Appendix B
Climatic Classifications

Koeppen's System

In 1900, Wladimir Koeppen published a climatic classification that with modifications (Koeppen 1936), is still used by geographers today. He conceived the idea that plants integrate climatic elements, and their distribution defines climatic regions. His main climatic classes for tropical America are as follows:

A. Tropical: coolest month has average temperatures above 18 °C
- Ar = Wet: driest month has at least 6 cm of rainfall
- Am = Monsoon: short dry season, but ground continually wet
- Aw = Wet and dry: distinct dry season of at least 1 month with less than 6 cm rainfall

B. Dry: evaporation exceeds precipitation
- Bs = Steppe: rainfall above the mean for the group
- Bw = Desert: rainfall below the mean for the group

The tropical wet climate (Ar) covers eastern Central America, parts of the Caribbean Islands, western Colombia, the Guianas, the Amazon Basin, and the Atlantic margins of Brazil (fig. B–1). Mean monthly temperatures are seldom higher than 27 °C because of cloudiness, which ranges up to 60 percent. Nevertheless, because of slight air movement, the atmosphere has low cooling power. Annual precipitation is generally more than 180 cm.

The Amazon Basin is the world's largest area of tropical wet climate. However, only the area upstream from Manaus is without 1 or 2 dry months. Along Brazil's Atlantic coast, from south of Cape St. Roque to about 13° S. latitude, late spring and summer are relatively dry. The heavy precipitation in the Pacific lowlands of Colombia results from unstable equatorial air that enters from the west and southwest and is blocked by high mountains. In this region, rains are most common between midnight and 4 a.m. On the Caribbean slopes of Central America and the West Indies, summer rains decrease briefly during July and August.

The tropical wet-and-dry climate (Aw) has less precipitation and a longer dry season than the tropical wet climate (Ar). It generally occurs between 5° and 20° S. latitude. The rain forests of the Aw areas give way to less dense, more deciduous forests and tree-studded grasslands called "savannas." The change in vegetation gradually intensifies as the latitude increases. The warmest season generally precedes a heavy rainy period. Annual precipitation is commonly 100 to 150 cm. The wet season (Koeppen's Aw) resembles the Ar climate, and the rest of the year resembles desert or arid (Bw) climate.

The campos of interior Brazil south of the rain forest areas are Earth's most extensive region of Aw climate. Rainfall is strongly concentrated in the high-sun season. The llanos of Venezuela and Colombia are a counterpart to the Brazilian campos. Other Aw areas in tropical America include a small section on the Pacific side of Ecuador near the Equator, the Pacific side of Central America, the Yucatan Peninsula, and the low-elevation islands of the West Indies.

Thornthwaite's System

Thornthwaite (1948) endorsed Koeppen's system of defining climatic regions according to the distribution of vegetation. Nevertheless, he concluded (Thornthwaite and Hare 1955) that the system was futile as a method for classifying forest climates, pointing out that simple temperature and precipitation values are not parameters of actual vegetation control by climate. However, he extended the climatic classification to include estimates of water loss as a balance against precipitation by estimating potential evapotranspiration; that is, evapotranspiration that would ensue if adequate water were continually available. Thornthwaite and Hare (1955) list four factors responsible for evapotranspiration:

- Supply of external energy to the evaporating surface (principally by solar radiation)
- Capacity of the air to remove the vapor (dependent on wind speed, turbulent structure, and the decrease of vapor concentration with height)
- Nature of vegetation (especially its capacity to reflect incident radiation, how extensively it occupies the soil, and the depth of its root system)
- Nature of the soil (especially the amount of water in the root zone).

The capacity of vegetation to reflect radiation (albedo), expressed as a percentage of the radiation received, was measured in the Temperate Zone in the 1920's (Angstrom 1925). For grasslands, the albedo was about

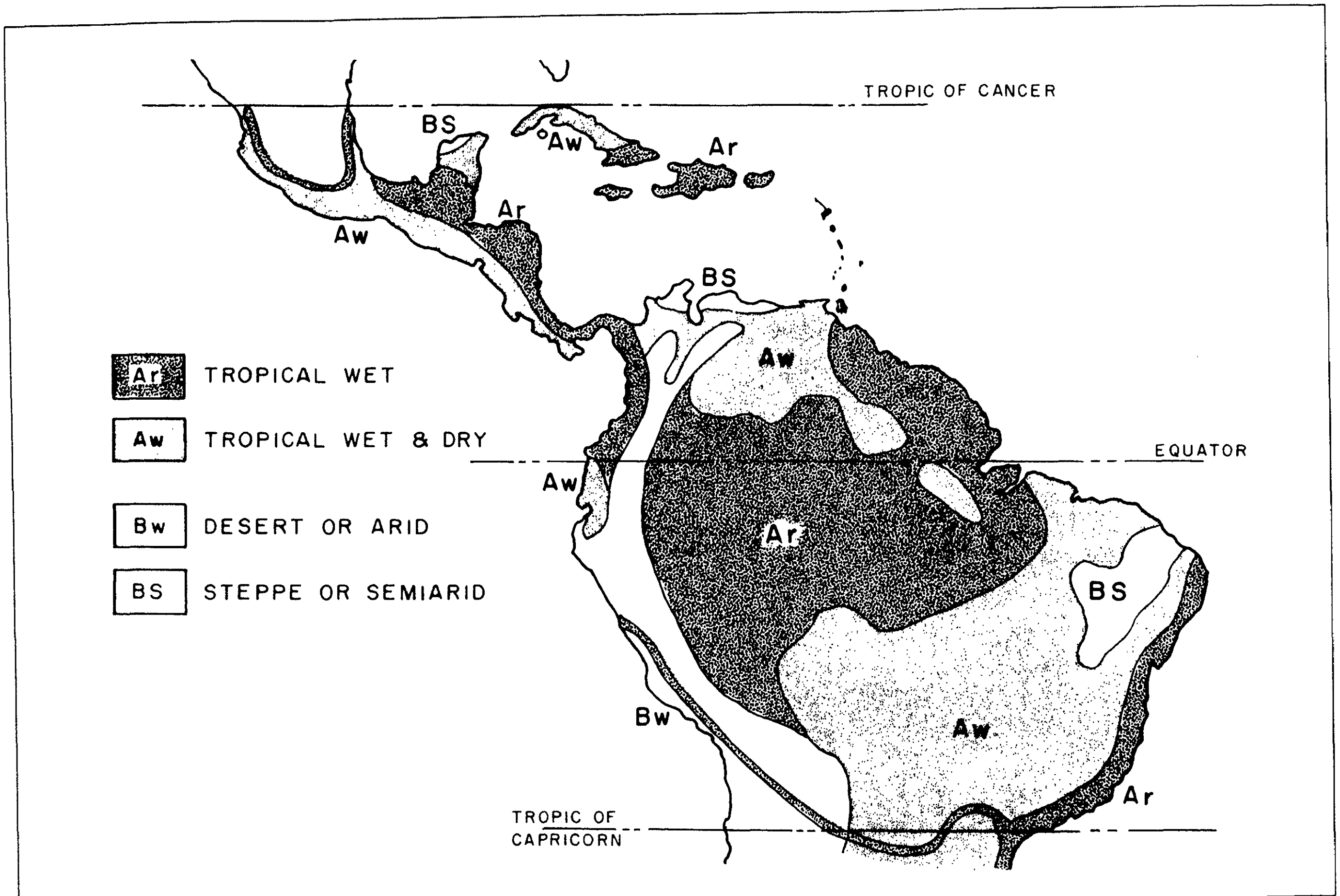

Figure B–1.—*Koeppen's climatic zones, as modified by Trewartha (1968) for tropical America.*

0.26 (26 percent), for oak woodlands, 0.175, and for pine forests, 0.14.

Potential evapotranspiration is an index of thermal efficiency. The relationship between the logarithm of potential evapotranspiration and the logarithm of temperature is linear; therefore, temperature, adjusted for day length, is a measure of thermal efficiency.

The first step in determining potential evapotranspiration by Thornthwaite's scheme is to determine the "heat index" by adding values derived for the mean temperature for each month (table B–1). Once the aggregate heat index is deduced, the potential evapotranspiration rate (unadjusted for day length) is derived from a chart for each monthly mean temperature. Each unadjusted monthly potential evapotranspiration value is then multiplied by a factor for day length (Thornthwaite 1948).

From these relationships, also assuming 30-cm water storage in the soil, Thornthwaite and Hare (1955) developed a water budget that includes actual monthly

Table B–1.—Heat index values for monthly mean temperatures between 10 °C and 30 °C

°C	Index	°C	Index
10	2.9	22	9.4
12	3.8	24	10.8
14	4.8	26	12.1
16	5.8	28	13.6
18	7.0	30	15.1
20	8.2		

Source: Thornthwaite 1948.

evapotranspiration and months of water deficit and surplus. The end result is illustrated in figure B–2 (Golfari 1968b). During any month of the year, water may be either deficient or excessive. Part of the excess may go to replenish soil-water storage before a surplus recurs.

A moisture index was derived by Thornthwaite as follows (1948):

$$Im = \frac{(100\,s - 60\,d)}{n}$$

where s = annual water surplus
d = annual water deficiency
n = annual potential evapotranspiration, or water need.

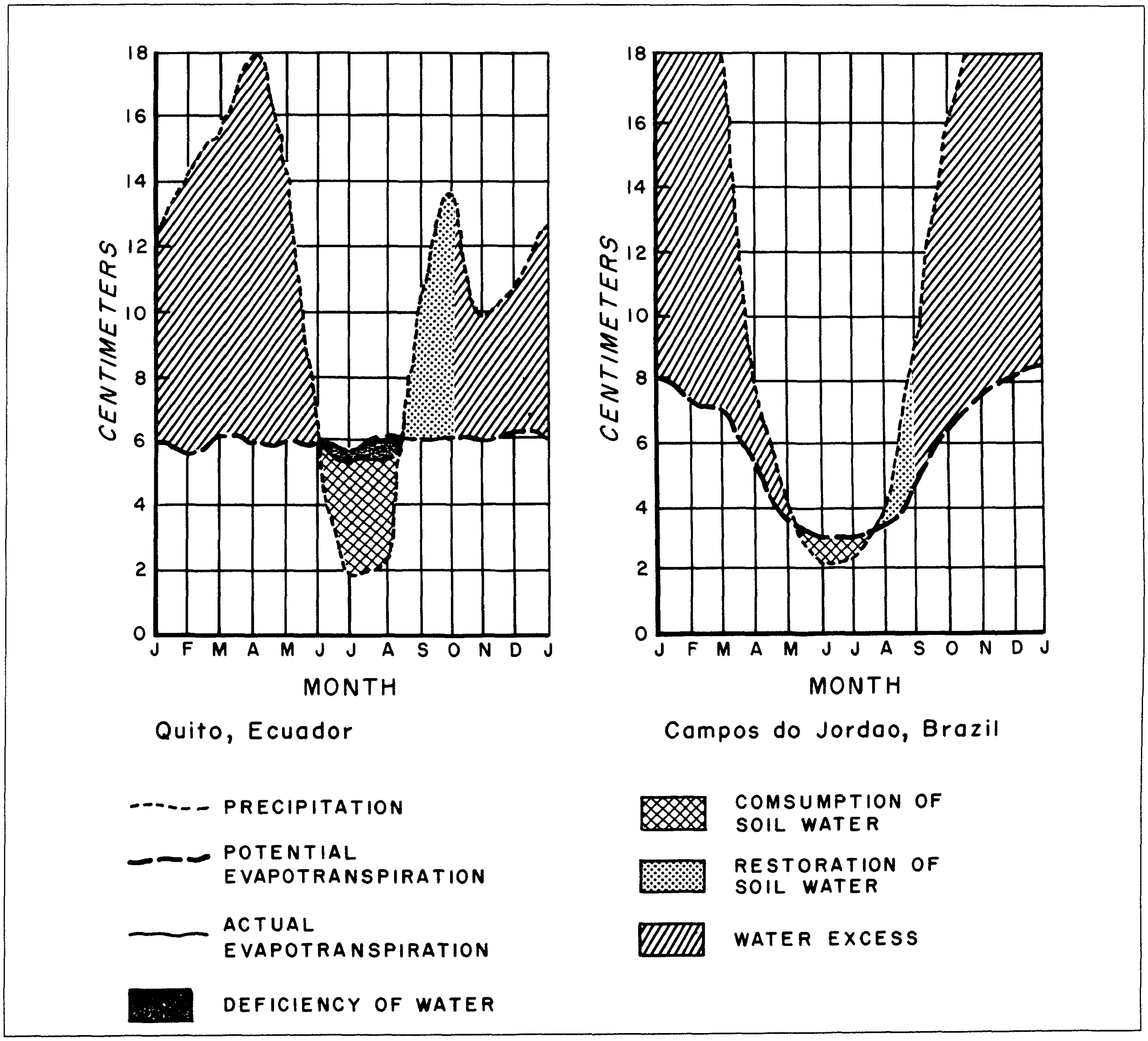

Figure B–2.—*Results of application of Thornthwaite procedures to two climates (Golfari 1968b).*

He classified climates with an index of +100 or more as "perhumid"; those +20 to +100 as "humid"; those −20 to +20 as "subhumid"; those −20 to −40 "semiarid"; and those below −40 "arid." A weakness of the system is the derivation of potential evapotranspiration from temperature data alone. The results are not always reliable, but the system permits an estimate where more accurate formulas cannot be applied (Cochrane and Sanchez 1981).

The Holdridge System

Holdridge (1947) published a diagrammatic classification of life zones worldwide, which, with subsequent modifications (Holdridge 1967), has been applied in many countries of tropical America. The zones are defined by geometrically progressive limits of mean annual precipitation and mean biotemperature. The latter is derived for an average year by adding all hourly temperatures between 0 and 30 °C (the presumed limits for plant growth) and dividing by the total number of hours in the year. Figure B–3 illustrates the system for the region.

Holdridge's tropical zones all have mean biotemperature in excess of 24 °C; his subtropical zones average 18 to 24 °C and are generally frost free. At low (basal) elevations, these two zones correspond roughly to the equatorial and outer Tropics defined elsewhere. The basal Tropics is at elevations corresponding to biotemperatures of about 24 to 18 °C (about 500 to 1,500 m). A premontane altitudinal belt is found at 18 °C or 1,500 m. Above it, from about 18 to 12 °C (1,500 to 2,500 m) is the lower montane zone, and so on. At latitudes classed subtropical at sea level (24 to 18 °C), the first altitudinal belt (18 to 12 °C) is called lower montane (500 to 2,500 m), and that from 12 to 6 °C (about 1,500 to 2,500 m) is termed montane, and so on. Land areas in each of Holdridge's life zones of Central America (excluding Belize) are summarized in table B–2 (Budowski 1964b).

One of the main advantages of Holdridge's system is that it is based on climatic parameters that may be already available: mean annual precipitation and biotemperature. The latter, however, requires a record of hourly temperatures. Where this is not at hand, Holdridge

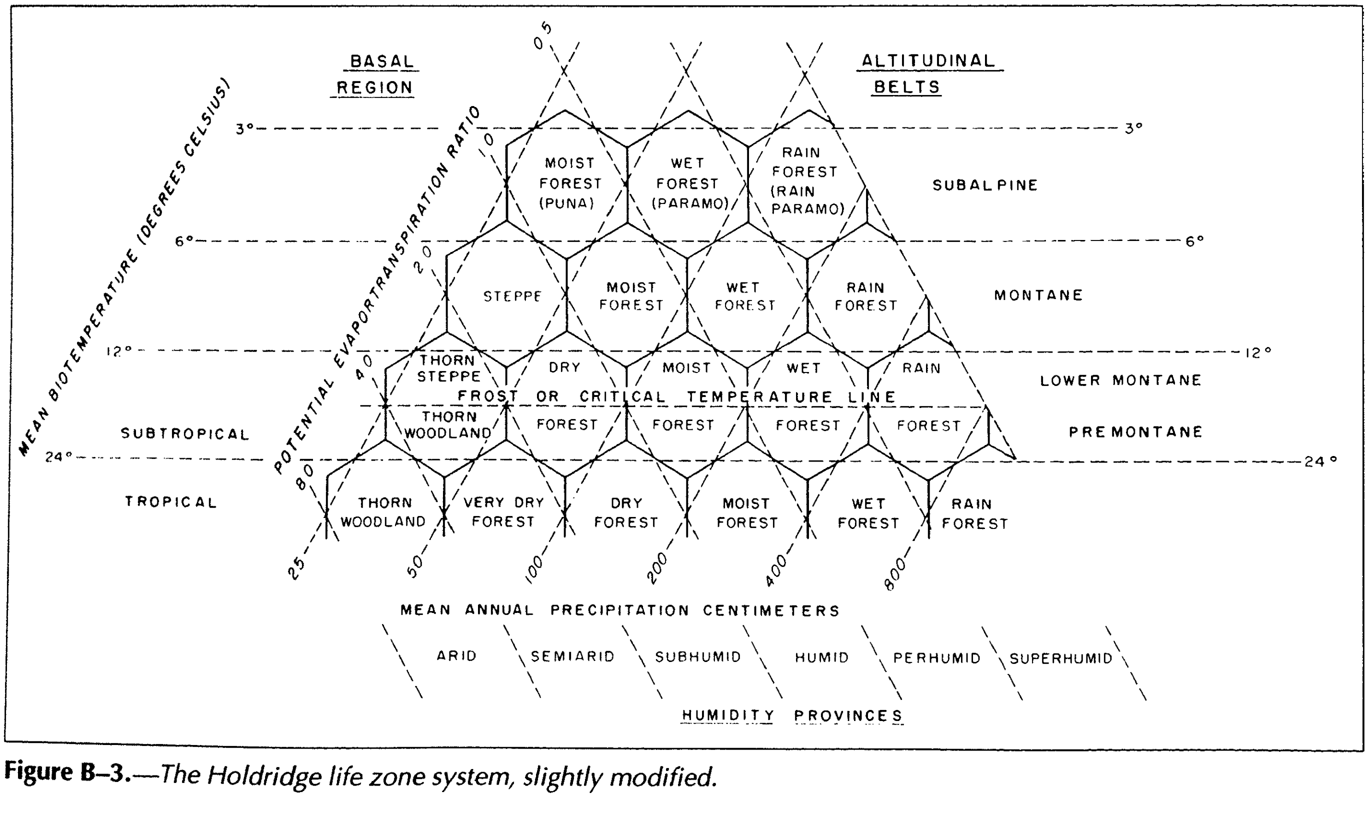

Figure B–3.—*The Holdridge life zone system, slightly modified.*

Table B-2.—Land area in life zones in Central America (thousand km²)

Altitudinal belt	Total area by precipitation zones					
	Very dry	Dry	Moist	Wet	Rain	Percent
Tropical	6.2	98.5	171.8	9.5	0.0	60
Subtropical	0.0	16.6	64.5	72.9	0.8	32
Lower montane	0.0	0.3	19.8	12.7	0.7	7
Montane	0.0	0.0	0.8	1.3	trace	1
Subalpine	0.0	0.0	0.1	1.3	trace	1
Percent	1	25	54	20	trace	100

Source: Budowski 1964b.

approximates biotemperature for the outer Tropics by the following formula (Holdridge 1978):

Biotemperature =

$$\frac{\text{Mean t °C} - (0.3)\ (\text{° latitude})\ (\text{mean t °C} - 24)^2}{100}$$

where t °C = temperature in degrees Celsius.

Holdridge's system differs from others in its geometrically progressive scales, primary reliance on annual means (for describing seasonal climate), and altitudinal belts. Its large number of zones complicates mapping on a global scale. Nevertheless, a series of large-scale (1:250,000 to 1:1,000,000) maps for individual countries in Central America, the Caribbean, and northern South America has been completed. Figure B–4 is a much-reduced map of Puerto Rico from this series (Ewel and Whitmore 1973).

Walter's System

In 1964, Walter (1971) diagrammed world climates by superimposing monthly temperature and precipitation on vertical scales in which 10 °C equaled 20 cm of precipitation (fig. B–5). In these diagrams, the station is identified at the top, followed by its elevation in meters. To the right are mean temperature in degrees Celsius and annual rainfall in millimeters. The number of years of record is indicated below the station name. At the lower left corner are the mean temperature of the coldest month and, below it, the extreme minimum temperature. The horizontal scale is the months of the year, with the warm season placed centrally (opposite in the southern and northern hemispheres).

The vertical scales are temperatures with 10 cm intervals on the left and 20 mm monthly rainfall intervals on the right, the scale reduced to one tenth above 100 cm. The dotted area is defined as "relatively droughty," and the area with the vertical lines "relatively humid." The solid black area indicates rainfall in excess of 100 mm monthly. This system shows the seasonal pattern of moisture availability without estimating potential evaporation or soil-moisture storage. World maps with charts for most regions, accompanied by data on elevation, mean temperature, and annual precipitation, facilitate broad comparisons of climate. This system recognizes nine climatic zones, two of which are clearly tropical (fig. B–6):

I. Equatorial zone—10° N. and 10° S. latitude, two rainy seasons, rainfall and humidity very high and little temperature variability.

II. Tropical zone—10° to 30° N. and 10° to 30° S. latitude, moist summer season, coinciding with or lagging behind the latitude of the Sun, rainfall decreasing with distance from the Equator; generally frost free.

Other zones shown on Walter's map (fig. B–6) include subtropical arid (III) and warm temperate (V). He notes that the mean temperatures decrease outward from the Equator more rapidly in the Southern Hemisphere than in the Northern, although the seasonal differences increase less rapidly, because of the buffering effect of the smaller land mass in the Southern Hemisphere. For the same reason, temperature differences increase with distance inland from the coast.

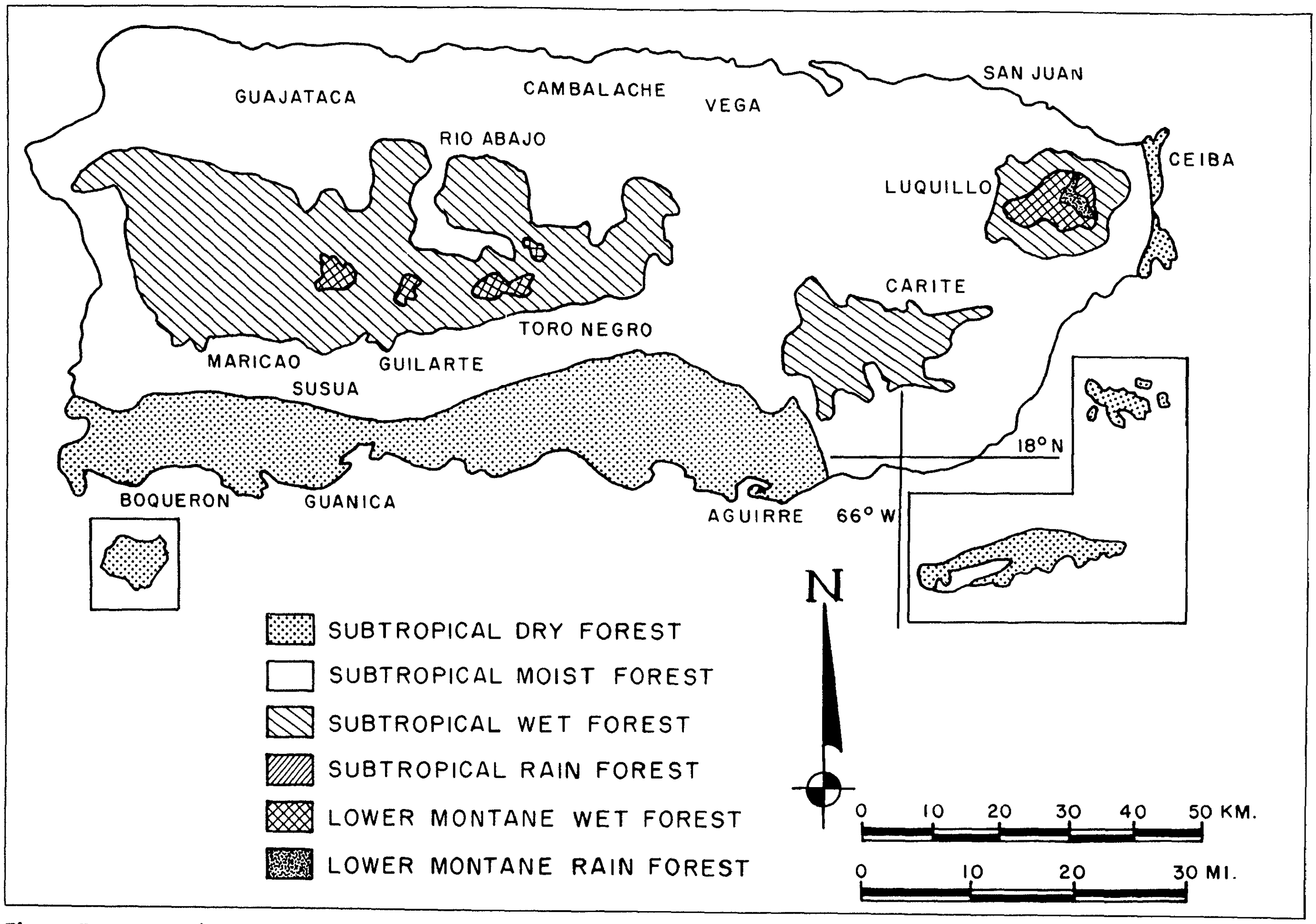

Figure B-4.—*Application of the Holdridge life zone system to Puerto Rico (Ewel and Whitmore 1973).*

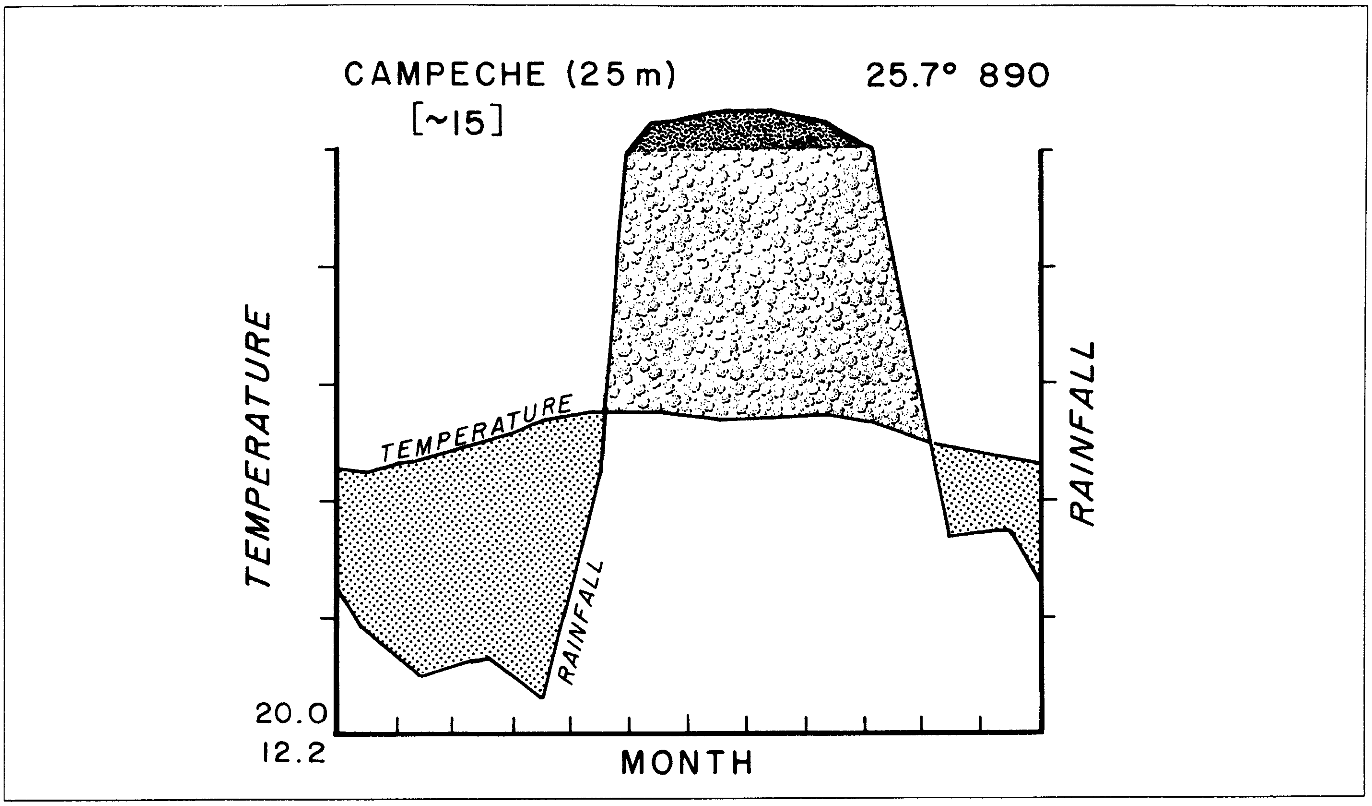

Figure B–5.—*Example of Walter's diagram of world climates (Walter 1971). Campeche = station being monitored; 25.7 = mean temperature in degrees Celsius; 890 = annual rainfall in millimeters; [~15] = number of years of record; 25.0 = mean temperature of coldest month; and 12.2 = extreme minimum temperature.*

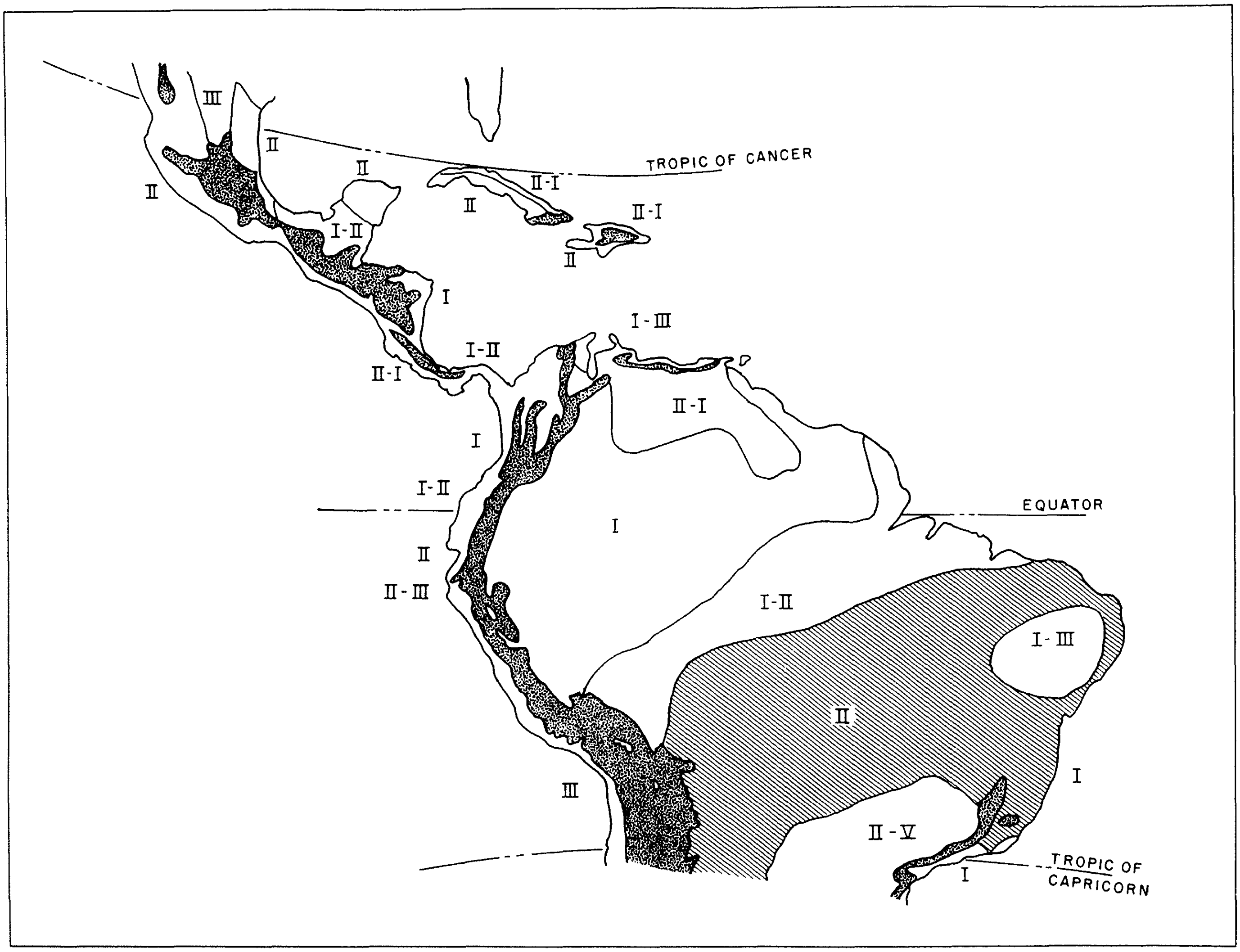

Figure B–6.—*Of the nine recognized climatic zones, four are in Central and South America: I = equatorial; II = tropical; III = subtropical arid; and V = warm temperate (Walter 1971).*