effect, up to the middle of the island, and disappears only in the southern plain. It is seen that the rainy winds getting over the northern range of Sierra de los Organos do not lose all the precipitation, and the southern range behind the drier central valley and the slatey outcrops in its foreground get more rain. In the alternating 5 climatic types the occurrence of 4 vegetation types may be expected: ***4 b Th—5 b Th:*** dry evergreen forests, ***4 b Th—4 c Th:*** semi-deciduous forests, ***4 d Th:*** seasonal evergreen rainforests, and **6 *a:*** true tropical rainforests.

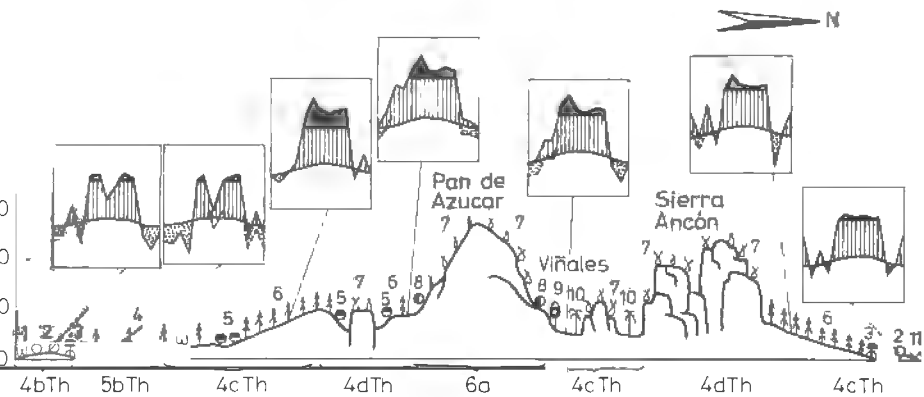


Fig. 25 Bioclimate and vegetation transect in the province of Pinar del Rio. 1. Sandy seashore, 2. Dry littoral forest, 3. Mangrove forest, 4. Pinewoodland on sand, 5. Evergreen oak-forest, 6. Pine forest on slatey sandstone, 7. Mogote-complex, 8. Semi-deciduous forest, 9. Seasonal evergreen forest, 10. Roystonea-grassland, 11. Littoral rock pavement

8.3.2 Bioclimatic and vegetation transects in the lowlands of Central Cuba

In the province of Havanna (Fig. 26) due to the slight relief, the climatic variability drops further, which is accompanied here by an even more geologic and pedologic uniformity. This climatic and edaphic conformity reaches its peak in Matanzas Province where an only climatic type dominates over the whole breadth of the island (Fig. 27). In both profiles it can be observed that there is a more even distribution of precipitation along the northern coastal region and a minimal rise in precipitation. According to what has been said about Camagüey Province (Fig. 28) the east Cuban lowland climate does not differ essentially from that of the west Cuban lowland. The only deviation from this is provided by the bixeric climatic types developing along the northern coastline which by the disappearing of the summer dry period, pass to a dry winter seasonal climate. The climax vegetation of these lowlands is rather uniform; semi-deciduous tropical forests are predominant

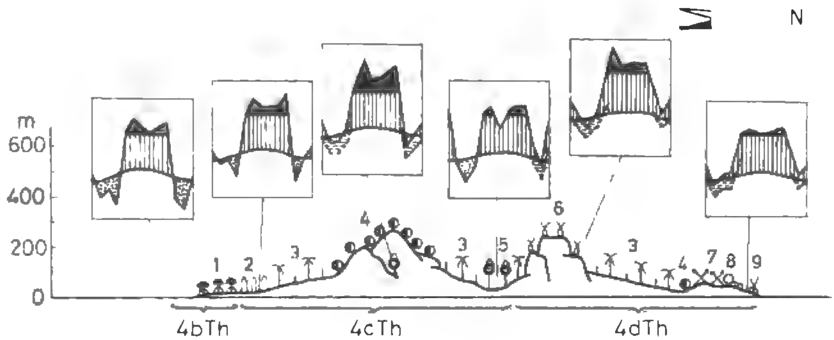


Fig. 26 Bioclimate and vegetation transect in the province of Havanna. 1. Mangrove forest, 2. Alluvial and swamp forest, 3. Roystonea grassland, 4. Semi-deciduous forest, 5. Seasonal evergreen forest, 6. Mogote-complex, 7. Lowland serpentine scrub-woodland, 8. Dry littoral limestone forest, 9. Littoral rock pavement

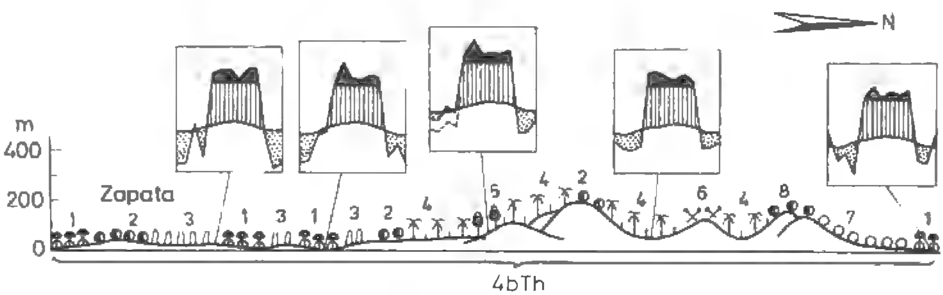


Fig. 27 Bioclimate and vegetation transect in the province of Matanzas. 1. Mangrove forest, 2. Semi-deciduous forest, 3. Swamp forest, 4. Roystonea grassland, 5. Seasonal evergreen forest, 6. Lowland serpentine scrubwoodland, 7. Dry littoral limestone forest

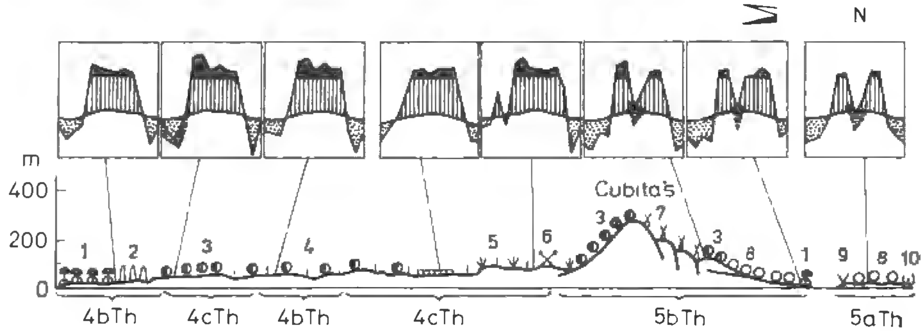


Fig. 28 Bioclimate and vegetation transect in the province of Camagüey. 1. Mangrove forest, 2. Alluvial forest, 3. Semi-deciduous forest, 4. Broad-leaved wooded grassland, 5. Low palm grassland, 6. Lowland serpentine scrub-woodland, 7. Mogote-complex, 8. Dry littoral limestone forest, 9. Littoral rock pavement, 10. Sandy seashore

which on more fertile soils (e.g. Matanzas clay) are substituted by seasonal evergreen rainforests. In the bixeric climatic belts dry evergreen forests and shrub forests are dominant.

8.3.3 Bioclimatic and vegetation transect through the Escambray mountains in the central provinces

The most varied region of western and central Cuba from orographic and climatic points of view is to be found in the central provinces (former Las Villas province, Fig. 29). On the northern coastal region in a narrow band, the bixeric climate has a relatively smaller effect on the vegetation in the wide mangrove belt and the flat swamp areas. The northern ranges of Villa Clara, the serpentine hills of Santa Clara and the northern forehills of Sierra de Escambray are under the influence of the winter dry seasonal climate where the variability of the vegetation is conditioned by the mosaic-like pattern of the basic rock. The succession progresses on limestone to a semi-deciduous forest climax, on the serpentine to the dry evergreen shrubland. On the northern slopes of the Escambray mountains the belt of the seasonal evergreen forests is developed which reaches up to about 800—900 m height since beside the notable rise of annual precipitation (2000—2300 mm average) there is a short winter dry period. This drought of 1—2 months, only stops at the highest point of Escambray where a relatively narrow (100—250 m wide) montane rainforest belt forms, and on the northern slopes and valleys it descends extrazonally. Southwards from the central plateau of Escambray (Topes de Collantes) the rainfall amount suddenly drops and an increasing dry winter period develops as a consequence of which, the evergreen shrub forests, dry evergreen forests and semi-deciduous forests extend upwards to the montane rainforest belt on the southern slopes. In the southern lowland of the mountain, a bixeric zone with 8—9 dry months is formed which favours the formation of sclerophyllous and thorny evergreen thickets.

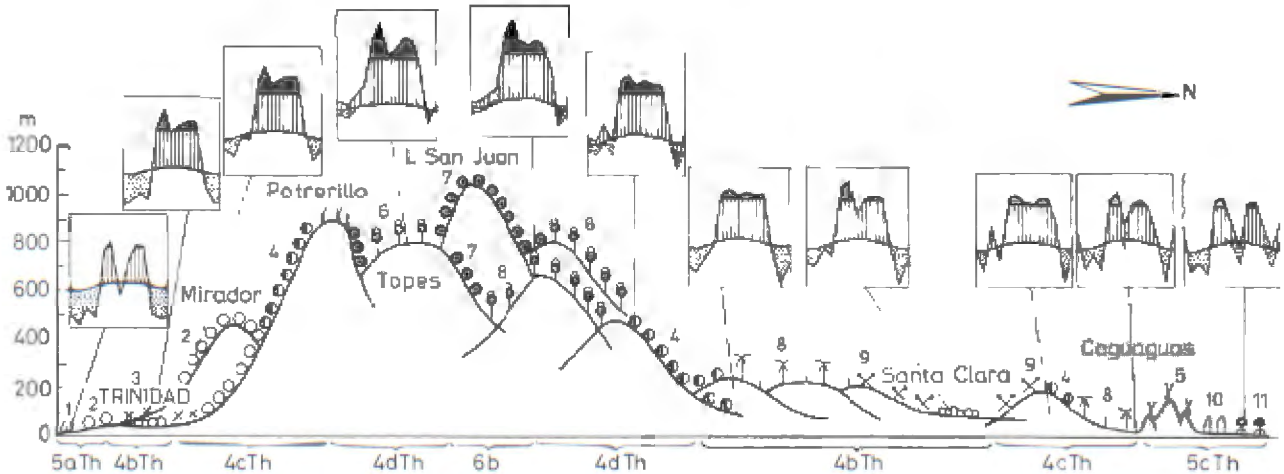


Fig. 29 Bioclimate and vegetation transect through the Escambray range in the province of Las Villas. 1. Sandy seashore, 2. Dry limestone forest, 3. Limestone thorn scrub-woodland, 4. Semi-deciduous forest, 5. Mogote formation, 6. Seasonal evergreen forest, 7. Montane rainforest, 8. Roystonea grassland, 9. Lowland serpentine scrub-woodland, 10. Alluvial or swamp forest, 11. Mangrove forest

8.3.4 Bioclimatic and vegetation transect through the western Maestra range in Oriente

We may find practically a similar distribution pattern of climate and vegetation developing in greater dimensions, in the western part of Sierra Maestra in Oriente Province (Fig. 30). It may be partly due to this, that ecological conditions of Sierra Maestra and Sierra de Escambray are rather alike. Here however, the lowland and colline regions are completely under the effect of the bixeric climate which only on the foothills of Sierra Maestra changes to a winter dry seasonal one. However, there is an essential difference in that there is a much greater vertical precipitation gradient than in the Escambray mountain and this precipitation surplus is spent on the elimination of the dry season. It may be due to this that the seasonal evergreen rainforests cover also the foothill belt of the mountain and the montane rainforest belt extends downwards more. Along the ridge of the mountain from 1400 m altitude upwards, above the montane rainforest belt, a milder form of wet temperate climate develops, and from 1800 m a cooler type corresponding as above 1600 m, a cloud forest or mossy forest or elfin forest belt appears (in Cuban terminology monte fresco) and above 1800 m the elfin thicket belt occurs.

8.3.5 Bioclimatic and vegetation transect through the eastern Maestra range and the Nipe mountains

The climatic variability of the eastern ridge of Sierra Maestra and of Sierra de Nipe is demonstrated in Fig. 31. The bixeric climate prevailing along the coasts in the mountains suddenly passes to axeric rainforest climate, the efficiency of the precipitation surplus here likewise surpasses the values experienced in western and central Cuba but rainforest climate still only forms in the montane belt. Seasonal climate, with one dry period develops in the intermontane central valley and its bordering colline areas.

8.3.6 Bioclimatic and vegetation transects through the Sagua-Baracoa mountains

Three bioclimatic and two vegetation profiles of East Oriente, the most varied part of Cuba climatically speaking, will be shown (Figs 32—34) of which each demonstrates the variations of the 7 bioclimatic types from the semi-desert to tropical rainforests. A common feature of all three profiles is that the ***2 c*** semi-desert type in all cases passes first through bixeric then through monoxeric climatic type, into axeric rainforest climate. Likewise another common aspect is that the summer dry seasonal climatic type appearing on the northern coastlines over a rather short phase goes over to wet tropical climate. In Fig. 32 it may be seen that the climatic type changes are fairly simple. The summer dry seasonal climate on the northern slopes of Sierra de Cristal suddenly goes over to a wet montane climate type. The rainforest climate however, similar to Sierra Maestra and Sierra de Nipe only develops in the montane regions. On the southern side of the mountain we find first

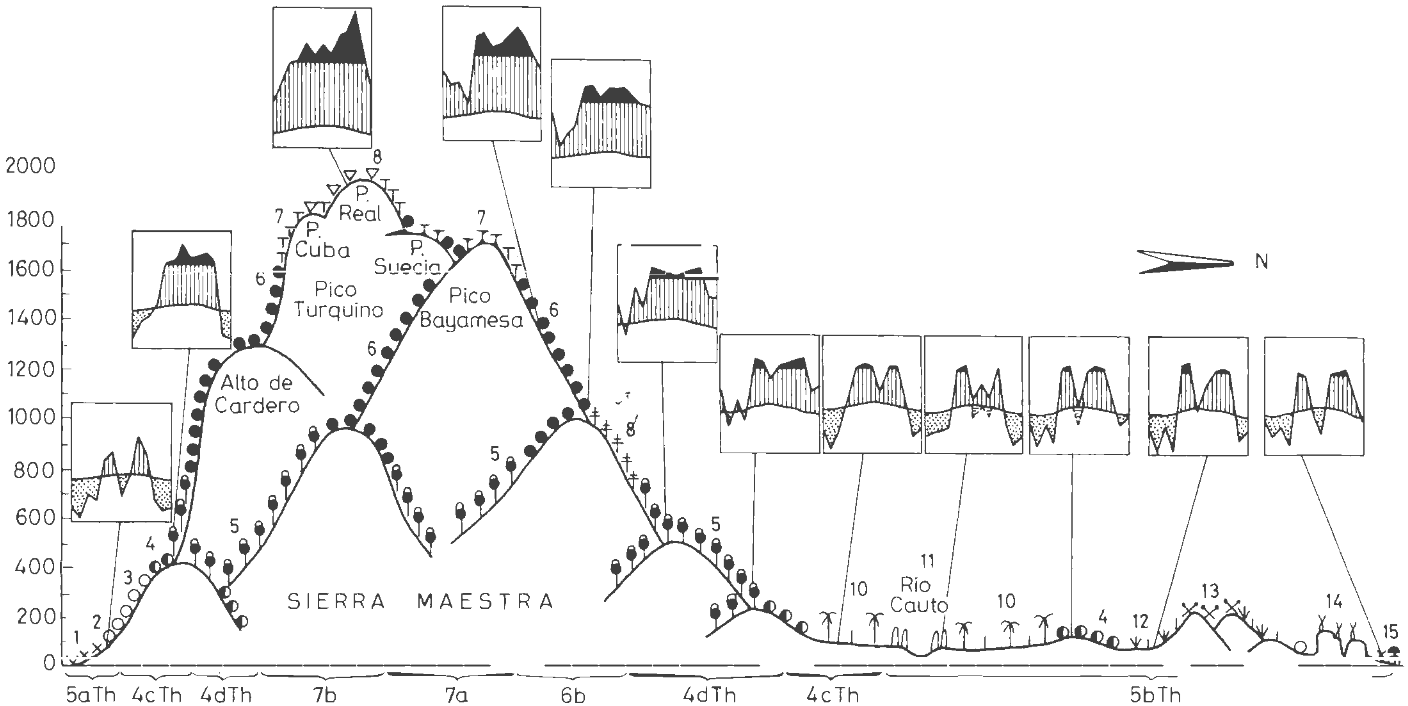


Fig. 30 Bioclimate and vegetation transect through the western Sierra Maestra range in the province of Oriente. 1. Littoral rock-pavement, 2. Littoral thorn-scrub, 3. Dry limestone forest, 4. Semi-deciduous forest, 5. Seasonal evergreen forest, 6. Montane rain forest, 7. Elfin mossy forest, 8. Elfin woodland and thicket, 9. Montane pine forest, 10. Roystonea grassland, 11. Alluvial forest, 12. Low palm serpentine grassland, 13. Lowland serpentine scrub-woodland, 14. Mogote-complex, 15. Mangrove forest

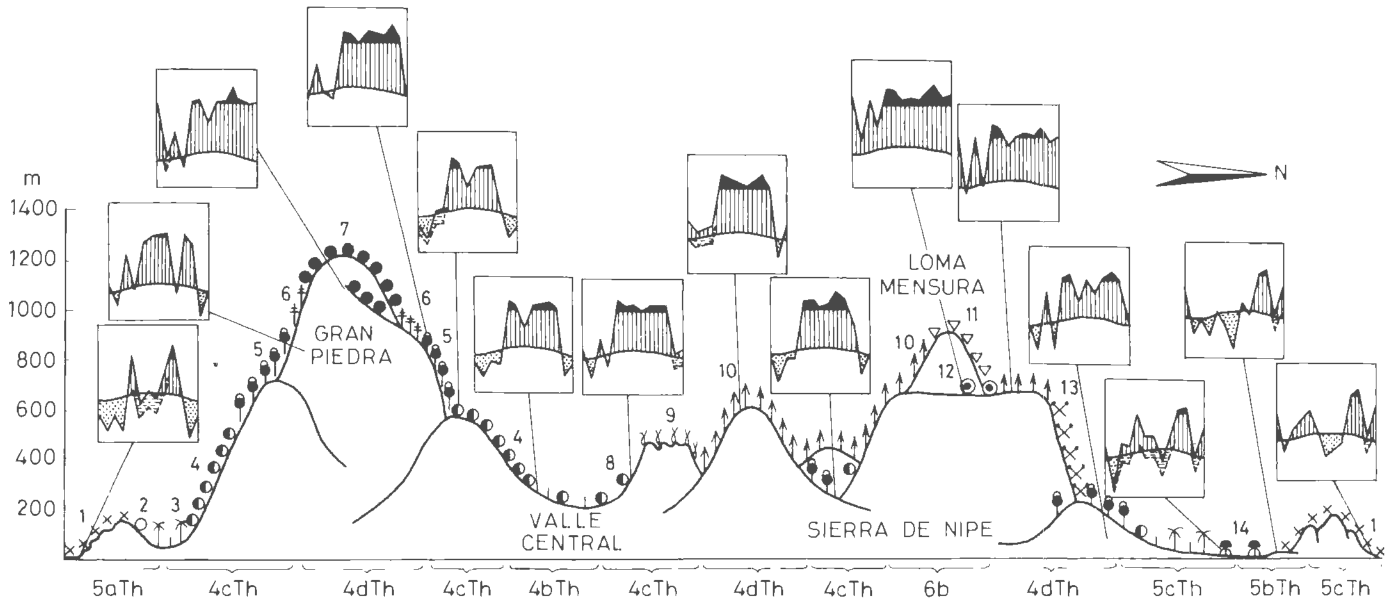


Fig. 31 Bioclimate and vegetation transect through the eastern Sierra Maestra range and the Nipe Mountains in the province of Oriente. 1. Thorn limestone scrub-woodland, 2. Dry limestone forest, 3. Roystonea grassland, 4. Semi-deciduous forest, 5. Seasonal evergreen forest, 6. Montane pine forest, 7. Montane rainforest, 8. Grassland with broad-leaved trees, 9. Mogote-complex, 10. Serpentine pine woodland, 11. Montane evergreen serpentine scrub-woodland, 12. Sclerophyllous montane rainforest (on serpentine), 13. Dry serpentine scrub-woodland. 14. Mangrove forest

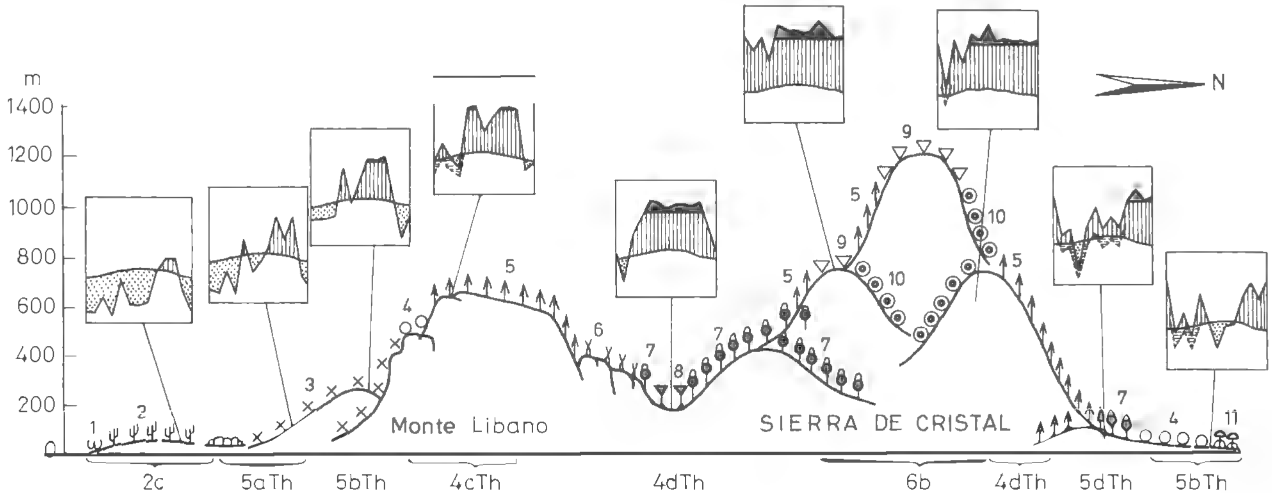


Fig. 32 Bioclimate and vegetation transect through the Cristal Mountains between Guantánamo and Cayo Mambi in the province of Oriente. 1. Sandy seashore, 2. Semi-desert thorn-cactus scrub, 3. Limestone thornscrub-woodland, 4. Dry limestone forest, 5. Serpentine pine woodland, 6. Mogote-complex, 7. Seasonal evergreen forest, 8. Submontane rainforest, 9. Montane evergreen serpentine scrub-woodland, 10. Sclerophyllous montane rainforest (on serpentine), 11. Mangrove forest

a heavy rainy winter dry climatic zone which soon loses its moisture along the Monte Libano plateau and reaching its southern edge turns into a very dry bixeric climate type. Due to the drying effect of the descending winds on the southern slopes the bixeric dry climate and the sclerophyllous shrub forests here reach the highest altitude a.s.l. in Cuba (700 m). The climate in the Guantanamo basin further dries and south from the city, we reach the semi-desert belt which forms here over a width of 20 km.

A much more differentiated picture is given by the spacing of the climate (Figs 33 and 34) where the triple range of Moa, Toa and Sierra de Puriales mountains meet with wetter oceanic air masses and the triple obstructing system to a larger extent 'exploits' the precipitation. The plateaus and northern slopes of the Sierra de Moa are only slightly wet but with a favourable balanced distribution. As a consequence of the turbulence of air masses reaching the Moa and Iberian plateau, most of the precipitation falls to the internal lower ridges of the mountain — on the northern slopes of the Toa and Sierra de Puriales — namely the deep valleys of Toa, Jaguani and Duaba on an average annually of 2000—3000 mm. As a consequence of this, the only submontane tropical rainforest belt in Cuba formed here. The climate on the southern slopes of Sierra de Puriales and Sierra de Imias rapidly becomes drier with the parallel appearance of the winter and summer dry seasons, the montane rainforest climate almost without a transition passes to a bixeric climate and further along the coastal sandy lowlands and on the karstic foothills into a semi-desert climate.

8.3.7 Bioclimatic and geomorphological transect of the Maisi-region

A climate diagram of the famous Maisi terrace regions on the eastern tip of Cuba is shown in Fig. 35. The registering stations are not frequent enough for us to follow the climatic analogy of changes of the vegetation belt from terrace to terrace (cf. Seifriz 1940, León 1942). The climatic types show the following variations:

a) The transition of the semi-desert climate of the southern side to the wet tropical climate within the Baracoa mountain lying behind the terraces.

b) A climatic change along the coastline of the island from a semi-desert climate through several bixeric types to a summer dry seasonal climate.

c) The development of a tropical summer dry seasonal climate on the north — north-eastwards directed on the upper terraces and its transition to a wet tropical climate.

9 Climate-vegetation relationships

Going beyond the basic relationship that the big climatic belts and vegetation more or less coincide, researchers on the bioclimate and vegetation are interested primarily in the depth and tightness of this relationship. The question is, at what level of the climatic and vegetation type hierarchy is the regular relationship to be expected and with what probability. It is extremely important for a botanist

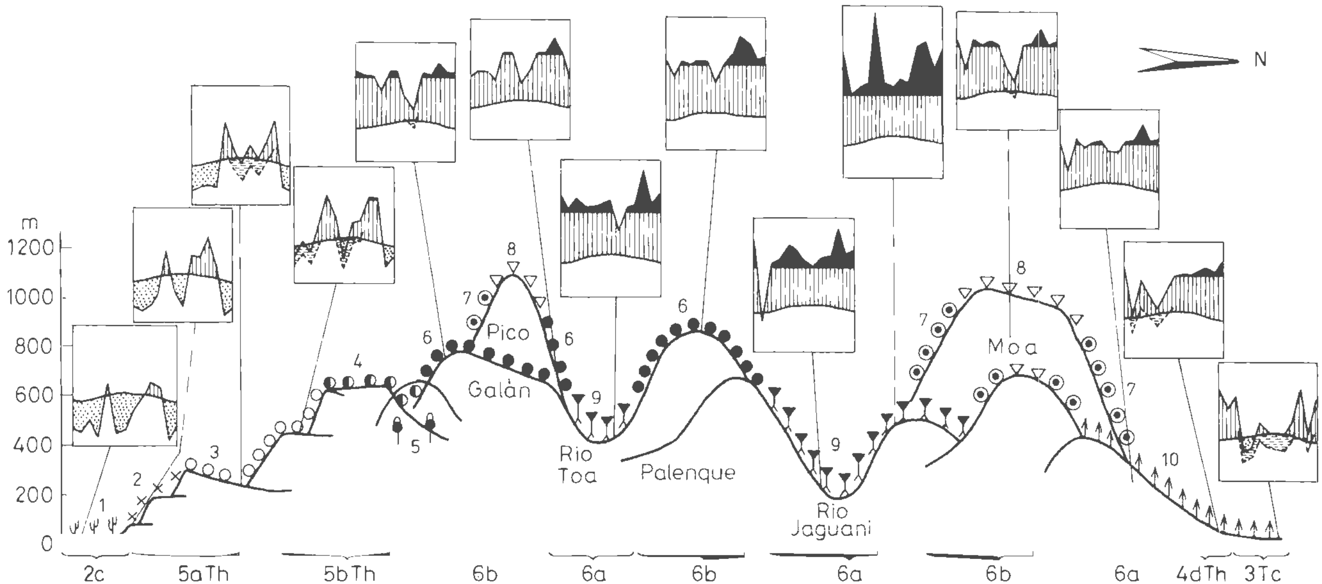


Fig. 33 Climate and vegetation transect through the Moa-Toa ranges between Baitiquiri and Punta Gorda in the province of Oriente (Borhidi 1974, modified). 1. Semi-desert thorn-cactus scrub. 2. Limestone thorn scrub-woodland, 3. Dry limestone forest, 4. Semi-deciduous forest, 5. Seasonal evergreen forest, 6. Montane rainforest, 7. Sclerophyllous (serpentine) rainforest, 8. Montane evergreen scrub, 9. Submontane rainforest, 10. Serpentine pine woodland

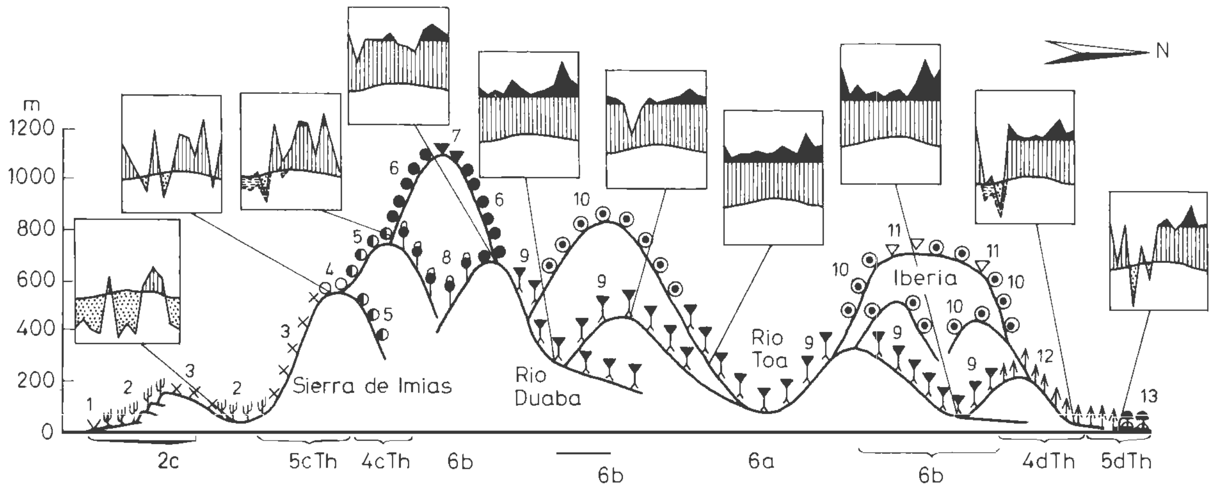


Fig. 34 Bioclimate and vegetation transect through the Imias and Iberia ranges between Imias and Cañete in the province of Oriente. 1. Littoral rock pavement, 2.Semi-desert thorn-cactus scrub, 3. Limestone thorn scrub-woodland, 4. Dry limestone forest, 5. Semi-deciduous forest, 6. Montane rainforest, 7. Montane evergreen scrub-woodland, 8. Seasonal evergreen forest, 9. Submontane rainforest, 10. Sclerophyllous (serpentine) montane rainforest, 11. Montane evergreen serpentine scrub, 12. Serpentine pine woodland, 13. Mangrove forest

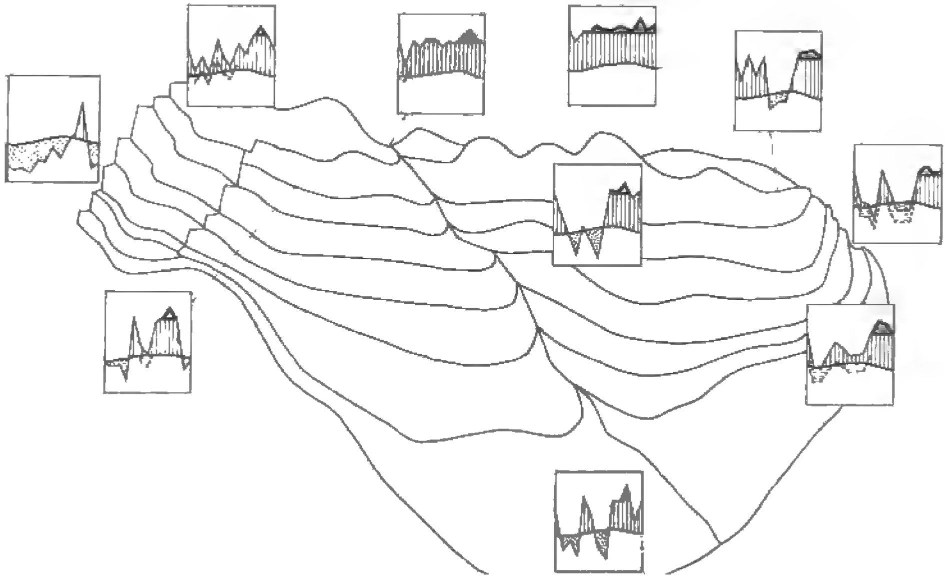


Fig. 35 Bioclimate transect in the terrace-region of Maisi at the easternmost point of Cuba

mapping vegetation to know the bioclimate and soil type, what the probability of estimating the potential vegetation of a landscape is—and its potential production—especially if what is involved, is a cultivated area bared of its original vegetation or the mapping of areas which have been disturbed by human activity. Most countries of the world have mainly such areas and the majority of tropical countries is no exception, as Cuba.

9.1 Correlation between the geographical patterns of climate and vegetation

A survey on the frequency and distribution of the various bioclimates of the vegetation types of the world was carried out by Meher-Homji (1963) based on the zonal vegetation and 1100 climate stations. I prepared a similar one from 250 data of my own climate and vegetation measurements in Cuba. The data referring to the bioclimatic types have been summarized in Table 3.

The following conclusions may be drawn from these:

a) Zonal vegetation is the most uniformly developed in climates dry all the year **1** and in climatic types which are wet throughout the year **6, 7**. Obviously the effect of other important non-climatic factors in forming the vegetation (rock, soil type) because the constant drought becomes of secondary importance or on the effect of constant wetness in some — e.g. by uniform soil development — is compensated or tapers out. Similarly in those seasonal climates, this is the case where the extent of the dry season is insignificantly short **4 *d*, 5 *d***. In the mentioned climatic types the zonal vegetation may be predicted with high probability.

b) In the seasonal climates distributed over dry and wet periods **2, 4, 5** the variation scatter of the vegetation types is quite marked, their number may even reach 7—9 within a climatic type. There is clearly such a tendency, for this with the shortening of the dry period, the ratio of the deciduous or semi-deciduous forests and savannas declines in the vegetation, while the frequency of the evergreen forests and rainforests increases. At the same time, it can be seen, that within a climatic type there is no predominant vegetation type, but 2—4 occur in equal proportions. This heterogeneity can only partly be explained by a slight flaw, in that one part of the vegetation types is not climax, being secondary (e.g. savanna) or predominantly edaphic (e.g. pine forests). This flaw is compensated for partly, by the fact that Meher-Homji's "forêt ombrophile tropicale" on account of the inaccurate descriptions of vegetation, with the exception of rainforests embraces the evergreen forests, the seasonal evergreen forests and a part of the montane rainforests.

9.2 Variability of the zonal vegetation in seasonal tropical climates

The variability of the vegetation of seasonal climates may be attributed to three main regulating factors:

- edaphic
- evolutionary
- anthropogenic

9.2.1 Edaphic factors

Considering that the length of the dry period basically determines the quality of the vegetation, the soils have a rather determining role due to the fact that their diverse structuring and water capacity enables water to be stored to varying degrees. Thereby edaphically, they can reduce the extent of the dry season or decrease the extent of aridity. Walter (1970a: 71, 80) has stressed several times that soil difference is the deciding factor in development of climatic savannas and climatic scrub. The deep clay sand favours herbaceous plants and grasslands, the looser pebbly soil favours the formation of shrub vegetation. According to him, below 500 mm precipitation, the soil will be the decisive factor in the quality of the vegetation. Our observations reveal that the effect of the soil does not diminish entirely even in the hyper-humid climate — above 2000 mm annual precipitation — for example in Cuba the montane rainforests and the semi-dry rainforests differ only in their edaphic conditions not in climates.

Table 3 Correlation between the occurrence of climate and vegetation types in percentage of territory occupied by vegetation types in each climate

Climate types:	1a	1b	1c	1d	2a	2b	2c	4a	4b	4c	4d	5a	5b	5c	5d	6a	6b	7a	7b
Vegetation types of the Earth according to Meher-Homji (1963)																			
Desert	100	82	93	94	28	9	8	—	—	—	—	—	—	—	—	—	—	—	—
Semi-desert	—	9	7	6	36	13	15	—	—	—	—	—	—	—	—	—	—	—	—
Scrub	—	9	—	—	25	21	39	4	2	—	—	34	11	—	—	—	—	—	—
Tropical grasslands	—	—	—	—	7	—	8	3	—	—	—	—	—	—	—	—	—	—	—
Dry subtropical forest	—	—	—	—	4	5	15	—	2	3	2	—	—	—	—	—	—	—	—
Thorn forest	—	—	—	—	—	35	15	23	1	—	—	—	—	—	—	—	—	—	—
Savanna	—	—	—	—	—	17	—	23	20	5	2	33	22	9	—	—	—	14	—
Dry tropical deciduous forest	—	—	—	—	—	4	—	42	16	1	—	33	22	—	—	—	—	—	—
Tropical semi-deciduous forest	—	—	—	—	—	—	—	1	19	10	—	—	—	—	—	—	—	—	—
Tropical evergreen forest	—	—	—	—	—	—	—	1	3	10	4	—	—	—	—	—	—	—	—
Tropical rainforest	—	—	—	—	—	—	—	3	20	52	90	—	34	82	100	100	70	9	—
Monsoon forest	—	—	—	—	—	—	—	—	17	19	2	—	11	9	—	—	6	18	—
Montane and subtropical rain-forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18	68	9
Montane shrublands	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	—
High montane shrubs, — paramos	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7

High montane coniferous forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Temperate evergreen forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42
Temperate deciduous forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	39
Vegetation types of Cuba according to Borhidi (1973)																			
Semi-desert with cacti	—	—	—	—	—	—	57	—	—	—	—	—	—	—	—	—	—	—	—
Scrub	—	—	—	—	—	—	33	—	2	—	—	25	6	—	—	—	—	—	—
Thorn forest	—	—	—	—	—	—	10	—	2	—	—	15	11	—	—	—	—	—	—
Dry evergreen shrub-forest	—	—	—	—	—	—	—	—	16	7	4	50	41	30	10	—	—	—	—
Tropical coniferous forest	—	—	—	—	—	—	—	—	4	2	23	—	4	10	10	—	—	—	—
Dwarf palm savanna	—	—	—	—	—	—	—	—	—	7	—	10	17	—	—	—	—	—	—
Tall palm savanna	—	—	—	—	—	—	—	—	44	33	11	—	13	—	—	—	—	—	—
Tropical semi-deciduous forest	—	—	—	—	—	—	—	—	30	35	7	—	8	40	10	—	—	—	—
Tropical seasonal evergreen forest	—	—	—	—	—	—	—	—	2	16	51	—	—	20	50	12	—	—	—
Tropical submontane rain-forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	88	—	—	—
Montane rainforest	—	—	—	—	—	—	—	—	—	—	4	—	—	—	10	—	64	—	—
Semi-dry (serpentine) rain-forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	—	—
Elfin forest	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	100	—
Elfin thicket	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100

9.2.2 Evolution of the vegetation as a factor group

The variability of the vegetation in seasonal climates may also be attributed to evolutionary reasons. Plants have adapted to aridity in many ways. As a consequence of this, the flora of different regions in accordance with their propensity for adapting, could develop vegetation types of different structures under similar climates. For example in the rainforest climate of Australia and in the Mediterranean belt, the forests consist of evergreen hard-leaved trees (c.f. Walter 1970a: 72) since the paleotropic rainforest flora could only transgress to New Guinea and Australia well after the development of tropical climate in the same area and until then the native hard-leaved flora occupied the major part of the tropical rainforest belt.

9.2.3 Historical factors

We consider the evolutionary aspects in the formation of the vegetation types to be made up of four kinds:

a) ecological background
b) adaptive capacity
c) migration possibility
d) colonization possibility

a) Obviously, even after rather diverse palaeoclimatological prior events two regions similar in climate can be in the same climatic belt. The consequence of this is, that just those elements of the flora become lost which have remained in the other.

b) As a consequence of this, the adaptive capacity of the flora becomes further restricted; namely those limits of its adaptability which are given by the anatomic-physiologic structure of the taxa and by their genetic plasticity. The major difference in these factors could only mark the different paths of adaptation for two floras. As an example we could mention that we found an analogous climate to that of Cuba in south-east India and south-east Africa. While in the latter two, seasonal deciduous forests prevail in Cuba there are no tropical deciduous forests at all but instead dry sclerophyllous evergreen forests.

c) Generally the already adapted migrating flora spreading with the climatic changes has an advantage in colonizing over the native flora which has not adapted. With island flora however, the opposite may be valid too. In the case of appropriate quick adaptation, the native flora may retain its stand in contrast with that of the migrating one.

d) Penetration of an outer vegetation type conditioned climate changes into an island flora may only be successful under favourable migration conditions (tides, prevailing wind) if as a consequence of some geological change e.g. raising up by tectonic elevation or by sedimentation of such surfaces which are suitable for colonization or the native flora tolerance drop — caused by climatic changes — provides an opening for new elements to penetrate into the ecosystem.

9.2.4 Anthropic influences

The heterogeneity of vegetation occurring under one climatic type may be largely increased by the anthropogenic effects. These thrived the best under the seasonal tropical climates especially in the semi-deciduous forest belt. The eradication and burning of these during the dry season provided better ploughing fields and pastures with higher yields than in the forest belts. This is how the high palm tall grasslands or so-called wet savannas creating the impression of original vegetation and the dwarf palm short grasslands or dry savannas originated many centuries ago. Only in **2 *b*** climate growing savannas can be accepted from Meher-Homji's table, as climatically conditioned ones, the others in the 8 climate types are in all certainty secondary. The two savanna types mentioned under Cuban vegetation types are merely for comparison since of these neither is climatic. The high palm savannas are residues of semi-deciduous and seasonal green forests, the dwarf palm savannas are the secondary semi-anthropic type derived from dry evergreen shrub forests and scrub vegetation.

9.2.5 Conclusions

It may be concluded from what we have discussed that:

a) The zonal vegetation type in extremely dry and wet climates **1, 6, 7** types may be listed here) may be estimated with a high degree of probability on the basis of the climatic information.

b) In seasonal climates **2, 4, 5** in relation to larger areas (the world *or* continents) prediction to similar degree of exactness is not possible.

c) In relation to continents, knowing the evolution of the flora, the ecological background of development and the predisposition for adaptation of the flora, as well as knowledge of the zonal soil vegetation relationships make possible a further more precise approach.

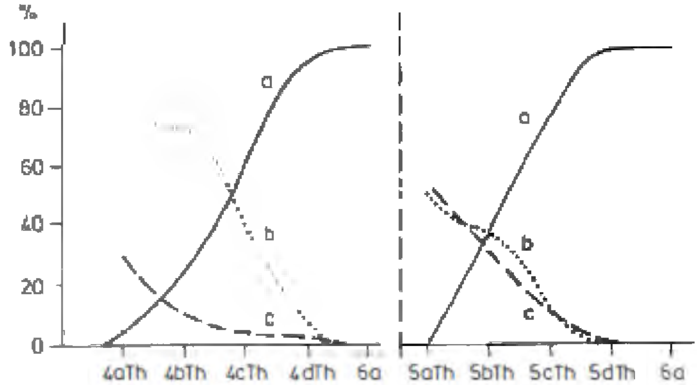
d) Knowledge of edaphic and cultural history conditions within smaller areas of flora having uniform development can provide an approximately exact estimation. But as our survey of Cuban vegetation shows the number of the possible zonal types in an area of this scale is too big.

e) Generally speaking we can say that the zonal vegetation of tropical seasonal climate types cannot be predicted with the accuracy needed.

So as to be able to do this the vegetation types have to be plotted in such a climatic coordinate function where the individual function phases versus space segments clearly define the zonal vegetation type of the given climate. Two such examples will be demonstrated, however, we have to clarify a point at this stage.

9.3 Ecological differences between monoxeric and bixeric tropical climates

From Table 3 it cannot be ascertained whether there is any essential difference between the vegetation of the winter dry **4 *Th*** climates and the bixeric **5 *Th*** ones. Meher-Homji could not draw any definite conclusions from this which is under-



4aTh 4bTh 4cTh 4dTh 6a 5aTh 5bTh 5cTh 5dTh 6a

Fig. 36 Relative frequency of tropical forest types of the world in different seasonal climates. a) rainforest, b) deciduous forests, c) sclerophyllous dry evergreen forest and scrubs

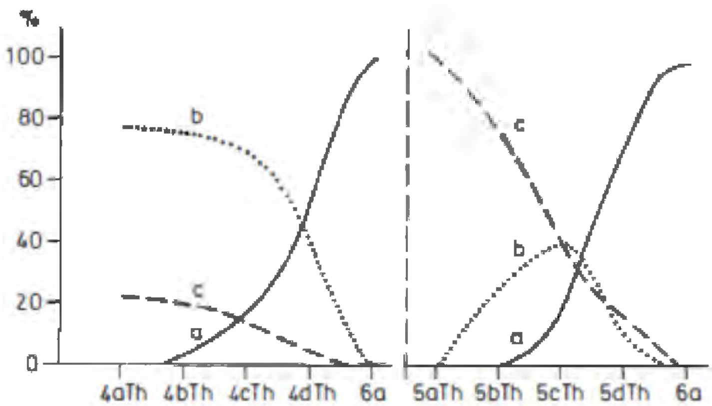


Fig. 37 Relative frequency of tropical forest types of Cuba in different seasonal climates: a) rainforests, b) deciduous forests, c) sclerophyllous dry evergreen forests and scrubs

standable since he had vegetation data for altogether 33 bixeric stations and not all of these were reliable too. In Cuba we examined 53 bixeric climatic stations with respect to their zonal vegetation and found that apart from the common tendency of the two climates (both are a transition from the semi-desert and rainforest climates) there is a decided difference in the vegetation. These differences become obvious if we carry out some combinations in Table 3. The vegetation types were grouped into:

- rainforests
- deciduous forest and shrublands
- sclerophyllous evergreen forests and shrublands and the savannas are classed into the forest group from which they derived. This distribution of the three groups may be seen in Figs 36 and 37.

9.3.1 Favourable water utilization of bixeric climates

Two important correlations may be detected from the figure with respect to the effect of the ***4 Th*** and ***5 Th*** climates. The one is concerned with the effect of the length of dry period which may be seen on the rain forest frequency curve. It may be seen well that the rainforests reach the same frequency in ***5 Th*** climates by half a class earlier than in ***4 Th***.

This means that the distribution of aridity into two periods spares the humidity of one wet month and has exactly the same effect as a winter dry tropical climate whose dry period is shorter by a month. In other words 4 dry months of a bixeric climate is equivalent to a 3-month dry xero-chimenic climate and a 3-month dry bixeric climate is equivalent to a 2-dry month xero-chimenic climate — from the point of view of the effect of the dry season.

9.3.2 Deciduous and sclerophyllous vegetation as two adaptive links

Another striking correlation is that the winter dry climate favours vegetation which has adapted to the deciduous life rhythm. In this climate the deciduous or semi-deciduous vegetation types prevail. In contrast with this, to avoid the two dry periods, different forms of sclerophylly e.g. coriaceous leaf, microphylly, thorny leaves, proved to be the successful ways of adaptation. In vegetation, the dry evergreen forests prevail composed of sclerophyllous elements as thorn evergreen forests and scrub formations. The bixeric climate therefore favours the sclerophyllous evergreen vegetation. This tendency can be observed already in the semi-desert climate belt — where the scrub and thorny forests are strikingly more frequent in the types ***2 b*** and ***2 c*** than in the winter dry ***2 a*** type — and it can be obviously demonstrated in the bixeric climates.

Probably, this effect of the bixeric climate is not simply the resultant of the two dry periods but to a large extent, it is attributable to the fact that one dry season occurs in summer. In frost-free climates, the summer aridity itself favours the hard-leaved evergreen vegetation. This also justifies that the rare summer dry tropical climates should not be listed under the xero-chimenic climates but under the tropical version of the Mediterranean climate or it should be regarded as the extreme case of the bixeric climate.

9.3.3 The high frequency of the sclerophyllous vegetation in Cuba

The fact that the frequency of the sclerophyllous evergreen vegetation type in Cuba (Fig. 37) well surpasses the average in the world can be attributed to three other local factors. One of these is the high relative humidity ensured by the proximity of the sea which considerably reduces leaf-fall and favours the higher frequency of evergreens, at the same time the marine winds contribute to the development of adaptive features serving reduction of transpiration (microphylls with thick cuticle). The other factor is represented by the oligotrophic soil types (white sands, acidic soils on slate and serpentine latosols) which over millions of years came to form a hard-leaved, evergreen flora. And finally, the evolution of a particular insular flora, the primordial native evergreen small-leaved trees and shrubs had a much greater role in that the deciduous elements migrated in mostly later.

9.4 Methods for predicting probable zonal vegetation in seasonal tropical climates

As we saw earlier, certain bioclimatic types and vegetation types often do not coincide especially in the different seasonal tropical climates. Therefore the actual climatic requirements, climatic limits of the zonal vegetation have to be outlined more accurately in a coordinate system comprising climatic elements determining the quality of the vegetation in the form of such phase functions or spatial range province from which the zonal occurrence of the given vegetation type can be anticipated with a fairly high probability.

9.4.1 Coordinate method of Walter

Walter (1962: 136, 1970: 71) suggested such a coordinate system whose Y axis represented annual precipitation amount and the X axis, the duration of the arid period or the number of dry months. With the aid of such a coordinate system it was possible to delineate the 6 zonal vegetation types of India — in my version 8 climax vegetation types (Fig. 38). Samek and Travieso (1968) supposed that the limits of zonal vegetation types of Cuba were located just where those of South India were, and they delegated climatic diagrams of Cuba into Walter's diagram. Although their supposition proved to be wrong Samek (1969) came to the conclusion that there are no climazonal savannas in Cuba. I myself applied this method successfully to delineate five zonal vegetation types of Cuba (Fig. 39). The method has the flaw that not having a temperature coordinate it is only suitable for distinguishing vegetation types of a single climatic belt. Distinguishing the vegetation types of vertical zones from those of lowland areas cannot be done using this method. In Fig. 39 the squares with a vertical line indicate the montane seasonal evergreen forests and the montane rainforests which obviously coincide with the appropriate lowland types on the same spatial range of the coordinate system.

9.4.2 Amount vs distribution of precipitation as a determining factor

The problem arises whether of the two coordinates the quantity of precipitation or the length of aridity is the more determining structure of the forest. Walter (1962a) rightly concludes that in the moist vegetation types it is the length of the dry period which is the more important factor whereas in the dry types the amount of precipitation. Later referring to his diagram he established that both factors were important, neither can be disregarded. He considered from the lines indicating the

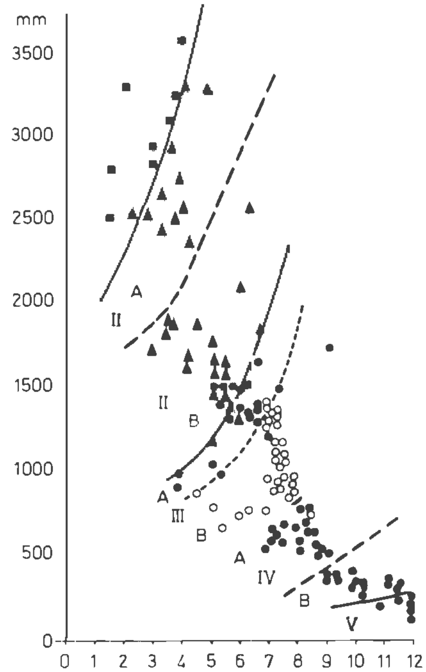


Fig. 38 Climatic delimitation of vegetation types of India in relation to annual precipitation average and the number of the dry months (Walter 1962, modified). I. Rainforests, II. A. Seasonal evergreen forests, II. B. Semi-deciduous forests, III. Deciduous monsoon forests, A: humid type; B: arid type, IV. A thorn scrub forests, IV. B. Savanna or semi-desert, V. Desert

limits of vegetation that the precipitation amount is more decisive for the wet forest types whereas for the dry types the length of the dry period.

However, this latter correction of the interpretation was probably a clumsy way of expressing it. The dividing line of the vegetation types by itself is not informative, only if we compare it with the curve describing mass of points. It can readily be seen that these points are distributed roughly along a hyperbolic curve the upper phase of which fits into the Y axis and the lower phase approaches parallelly to the X axis. But the same tendency characterizes the limit values of vegetation types. Namely the limiting curve of wet forest types above a certain amount of precipitation run parallelly to the Y axis. This means that above certain Y values the vegetation limit can only be transgressed in the direction of the X axis. The opposite is true for dry types where the distribution of the vegetation points and the limit lines flatten to a curve approaching and running parallelly to the X axis.

In this range however, the transgression of the vegetation limit is shorter in the direction of the Y axis, i.e. for the qualitative change in the vegetation the precipitation amount is more important.

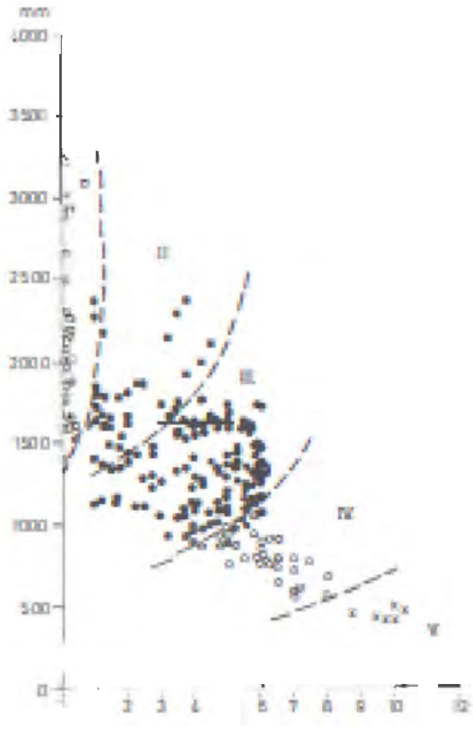


Fig. 39 Climatic delimitation of Cuban vegetation types related to annual average precipitation and to the number of the dry months. I. Rainforests, II. Seasonal evergreen forests, III. Semi-deciduous forests, IV. Dry evergreen and thorn forests, V. Semi-desert scrubs

9.4.3 Conclusions

Our findings in point *4.4.1* may be considered to be proved concerning the geobotanical importance of the amount and distribution of precipitation. Below a certain threshold level when determining the vegetation structural type or a terrestrial ecosystem, the total amount of precipitation is more important than the annual distribution, however, the annual distribution is vital above a certain threshold level in contrast with the annual total. This tendency is valid not only for the extreme values of the series but with certain vegetation types in the middle range. The concrete threshold values diverge in the different temperature zones; within a temperature zone they vary depending on the relative humidity and the soil.

In Cuba, the upper threshold value derived from Fig. 39 is about 1700 mm and the lower one about 500 mm. In India however, probably due to the lower atmospheric moisture — the higher threshold value is above 2 000 mm the lower is at 500 mm. The quantity and distribution effects are equivalent especially in those regions where the total annual rainfall varies between 500—1500 mm.

9.5 Ecological effectiveness of the water surplus

As we discussed in *4.2.1* in connection with the distribution of precipitation, in Cuba, rainfall increases from the sea coast towards the interior of the island and intensifies above the mountains. These precipitation gradients in certain areas remain completely ineffective, they neither change the climatic type nor the vegetation type (Fig. 27). On the whole, however, along the vertical precipitation gradient several climatic and vegetation types alternate. It is striking however, that in the western and central Cuban mountains (Figs 25—29) the same number of bioclimatic types are associated with a smaller number of vegetation type changes as in the mountain regions of Oriente (Figs 30—34). This raises another question which may be called the problem of the precipitation growth (P_i) efficiency (EP_i) which we touched on in the course of discussions of bioclimate transects in the former chapter *(8.2.1)*. If between A_1 and A_k stations, precipitation gradient develops in connection with some kind of geographical factor, changing continu-ously (e.g. increasing above sea-level height or as a consequence of distancing from the coast) so that annual rainfall at the stations A_1 A_2 A_3 A_k are:

$P_1, P_2, P_3 \dots P_k$ than compared to P_1 each station will have ($i_1, i_2, i_3 \dots i_k$) amount of precipitation surplus. This is called precipitation rise (P_i) whose value between P_1 and P_k could even be 2000—3000 mm. It depends on the efficacy of P_i (EP_i) as to what kind of changes are brought about by concrete values of P_i in the zonal vegetation.

It may be read from Figs 38—39 that there could even be 1000 mm difference between two stations in the precipitation without it affecting the number of dry months and the quality of vegetation. This means that the $i_1, i_2, i_3, \dots i_k$ surplus increases mostly the precipitation amount of the wet season — at a time when precipitation is overabundant and most of it flows off the surface, — in other words, P_i is practically ineffective. If however, a major part of $i_1, i_2, i_3 \dots i_k$ results in the shortening or elimination of the dry season then P_i is effective and those cases P_i = 200—300 mm may be followed by the change in zonal vegetation type.

9.5.1 EP_i evaluation

Evaluation of EP_i may be carried out in several ways. The most appropriate for EP_i analysis is to introduce the concept of (Qpx) dry season precipitation participation:

$$Qpx = \frac{\bar{P}100}{P}$$

where $\bar{P}$ = total precipitation of dry season divided by the number of dry months

P = total annual precipitation divided by 12.

9.5.2 Efficiency of precipitation gradient

P_i is efficient when $P_1, < P_2 < P_3 < \dots < P_k$ and simultaneously also $Q_{px1}, < Q_{px2}, < Q_{px3} < \dots < Q_{pxk}$ and $Q_{pxk} > 50$.

This means that increased precipitation is the more effective, the more the average precipitation amount of the dry months approaches that of the annual average months, or the more the difference disappears between the dry and wet months. In such cases, it is highly probable, that along the precipitation gradient one, two or perhaps more zonal vegetation types alternate. If however $P_1 < P_2 < P_3 < \dots < P_k$, and simultaneously $Q_{px1} > Q_{px2} > \dots > Q_{pxk}$; and $Q_{pxk} < 50$ then the P_i between the stations A_1 and A_k is ineffective and at the most one zonal vegetation type limit is expected with little probability. However, we should like to note that the number of dry months and that which one must be considered as dry is defined by the starting station of every series (A_1). Therefore if Q_{px2}, Q_{px3} and Q_{pxk} are to be counted from the same months as Q_{px1} even if in the case of A_2 A_3 and A_k stations, the referred months are not at all dry. The change can only be measured objectively in this form.

9.5.3 EP_i description

We attempted to demonstrate the EP_i value with the aid of a coordinate system consisting of two vertical and one horizontal axis. The left vertical axis represents the annual precipitation amounts, the right the Q_{px} values, on $(A_i \dots A_k)$ situated on the precipitation gradient. In the middle the $Q_{px} = 50\%$ value implying the efficiency level. Below it the complex aridity index of Meher-Homji has been depicted related to certain stations.

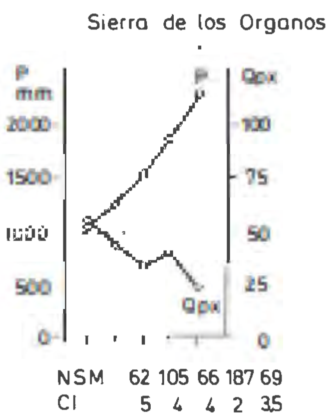


Fig. 40 The efficiency diagram of the precipitation surplus in the Organos-range of West Cuba. P=annual average precipitation, Q_{px}=precipitation-rate of the dry season, according to the text, NMS=number of the meteorological station, CI=complex index S+x+g of Meher Homji (1963)

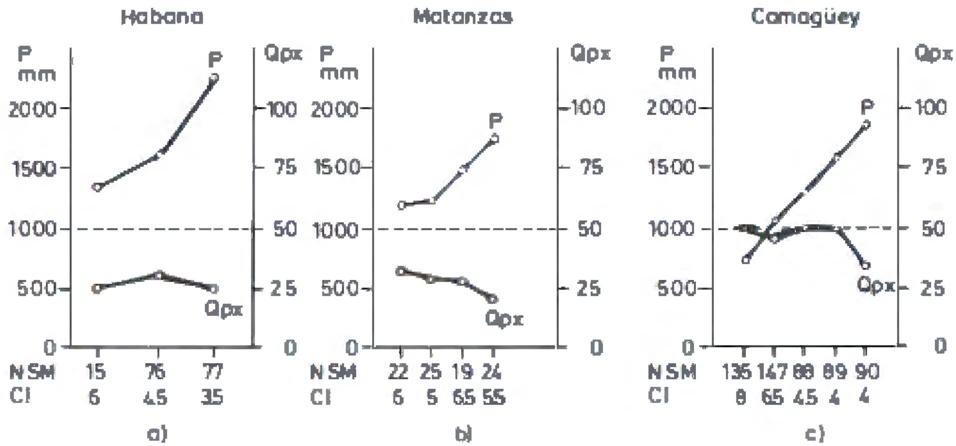


Fig. 41 The efficiency diagrams of the precipitation surplus in the Cuban lowland areas. a) Habana b) Matanzas; c) Camagüey. For symbols see Fig. 40

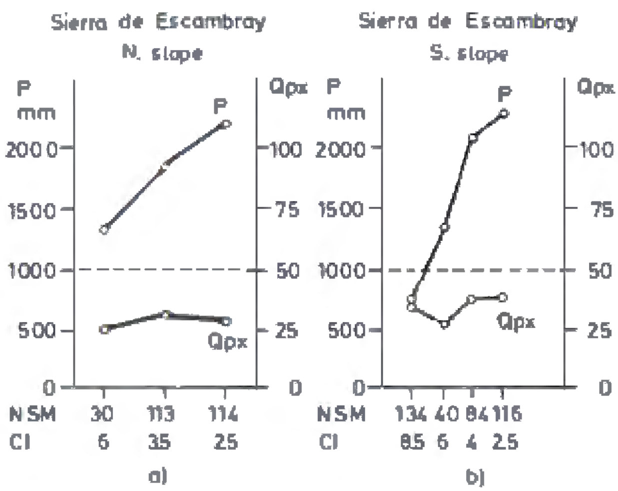


Fig. 42 The efficiency diagrams of the precipitation surplus in the Sierra de Escambray range in Central Cuba. a) North slope; b) South slope. For symbols see Fig. 40

9.5.4 Formation of EP_i in Cuban precipitation gradients

Of the Cuban bioclimatic profiles, we studied 14 characteristic precipitation gradients from the point of view of EP_i which are shown in Fig. 40. From these it can be established that:

a) The efficiency of precipitation gradients of West and Central Cuba is rather low (Figs 40—42), obviously in the lowland and mountain belt even with 2000 mm annual precipitation a climax rainforest cannot develop.

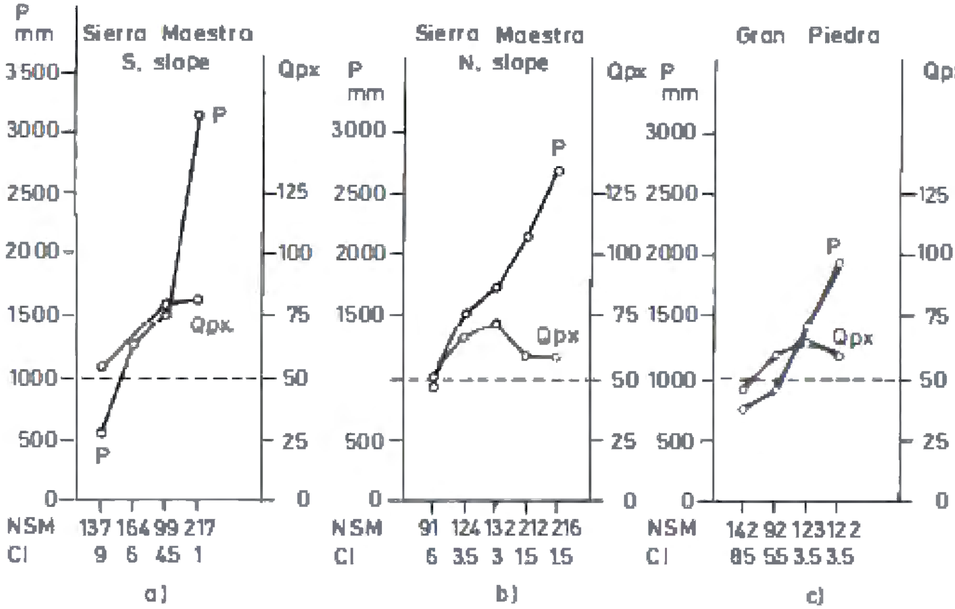


Fig. 43 The efficiency diagrams of the precipitation surplus in the Maestra-range in eastern Cuba. a) Sierra Maestra, South slope; b) Sierra Maestra, North slope; c) Gran Piedra. For symbols see Fig. 40

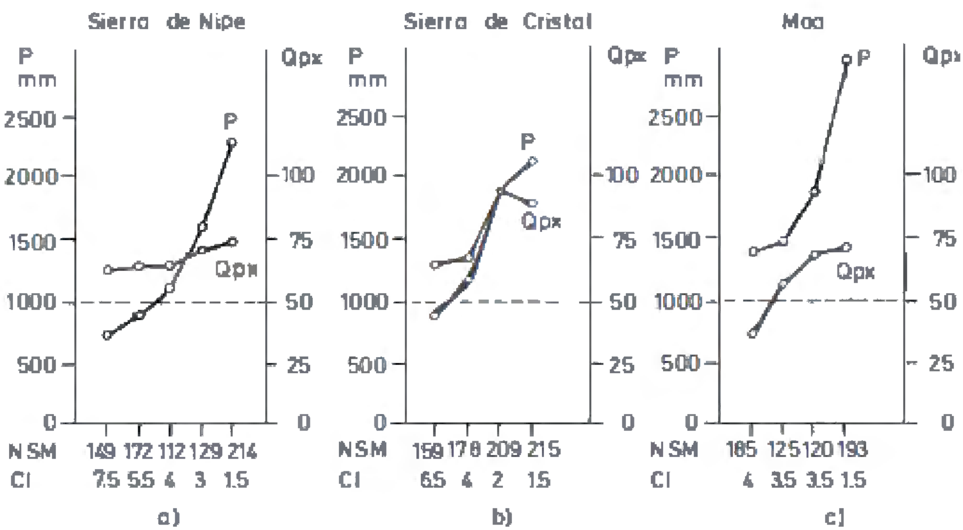


Fig. 44 The efficiency diagrams of the precipitation surplus in the northern Sagua-Baracoa range in eastern Cuba. a) Sierra de Nipe; b) Sierra de Cristal; c) Moa. For symbols see Fig. 40

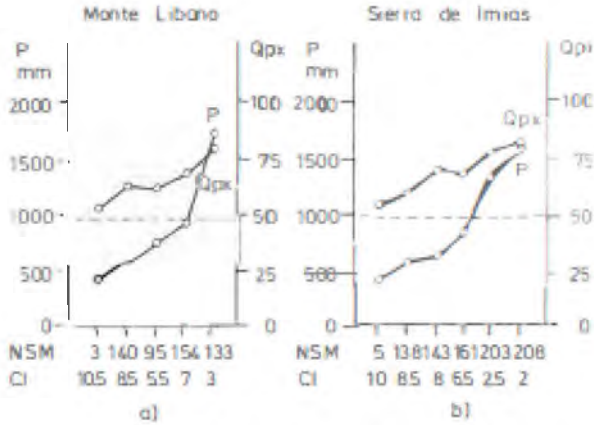


Fig. 45 The efficiency diagrams of the precipitation surplus in the southern Sagua-Baracoa range in eastern Cuba. a) Monte Libano; b) Sierra de Imias. For symbols see Fig. 40

b) Progressing in a south-east direction the EP_i shows an improving tendency. In Camagüey Province, it approaches the 50% efficiency level (Fig. 41 *c*) and in Oriente Province in all mountain regions the precipitation rise is effective (Figs 43—45). A result of this, is, that at 1500—1600 mm annual rainfall the rainforest zone develops and the steep precipitation gradient is accompanied by a likewise steep vegetation gradient.

c) In the lower and less extended colline regions, the rise in precipitation is not accompanied by a change in climate types (Figs 40 and 42 *a, b*) in contrast with the larger mountains of Oriente. The diagram pairs 42 *a, b*, and 43 *a, b,* at the same time serve to answer why montane rainforests form a continuous belt in Sierra Maestra (Q_{pxk} 50%) while in the Escambray mountains they occur only sporadically mainly in the form of extrazonal or local climatic stands, even in similar conditions of temperature, rainfall and altitude.

It is obvious from the above, that the vegetation types may be classified roughly according to precipitation amount and distribution. Spatial variations of these factor pairs may be refined — as above — with more sophisticated methods.

9.6 Universal bioclimatic classification of zonal vegetation using the S + x + g index of Meher-Homji

As we have already referred to it in point *9.4.1,* the vegetation types only of a single climatic belt can be distinguished on the basis of precipitation distribution and amount where temperature does not have a role in their separation. The universal classification of the zonal vegetation however, is only possible in such a coordinate system where one axis is the temperature, the other is moisture in some index form. Meher-Homji (1963: 117, 118) prepared such a coordinate on which the

Y axis was divided into 9 temperature climate classes, the X axis had 12 moisture classes based on his complex S + x + g index. S+ x + g index is based on annual rainfall amount and distribution (S), the number of dry months (x) and the number of frosty months (g) (Meher-Homji e.c. 47—57).

9.6.1 The t-index values

The t-index distinguishes 9 classes according to Meher-Homji (1963: 47). These are:

t_1 –	$M < 10$ °C,		
$t_{1/2}$ –	$M > 10$ °C,	$m < -15$ °C;	
t_2 –	$M > 10$ °C,	$m < 5$ °C;	
t_3 –		$-5 < m < 0$ °C;	
$t_{3/4}$ –		$0 < m < 10$ °C;	
t_4 –		$10 < m < 15$ °C;	
$t_{4/5}$ –		$15 < m < 20$ °C;	
t_5 –		$m \quad 20$ °C;	annual mean < 30 °C;
t_6 –			annual mean > 30 °C;

where M — is the mean temperature of the warmest month
m – is the mean temperature of the coldest month.

9.6.2 S-index values

The S-index expresses the wetness and aridity of the climate according to Meher-Homji (1963: 49) and slightly modified by me distinguishing altogether 11 categories:

Annual precipitation in mm

S_1 –	$P > 3000$	
$S_{1/2}$ –	$3000 > P > 2000$	
S_2 –	$2000 > P > 1500$	
$S_{2/3}$ –	$1500 > P > 1000$	with 1—2 dry months
S_3	$1500 > P > 1300$	with 3—5 dry months
S_3 – or	$1500 > P > 750$	with 0 dry months

and with negative temperatures at certain periods of the year

$S_{3/4}$ –	$1000 > P > 750$	with 1—6 dry months
S_4 –	$1000 > P > 750$	with 7—8 dry months
$S_{4/5}$ –	$750 > P > 500$	
S_5 –	$500 > P > 250$	
$S_{5/6}$ –	$250 > P > 100$	
S_6 –	$P < 100$	

9.6.3 The x-index values

The x=index according to the dry months is distributed into 11 categories (Meher-Homji 1963).

x_1	1	dry month
$x_{1/2}$	2	dry months
x_2	3	dry months
$x_{2/3}$	4	dry months
x_3	5	dry months
$x_{3/4}$	6	dry months
x_4	7	dry months
$x_{4/5}$	8	dry months
x_5	9	dry months
$x_{5/6}$	10	dry months
x_6	11—12	dry months

9.6.4 The g-index values

The g-index values can be divided according to the number of frosty i.e. "physiologically" dry months into 11 classes (Meher-Homji 1963: 56). Frosty month is considered to have a mean temperature below −2 °C. The values of the g-index are the following:

g_1	one	frosty month
$g_{1/2}$	2	frosty months
g_2	3	frosty months
$g_{2/3}$	4	frosty months
g_3	5	frosty months
$g_{3/4}$	6	frosty months
g_4	7	frosty months
$g_{4/5}$	8	frosty months
g_5	9	frosty months
$g_{5/6}$	10	frosty months
g_6	11—12	frosty months

The g-index in Cuba has no role in the development of the complex s + x + g index.

9.6.5 The Meher-Homji coordinate system

This coordinate system proved to be suitable for ordering the zonal vegetation types of India and the world according to their climatic demands and for their partition according to certain statistical frequencies (Meher-Homji, see 132—133). On the Cuban diagrams — left below the X axis — we also demonstrated the s + x + g and t-values of the diagrams and arranged them according to geographic areas and the s + x + g index values. Further we attempted to show the Cuban vegetation types in the above coordinate system.

9.7 Cuban vegetation belts

We found that the method was very useful for selecting and characterizing the zonal vegetation types in Cuba. We distinguished the following 8 zonal vegetation belts (Fig. 46):

- Semi-desert scrubs
- Evergreen shrub-forests
- Deciduous forests or small-leaved, semi-deciduous forests
- Semi-deciduous forests
- Submontane rainforests
- Montane rainforests
- Mossy cloud forests or elfin forests
- Elfin woodland

9.8 Examining special problems with Meher-Homji diagram

We found this diagram, apart from distinguishing vegetation types, and climatic classification suitable for studying questions of zonality and ecology.

9.8.1 Distinguishing zonal, edaphic and paraclimax vegetation types

The Meher-Homji diagram is suitable furthermore, for clarifying the zonality of certain edaphic associations and to demonstrate their intrazonal, paraclimax or edaphic climax character. Thus, it could be shown of the pine forests of Cuba that each type of them actually belong to one determined vegetation belt (Fig. 47). As

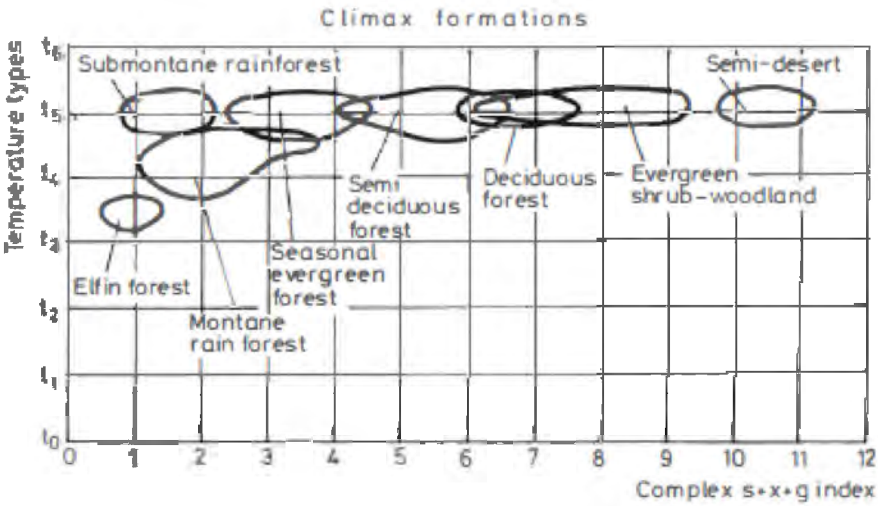


Fig. 46 Distribution of the Cuban zonal vegetation types in the "ecological coordinate system" of Meher-Homji

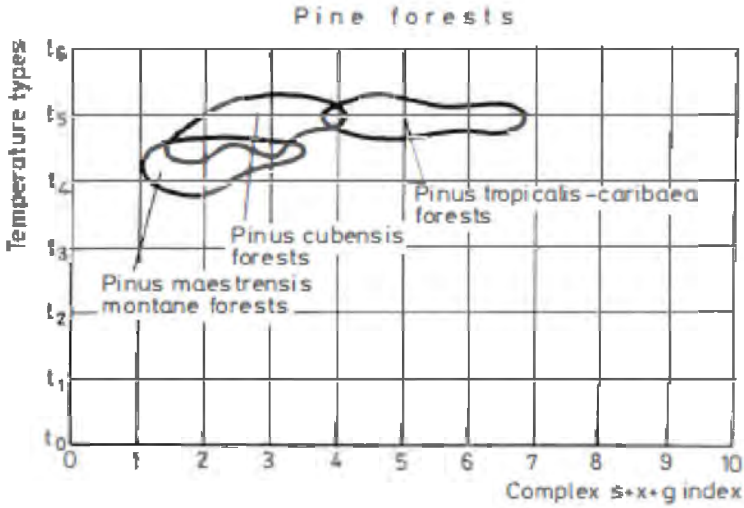


Fig. 47 Distribution of the Cuban pine forests and pine woodlands in the ecological coordinate system of Meher-Homji

such, they may be regarded as intrazonal edaphic climax communities on latosols. The *Pinus tropicalis* and *P. caribaea* forests belong to the semi-deciduous forest belt. The distribution of *Pinus maestrensis* forests coincides completely with the montane rain forests while the *Pinus cubensis* forests can be considered as the paraclimax communities of the seasonal evergreen forest belt but, as we shall see later, for historical reasons they overlap to the lower part of montane rainforest belt as well.

9.8.2 Investigation of anthropic and semi-anthropic vegetation types

The great merit of the diagram is that by means of it, the different anthropic formations and derivation types can be traced to their origins, that is, it is useful for the reconstruction of the vegetation of cultivated landscapes. It can be clearly demonstrated for the Cuban savannas (Fig. 48) that they all fall without exceptions to any of the forest formation climax belts. The royal palm mesophilous savannas are derivatives to a small extent, of the seasonal evergreen forests and for the most part the semi-deciduous forests. The low palm *(Copernicia, Sabal)* savannas originated from the deciduous forests or from the small-leaved, semi-deciduous forests, and the dwarf palm savannas *(Copernicia, Coccothrinax)* are derivatives of the evergreen shrubforests and scrubs.

9.8.3 Analysis of the zonality of savannas

Our investigations confirmed the statement of Samek (1969) in that climatic savannas do not exist in Cuba. Savanna climate only occurs southward from Guantanamo over a small area but there the soil conditions favour the formation of

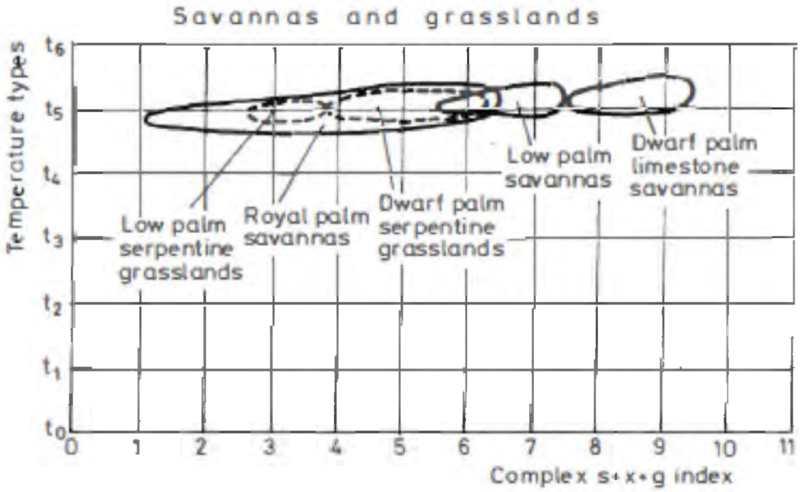


Fig. 48 Distribution of the Cuban savannas and grasslands in the ecological coordinate system of Meher-Homji

a semi-desert cactus scrub. Discounting this small area the climate over the whole area of Cuba is suitable for forest vegetation. The large savanna regions of west and central Cuba are natural, edaphic savannas in a small area (in greater detail in the chapter of plant soil relationships) the majority of the region is made up of anthropo -zoogenic secondary savannas.

9.8.4 Analysis of ecological equivalences

By comparing formation of similar structures conditioned by different soils it may be ascertained from the diagram, to what extent the physiological effect of any basic rocks or soil types may be equivalent to the kind of climatic difference. From this it can be seen, that on the effect of latosols of the serpentine rocks, such vegetation types develop as on limestone with 500 mm less annual precipitation or with a 3—4 months longer dry period. That is, the effect of the serpentine rocks is ecologically equivalent to the mentioned difference.

10 Potential evapotranspiration and the possibilities of utilizing the life-zone system in the classification of plant formations

These two bioclimatological concepts and methods need to be reviewed because;

- So far no such universal bioclimatic method has been worked out for classifying vegetation types which could completely meet the requirements of vegetation research in each climatic belt and preferred dimensions. Of course, it is not at all likely, that on account of the deviating palaeoecological past and the diverse adaptation trend and capacity of flora, such a universal bioclimatic method will ever be found.

- Numerous examples have confirmed (see point *9.1*) that different zonal vegetation types may develop in analogous climatic types which restricts the suitability of bioclimatic formulae and the validity of conclusions to be drawn on spatial arrangements.
- Just on account of this, it would not have been right to use *a priori* the Gaussen's concept — partly refined and further developed by us — as optimal.
- The even more so, since the method has until now, been used only in Africa and Asia and in the New World tropics rather for illustrative purposes than for documentation (Knapp 1965, Hueck 1966) while Thornthwaite's and Holdridge's concepts are used rather widely on the American continent.

10.1 Criticism of the PE concept

Thornthwaite's theory and method based on PE was most popular in America not only among geographers but agriculturalists and forestry experts, even biologists. The sharp criticism by botanists of the old world (apart from an overview in point *7.2:* Aubréville 1965 *c*: 297—300) went unheeded by the American experts. From this, it may be concluded that Thornthwaite's concept has produced satisfactory results at least for classifying American vegetation.

10.2 Climatic water balance of Cuba

Not having the necessary data for calculating PE, we estimated the basic parameter of the general moisture, the precipitation surplus (S = P − E) or annual values of the climatic water balance and drew them in a map (Fig. 49).

10.2.1 Climatic water balance

The climatic water balance map is similar to the precipitation map. It is striking that a clearly humid climate according to this map, is only to be found in rainforest areas. Even the dry season of 1—2 months, gives a deficit in water balance which geobotanically can be objected to, because such a short dry period generally allows the formation of rainforests but in the worst case it enables the development of zonal seasonal evergreen forests which is likewise of a humid vegetation type and in no way can be regarded as water deficient in an ecological sense.

It can be established that the climatic water balance values even over such a small area as Cuba do not correlate closely with the limits of the vegetation belts. In the mountains of Pinar del Rio and Las Villas the P− E = 0 line only runs along the limits of the seasonal forests. In the montane regions of Oriente it coincides with the lower limits of the montane rainforests but in numerous places (Sierra del Cristal, Sierra del Purial) in areas of even 400–600 mm precipitation deficit there are wet montane rainforests. On the other hand, the south-east coast of Oriente and the middle of the Cauto basin are depicted on the map as equally deficient areas although the wetness and vegetation of the two regions are quite different.

10.2.2 Conclusions

We can conclude from all this, that precipitation surplus (S) precipitation deficit (d) and the PE terms in Thornthwaite's interpretation are primarily theoretical which do not or only minimally take into consideration the ability of the vegetation to economize with climatic and edaphic water resources by different means and ways. Thus it is not surprising that there is only a vague correlation between the vegetation types and Thornthwaite's formulae. Therefore his terms lack a bio-climatological and synecological concept. These terms can only be regarded ecological in relation to plant cultures where we are faced with an artificially simplified synbiological situation, namely the population of a single species and the only water utilization parameter being the useful yield.

10.2.3 New attempts at a rational climatic explanation

Thornthwaite's method was used by Blackie (1965) in the high montane regions of East Africa, while in West Africa Davies (1965) used it but he did not find the results to be satisfactory. More recently, Penman's PE formula (1948, 1956) has been judged to be more successful. Davies and Robinson's (1969) potential water loss, R_R formula is partly a further development of this. The spatial pattern of certain values of the water balance formula of these authors ($P-E_R$ i.e. precipitation – potential water loss) corresponds to the distribution of certain vegetation types in Nigeria.

10.3 The life-zone theory of Holdridge

In connection with the PE and vegetation mapping relationships, mention should be made of Holdridge's so-called ecological vegetation maps which mainly reflect Thornthwaite's influence.

Holdridge (1962) studying the relationship in atmospheric water cycles carried out an ingenious universal classification scheme of the world plant formation as "natural life-zones" (1967). The classification diagram devised by him rests on three factors:

- Annual total precipitation (P)
- Quotient of potential evapotranspiration (PE/P)
- Annual mean biotemperature (t°) where

$$t^\circ = \frac{\Sigma\, t\, 0^\circ}{12}$$

All three factors are projected in logarithmically graded scales; the first two reflected in a 60° angle to each other giving a tirangle of equal sides. This is divided along the presumed bioclimatic limit values P = 125, 250, 500, 1000, 2000, 4000, 8000 mm and PE (P = 0.25, 0.5, 1.2, 4, 8, 16, 32) parallel lines (t° = 1.5, 3, 6, 12, 24) are divided into hexagonal areas of equal sides of which each, represents a zonal formation and its ecological space.

10.3.1 The PE constant of Holdridge

The diagram is supplemented by a fourth coordinate axis which is parallel to the vertical axis t°. This represents the annual PE total which according to Holdridge is directly proportional to biotemperatures as in the equation below:

$$PE = t^\circ \times 58.93$$

In Holdridge's system, all plant formation bioclimatic limits are determined by the upper and lower limits of three factors P, PE/P and t°. In fact, going further, as PE is proportional to t°, the number of determining factors is two: the annual precipitation and annual biotemperature.

10.3.2 Critical remarks on Holdridge's formulae

Although Hämet-Ahti *et al* (1974) established that the bioclimatic vegetation sector worked out by them, in basic principles agrees with Holdridge's life-zones, the biotemperature index is not considered to be informative enough.

As for the Holdridge's PE constant, Borhidi (1973, 1976) demonstrated that it is valid only for tropical lowland climates which are wet all the year. Extending this to the whole life-zone is not right and it only serves to aggravate the uncertainty arising from the methodological flaws of Thornthwaite's PE. Borhidi furthermore proved that different empirical constants have to be worked out for all such areas where the distributions of temperature and atmospheric moisture do not change parallelly. In, for example, the montane regions, a special altitude correction factor has to be included whose value grows progressively, proportionally to the altitude.

10.3.3 Ecological maps of the life-zone system

With his graphical method, Holdridge established a school among forest experts in Latin America and in extratropical America too (Sawyer and Lindsay 1964, Steila 1966, Thompson 1966). Ecological maps have been prepared in Holdridge's system for all countries of Central America (1953—1962) furthermore, for Peru (Tosi 1960), Columbia (Espinal and Montenegro 1963), Equador and Venezuela too. The simplicity of the method provides a rather tempting opportunity to draw up an ecological vegetation map knowing the relief map and P and T values of the meteorological network of any country without even having seen the country, its vegetation and ecological conditions.

This possibility should be contemplated even if we have no reason for doubting whether the authors of those maps did visit the country they mapped. At the same time it is striking that, inspite of the often digressing or contradictory results of the vegetation plot analyses and the structural profiles diagrams made by them, they still rigidly adhere to the theoretical limits of the graphical system. In any case, the Holdridge's life-zone maps create the impression that very often there is no real correlation between the theoretical structure and the real distribution patterns of the vegetation. This seems to be confirmed by Holdridge *et al.* (1971) imposing huge book on the forest ecosystems of Costa Rica where within a life-zone the most diversely structured and composed forests are discussed by the authors.

10.3.4 A few critical observations

Holdridge's classification system can be rightly criticized for its theory. Only the more important flaws are listed:

- The annual 24° isotherm can hardly be regarded as the limit of the tropical and subtropical belt everywhere.
- A general flaw of the classification is that Holdridge's terms such as rather dry forest, dry forest humid forest, moist forest, wet forest etc. are very uncertain categories whose concrete physiognomic properties — at least for a time — have not been clarified and this makes for rather subjective interpretation.
- The formation frameworks given by way of the Holdridge system in certain intervals — for example between P = 500—2000 m – is grossly exaggerated, since in this province only two formations are distinguished:

a) tropical rather dry forest and

b) tropical dry forest

whereas — not to mention the impossible terminology; in reality 3—5 zonal formations may alternate under appropriate seasonal precipitation distribution (c.f. Figs 37, 38 and Walter's and Borhidi's diagram). At the same time, in other intervals e.g. P = 2000—8000 mm — the number of possible plant formations is much too high. There is no real, well-defined structural difference between Holdridge's tropical humid, moist, wet rainforests.

It is a mistaken presumption that with an annual precipitation throughout the year of 8000—10 000 mm, the quality and production of the forests improves continuously. In reality, above an evenly distributed annual precipitation of 3000 mm the quality of the forests does not improve, in fact, above 4000 mm it definitely deteriorates as for example in Africa and the Amazonas basin (c.f. Aubréville 1965:305) probably in consequence of the accelerated latosolization and soil deterioration due to soil erosion.

10.3.5 The ecological map of Cuba and its critical appraisal

In judging the merit of a method it is often worth more to try it in practice. So I made an ecological map of Cuba (Fig. 50) according to Holdridge's method and compared it to my field experiences. The findings which I concluded are the following:

a) The Holdridge system of ecological maps gives 10 climazonal formations instead of, in reality, 8 vegetation belts.

b) The "tropical thorn forest" in its distribution corresponds to that of the cactus scrub vegetation of semi-desert shrubs.

c) Instead of the "tropical very dry forest" or savanna, there are xerophilous evergreen shrub forests in Cuba, their distribution however, differs considerably from the area on the ecological map because in reality they occur in the north and southern coastal areas of West and Central Cuba but are missing in the Cauto basin.

d) The "tropical dry forest" belt roughly corresponds to the semi-deciduous forest zones, but in reality within this belt there are a further 3 climazonal vegetation types to be found depending on the seasonal precipitation distribution and the rock formation or quality of the soil (seasonal evergreen forests, small-leaved, semi-deciduous and evergreen shrub forests).

e) The tropical wet forest is exactly equivalent to the submontane rainforest belt.

f) The "subtropical dry forest" formation only exists on the map, in reality it does not differ from the semi-deciduous forests.

g) The equivalent of the "subtropical wet forest" in reality is the seasonal evergreen forest which is not subtropical at all and is not confined to the montane regions as is supposed to be according to the ecological map. Holdridge considers that this formation type in Cuba should be widespread in the mountains up to 1000 m. Instead, in reality, the seasonal evergreen forest belt is to be found in Sierra Maestra up to 800 m and in the Sagua Baracoa mountains not higher than up to 400 m.

h) Holdridge's "subtropical very wet forest" in Cuba does not differ from the "rather wet montane forests," in reality, both are montane rainforests whose distribution actually is much larger than on the map.

i) Between the "montane very wet forest" and the "high montane very wet forests" there is no difference — at least in Cuba. Both are mossy forests.

10.3.6 Conclusions on the life-zone system

We are of the opinion that the Holdridge's ecological model is to be praised for its originality. It would deserve to be scrutinized and by extensive comparison and critical appraisal be rid of its theoretical flaws and its rigid application by which this model has mostly been used. I agree totally with Holdridge in his attempts to model the world vegetation types according to bioclimatologic parameters (see point *6.2.1*). The key problem of success in vegetation mapping is to be able to determine the closeness of the correlation between bioclimate and vegetation types. This task was attempted by me using several methods and for smaller areas relating to Cuba.

There is no question of the need for such a large-scale and valid ecological model, and it is not unlikely that the Holdridge's life-zone system may be the starting point for such a model. For this, however, several things would be needed:

- Much parallel bioclimatic and vegetation research,
- Critical and reciprocal checking of the results of theoretical and field research
- Dynamic approach. The vegetation type should not match the theoretical compartment but the theoretical aspect should be determined on the basis of the real distribution patterns of the vegetation.
- Development of a nomenclature approaching the modern physiognomic classification of vegetation types.

10.3.7 Life-zone system and biotypes of tropical trees

I should like to point out several ecological fields where the Holdridge model in its present form is extremely suitable. Such is, for example, the study of the ecological amplitude of tree species and in connection with this the biotype research of trees. Holdridge in his excellent book (Holdridge *et al.* 1971) described the ecological pattern of numerous tree species in a very instructive way in the life-zone system. In my experience, numerous neotropical tree species could be observed with various ecological patterns of behaviour in the Antilles (e.g. in Cuba) as the diagrams prepared in Costa Rica show. Such surveys on the whole area of distribution of tree species could greatly promote knowledge on the biotypes of tropical tree species.