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# ENVIRONMENT AND SEASON IN A TROPICAL DECIDUOUS FOREST IN NORTHWESTERN MEXICO

by

Richard Donald Krizman

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THE UNIVERSITY OF ARIZONA

GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by Richard Donald Krizman

entitled ENVIRONMENT AND SEASON IN A TROPICAL DECIDUOUS FOREST IN NORTHWESTERN MEXICO

be accepted as fulfilling the dissertation requirement of the degree of DOCTOR OF PHILOSOPHY

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After inspection of the final copy of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

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SIGNED: Richard Donald Krizman

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ABSTRACT

During each of the four seasons of the year, with special emphasis at the time of the onset of the summer monsoon, micro-environmental parameters were monitored near Alamos, Sonora, Mexico, in the northern edge of the tropical deciduous forest.

The vegetation of this area is characterized as being seasonally, spring and early summer, deciduous. Forest stature is very low, 10-15 m, and is composed of two tree strata. The A-stratum canopy is discontinuous and consists of widely spaced individuals or clumps. The B-stratum is nearly continuous and is composed of numerous codominant species of short trees. Giant cacti constitute a significant component. Woody lianas are common while epiphytes are rare.

Two shrub strata exist. C-stratum shrubs, composed of a small number of species, are 2-5 m tall, often multiple stemmed and may obtain coverages of 50%. D-stratum shrubs are less than 1 m tall, are often in consociation, and make up coverages of 65%. An ephemeral herbaceous E-stratum exists, mainly following the summer rains.

The monitoring of nine thermistors on an 18 m tall mast showed air temperature profiles which changed in character during the seasons of the year. In all seasons nocturnal mean temperatures at crown height were warmer than those near the ground. Diurnal temperatures were

observed to switch; in the leafless seasons ground-level temperatures were warmer and during the remainder of the year crown-level temperatures were warmer.

Surface soil temperatures in the forest reached high levels and fluctuated widely in the leafless positions of the year. With the onset of the summer rains and subsequent foliage development, maximum surface temperatures dropped by 30°C and daily fluctuations were one-fifth of earlier values.

Mean daily relative humidity (computed from readings taken every 2 hrs for two days) was lowest in the spring, 31%. This value rose to 86% during the monsoon season.

Light reaching the substrate approached the value of open light when the forest was leafless (90%). In late summer this value dropped to 3-5%. It then increased through autumn and winter as the forest sheds its leaves.

Soil moisture was near field capacity during the monsoon period and reached far below the permanent wilting point in the leafless seasons.

# INTRODUCTION

The tropical deciduous forests of North America form a continuous ribbon of vegetation along the foothills of the Pacific coast from southern Sonora, Mexico, to Panama. This band has an average width of 50 kilometers and shows two significant extensions inland. One of these extensions follows the periphery of the Rio Balsas Basin eastward to a point between the cities of Puebla and Tehuacan. The second major extension is in extreme southern Mexico, cutting into the Isthmus of Tehuantepec and the interior valley of Chiapas. Discontinuous portions of the forest are found in southern Tamaulipas, northern Yucatan and the tip of Baja California. In the south the tropical deciduous forest grades into tropical evergreen forest and rain forest. In the north the tropical deciduous forest gradually gives way to thorn forest and desert scrub (Leopold 1950, Shelford 1963).

As a forest type the tropical deciduous forests are associated with distinct annual wet and dry seasons. The trees are one or at most two storied and most are wholly or partly deciduous during the dry season. Barbour (1942) classified this forest type as intermediate between dry forests (= thorn forests) and rain forests.

Beard (1944, 1955) systematically subdivided American tropical forests into several formation series. Rain forest (three stories of evergreen trees with the upper stratum continuous) is considered the optimum formation. Following it, in the seasonal formation series are evergreen seasonal forest (three stories with the upper stratum discontinuous and strongly deciduous); semi-evergreen seasonal forest (two stories with the upper continuous and facultively deciduous); and deciduous seasonal forest (two stories with the upper discontinuous and obligatively deciduous). This series proceeds through thorn woodland and cactus scrub.

Leopold (1950) presented the first reasonable map of Mexican vegetation. He divided tropical forests into: rain forest, evergreen forest, deciduous forest, and thorn forest. The tropical evergreen forest was described as a secondary and dry phase forest.

Shelford (1963) refers to the luxuriant tropical rain forest, poor tropical rain forest, tropical deciduous forest and thorn forest. He equates poor tropical rain forest to Leopold's tropical evergreen forest and states that it includes hydroseral and xeroseral stages and secondary forests. Shelford divides the tropical deciduous forest into northern short tree communities which extend southward to Chiapas and southern tall tree communities which continue to Panama. It is not clear how Beard's forest types relate to the vegetative types of Leopold and Shelford.

In The Ecology of North America, Shelford (1963) includes sections on the general ecology of the tropical deciduous forests. Regional descriptions of the tropical deciduous forest have been written by the following: Miranda (1952), the Chiapas region; Miranda (1942, 1947), the Balsas Basin; Martin (1958), Tamaulipas; Gentry (1946a, 1946b), northern Sinaloa and Gentry (1942), the Rio Mayo of southern Sonora. Gentry (1942) is an excellent presentation of, as he named it, the short tree forest (= tropical deciduous forest) of southern Sonora.

Based upon plants and/or vertebrates Smith (1940), Dice (1943) and Goldman and Moore (1946) treated the tropical deciduous forests of Sonora as the Sinaloa Biotic Province. Alden's (1969) bird guide to western Mexico provides bird lists for several localities in the tropical deciduous forests of Sonora, Sinaloa and Nayarit. Burt (1938) is a good reference for the mammals of Sonora and Bogert and Oliver (1945) for its herpetofauna. Recent publications regarding the biota of the tropical deciduous forest of southern Sonora include: Leshan et al. (1965), natural history; Patton (1969), pocket mouse evolution; and Wiewandt (1971), leaf-frog breeding.

The immense amount of work done by the Holdridge group in Columbia, Central America, and especially Costa Rica suggests, that in these regions the Life Zone Classification of Holdridge may supplant previous systems. This orderly and predictive classification of world vegetation is based upon climatic parameters. Costa Rica was mapped after the Holdridge classification and recent quadrat analyses have described vegetation units. Macroclimatic data from stations in the tropical deciduous forest of northwestern Mexico fall near Holdridge's tropical very dry forest life zone. This type does not occur in Costa Rica, so was not described by Holdridge et al. (1971).

The extreme northern limit of tropical deciduous forest in northwestern Mexico is not known. Gentry (1942, p. 31) in his treatise on the vegetation of the Rio Mayo, states in reference to the tropical deciduous forest that, "To the north it is like a tail pinching out in the northern barrancas."

Shreve (1951) placed the southern boundary of the Sonoran desert, therefore the northern boundary of thorn forest and tropical deciduous forest, in southern Sonora between the Rio Yaqui and Rio Mayo

Leopold (1950) extended the tropical deciduous forest northward into the basin of the Rio Yaqui. This region is the eastern portion of Shreve's Foothills of Sonora subdivision of the Sonoran Desert.

The last contiguous portions of tropical deciduous forest are probably in the Rio Mayo Basin, but a few patches are found in the Rio Yaqui. Shreve was stretching the point in calling the Yaqui Basin a desert and Leopold was stretching in calling it tropical deciduous forest. In any event there is no dispute that tropical deciduous forest is found in the Rio Mayo Basin.

The basic question asked in this study is what is the seasonal character of physical and botanical parameters in the tropical deciduous forest of the Rio Mayo. It is hoped that this study constitutes a step toward the understanding of some of the factors which influence the distribution and behavior (therefore evolution) of species in this northern most extension of tropical deciduous forest in North America.

# PROCEDURE

## The Trip

From Tucson a round-trip to the tropical deciduous forests of northwestern Mexico is about 1,600 kilometers (1,000 miles). Driving south from Tucson one quickly leaves the Arizona Upland subdivision of the Sonoran Desert (Shreve 1951) and climbs through grasslands. The Mexican border, higher yet, is in evergreen oak woodland.

The road then descends back into Arizona Upland subdivision desert. This grades into the Plains of Sonora subdivision and it, prior to Guaymas, into the Central Gulf Coast subdivision. Near Cuidad Obregon a strip of Foothills of Sonora subdivision is crossed and north of Navojoa one finally leaves the desert and enters thorn forest. This vegetation type covers the coastal plain and extends well into southern Mexico. Tropical deciduous forests are found back from this coastal strip along the foothills of the Sierra Madre Occidential.

The only all-weather road to penetrate the northern extensions of the tropical deciduous forests of northwestern Mexico is the highway to Alamos in southern Sonora. Replacing an unreliable dirt road, this modern highway was opened to traffic in 1960. It branches east from Highway 15, Mexico's Pacific Coast Route, at the city of Navajoa and extends for 57 km (34 mi) to end at the foothill town of Alamos.

Navojoa lies on the coastal plain of northwestern Mexico just south of the point at which the thorn forest vegetation from the south grades into the Sonoran Desert scrub vegetation to the north. In recent years agriculturalists have converted much of this plain to modern farms irrigated by gravity flow from major river dams in the adjacent mountains (Dunbier 1968). The elevation of Navojoa is 38 m (120 ft), average annual precipitation is 385.9 mm (15.2 in.) and the natural vegetation is thorn forest. This vegetation type extends east along the Alamos Highway for about 17 km (10 mi). Here, at an elevation of about 115 m (350 ft), the highway passes the base of the first of numerous rocky hills. Noticeable tropical deciduous forest elements appear on these hillsides. In the next 25 km (15 mi) the highway climbs to 344 m (1050 ft). The adjacent hills grow into mountains and tropical deciduous forest elements become common along the roadside. This is an ecotone area.

For the next 7 km (4 mi) the highway climbs through a dissected escarpment to "top-out" at 524 m (1600 ft). Well-developed tropical deciduous forest mantles this hilly section. After "topping-out" the road leaves the Rio Mayo Basin and enters the drainage of the Rio Fuerte. It straightens, passes the village of Minas Nuevas and gradually descends for 8 km (5 mi) before entering the old mining town of Alamos. The elevation here is 389 m (1276 ft) and the average annual precipitation is 638.6 mm (25.1 in.). The vegetation surrounding Alamos is disturbed by small-scale farming and livestock. It is more xeric and again suggests a tropical deciduous forest-thorn forest ecotone.

## Study Area

A primary study area was established about one mile south of the Alamos Highway in the hilly section mentioned above. Here a side road allows access to the north flank of the Sierra Alamos, an isolated mountain mass which attains an elevation of 1914 m (5837 ft). In selecting the exact location to monitor environmental parameters and establish a one-tenth hectare study plot (0.247 acre) several factors were considered: 1) the tropical deciduous forest had to be well developed and representative, 2) the topography should be typical of the area, 3) disturbance must be minimal, and 4) it was desired to have within the plot one of the overstory trees (Conzattia sericea) and also a large hecho cactus (Pachycereus pecten-aboriginum).

The site chosen was at an elevation of 524 m (1600 ft) and was on the south side of a small westward drainage. The 50 m long baseline of the plot extended east-west across the elevational gradient and was slightly up from the bottom of the drainage. The short dimension of the quadrat (20 m) was oriented north-south and followed the gradient. Slope angle in the eastern half of the plot measured 26° with slope direction 15° east of north. The irregular slope angle along the western portion of the plot had an average angle of 21°. In the middle of this part of the plot a shelf containing a slight raise protrudes from the slope, this irregularity produces a variable slope direction. Its direction was generally northward but there was significant exposure to the west and even south. All quadrat analysis and microenvironmental studies were conducted within this 20 x 50 m plot. Permanent stakes mark the corners.

## Disturbance

Little is known of the pre-historic inhabitants of southern Sonora. The region is on the southern edge of what is called the southwest culture area (Willey 1966), an area characterized by pre-historic native agriculture. This character was shared with the mesoamerican culture area to the south. But the southwest culture area is separated from the mesoamerican culture area by the latter's more highly developed level of social integration. Other adjacent culture areas (Great Basin, Plains and Northeast Mexico-Texas) lacked agriculture. Historically, the Mayo Indians inhabited the flood plains of the lower Rio Mayo Basin (Spicer 1962). They were community dwelling farmers and probably had little effect on the tropical deciduous forest which covers the adjacent foothills.

After the coming of the Spanish, and the discovery of silver in the Alamos region in 1683 (French 1962), the loc l forests provided mine and building timbers and fuel. Cattle, horses and burros were grazed everywhere and fields were cleared for agriculture.

The area selected for the study site had probably been disturbed only by grazing until the completion in 1960 of the new Navajoa-Alamos Highway. Since that time the forest has been subjected to extensive cutting for fence posts and firewood. Local, especially rural inhabitants, still use selected forest materials in home and furniture construction (Gentry 1942, Krizman 1968). During the past ten years numerous fields have been cleared in the ecotone areas. The hilly area of well-developed tropical deciduous forest is generally too steep for cultivation but is subjected to grazing and increased woodcutting.

## Instrumentation

Environmental parameters were monitored during each season of the year and in detail at the onset of the summer rains. At each visit an 18 m tall telescoping radio antenna mast, with thermistor probes attached at intervals, was set up (Figure 1). This air temperature column was located next to and supported by the overstory tree contained within the plot, a 17 m tall Conzattia sericea. The base of the mast was located near meter 46 on the abscissa of the profile diagram shown in Figure 4.

Each probe was shielded from direct solar radiation and rain by securing it within a short aluminum foil-covered cylinder which was in turn suspended vertically beneath an inverted foil-covered plastic funnel. Shielded probes were attached to the mast at increasing intervals (0.5, 1, 2, 3, 5, 7, 10, 14, and 18 m) above the ground. Temperatures were read on a multi-channel telethermometer (Yellow Springs Instrument Co., Inc., Model 44TZ, Yellow Springs, Ohio).

Air temperature at one centimeter above ground was determined with a rapid adjusting mercury-in-glass thermometer (E. W. Schultheis Corp., Arkville, New York). To measure surface temperature the mercury bulb of this same thermometer was partly embedded in the substrate. For soil temperatures spike thermistors and/or mercury-in-glass thermometers were set at depths of 2, 5, 10, 20 and 50 cm. Surface and soil temperatures were taken at a level station in the west portion of the plot.

Ambient on-plot relative humidity was measured with a sling psychrometer. Light meter readings (Weston Illumination Meter, Model


Figure 1. Photograph of Air Temperature Column. -- Mast with attached shielded thermistors is supported by an overstory tree, Conzattia sericea. Photographed October 20, 1967.

756, Weston Instrument Division, Newark, New Jersey) were made with the sensing plate laying on the ground surface and held one meter above. At both levels readings were made at several locations and the mean was recorded. Light meter readings in foot candles (fc) may be roughly converted to Langleys by dividing by 6700 (Kimball 1924). The intensity of open (unobstructed) light was measured in a nearby clearing. A rain gauge (Tru-chek, Edwards Mfg. Co., Albert Lea, Minnesota) was also set up in this open area.

A maximum-minimum registering thermometer of the Six's type (Taylor Instrument Co., Rochester, New York) was placed two meters off the ground in a louvered shelter near the center of the plot. All instruments were calibrated in the laboratory and proper corrections applied to field data.

## Monitoring Schedule

Monitoring periods were as follows: Winter--December 22, 1966; Spring--April 19, 1967; Summer--August 7, 1967; and Autumn--October 18, 1967. On each of these dates the first instrument readings were usually made at six in the evening and subsequently at two-hour intervals for 48 hours. A detailed monitoring of the onset of the summer rains involved readings over 24-hour periods commencing again at six in the evening on June 20, July 5, July 12 and July 19, 1968. Since the last date additional visits have been made to the study area. Plant collections and notes regarding phenology were made at the time of each monitoring and at each subsequent visit. Mountain standard time is used throughout. Night and day divisions are based upon field determinations of civil twilight.

## Soil

At each visit a soil trench one-half meter in depth was dug off-plot and two samples obtained from each of the following depths: 5, 10, 20 and 50 cm. These samples were sealed in metal cans and returned to Tucson for weighing, drying (100-110$^{\circ}$C) and reweighing. Soil moisture was then computed as a percent of dry weight. A representative set of soil samples from the 5 cm through 50 cm depths were analyzed by the University of Arizona Soils Laboratory for textural composition, moisture retention and pH (for results see Quadrat Analysis).

## MACROCLIMATE

The closest weather station to the study site is 8 km to the east at Minas Nuevas (27° 05' N Lat, 108° 58' W Long). This village is located at an elevation of 520 m at the north slope of the Sierra Alamos. The station records daily maximum and minimum temperatures and precipitation for the Servicio Meteorologico Mexicano. The thermometer and rain gauge are located in a clearing several hundred meters from well-developed tropical deciduous forest. Data have been recorded with minor exceptions since 1927.

Boletin Hidrologico No. 13 (Secretaria de Recursos Hidraulicos 1959) indicates that the extreme temperatures recorded for Minas Nuevas are 0.0° and 44.5°C (Alamos, -9.0 and 48.0°C). Mean monthly temperatures, ranges and confidence intervals (Hastings 1964, Hastings and Humphrey 1969) with mean monthly maximum and minimum temperatures (Soto Mora and Jauregui O. 1965) are plotted in Figure 2.

Mean temperatures increase uniformly during the first six months of the year. A plateau is reached in June and July. Subsequently an abrupt drop in temperature occurs near the end of the year. The interval between mean monthly maxima and minima is greatest in the spring, less great in winter, smaller yet in autumn and least in summer. Mean annual temperature for Minas Nuevas is 23.4°C (Alamos, 23.5°C).

Mean monthly precipitation, ranges and confidence intervals (Hastings 1964, Hastings and Humphrey 1969) are plotted in Figure 3.

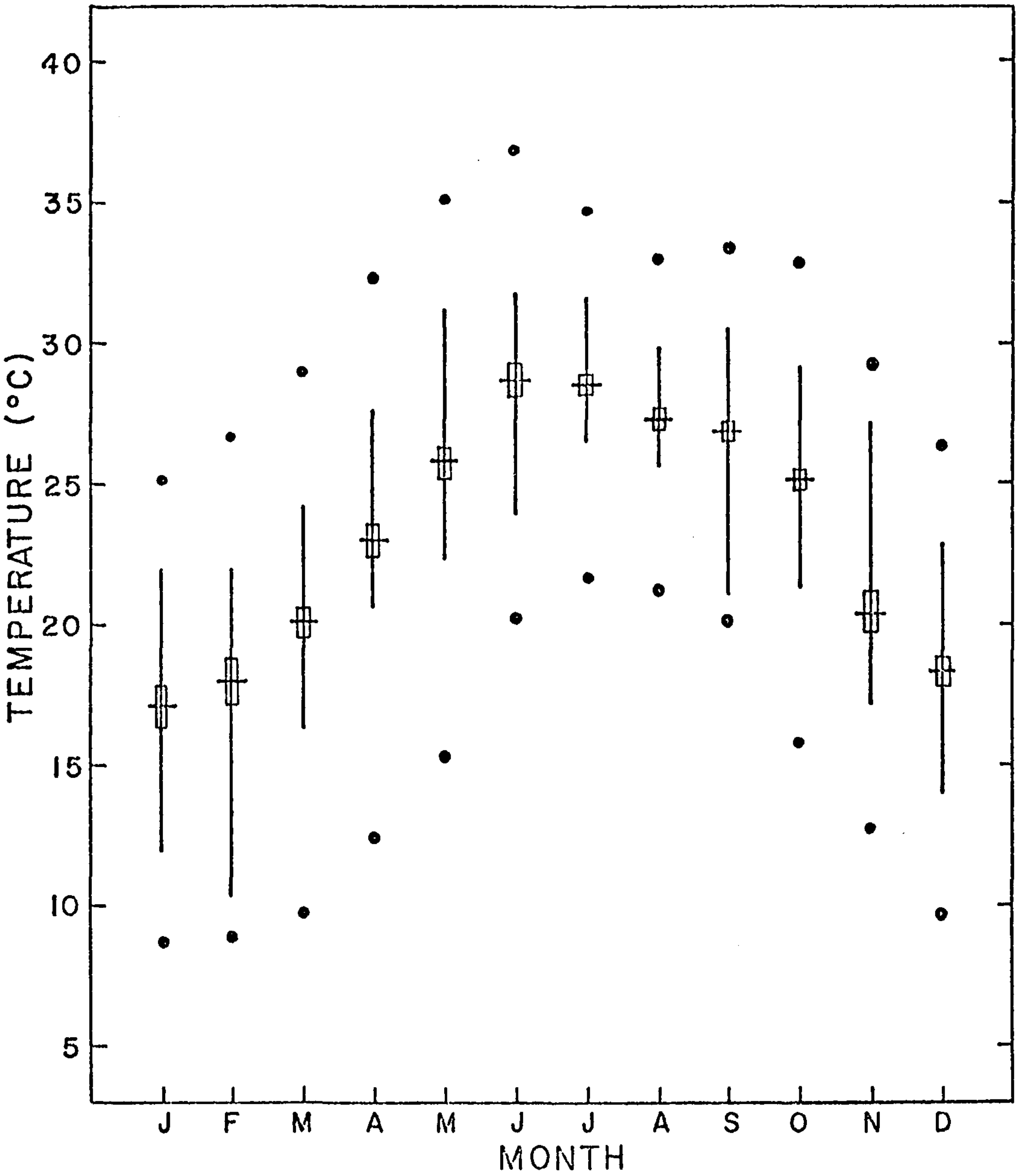



Figure 2. Graph of Monthly Temperatures at Minas Nuevas, Sonora, Mexico. -- Dice-Leraas figures illustrate monthly means, extremes and confidence intervals for the means. Dots above and below are mean monthly maxima and minima. Mean annual temperature equals 23.4°C. Data from Hastings (1964), Hastings and Humphrey (1969) and Soto Mora and Jauregui, O.(1965). N = 38-40.

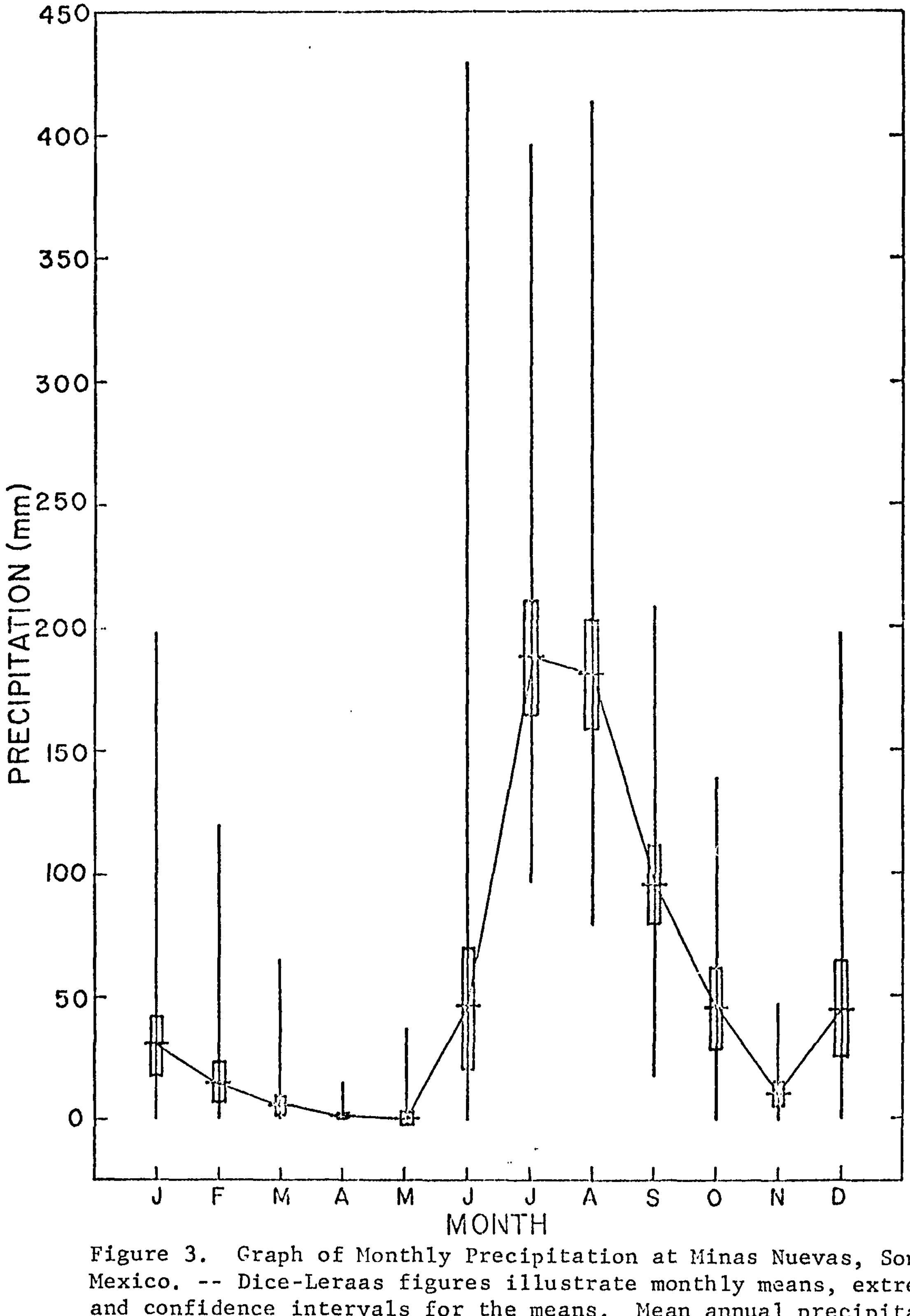



Figure 3. Graph of Monthly Precipitation at Minas Nuevas, Sonora, Mexico. -- Dice-Leraas figures illustrate monthly means, extremes and confidence intervals for the means. Mean annual precipitation equals 664.3 mm. Data from Hastings (1964) and Hastings and Humphrey (1969). N = 38-40.

The three winter months (December, January, February) account for about 13% of mean annual precipitation. These rains are typically frontal in nature. Spring is a period of harsh drought and accounts for only one percent of annual precipitation. Summer through mid-autumn (June to October) is the monsoon period and accounts for 85% of the annual total. The monsoon begins in late June or early July. In the late autumn month of November a second but weak drought occurs. It is interesting to note that all months except July, August and September have in the past received zero rainfall. Mean annual precipitation for Minas Nuevas is 664 mm (26.1 in.) and for Alamos is 639 mm (25.2 in.).

Highest temperatures occur just prior to the monsoon and lowest temperatures occur with the winter rains. Drought period temperatures are generally intermediate. All macroclimatic data presented in this paper are from the four publications cited above.

## RESULTS AND DISCUSSIONS

### Quadrat Analysis

Quadrat analysis is used to describe the plant community in which environmental studies were conducted. The majority of quadrat determinations and measurements were made in November, 1971. Nomenclature, with few exceptions, follows Shreve and Wiggins (1964) and/or Standley (1920-1926). Representative specimens are deposited in the University of Arizona Herbarium.

#### Species

Thirty-four species of trees and shrubs (including cacti) and woody lianas were counted in the 0.1 ha (20 x 50 m) quadrat. These species represent 28 genera and 16 families. The most frequently occurring families are: Leguminosae with nine species; Burseraceae, four species; and Euphorbiaceae and Cactaceae, three species each. The most common genus is *Bursera*, four species (Table 1). For a regional flora see Gentry (1942).

On-plot species can be divided into seven growth-forms (Table 2). Twenty of the 34 species are trees. Eighteen of the trees (ca. 53% of species) are broad-leaved deciduous (Tbd). One species, *Pithecollobium tortum*, is a thorn tree (Tth) and one, *Pachycereus pecten-aboriginum*, the giant columnar cactus commonly called the hecho, is a stem succulent tree (Tss).

Table 1. Trees and Shrubs, Including Cacti, and Woody Vines Occurring on 0.1 ha Plot; Stratum, Species, Author and Family. -- Species are grouped alphabetically by stratum; A-stratum is the overstory tree; B-stratum, main forest canopy; C-stratum, tall shrubs; and D-stratum, lesser shrubs.

| STRATUM | SPECIES | AUTHOR | FAMILY |
|---|---|---|---|
| A | 1. Conzattia sericea | Standl. | Leguminosae |
| B | 2. Brongniartia alamosana | Rydb. | Leguminosae |
| | 3. Bursera bipinnata | (Moc. & Sesse)Engl. | Burseraceae |
| | 4. Bursera confusa | (Rose) Engl. | Burseraceae |
| | 5. Bursera grandifolia | (Schl.) Engl. | Burseraceae |
| | 6. Bursera laxiflora | S. Wats. | Burseraceae |
| | 7. Cassia emarginata | L. | Leguminosae |
| | 8. Ceiba acuminata | (S.Wats.)Rose | Bombacaceae |
| | 9. Erythroxylon mexicana | H.B.K. | Erthroxylaceae |
| | 10. Exogonium bracteatum | (Cav.) Choisy | Convolvulaceae |
| | 11. Guazuma ulmifolia | Lam. | Sterculiaceae |
| | 12. Heliocarous attenuatus | S. Wats. | Tiliaceae |
| | 13. Heteropteris palmeri | Rose | Malpiahiaceae |
| | 14. Hintonia latiflora | (Sesse & Moc.)Bullock | Rubiaceae |
| | 15. Ipomoea arborescens | (Humb. & Bonpl.)Don | Convolvulaceae |
| | 16. Jatropha cordata | (Ort.)Muell. Arg. | Euphorbiaceae |
| | 17. Lysiloma divaricata | (Jacq.)Macbr. | Leguminosae |
| | 18. Nissolia hirsuta | DC.(Engelm.) | Leguminosae |
| | 19. Pachycereus pecten-aboriginum | (Engelm.) Britt.& Rose | Cactaceae |
| | 20. Pithecollobium tortum | Mart. | Leguminosae |
| | 21. Tabebuia palmeri | Rose | Bignoniaceae |
| | 22. Willardia mexicana | (S.Wats.)Rose | Leguminosae |
| | 23. Wimmeria confusa | Hemsl. | Celastraceae |
| C | 24. Acacia cymbispina | Sprague & Riley | Leguminosae |
| | 25. Croton fragilis | H.B.K. | Euphorbiaceae |
| | 26. Jatropha platanifolia | Standl. | Euphorbiaceae |
| | 27. Karwinskia humboldtiana | (Roem. & Sch.)Zucc. | Rhamnaceae |
| | 28. Montanoa rosei | Robins. & Greenm. | Compositae |
| | 29. Opuntia kleiniae | DC. | Cactaceae |
| | 30. Randia echinocarpa | Moc. & Sesse | Rubiaceae |
| D | 31. Cassia biflora | L. | Leguminosae |
| | 32. Franseria cordifolia | Gray | Compositae |
| | 33. Lantana velutina | Mart. & Gal. | Verbenaceae |
| | 34. Opuntia fuliginosa | Griff. | Cactaceae |

Table 2. Growth-form and Frequency of Species Occurring on 0.1 ha Plot. -- Growth-forms are primarily, Tree, Shrub and Liana; and secondarily, broad-leaved deciduous, stem succulent and thorn. Frequency is expressed as percent occurrence on forty sub-plots. Species are grouped by stratum.

| STRATUM | SPECIES | GROWTH-FORM | FREQUENCY (%) |
|---|---|---|---|
| A | 1. Conzattia sericea | Tbd | 2.5 |
| B | 2. Brongniartia alamosana | Tbd | 50 |
| | 3. Bursera bipinnata | Tbd | 7.5 |
| | 4. Bursera confusa | Tbd | 2.5 |
| | 5. Bursera grandifolia | Tbd | 5 |
| | 6. Bursera laxiflora | Tbd | 10 |
| | 7. Cassia emarginata | Tbd | 30 |
| | 8. Ceiba acuminata | Tbd | 5 |
| | 9. Erythroxylon mexicana | Tbd | 7.5 |
| | 10. Exogonium bracteatum | L | 10 |
| | 11. Guazuma ulmifolia | Tbd | 2.5 |
| | 12. Heliocarous attenuatus | Tbd | 2.5 |
| | 13. Heteropteris palmeri | L | 12.5 |
| | 14. Hintonia latiflora | Tbd | 2.5 |
| | 15. Ipomoea arborescens | Tbd | 7.5 |
| | 16. Jatropha cordata | Tbd | 7.5 |
| | 17. Lysiloma divaricata | Tbd | 30 |
| | 18. Nissolia hirsuta | L | 12.5 |
| | 19. Pachycereus pecten-aboriginum | Tss | 70 |
| | 20. Pithecollobium tortum | Tth | 2.5 |
| | 21. Tabebuia palmeri | Tbd | 25 |
| | 22. Willardia mexicana | Tbd | 47.5 |
| | 23. Wimmeria confusa | Tbd | 2.5 |
| C | 24. Acacia cymbispina | Sth | 2.5 |
| | 25. Croton fragilis | Sbd | 55 |
| | 26. Jatropha platanifolia | Sbd | 92.5 |
| | 27. Karwinskia humboldtiana | Sbd | 5 |
| | 28. Montanoa rosei | Sbd | 50 |
| | 29. Opuntia kleiniae | Sss | 5 |
| | 30. Randia echinocarpa | Sth | 17.5 |
| D | 31. Cassia biflora | Sbd | 87.5 |
| | 32. Franseria cordifolia | Sbd | 100 |
| | 33. Lantana velutina | Sbd | 20 |
| | 34. Opuntia fuliginosa | Sss | 5 |

Three growth-forms are represented by eleven species of shrubs. The majority, seven, are broad-leaved deciduous shrubs (Sbd), two are thorn shrubs (Sth), and two are cacti or stem succulent shrubs (Sss). Three species of woody lianas (L) are also present.

The thorn tree and thorn shrubs are more representative of open habitats. One thorn shrub, Acacia cymbispina, is the dominant species of the coastal thorn forest vegetation.

Tree leaf-size varies from the small (ca. 1 x 4 mm) primary leaflets of Lysiloma divaricata to the large (ca. 80 x 180 mm) simple, entire leaves of Ipomoea arborescens, the tree morning glory.

In the shrub community leaf-size again varies from the small primary leaflets of Acacia cymbispina to the large, simple, lobed leaves of Jatropha platanifolia (ca. 150 x 150 mm).

Most species have deciduous compound leaves with entire edges and smooth, near glabrous surfaces. Tropical "drip-tip" leaves are characteristic of three tree species, Bursera grandifolia, Hintonia latiflora, and Tabebuia palmeri. None of the shrubs have this type of leaf.

Smooth thin bark, with or without paper-like exfoliation, is common to seventy-five percent of the trees. The heaviest bark is that of Lysiloma divaricata, it is dark and flaking. Ceiba acuminata, a kapok, develops interesting cone-shaped protruberances on its bark.

Most of the trees have straight trunks and lack lower branches. No on-plot species exhibits buttressing nor aerial rooting. The most common type of tree-crown is obovate in profile but the ubiguitous Lysiloma divaricata has a cone-like crown suggesting the shape of an umbrella.

The majority of species are considered endemic to the tropical deciduous forests of northwestern Mexico. About one-third of the genera occur in Arizona but only one species, Franseria cordifolia, enters the southern part of that state (Kearney and Peebles 1960).

Pockets of weakly developed tropical deciduous forest are found further north in favorable locations along the Rio Sonora, Rio Montezuma and Rio Yaqui-Bavispe, between 29° and 30° north latitude. These communities reflect the physiogomy of tropical deciduous forest but are species poor. The sites are near the junction of the northern and middle thirds of Shreve's (1951) Foothills of Sonora subdivision of the Sonoran Desert. This subdivision can better be thought of as being a broad, desert scrub-thorn forest-tropical deciduous forest, ecotone.

Six of the species, Bursera laxiflora, Ipomoea arborescens, Jatropha cordata, Acacia cymbispina, Ceiba acuminata and Pachycereus pecten-aboriginum, are known to enter the Plains of Sonora subdivision of the Sonoran Desert (Shreve 1951). The first three species listed reach northward to near the level of Carbo and one, Bursera laxiflora, is found on hills 75 km northwest of Carbo (Shreve 1951).

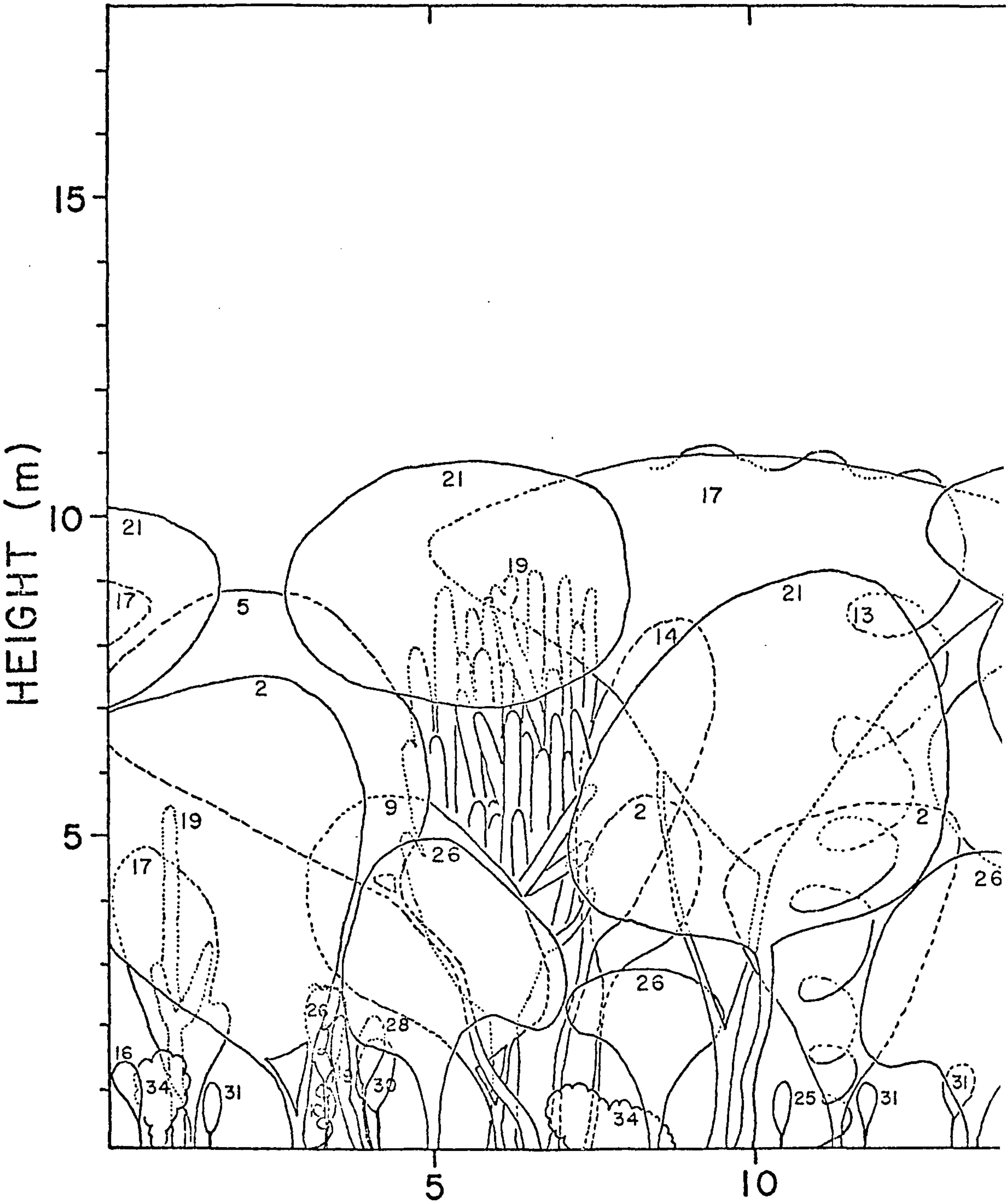
Nearly half of the on-plot species are listed by Gentry (1942) as occurring in the adjacent thorn forest communities of the lower Rio Mayo basin. Martin (1958) mentions Guazuma ulmifolia and Cassia emarginata as present in a tropical deciduous forest in southern Tamaulipas. The species Guazuma ulmifolia, Tabebuia palmeri and twelve additional on-plot genera are listed by Holdridge et al. (1971) as occurring in Costa Rica.

Stratification

A primary consideration in selecting a 0.1 ha study plot was the presence of both a large hecho cactus, Pachycereus pecten-aboriginum, and an overstory tree, Conzattia sericea. These two individuals were also present on the sub-plot strip which was illustrated as a profile diagram (Figure 4). This 5 x 50 m strip was the third such strip back from the baseline of the 20 x 50 m plot. The profile illustration is viewed from the south. The more mesic eastern portion is to the right and the more xeric western portion is to the left.

The profile diagram was drawn to scale using field notes on individual plant position, trunk diameter, free bole height, total height, width of crown and general shape. The resultant drawing was subsequently checked and modified in the field. An attempt is made to reflect depth and the entrance of crowns from trees rooted outside the actual strip. The positions of woody lianas are included. Plants less than one meter tall are not shown. A number on each plant indicates the species as numbered in Tables 1 through 4 and 7. Names in these tables are arranged alphabetically within stratum groups. Species are assigned to a stratum depending upon the crown position most commonly occupied by adult individuals.

The A or tallest tree stratum is discontinuous and is locally formed by a single species, Conzattia sericea. The lower and higher crown margins of individuals of this species generally range between eight and twenty meters. Individuals or colonies from conspicuous protrusions above the more even canopy of the B-stratum.


HEIGHT (m)
15
10
5
5
10

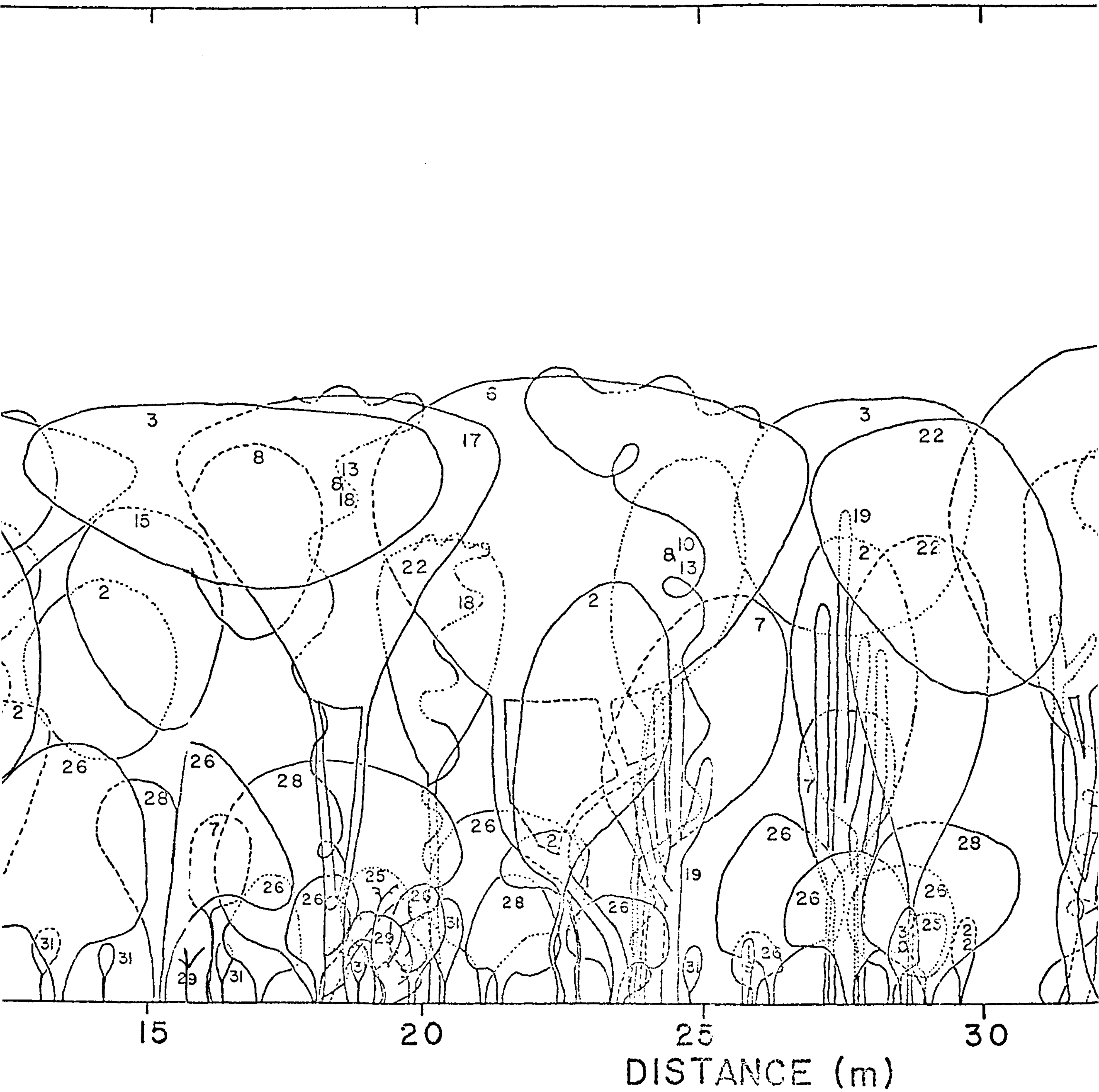
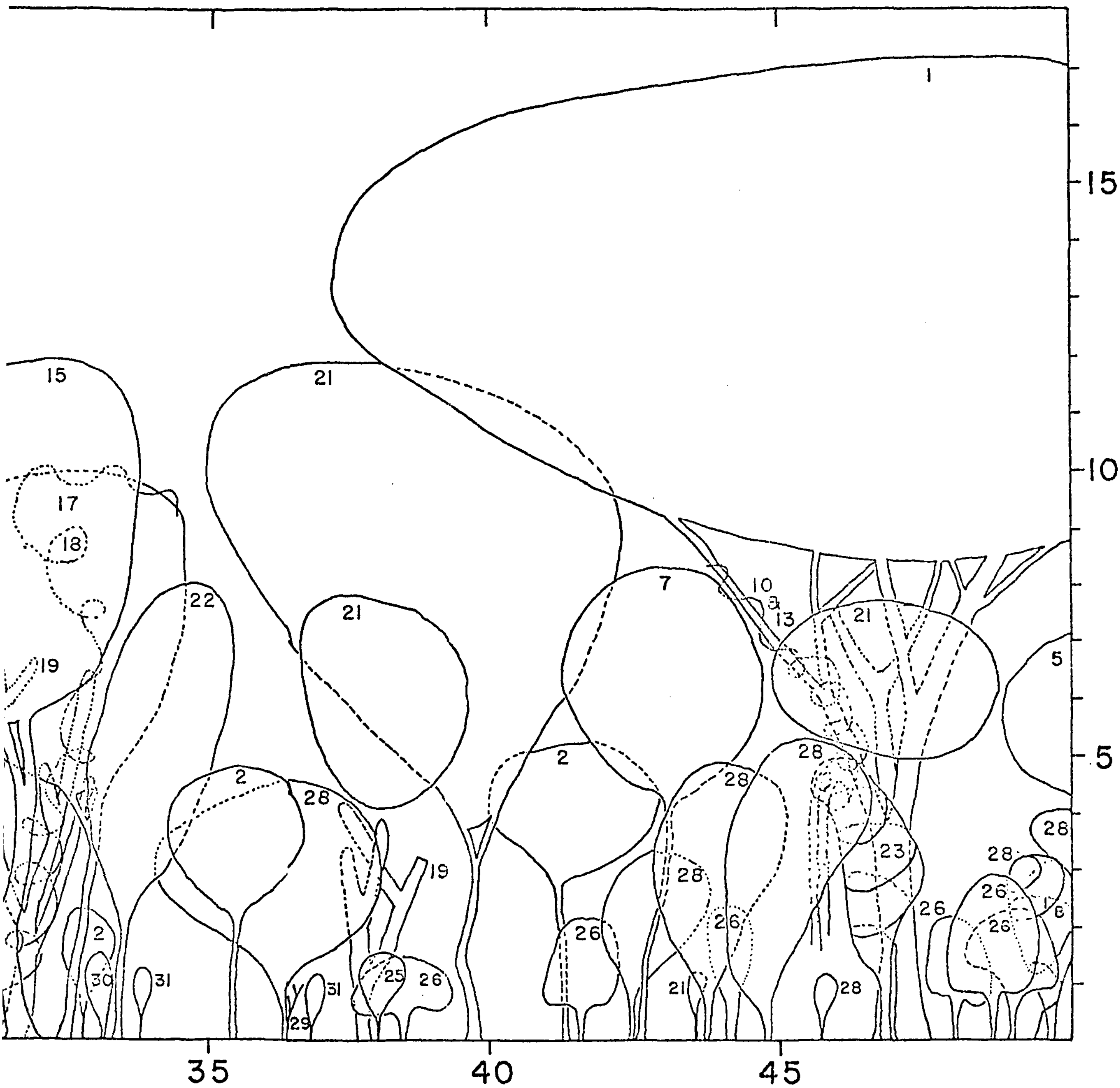



Figure 4. Profile Diagram Representing a 5 x 50 m Strip of Tropical Dec
Numbers refer to species as listed in Tables 1-4 and 7. Vegetation less
in height is not shown. Trunkless crowns are off-plot rooted individual




Deciduous Forest. --
less than one meter
luals.

The B-stratum, of the vegetation diagrammed, is formed by 12 species of trees and three of lianas. An additional four tree species are found in the remaining three-quarters of the full 0.1 ha plot. Plants are judged members of the B-stratum if the greater portion of their crown is between five and twelve meters in height. Frequently B-stratum species, especially Ceiba acuminata, Ipomoea arborescens, and Lysiloma divaricata form slight projections above the more even canopy. Brongniartia alamonsana and Willardia mexicana are usually shorter and seldom become canopy species in well-developed forests. Most woody lianas extend to the top of the B-stratum and are considered part of it.

Several species listed as B-stratum (Tables 1-4 and 7) warrant special mention. Guazuma ulmifolia is represented on-plot by one young individual 2.3 m tall. This species is commonly riparian and there it attains heights of 10 m. Erythroxylon mexicana, Pithecolobium tortum and Wimmeria confusa are small trees which are more typically found in open sites. Giant columnar cacti, especially Pachycereus pecten-aboriginum extend into the B-stratum but most individuals are smaller and are functional members of lower stratum.

Younger individuals of some B-stratum species (e.g., Brongniartia alamosana, Cassia emarginata, Tabebuia palmeri, and Willardia mexicana) are common, and are in the process of filling openings in the B-canopy. Ceiba acuminata, Ipomoea arborescens, and Lysiloma divaricata were not observed growing directly beneath A-stratum individuals. Those B-stratum trees which grow under the shading influence of the A-stratum, such as Brongniartia alamosana, Willardia mexicana, Cassia emarginata, and Tabebuia palmeri, are generally the smaller trees of the B-canopy and are here even more depressed in height.

The C- and D-strata are composed of shrub species but frequently tree saplings are functional members. Plants are considered C-stratum if the major portion of their crown is less than five meters in height and if the plant itself is taller than one meter. On-plot C-stratum vegetation is dominated by two species of large multiple-stemmed shrubs, Jatropha platanifolia and Montanoa rosei. Another shrub, Croton fragilis, is common but in stratified forests it never attains the dominance it does when growing in open sites. Seven species are listed in the C-stratum and another 13 species have functional representatives in the stratum.

The D-stratum is generally below one meter in height and is dominated by the shrub Franseria cordifolia. Although placed in this stratum because of the stature of the majority of on-plot individuals, Cassia biflora reaches three to four meters in height when growing in open sites. Four on-plot species are listed in the D-stratum but another 10 species had functional representatives in this stratum.

An ephemeral E-stratum of herbaceous species exists during the winter and following the summer monsoons. The D- and E-strata are not included in the profile diagram (Figure 4).

In summary, the vertical structure of these northern stands of tropical deciduous forest contain one discontinuous overstory tree stratum, a second continuous tree stratum, two shrub layers and an ephemeral herbaceous ground-cover.

Density

Densities of species rooted within the 0.1 ha plot are given in Table 3. Individuals in this table are tabulated by position held in the vertical structure of the plot. For example, with Brongniartia alamosana 25 individuals are functional members of the B-stratum, 6 shorter individuals belong to the C-stratum and one in the D-stratum, totaling 32.

The A-stratum has a density of one, a single Conzattia sericea. The B-stratum has a density of 104 with Brongniartia alamosana accounting for about 24 percent of that number. Also in this stratum are Willardia mexicana (14%), Lysiloma divaricata (10%), Tabebuia palmeri (9%), Cassia emarginata (6%), Pachycereus pecten-aboriginum (6%) and others. Trees of nearly all species are cut by natives for fence posts and fuel. A total of 16 on-plot stumps were observed. These have been removed during the past ten years and today little effect is noticed.

The C-stratum has a density of 239 with Jatropha platanifolia accounting for 33% of that number. Next is Cassia bioflora (18%) although this plant is actually considered a D-stratum species. Then comes Montanoa rosei (14%) and Croton fragilis (13%). The density of the D-stratum is 1573. It is dominated by Franseria cordifolia (88%), followed by Cassia biflora (7%).

The total density of woody perennials, including cacti, is 1917 per 0.1 ha (= 7700/acre). Density increases in a near logarithmic rate as one descends through the successive layers of the vegetation (1-104-239-1573). Single species dominance also increases abruptly along this same gradient.

Table 3. Density of Species Occurring on 0.1 ha Plot. -- Density is given by stratum occupied by individuals of each species. Species are grouped by stratum.

| STRATUM | SPECIES | DENSITY A | B | C | D | Total |
|---|---|---|---|---|---|---|
| A | 1. *Conzattia sericea* | 1 | | | | 1 |
| | Total A-stratum | 1 | 0 | 0 | 0 | 1 |
| B | 2. *Brongniartia alamosana* | | 25 | 6 | 1 | 32 |
| | 3. *Bursera bipinnata* | | 3 | | | 3 |
| | 4. *Bursera confusa* | | 2 | | | 2 |
| | 5. *Bursera grandifolia* | | 2 | | | 2 |
| | 6. *Bursera laxiflora* | | 4 | | | 4 |
| | 7. *Cassia emarginata* | | 6 | 4 | 3 | 13 |
| | 8. *Ceiba acuminata* | | 2 | | | 2 |
| | 9. *Erythroxylon mexicana* | | 2 | 1 | | 3 |
| | 10. *Exogonium bracteatum* | | 4 | | | 4 |
| | 11. *Guazuma ulmifolia* | | 0 | 1 | | 1 |
| | 12. *Heliocarous attenuatus* | | 1 | | | 1 |
| | 13. *Heteropteris palmeri* | | 5 | | | 5 |
| | 14. *Hintonia latiflora* | | 1 | | | 1 |
| | 15. *Ipomoea arborescens* | | 3 | | | 3 |
| | 16. *Jatropha cordata* | | 1 | 2 | | 3 |
| | 17. *Lysiloma divaricata* | | 10 | 2 | | 12 |
| | 18. *Nissolia hirsuta* | | 4 | 1 | | 5 |
| | 19. *Pachycereus pecten-aboriginum* | | 6 | 14 | 28 | 48 |
| | 20. *Pithecollobium tortum* | | 0 | 1 | | 1 |
| | 21. *Tabebuia palmeri* | | 9 | 2 | 2 | 13 |
| | 22. *Willardia mexicana* | | 14 | 3 | 11 | 28 |
| | 23. *Wimmeria confusa* | | 0 | 1 | | 1 |
| | Total B-stratum | 0 | 104 | 38 | 45 | 187 |
| C | 24. *Acacia cymbispina* | | | 1 | | 1 |
| | 25. *Croton fragilis* | | | 32 | 5 | 37 |
| | 26. *Jatropha platanifolia* | | | 78 | 11 | 89 |
| | 27. *Karwinskia humboldtiana* | | | 2 | | 2 |
| | 28. *Montanoa rosei* | | | 34 | 1 | 35 |
| | 29. *Opuntia kleiniae* | | | 2 | 1 | 3 |
| | 30. *Randia echinocarpa* | | | 7 | 1 | 8 |
| | Total C-stratum | 0 | 0 | 156 | 19 | 175 |
| D | 31. *Cassia biflora* | | | 42 | 114 | 156 |
| | 32. *Franseria cordifolia* | | | | 1384 | 1384 |
| | 33. *Lantana velutina* | | | 3 | 9 | 12 |
| | 34. *Opuntia fuliginosa* | | | | 2 | 2 |
| | Total D-stratum | 0 | 0 | 45 | 1509 | 1554 |
| | Grand Totals | 1 | 104 | 239 | 1573 | 1917 |

Frequency

The 0.1 ha plot was divided into 40 sub-plots (each 5 m square) and rooted plants have been counted, measured and recorded within these smaller units. If a species occurred in only one sub-plot its frequency is 2.5%, occurrence in 20 sub-plots equals 50%. The species with the highest frequency in the B-plant group is Pachyereus pecten-aboriginum (70%). Both Brongniartia alamosana and Willardia mexicana have frequencies approximating 50% (Table 2).

In the C-group Jatropha platanifolia is highest with 92.5%. Next are Croton fragilis and Montanoa rosei, both close to 50%. The D-group has the most frequently occurring species, Franseria cordifolia. It was found in all of the sub-plots, a frequency of 100%. Second in the D-group is Cassia biflora (87.5%).

A comparison between the more mesic (east) and the more xeric (west) halves of the plot indicate some important differences in species composition. Tabebuia palmeri and Montanoa rosei are more than twice as frequent on the mesic half of the plot and Brongniartia alamosana, Lysiloma divaricata and Croton fragilis are twice as frequent on the xeric half.

Coverage

Coverage was determined by the line intercept method (Greig-Smith 1964). Eleven 20 m long on-plot lines, 220 m total length, were established and intercept along these lines was recorded by species. Intercept for each species was summed and converted to a percent of total line. The resultant figure equates to percent of plot covered. Community coverage was obtained by summing species coverage.

C-stratum coverage totaled 47%. This value is dominated by two species, Jatropha platanifolia (25%) and Montanoa rosei (17%). Croton fragilis covered 4% and the remaining four species intercepted collectively covered about 1%. D-stratum coverage totals 66%. Franseria cordifolia accounted for nearly 54%. The only other significant contribution is by Cassia biflora with 2%. Combined C- and D-strata coverage is 113%.

Table 4 indicates percent of plot covered by the crowns of shrubs. Species coverage has been converted to relative coverage by dividing by community coverage, 113%. Importance values (= relative coverage for shrubs) are plotted on species sequence in Figure 5. The resulting line suggests a preempted distribution of niche space (Whittaker 1970). In this situation each species occupies the major share of space available to them.

The A-canopy consists of a single tree. The line intercept plot coverage by this Conzattia sericea is 31%. The diameter of its entire crown measured 22 m. As the plot was selected to include this sparsely distributed overstory tree its on-plot coverage is not representative. Its closest species neighbor is 130 m away.

Plot coverage by the B-canopy is 94%. This canopy is continuous except for a few small holes occurring under the overstory Conzattia sericea. Frequently this canopy extends unbroken over broad areas. It is often interrupted only by topographic and/or edaphic factors such as

Table 4. Coverage for Shrubs and Diameter Breast Height for Trees Occurring on 0.1 ha Plot. -- Coverage is percent of plot covered by the crowns of each species as determined by line intercept method. Relative figures are species data divided by community totals. Species are grouped by stratum. See graph, Figure 5.

| STRATUM | SPECIES | SHRUBS Coverage (%) | SHRUBS Rel. Cov. (%) | SHRUBS Sequence | TREES dbh (m) | TREES Rel. dbh (%) | TREES Sequence |
|---|---|---|---|---|---|---|---|
| A | 1. *Conzattia sericea* | | | | 0.53 | 4.29 | 10 |
| B | 2. *Brongniartia alamosana* | | | | 1.77 | 14.32 | 2 |
| | 3. *Bursera bipinnata* | | | | .69 | 5.58 | 8 |
| | 4. *Bursera confusa* | | | | .19 | 1.54 | 14 |
| | 5. *Bursera grandifolia* | | | | .27 | 2.18 | 13 |
| | 6. *Bursera laxiflora* | | | | .68 | 5.50 | 9 |
| | 7. *Cassia emarginata* | 0.7 | 0.62 | 6 | .70 | 5.66 | 7 |
| | 8. *Ceiba acuminata* | | | | .41 | 3.32 | 12 |
| | 9. *Erythroxylon mexicana* | | | | .46 | 3.72 | 11 |
| | 10. *Exogonium bracteatum* | | | | | | |
| | 11. *Guazuma ulmifolia* | | | | | | |
| | 12. *Heliocarous attenuatus* | | | | .12 | 0.97 | 16 |
| | 13. *Heteropteris palmeri* | | | | | | |
| | 14. *Hintonia latiflora* | | | | .09 | 0.73 | 18 |
| | 15. *Ipomoea arborescens* | | | | .79 | 6.39 | 5 |
| | 16. *Jatropha cordata* | | | | .12 | 0.97 | 15 |
| | 17. *Lysiloma divaricata* | | | | 1.86 | 15.06 | 1 |
| | 18. *Nissolia hirsuta* | | | | | | |
| | 19. *Pachycereus pecten-aboriginum* | | | | 1.56 | 12.62 | 3 |
| | 20. *Pithecollobium tortum* | | | | | | |
| | 21. *Tabebuia palmeri* | 0.1 | 0.09 | 9 | 1.23 | 9.95 | 4 |
| | 22. *Willardia mexicana* | 0.2 | 0.18 | 8 | .79 | 6.39 | 6 |
| | 23. *Wimmeria confusa* | | | | .10 | 0.81 | 17 |
| C | 24. *Acacia cymbispina* | | | | | | |
| | 25. *Croton fragilis* | 3.6 | 3.18 | 4 | | | |
| | 26. *Jatropha platanifolia* | 25.0 | 22.08 | 2 | | | |
| | 27. *Karwinskia humboldtiana* | | | | | | |
| | 28. *Montanoa rosei* | 17.2 | 15.19 | 3 | | | |
| | 29. *Opuntia kleiniae* | | | | | | |
| | 30. *Randia echinocarpa* | 0.4 | 0.35 | 7 | | | |
| D | 31. *Cassia biflora* | 2.3 | 2.03 | 5 | | | |
| | 32. *Franseria cordifolia* | 63.6 | 56.19 | 1 | | | |
| | 33. *Lantana velutina* | 0.1 | 0.09 | 10 | | | |
| | 34. *Opuntia fuliginosa* | | | | | | |
| | Totals | 113.2 | 100 | | 12.36 | 100 | |

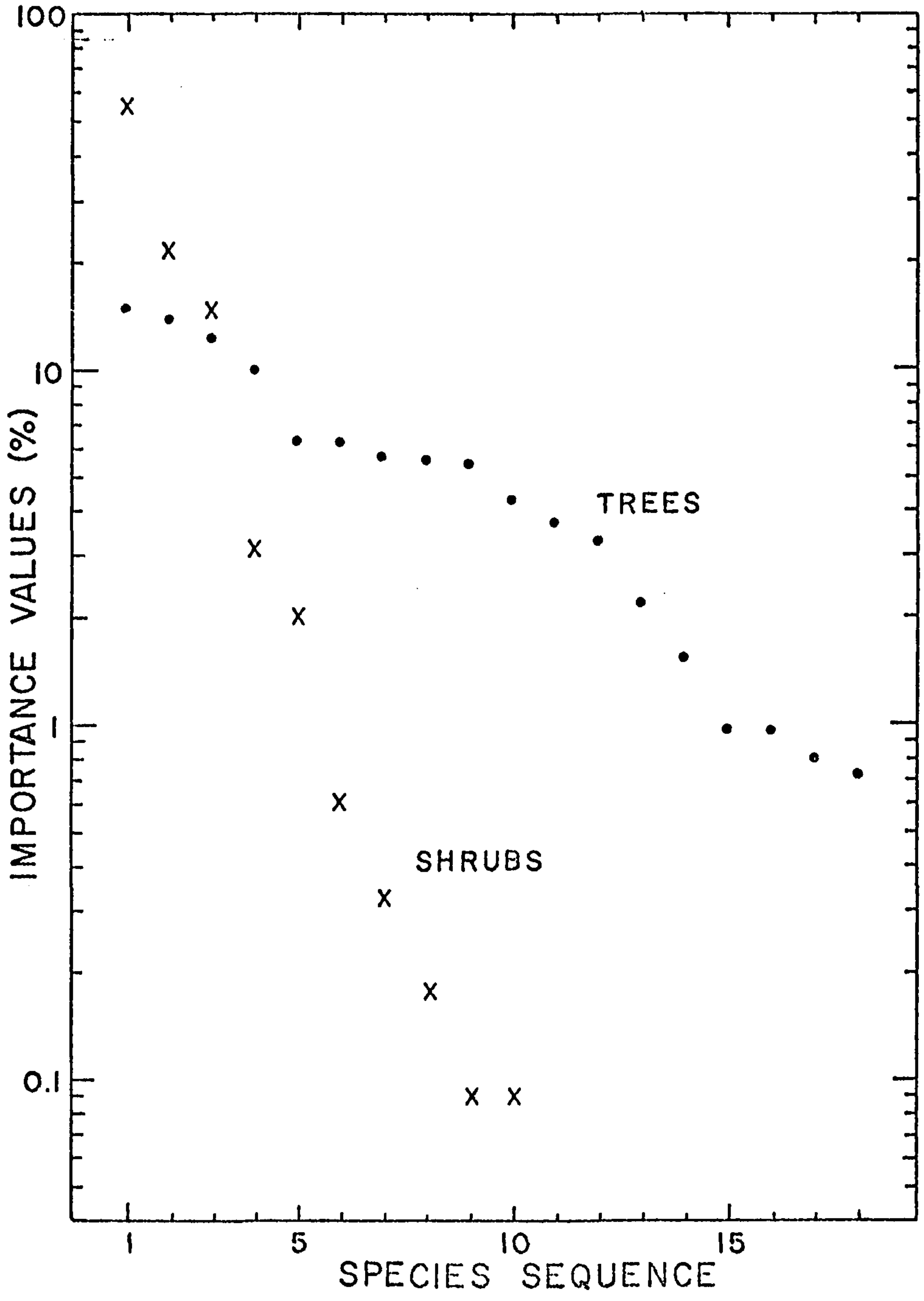



Figure 5. Importance Values of On-plot Perennials on Species Sequence. -- Relative diameter at breast height is used as the importance value for trees and relative crown coverage is used for shrubs. Shrubs form a geometric series and trees approach lognormal. Plotted on semi-logarithmic coordinates. Data in Table 4.

extremely steep slopes, rocky substratum, sharp ridges and washes. Openings in the canopy resulting from selective woodcutting or the natural death of individuals are quickly filled by young trees or by the expanding crowns of adjacent trees. The sum of plot coverage of A- through D-strata is 238%.

## Diameter Breast Height

Tree diameters were measured with a steel diameter tape at a point 1.3 m off the ground on the up-hill side of each trunk. A summary of trunk diameters at breast height (dbh) is given by species in Table 4. The same table includes computed relative diameters (species diameter divided by community diameter x 100) and species sequence. The individual with the greatest diameter is *Conzattia sericea* (0.53m). The species with the greatest collective diameter is *Lysiloma divaricata* (1.86 m).

Importance values (= relative diameter for trees) are plotted on species sequence in Figure 5. The line formed approaches a lognormal distribution (Whittaker 1970). This suggests that there are a large number of tree species of near equal importance and that there are few extremely important and few extremely unimportant species.

## Soil

Representative off-plot soil samples from the 5 through 50 cm depth were analyzed by the University of Arizona Soil Laboratory. Mechanical analysis provided the following data: rock and gravel 32%, sand 29.6%, silt 32.4% and clay 6%. Field capacity (moisture retention under 1/3 atmosphere) was determined to be 14.3%. Permanent wilting point (moisture retention under 15 atmospheres) was 8.4%. A near-neutral pH of 6.9 was reported. Soluble salts content was low, 461 ppm. The soil parent material was granite.

## Seasonality

With emphasis on the onset of the summer monsoon, selected physical parameters were monitored and phenological activities of the important plants were documented during all seasons of the year.

### Winter (November, December, January)

Winter environmental monitoring commenced 1800 hours December 22, 1966, and continued with readings at two hour intervals for 48 hours. Both nights were partly cloudy while both days were overcast. The first day was slightly more overcast than the second. Light breezes occurred during the first day. A trace of rain fell the second morning.

Temperature. Of the nine thermistors mounted on the air temperature column the lowest in height (0.5 m above the ground) and the highest (18 m, slightly above the A-canopy) generally produced the most divergent temperature readings. Air temperatures at these two heights are plotted on time in Figure 6. Nocturnal temperatures at 0.5 m are about 2°C cooler than are temperatures at the 18 m height. Diurnally this situation reverses so that air temperatures near the ground become warmer than that above the canopy.

Figure 7 shows profiles of thermometer height on temperature. Time periods selected for illustration are those of the coolest

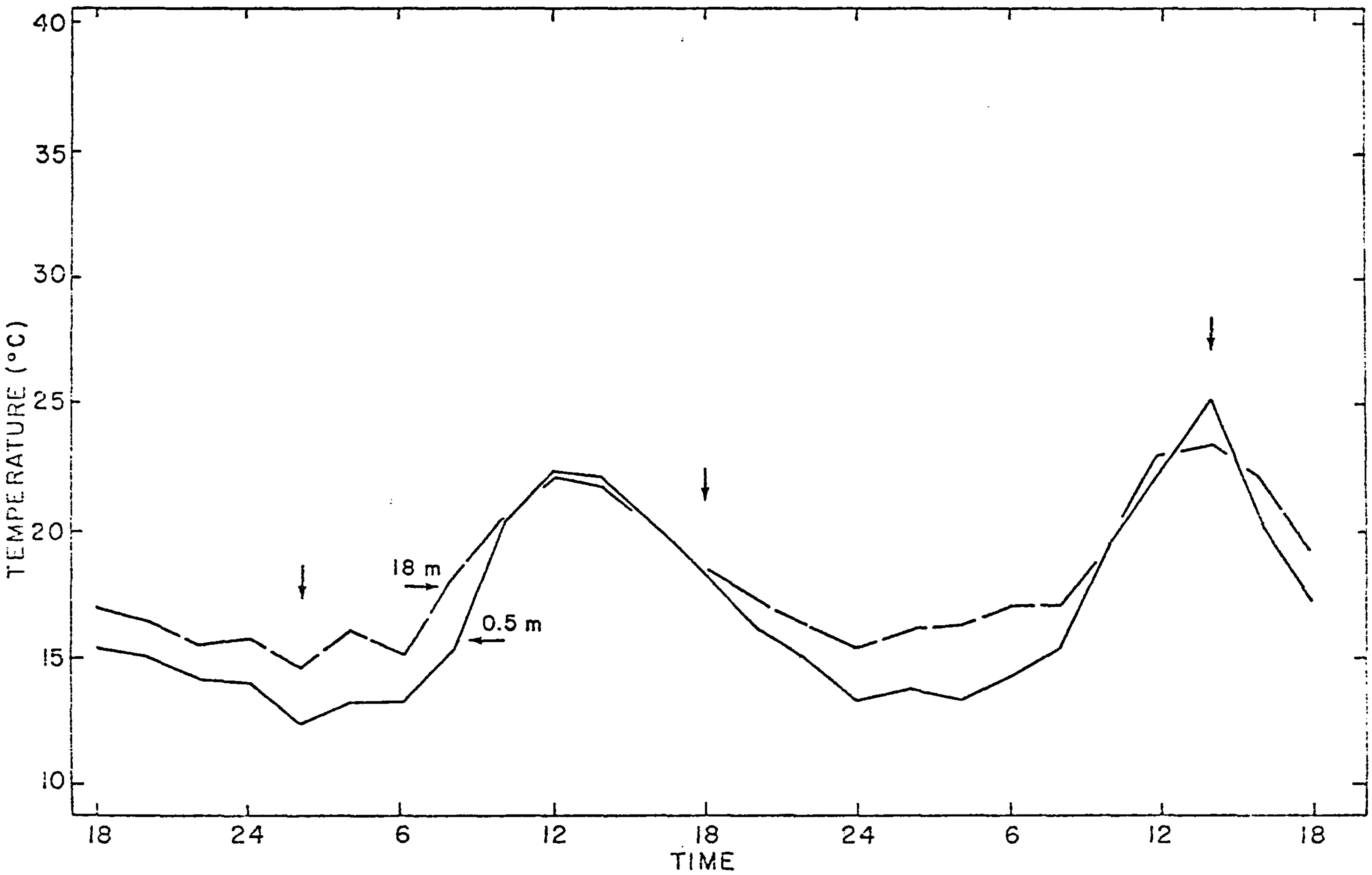



Figure 6. Winter March of Air Temperatures Above the Canopy of the Tropical Deciduous Forest (18 m) and Near Ground-level (0.5 m). -- Monitoring commenced 1800 hrs December 22 and continued for 48 hrs. Vertical arrows indicate times of temperature profiles shown in Figure 7.

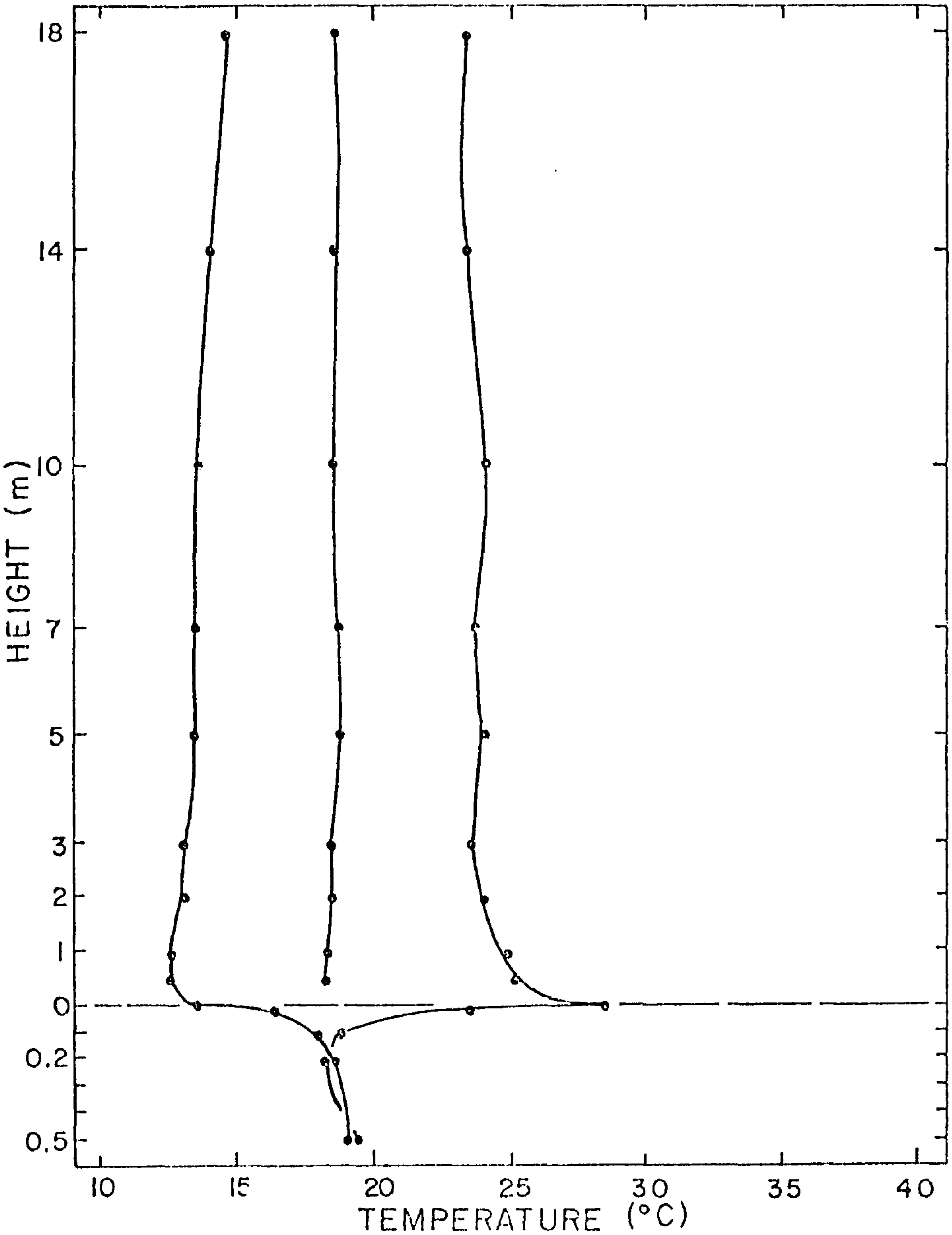



Figure 7. Winter Temperature Profiles in the Tropical Deciduous Forest. -- Left, profile at time of lowest occurring 0.5 m temperature, 0200 hrs December 23. Right, profile at highest occurring 0.5 m temperature,1400 hrs December 24. Center, a transition profile, 1800 hrs December 23. Subsurface depth scale is enlarged.

occurring temperature at the 0.5 m height (0200, December 23), the warmest occurring temperature (1400, December 24) and a transition period (1800, December 23). Concurrent substrate surface and subsurface temperatures to a depth of 50 cm are added to these air temperature profiles. All profiles reflect smooth gradients of temperature. The curve on the right illustrates a typical in-coming diurnal radiation profile while the profile on the left approaches an outward nocturnal radiation curve. Generally other profiles occurring during the 48 hr period monitored ranged between these two extremes.

Soil temperatures (surface, 2, 10 and 50 cm) are plotted on time in Figure 8. Surface temperatures range from near 13$^{o}$C to 29$^{o}$C while the line representing temperature at the 50 cm depth deviates slightly from 19$^{o}$C. The remaining lines fluctuate between these extremes.

Relative Humidity. Ambient measurements were made using a sling psychrometer. Diurnal lows reached 40% and nocturnal highs hovered near 85% (Figure 9). A noticeable increase in relative humidity occurred with the rain shower on the second morning. Computed vapor pressure deficit was generally low, ranging from one to 13 mm Hg (Figure 9).

Light. Because of the presence of sun flecks it is difficult to obtain representative light values under a partly leafless canopy. Winter ground-level readings were frequently 50% of the value obtained in open light. The top of the D-stratum at a height of 1 m received about 75% of open light.

Soil Moisture. Winter soil moisture decreased slightly with depth. A value of 7.4% (based on dry soil weight) was obtained at the

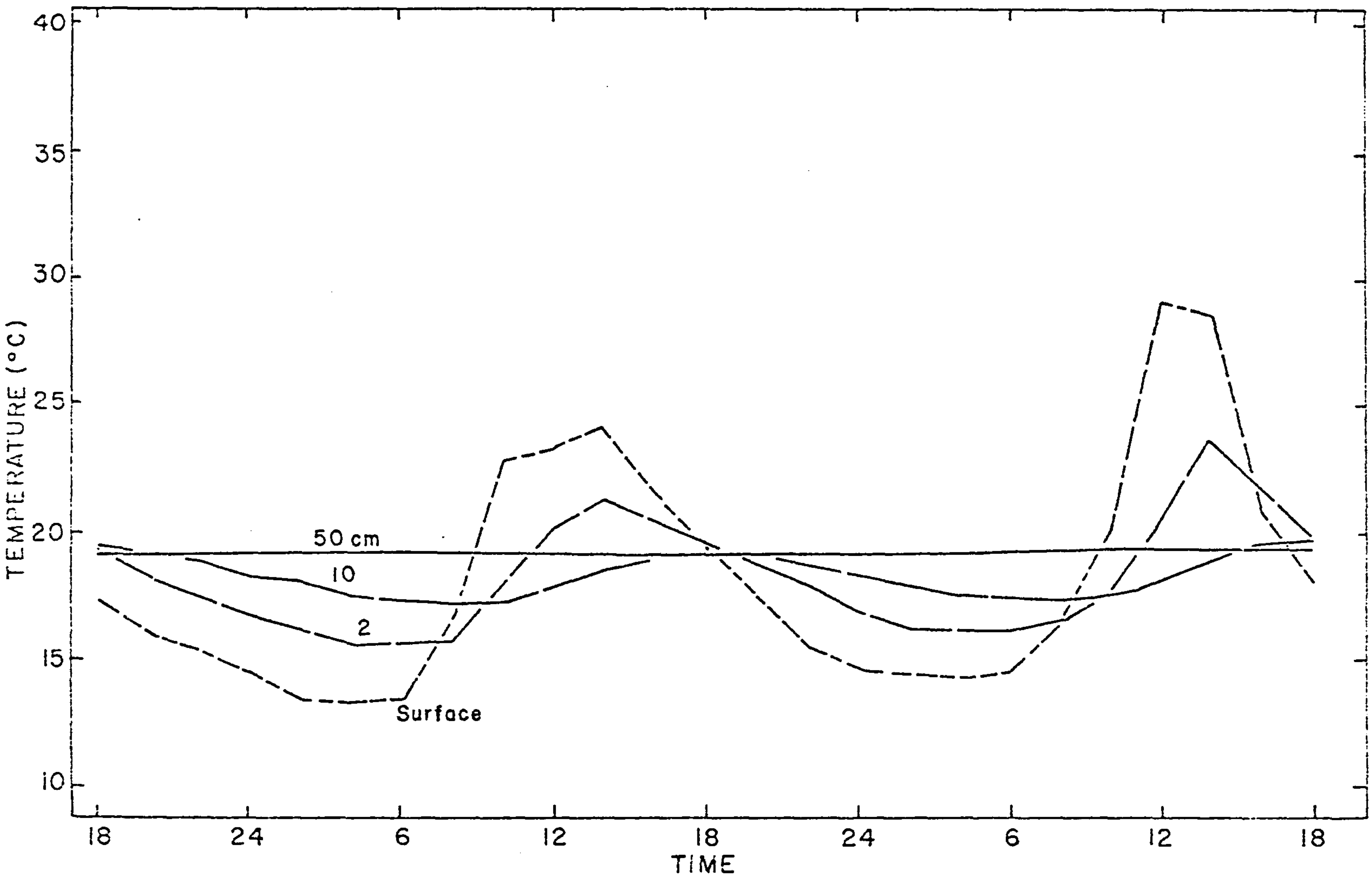



Figure 8. Winter March of Soil Temperatures in the Tropical Deciduous Forest. -- Monitoring commenced 1800 hrs December 22 and continued for 48 hrs. Thermometer depths are indicated.

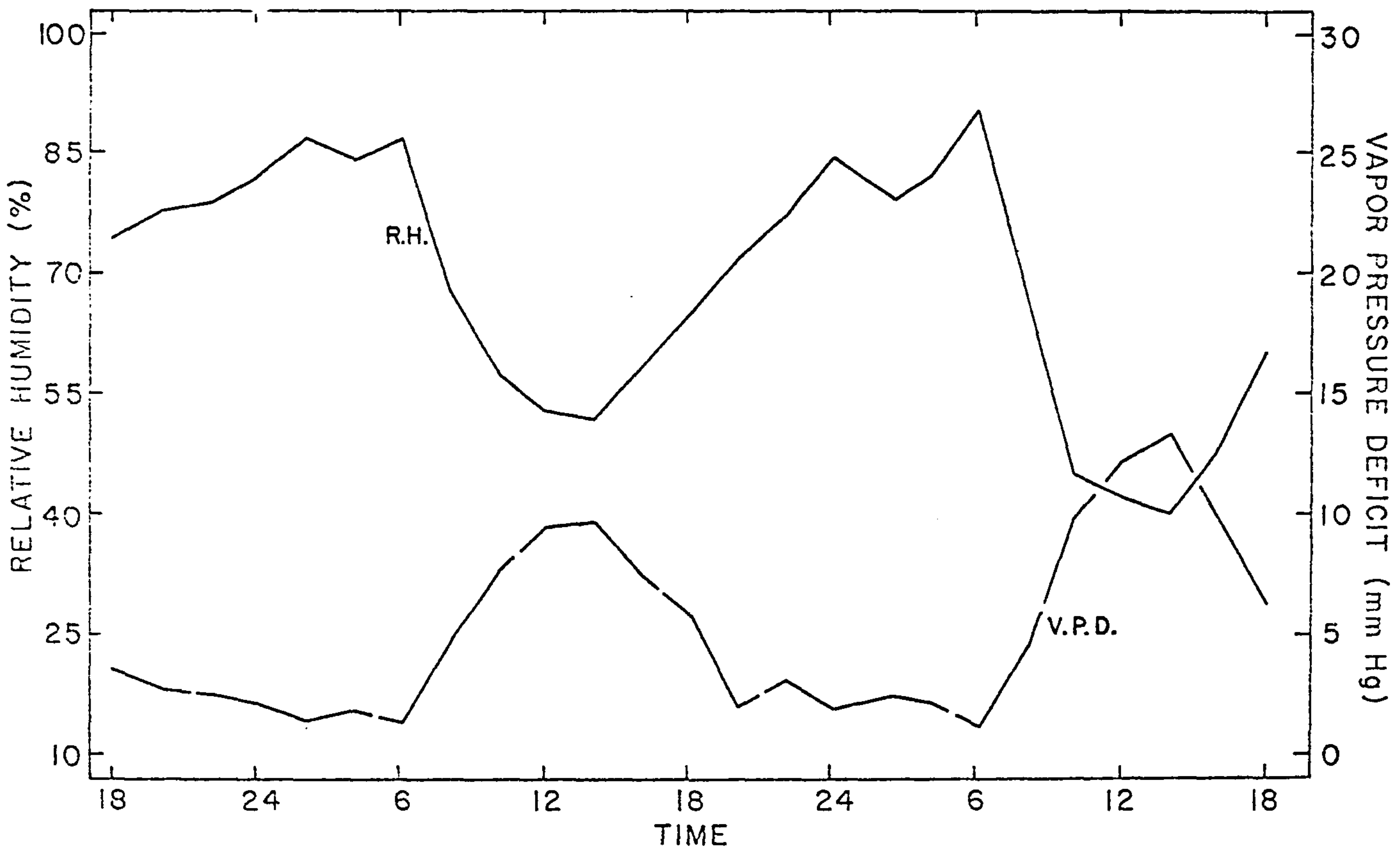



Figure 9. Winter March of Relative Humidity and Computed Vapor Pressure Deficit in the Tropical Deciduous Forest. -- Monitoring commenced 1800 hrs December 22 and continued for 48 hrs.

5 cm depth, 6.9% at 10 cm, 6.8% at 20 cm and 5.7% at 50 cm. Soil moisture for all samples averaged 6.7%. Samples were collected on February 2, 1968.

Phenology. Winter is the season of leaf drop and of spectacular flowering. It is also the most unpredictable season. In unfavorable years the vegetation is nearly leafless. But in favorable years leaves are retained by some species until spring. See Figures 10 and 11; these photographs should be compared with subsequent photographs taken at the same locations but in different seasons.

The following phenological notes most closely describe conditions as they occurred on the study plot but also reflect seasonal plant responses on similar slopes within adjacent areas. Some on-plot species, e.g., Guazuma ulmifolia, Pithecollobium tortum, Acacia cymbispina and Randia echinocarpa are more typical of drainage sites or open slopes and do not generally show reproductive activities in well developed forests. Statements concerning these species were drawn from nearby off-plot adult individuals. Drainage-way communities vary from typical forests in species composition and physiognomy, and generally have longer periods of leaf retention. Xeric communities have shorter periods of leaf retention.

In mid-winter (January) the tall overstory tree, Conzattia sericea, is leafless but may retain its open fruits. Some major B-stratum trees, e.g., Bursera spp., Ceiba acuminata, Ipomoea arborescens, and Jatropha cordata are also leafless at the beginning of the winter season. Others, e.g., Bromgniartia alamosara, Tabebuia palmeri and

Figure 10. Winter Photograph of Lower Portion of Air Temperature Column. -- Photographed on-plot December 24, 1966, looking east to over-story tree, Conzattia sericea; cacti, Pachycereus pecten-aboriginum; right midground tree, Tabebuia palmeri; left foreground leafless shrub, Jatropha platanifolia; left foreground shrub with dry leaves, Montanoa rosei; and right foreground small shrub, Franseria cordifolia. See re-photographs.

Figure 11. Winter Photograph of Giant Hecho Cactus (Pachycereus pecten-aboriginum). -- Center tree with seed clumps and peeling bark is Bursera grandifolia; center, in front of ladder, tree partly in leaf, Erythroxylon mexicana; and top right background, edge of tree crown with fine leaves, Lysiloma divaricata. Photographed on-plot looking north December 24, 1966. See re-photographs.

Willardia mexicana enter winter with drying leaves which soon drop. Cassia emarginata is opportunistic in that during winter it either retains its old leaves, produces fresh ones or is leafless. This plant may also flower in winter and at the same time it may retain some mature legumes. Lysiloma divaricata has sparse dry and dropping leaflets and mature legumes. Some less important B-stratum trees, such as Erythroxylon mexicana and Wimmeria confusa, and those more characteristic of drainages, such as Guazuma ulmifolia, Pithecollobium tortum and Randia echinocarpa frequently retain their dried leaves through the winter months. Fruits are present on Bursera grandifolia, Ceiba acuminata, Guazuma ulmifolia and Pithecollobium tortum and leaves remain on Heteropteris palmeri and Nissolia hirsuta, both of which are vines.

Those B-stratum trees which flower in the winter are spectacular. The tree morning-glory (Ipomoea arborescens) reliably flowers and sets seed in mid-winter while leafless. Its white blossoms are held high on upper branches. The hecho cactus (Pachycereus pecten-aboriginum) has blossoms which are similar to those of the saguaro (Cereus giganteus) but their outer petals are attenuated and give the corolla the appearance of a sun-star. However, the most showy of the regions flowering trees is the amapa (Tabebuia palmeri). This species usually flowers in mid-winter, while leafless, but occasionally does so in late autumn before it drops its leaves. This plant is common and its blossoms are large and numerous. When it is flowering the entire hillside appears splashed with brilliant lavender.

*Montanoa rosei*, the co-dominant in the C-stratum, still has leaves in the winter and is usually in flower. In favorable years this plant, which is a common drainage-side species, displays massive reproductive activities and may also produce additional winter leaves. Its co-dominant, *Jatropha platanifolia*, has been leafless since the beginning of autumn and will remain so until the summer monsoon. Less prominent C-stratum shrubs are normally with a few drying leaves. The large spiny fruits of *Randia echinocarpa* are ripe in mid-winter.

The dominant D-stratum shrub, *Franseria cordifolia*, is opportunistic. In favorable years, it flowers heavily and produces additional winter leaves. In dry years it does neither and is grazed upon by cattle.

*Discussion*. In winter most of the trees of the northern tropical deciduous forest are nearly leafless. Of the dominant shrubs, *Montanoa rosei* and *Franseria cordifolia* often retain their old leaves and in favorable winters produce additional ones. The shrub *Jatropha platanifolia* remains bare from early autumn to mid-summer. The three winter months normally produce 90.6 mm of precipitation, 13% of average annual. Mean monthly macroclimate temperature, at Minas Nuevas, is at its lowest in January, 17.1$^{o}$C.

The near leafless vegetation allows 50% of open light to penetrate to the forest floor. Winter soil moisture is moderate (6.7%); mean relative humidity is quite high (68%); and average vapor pressure deficit is very low (5.2 mm). Sufficient direct solar radiation penetrates to ground-level to raise surface temperatures to moderate levels

(22.4°C diurnal mean). Adjacent air temperatures then attain readings higher than those occurring in or immediately above the forest canopy. During the short days of winter this diurnal pattern of ground-level heating is not strongly developed. Nocturnally terrestrial radiation produces a temperature inversion so that ground-level air becomes cooler than air higher in the canopy.

Spring (March, April, May)

Environmental monitoring commenced 2000, April 19, 1967, and extended through 2000, April 21. Afternoons and evenings were slightly to moderately cloudy, and with light breezes. Nights and mornings were clear and calm.

Temperature. The two thermistors which gave the most divergent temperatures, 0.5 m and 18 m, are plotted on time (Figure 12). Nocturnal temperatures at the 0.5 m height are frequently 2°C cooler than that at the 18 m height. Diurnally the situation reverses and the temperature at 0.5 m often becomes 2°C warmer than at 18 m.

Figure 13 shows temperature profiles at the time of the lowest occurring temperature at the 0.5 m height (0400, April 21), the highest temperature (6400, April 21), and an in-between temperature (1880, April 21). Concurrent ground surface and subsurface temperatures are included. The diurnal profile is a typical incoming radiation curve and the nocturnal profile approaches a typical outward radiation curve.

In Figure 14 soil temperatures (surface to 50 cm) are plotted on time. The line depicting temperature at the 0.5 m depth barely deviates from 26°C. Surface temperatures range widely, 12.5-53°C. Temperatures at intermediate depths vary considerably less.

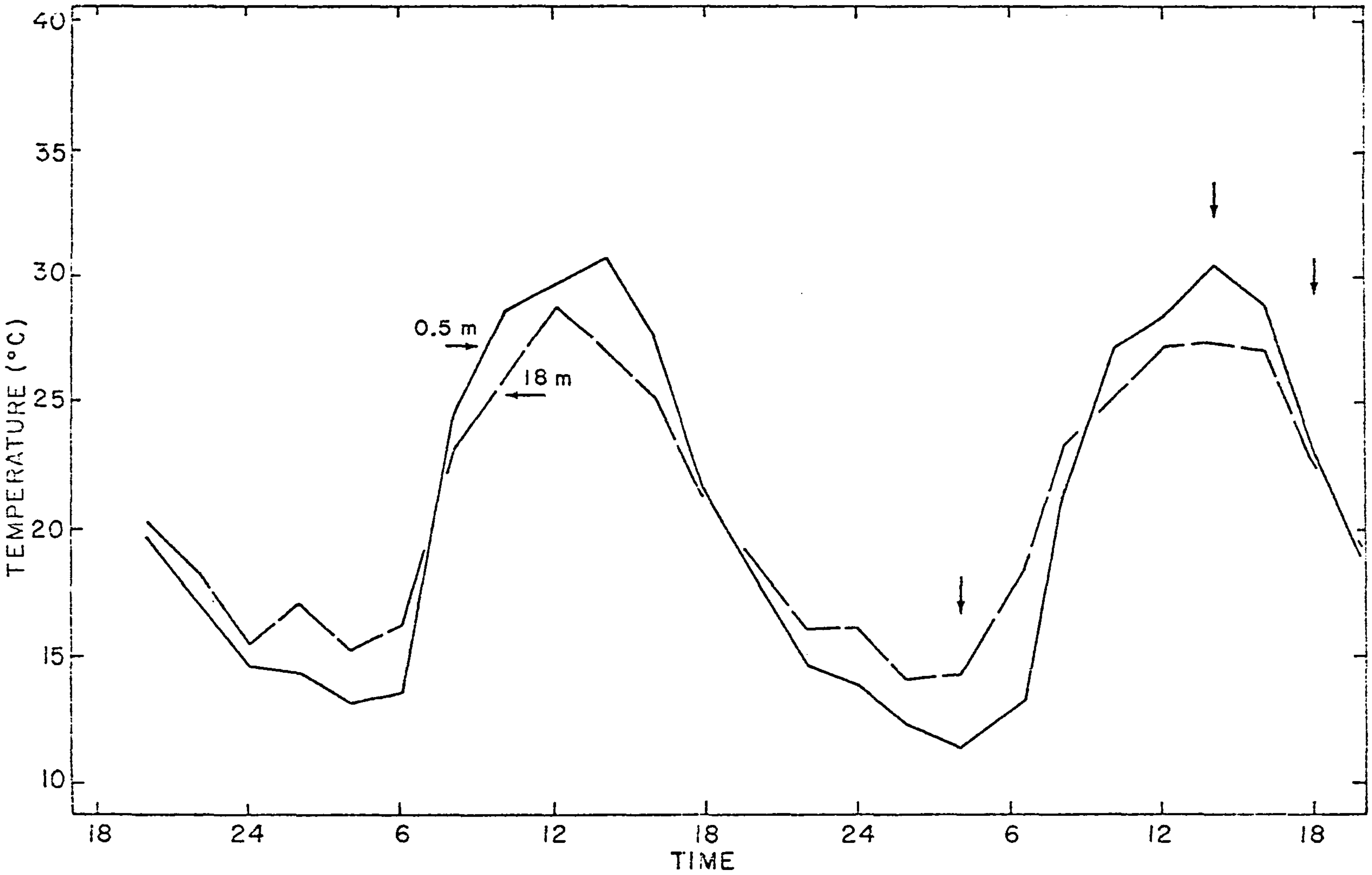



Figure 12. Spring March of Air Temperatures Above the Forest Canopy (18 m) and Near the Ground (0.5 m). -- Monitoring commenced 2000 April 19 and continued for 48 hrs. Vertical arrows indicate times of temperature profiles shown in Figure 13.

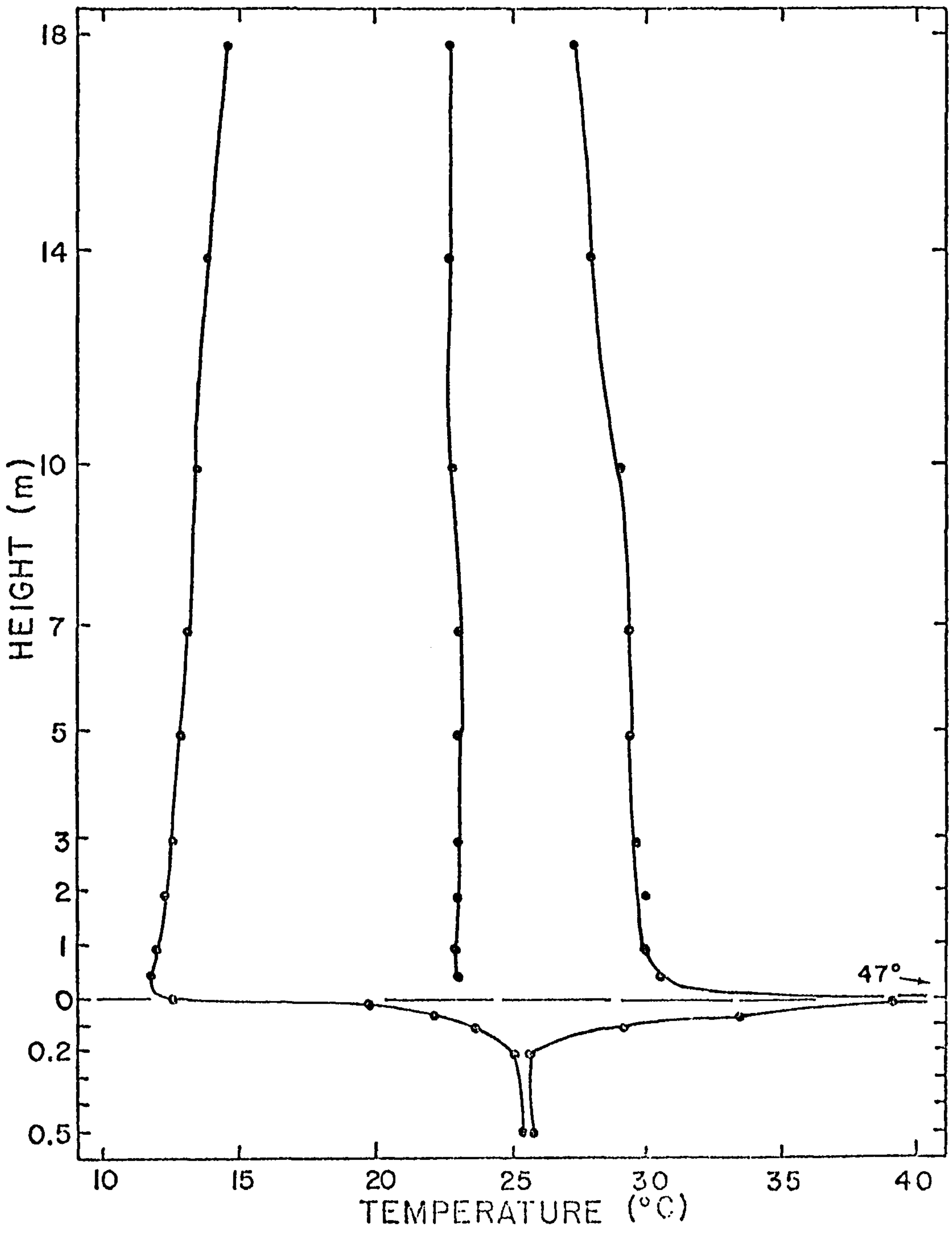



Figure 13. Spring Temperature Profiles. -- Left, profile at the time of lowest occurring 0.5 m temperature, 0400 April 21. Right, profile at time of highest 0.5 m temperature, 1400 April 21; surface temperature attained 47°. Center, a transition profile, 1800 April 21. Subsurface depth scale is enlarged.

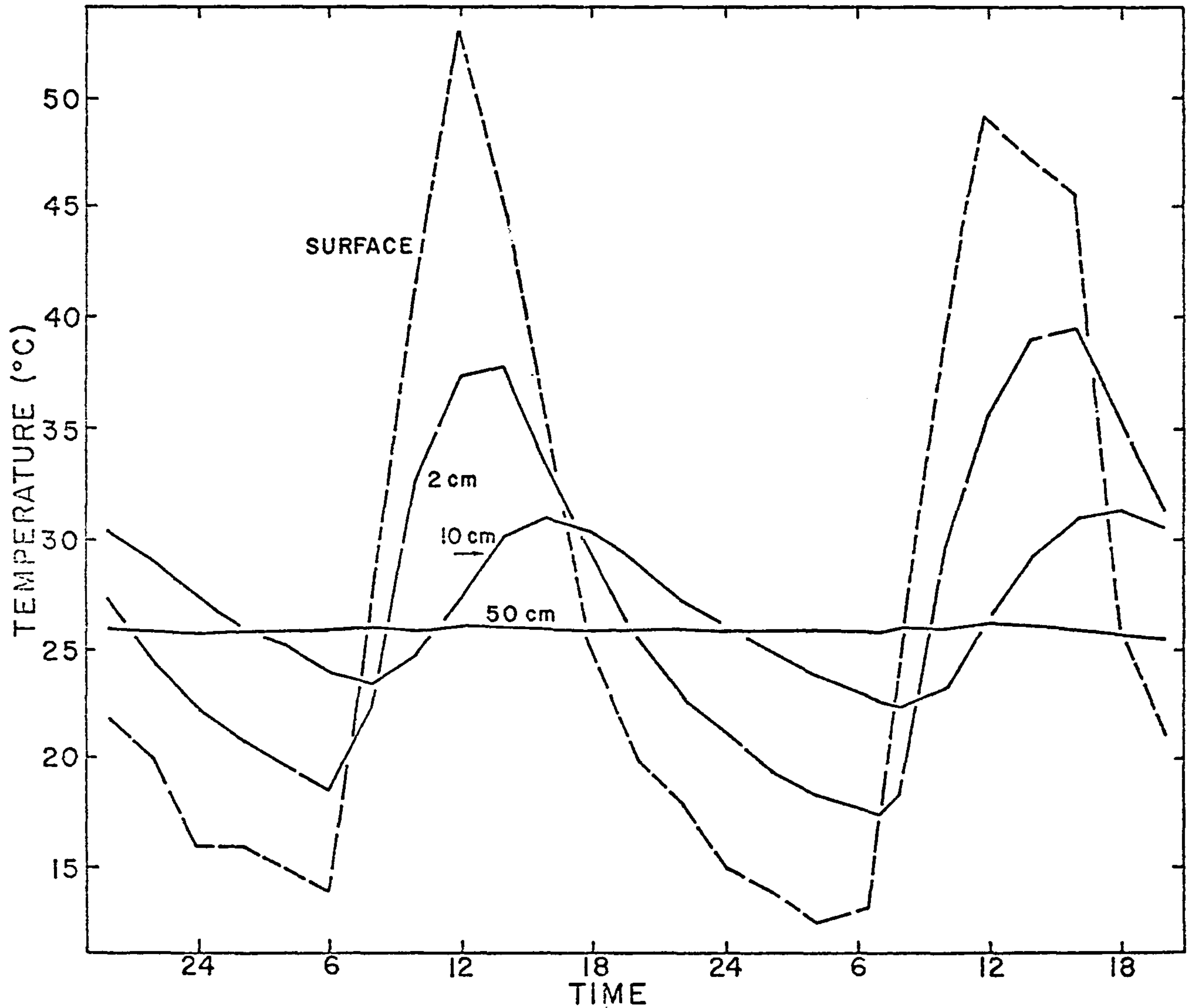



Figure 14. Spring March of Soil Temperatures. -- Monitoring commenced 2000 April 19 and continued for 48 hrs. Thermometer depths are indicated.

Relative Humidity. Diurnal lows reached 15% and nocturnal highs leveled near 45% (Figure 15). Computed vapor pressure deficit ranged quite high and at mid-day climbed to 28 mm Hg (Figure 15).

Light. Ground level values were generally about 90% of those taken in open light. Light readings at a height of one meter were near 100% of open light values.

Soil Moisture. Spring soil moisture was low and increased slightly with depth. A value of 2.5% was obtained at the 5 cm depth, 1.2% at 10 cm, 3.8% at 20 cm and 3.9% at 50 cm. Soil moisture for all samples averaged 3.4%. Samples were collected April 22, 1967. Additional spring samples collected April 10, 1968, displayed similar soil moisture increases with depth and averaged 3.7%. Samples collected March 30, 1972, averaged 3.5%.

Phenology. Spring is the leafless season. All on-plot trees and shrubs are generally bare. See Figures 16 and 17. Limited flowering and maturing of seeds occurs. Green vegetation is seen only along drainages or on very favorable sites.

A few empty legumes remain attached to leafless *Conzattia sericea*. *Ceiba acuminata* are dispersing its wind borne seeds. Occasional leaves and open legumes remain on the *Lysiloma divaricata*. The black and legume-like fruits of *Tabebuia palmeri* are opening and dropping tufted seeds. The hecho cacti (*Pachycereus pecten-aboriginum*) have finished flowering and their fruits are developing. Fruits with mature seeds are on *Bursera grandifolia*, *Guazuma ulmifolia*, *Hintonia latiflora* and *Pithecollobium tortum*. Frequently in the spring *Cassia emarginata*

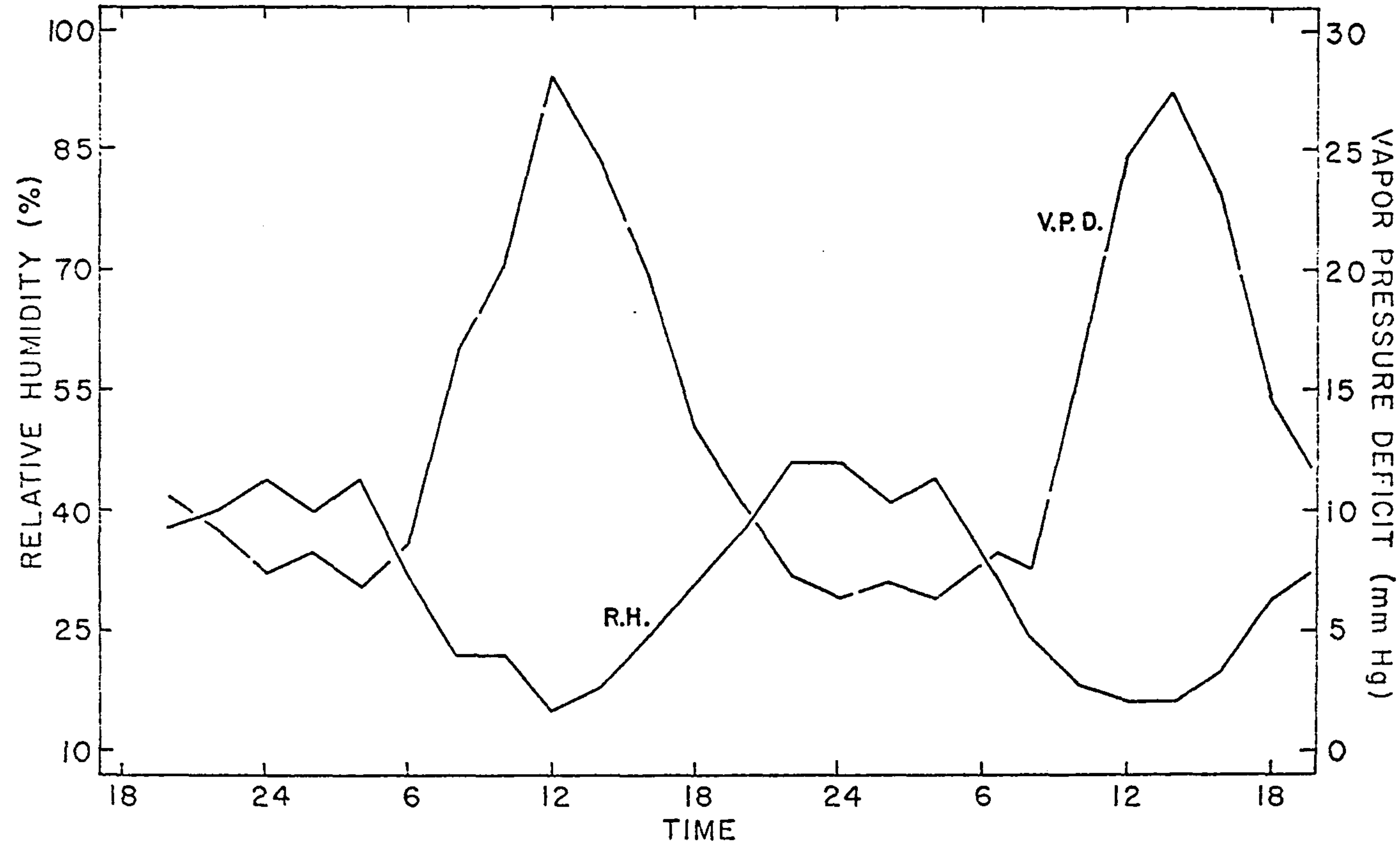



Figure 15. Spring March of Relative Humidity and Computed Vapor Pressure Deficit. -- Monitoring commenced 2000 April 19 and continued for 48 hrs.

Figure 16. Spring Photograph of Lower Portion of Air Temperature Column. -- Major tree is Conzattia sericea; cacti, Pachycereus pecten-aboriginum; right midground tree, Tabebuia palmeri; left foreground shrubs, Jatropha platanifelia and Montanoa rosei; and right foreground small shrubs, Franseria cordifolia. Photographed April 21, 1967. See re-photographs.

Figure 17. Spring Photograph of Giant Hecho Cactus (Pachycereus pecten-aboriginum). -- Tree with seed clumps is Bursera grandifolia; and top foreground branch, Tabebuia palmeri. Photographed April 21, 1967. See re-photographs.

displays impressive yellow blossoms. The vine Exogonium bracteatum is in flower and fruit.

In favorable years Montanoa rosei and Franseria cordifolia retain drying leaves and have numerous ripe fruits. The cholla, Opuntia kleiniae, and the prickly pear, Opuntia fuliginosa, are both in flower in the spring. During dry years Franseria cordifolia are nearly completely devoured by cattle and so are the pads of Prickly pear and the bark and twigs of some trees.

Discussion. By mid-spring the vegetation is essentially leafless, flowerless and fruitless. The three spring months collectively receive an average of only 8.7 mm precipitation, about 1% of the average annual total. During this period temperatures are intermediate between winter and summmer.

About 90% of open light was received at the forest floor. Average on-plot relative humidity (31%) is much lower than in winter (68%). Average vapor pressure deficit is very high (13.7 mm). Soil moisture (3.5%) is about half that of winter (6.7%). Soil temperature at a depth of 50 cm (26°C) has risen 7°C since winter. Surface temperatures show characteristics which are almost desert-like, with high maxima (53°C) and wide daily ranges (40.5°C).

Because of the leaflessness of the vegetation solar radiation easily reaches the ground. Diurnal air temperatures near ground-level are much higher than were temperatures above the canopy. Nocturnal ground-level temperatures are considerably lower than temperatures directly above the canopy, as in the winter. Spring temperature profiles are similar in character to those obtained in winter, but the curves show greater temperature change with height and a broader range between daily extremes.

Onset of Summer Rains (June and July)

Five weeks were spent at Alamos in 1968 (June 20 to July 26) observing the onset of monsoons and the subsequent leafing of vegetation. On four occasions environmental parameters were monitored for 24 hour periods: 1) June 20, prior to the first summer rains; 2) July 5, three days after the first on-plot rainfall and subsequently at weekly intervals on; 3) July 12; and 4) July 19. All monitoring commenced at 1800 hours.

Torrential rains fell in Alamos on June 23 and 30. These came out of the Sierra to the east but did not reach as far west as the study plot. The first on-plot rains fell on July 2 and thereafter nearly every other day for the rest of the month. An on-plot recording maximum-minimum thermometer showed that during these weeks daily maximum temperatures decreased while minimum temperatures held constant (Figure 18).

The first 24-hour period monitored for environmental parameters (1800, June 20 through 1800, June 21) was clear and calm except for light to gentle breezes during the last six hours and a completely overcast sky in the final hour. The second period, (July 5-6) was cloudy with light breezes during the first few hours. It then cleared and was calm but again became cloudy and breezy for the last six hours. Rain fell (7.1 mm) between 1600 and 1700 hours on July 6. The third period

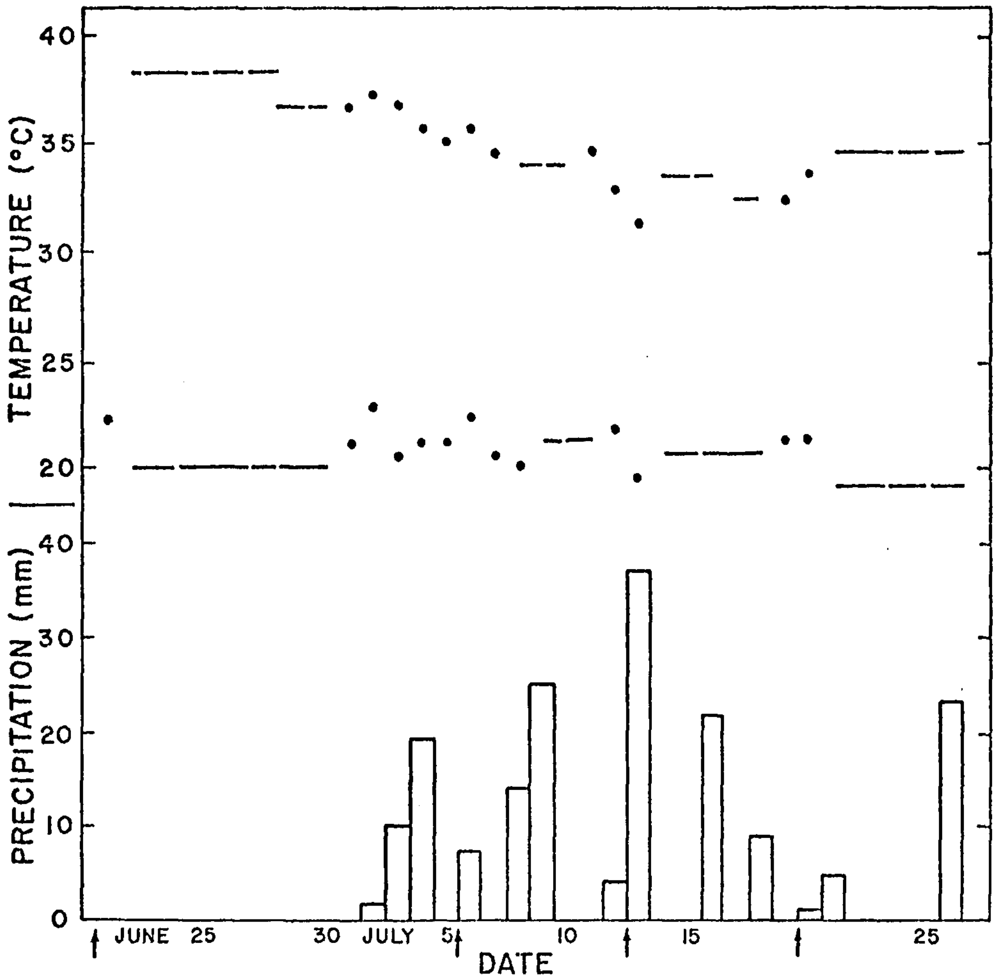



Figure 18. Monsoon Onset Daily Maximum-minimum Temperatures and Precipitation. -- Dots indicate daily temperature extremes while broken lines are extremes over extended periods. Arrows at dates are periods monitored for micro-environmental parameters. Data are from study area, summer, 1968.

(July 12-13) was totally cloudy except for a change to partly cloudy sky in mid-morning. Calm existed except for light air in the early evening. Rain (3.8 mm) fell between 2000 and 2200 hours on July 12. The fourth (July 19-20) period was generally calm and with nearly complete and continual cloud cover. Rain fell during the first and last hours of the period.

Temperature. Variation in temperature at the 0.5 m and 18 m heights, for the first and last periods monitored, are shown in Figure 19. During the first period, the two lines representing temperature undergo a daily flip. That is, during the night temperatures near the ground are cooler than those at 18 m, but flip to be the warmer of the two by day. Temperatures from the last period monitored do not undergo this reversal. Air temperatures near the ground are now always cooler than those in the canopy. Daily range of temperature at the 18 m level is nearly the same during both periods while range of temperature at the 0.5 m level is more than halved in the last period. Relationships during the two intervening periods, not graphed, were intermediate. Extreme minimum temperatures along all four curves in Figure 19 are closely clumped while maximum readings are sharply separated and in the case of the July 19 values, depressed.

Figure 20 shows profiles of thermistor height on temperature. The minimum and maximum temperature profiles occurring during each of the four time periods monitored are illustrated. In all cases there is little difference between the minimum temperature profiles. The June 20 minimum profile does approach a terrestrial radiation, ground-level

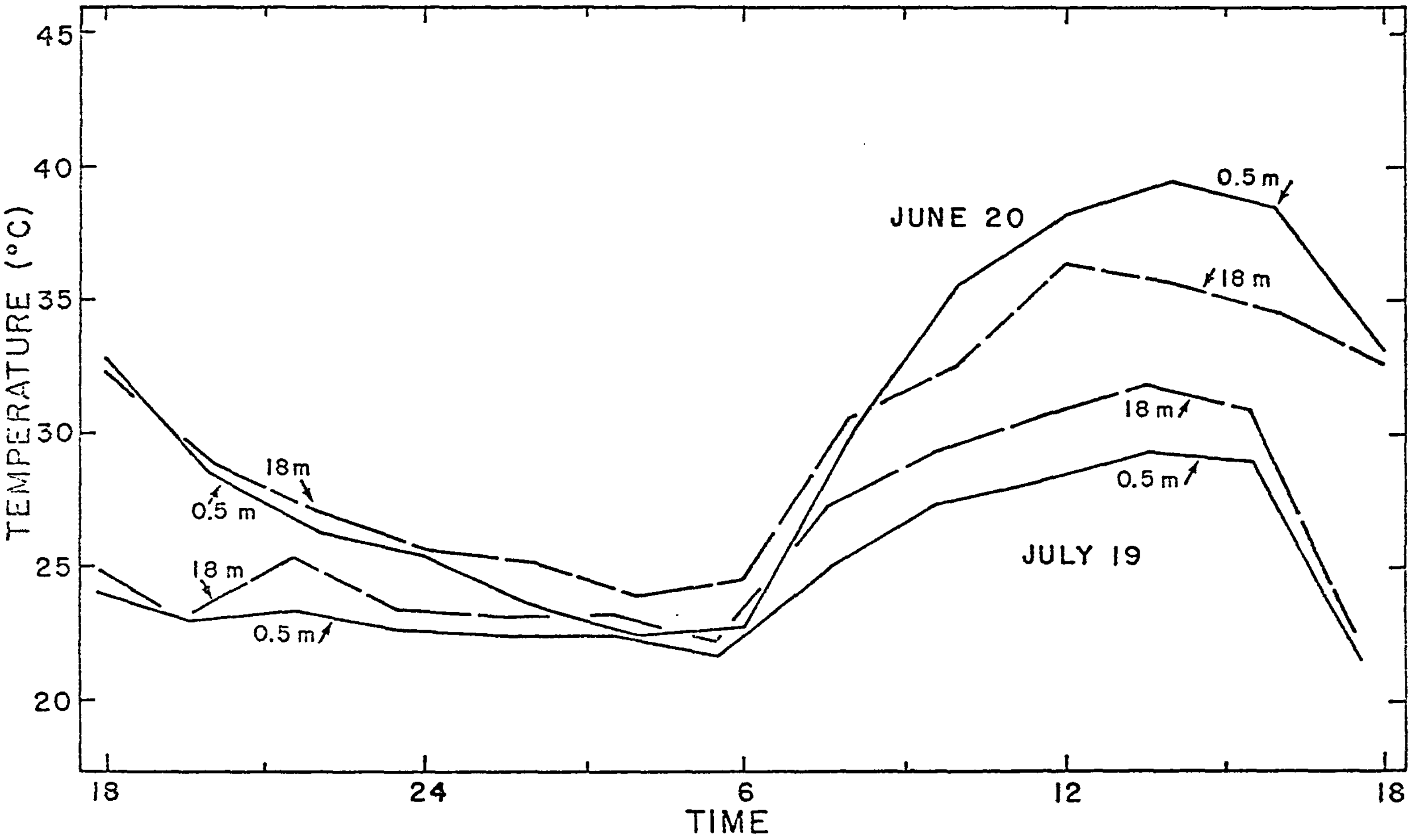



Figure 19. Monsoon Onset March of Air Temperatures at 18 m and 0.5 m. -- Data from both the pre-rain monitoring, June 20 and the last post-rain monitoring, July 19, are illustrated.

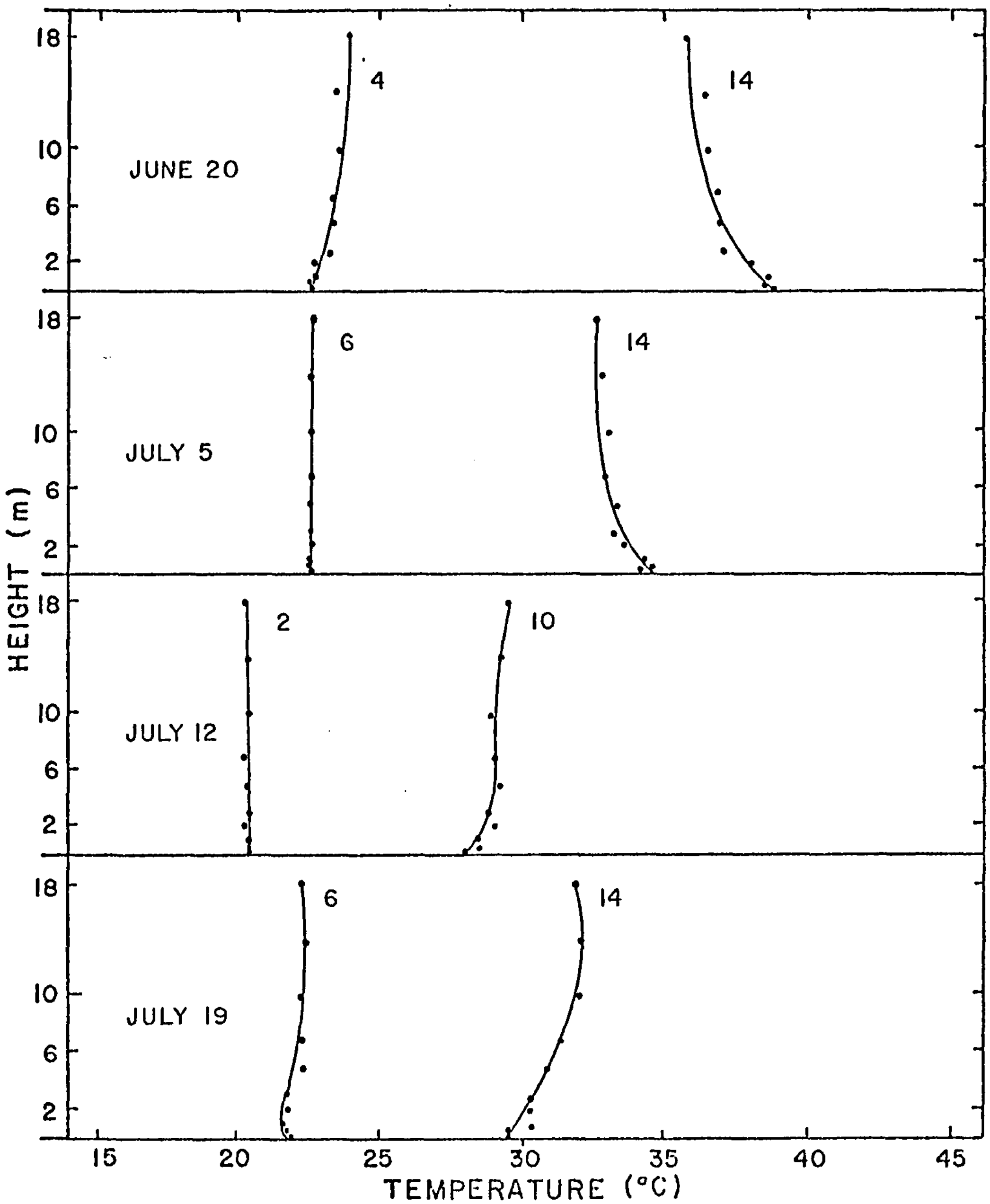



Figure 20. Monsoon Onset Air Temperature Profiles. -- Illustrated are the extreme profiles from the four periods monitored; time of day is given. First rains occurred July 2. Leafing was near complete by July 19.

cooling type curve, while the others are more vertical in character. Interestingly the minimum profile on July 12 shows canopy air to be slightly cooler than the air below.

The June 20 and July 5 maximum temperature profiles are typical incoming radiation type curves with strong ground-level heating. The July 12 and July 19 maximum profiles are different in character. They lack ground-level heating; temperatures now decrease as one goes from canopy height down to ground level.

Soil temperatures (surface to 50 cm) are plotted on time. Figure 21 illustrates the pre-rain period, June 20. At this time surface temperatures fluctuate widely and reach very high readings. With increasing soil depth temperature range decreases until at 50 cm, where little fluctuation was observed during the 24 hours monitored. Figure 22 shows soil temperatures during the last time period monitored, July 18. All curves are now flattened and depressed. Range of surface temperature is only one-fifth that of the pre-rain period. Soil temperature curves from July 5 (not illustrated) were slightly flattened suggestive of the pre-rain period (Figure 21). Curves from July 12 (not illustrated) were greatly flattened and approach the July 19 data (Figure 22).

Relative Humidity. Ambient relative humidity from all four time periods monitored are graphed in Figure 23. The lowest curve illustrates data from the pre-rain, June 20, monitoring. The data from July 5 are intermediate while the upper two curves, July 12 and 19, are equally high and similar in character.

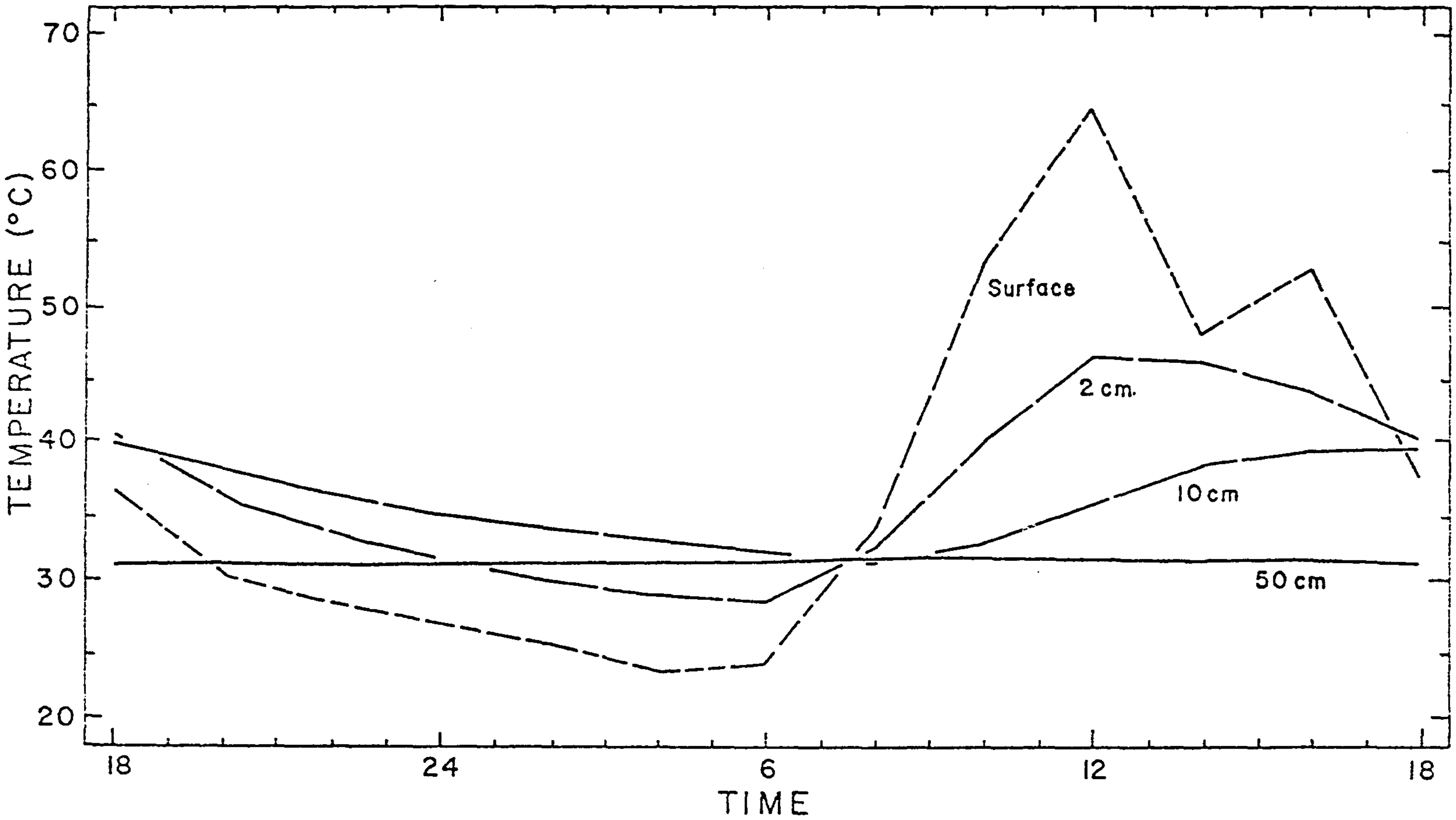



Figure 21. Pre-monsoon March of Soil Temperatures. -- Monitoring commenced 1800 June 20 and continued for 24 hrs. Thermometer depths are indicated.

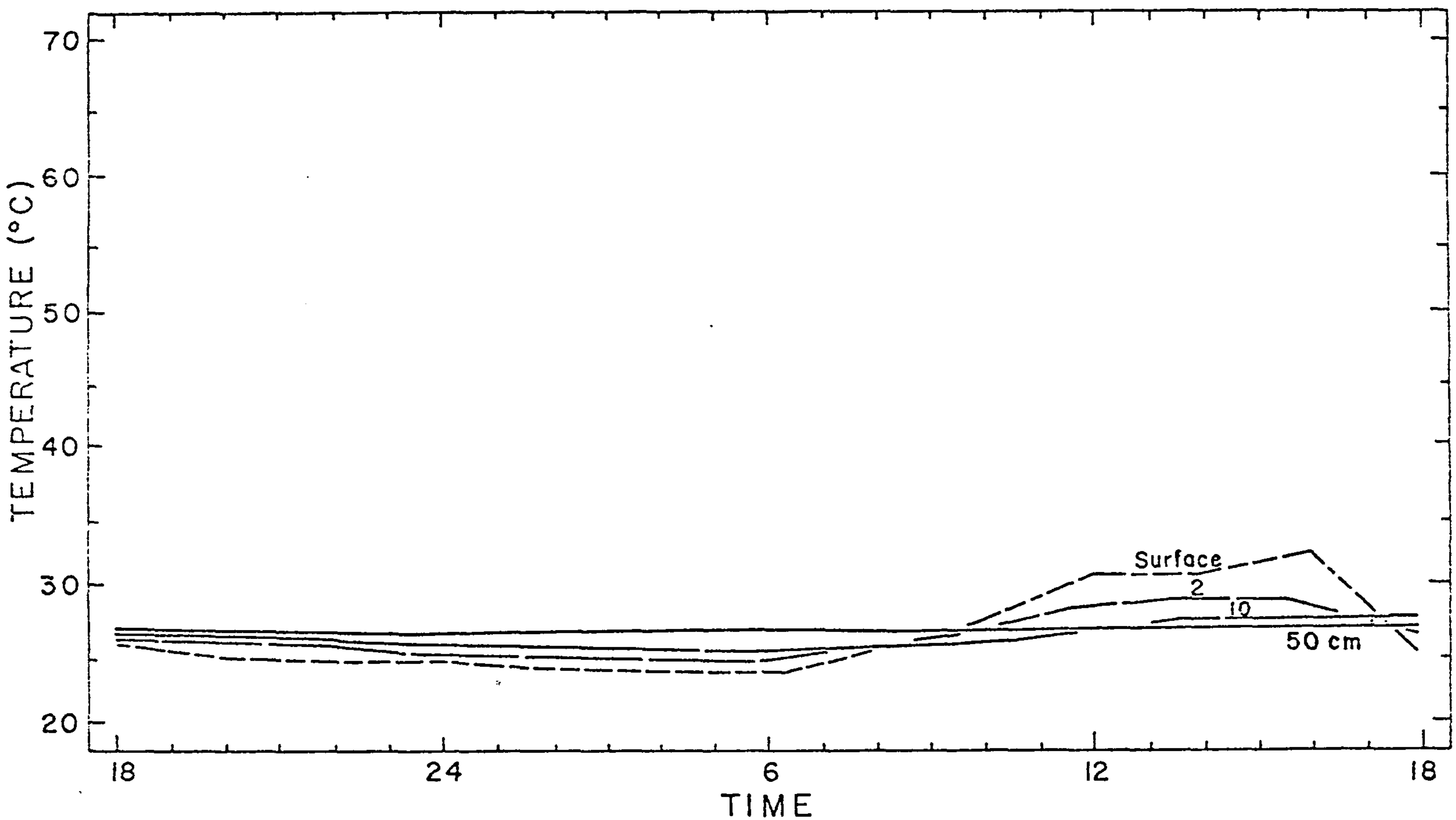



Figure 22. Monsoon Onset, Post-leafing, March of Soil Temperatures. -- Monitoring commenced 1800 July 19 and continued for 24 hrs. Thermometer depths are indicated.

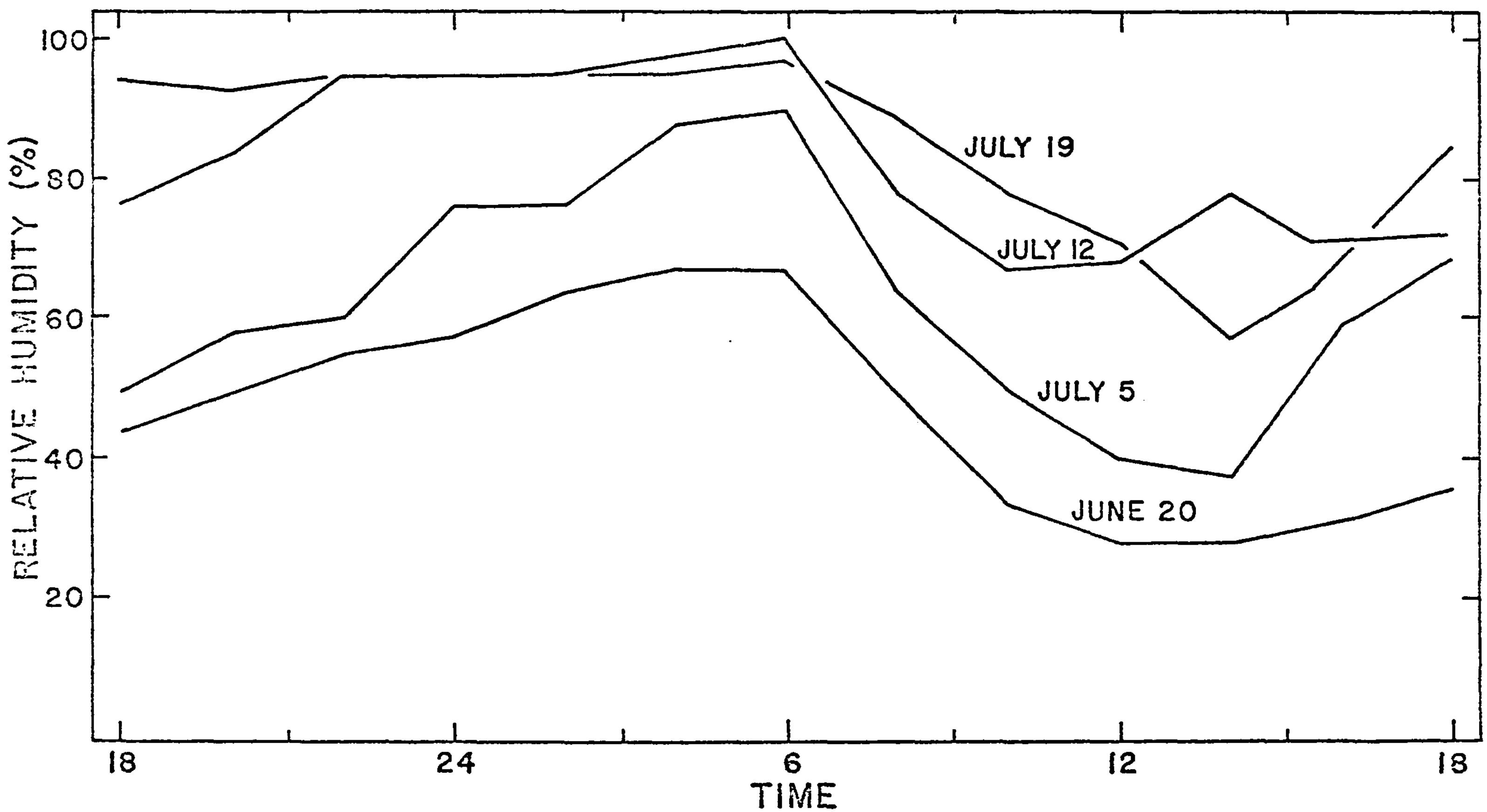



Figure 23. Monsoon Onset March of Relative Humidity. -- Dates of the four intervals monitored are shown. First rainfall occurred July 2.

Curves of computed vapor pressure deficit show reversed relationships (Figure 24). The pre-rain, June 20, values are high. The July 5 curve is intermediate and the last two time periods are low and similar.

Light. Pre-rain light values at the forest floor were about 90% that of light in the open. On July 5 this value was still 80%. By July 12 the value had reduced sharply and was now down to 30%. On July 19 it was at 5-10%.

Soil Moisture. Soil samples for moisture determination were collected before the first summer rains on June 23 and during the monsoons on July 7, 13 and 21. The pre-rain samples increased slightly in moisture while going downward from the surface, 2.4% at 5 cm and 4.4% at 50 cm. All depths together averaged 3.5%. On July 7, after a total of 38 mm of precipitation, soil moisture decreased with depth and averaged 7.7%. On July 13, after a total of 114.7 mm of precipitation, and following closely a 36.8 mm rain, soil moisture again decreased with depth but averaged 15.5%. On July 22, after a total of 150.5 mm of rain, soil moisture was constant with depth and averaged 11.0%.

Phenology. The onset of summer rains begins the period of vegetation renewal. In spring, and especially in early summer, the tropical deciduous forests of northwestern Mexico are a leafless tangle of bare twigs. A few short weeks after the onset of the monsoon the forest becomes verdant.

The general appearance of the vegetation at the time of the pre-rain monitoring, June 20, was much like it had been in spring--leafless and dormant (Figures 25, 26, and 27). Upon closer observation, however,

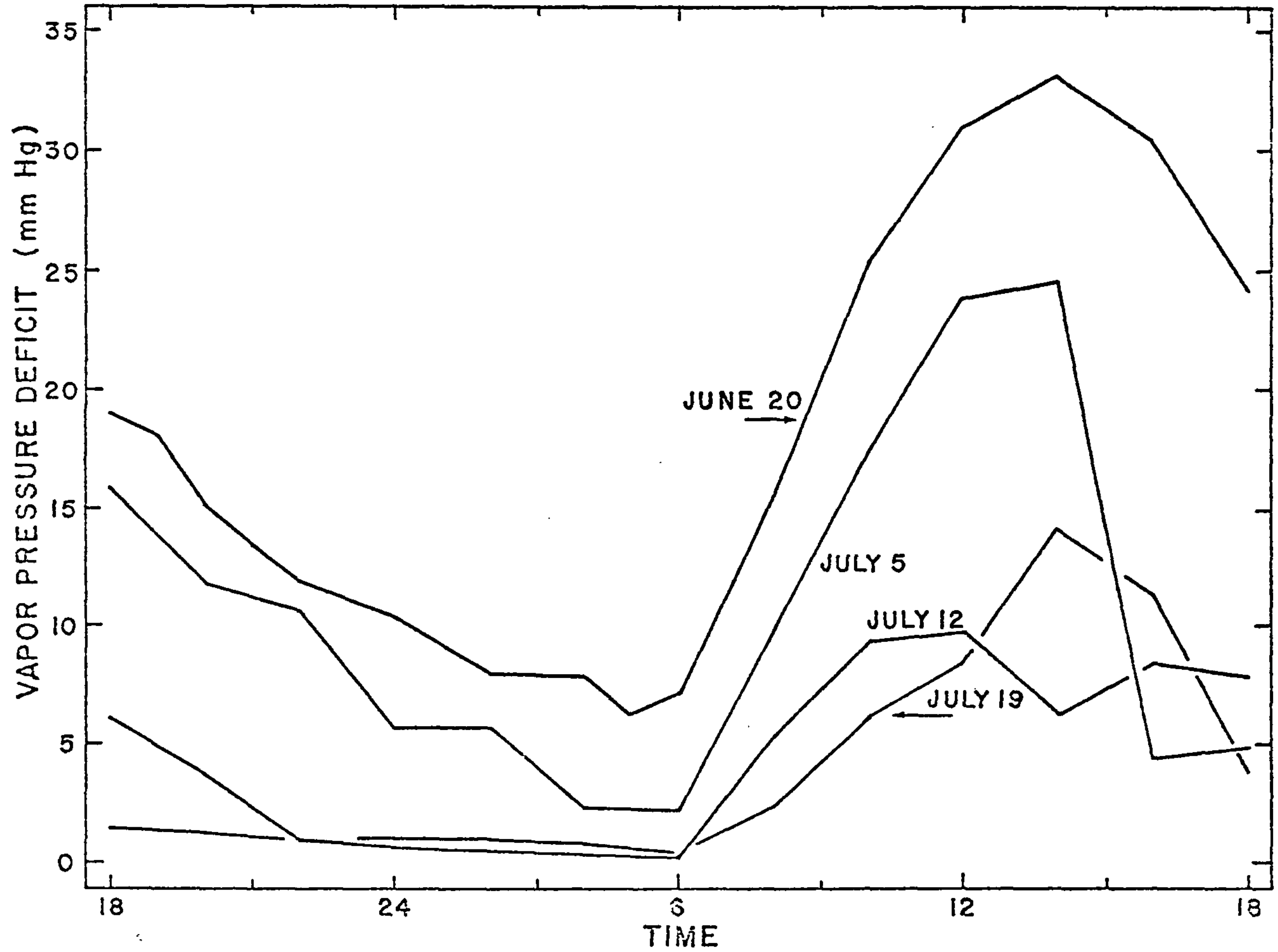



Figure 24. Monsoon Onset March of Vapor Pressure Deficits. -- Dates of the four intervals monitored are shown. First rainfall occurred July 2.

Figure 25. Pre-monsoon Photograph of Hecho Cactus (Pachycereus pecten-aboriginum). -- Photograph taken on-plot looking north June 22, 1968. Open pods in upper foreground are Tabebuia palmeri. See re-photographs.

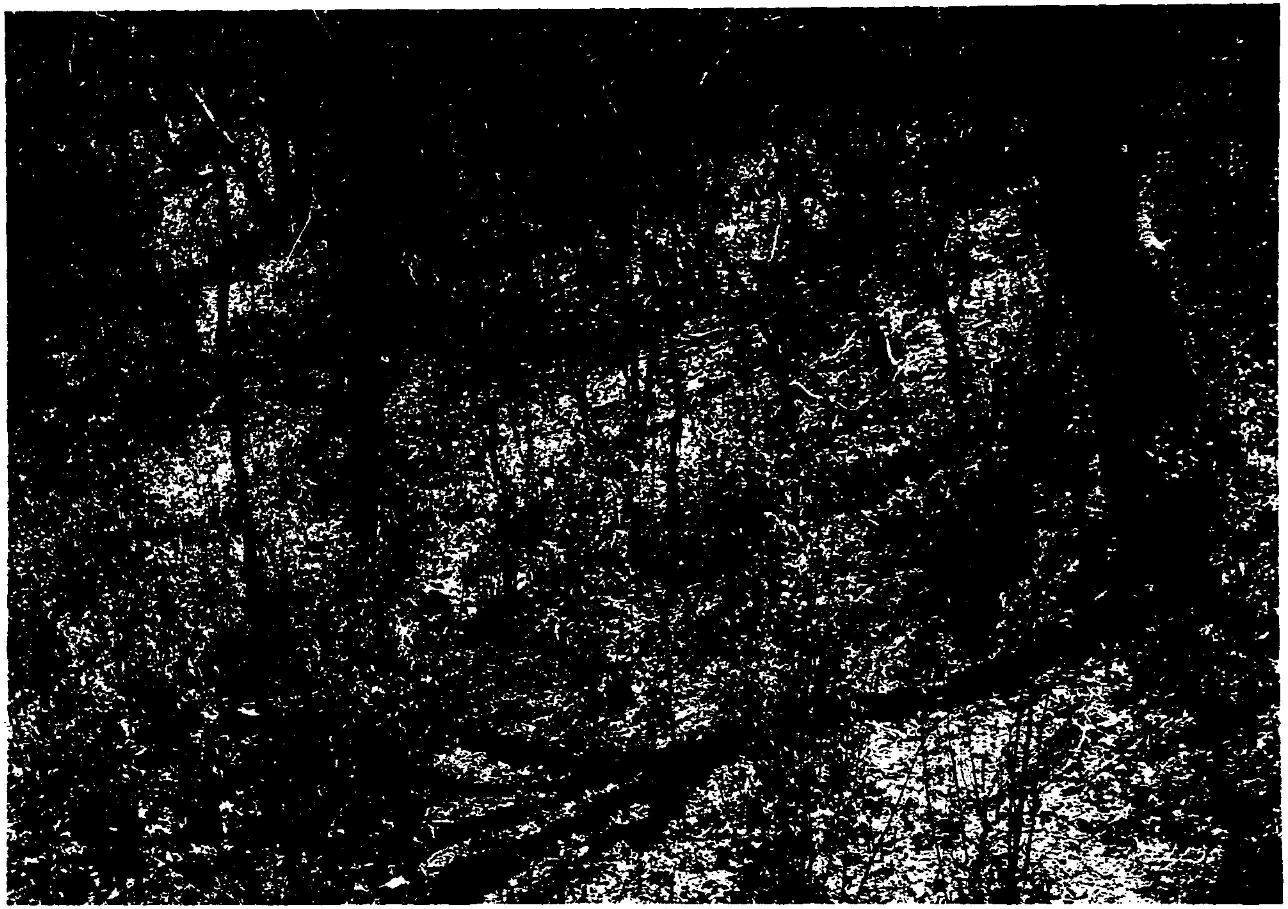


Figure 26. Pre-monsoon Photograph of Ground-cover. -- Small foreground shrubs are <u>Franseria</u> <u>cordifolia</u>; and tree trunk at right, <u>Bursera</u> <u>bipinnata</u>. Photographed on-plot June 22, 1968. See re-photograph.

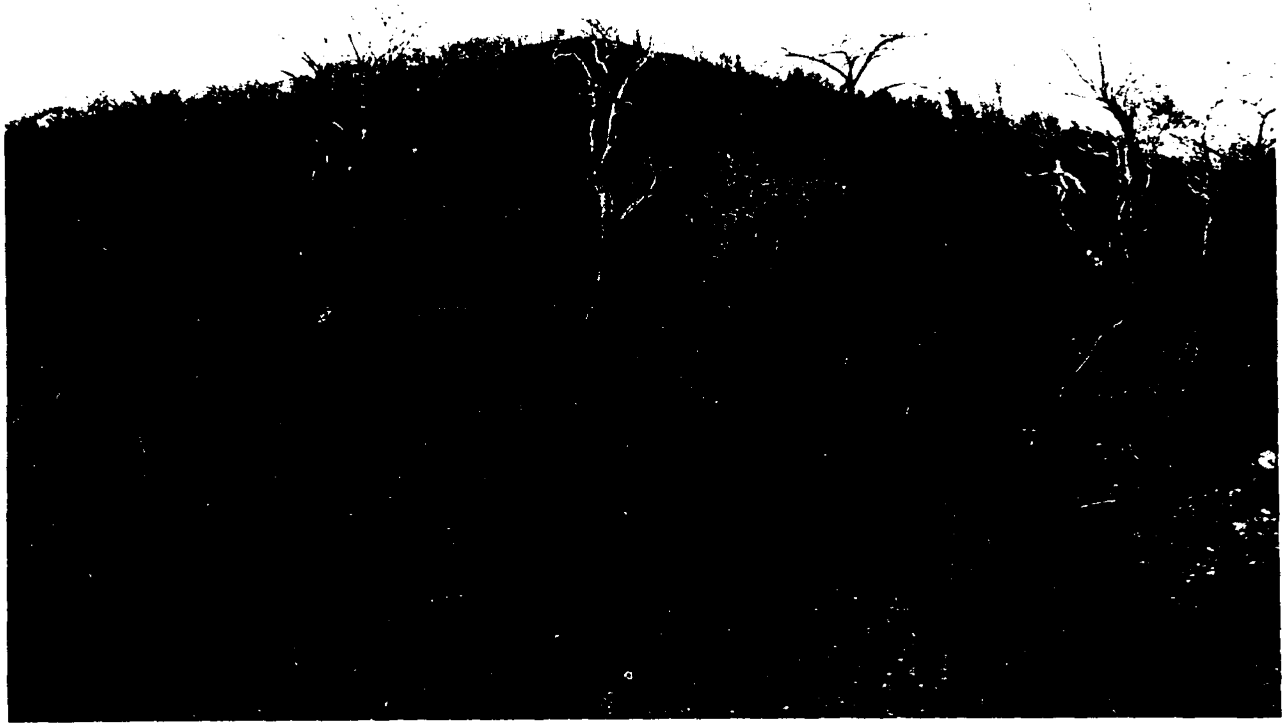


Figure 27. Pre-monsoon Photograph of Near Leafless Forest. -- Trees protruding above the skyline are, left to right: Lysiloma divaricata, Ipomoea arborescens, Ceiba acuminata, Ipomoea arborescens and Ceiba acuminata.

considerable activity was apparent. Their were flowers on Conzattia sericea, also leaf initiation has begun. Among B-stratum trees, Brongniartia alamosana, Bursera grandifolia, Cassia emarginate and Ceiba acuminata, had flowers and opening leaves. Only flowers were present on Willardia mexicana and only leaves on Ipomoea arborescens. Mature off-plot Guazuma ulmifolia exhibited new leaves and flowers. Some old fruits still remained upon Bursera grandifolia, Cassia emarginata, Ceiba acuminata, Guazuma ulmifolia and Tabebuia palmeri. The only newly opening fruits were on the hecho (Pachycereus pecten-aboriginum). This cactus flowers in the winter and its fruits mature in early summer. Its large (ca. 3 x 4.5 mm) seeds may now be dispersed and subsequently germinated by the summer rains. In the shrub strata, immature leaves are present during this period on the dominants, Jatropha platenifolia, Montanoa rosei, and Franseria cordifolia. Flowers are present on Jatropha platanifolia and mature off-plot Randia echinocarpa.

Two weeks later, at the time of the first post-rainfall monitoring (July 5) there was slight change in the phenological development among the major components of the vegetation (Figures 28, 29 and 30). Those trees which earlier had newly developed leaves now displayed a better foliage. Those formerly without leaves were now sparsely clothed with the beginning of a green mantle. Lysiloma divaricata and Erythroxylon mexicana are the only trees without noticeable leaf initiation. The rapid leaf development of Jatropha platanifolia, a C-stratum shrub, was of special interest. The photograph in Figure 31 was taken half way between the time of this monitoring and the next.

Figure 28. Monsoon Onset Photograph of Hecho Cactus (*Pachycereus pecten-aboriginum*). -- Foreground shrubs with young leaves are *Jatropha platanifolia*. Photographed on-plot July 6, 1968. See re-photographs.

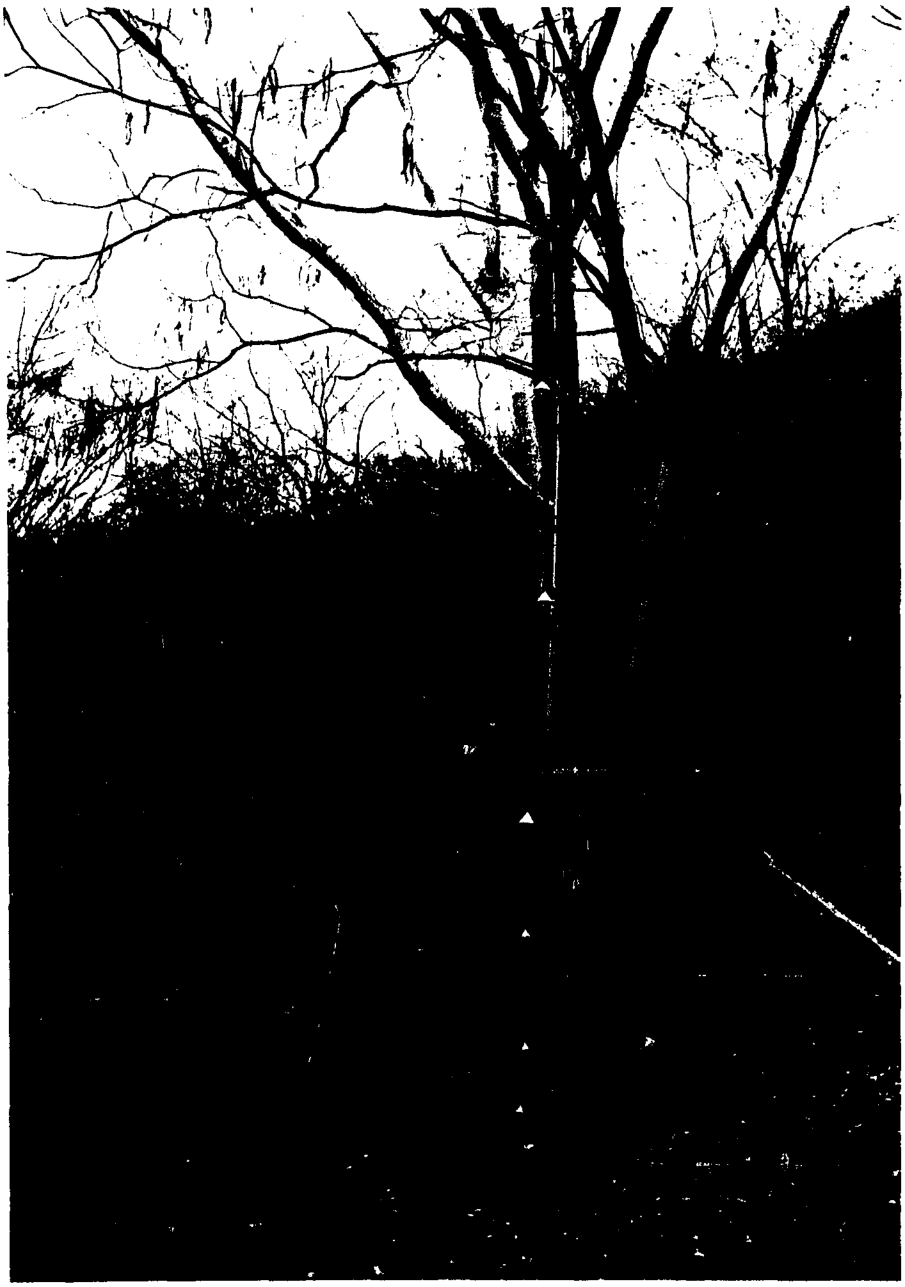


Figure 29. Monsoon Onset Photograph of Lower Portion of Air Temperature Column. -- Major tree is Conzattia sericea; open pods, Tabebuia palmeri; left foreground shrubs, Jatropha platanifolia; and right foreground shrubs, Franseria cordifolia.

Figure 30. Monsoon Onset Photograph of Study Area Drainage. -- Upper left limb is Ceiba acuminata and center tree, Guazuma ulmifolia. Taken July 6, 1968. Compare with re-photograph.

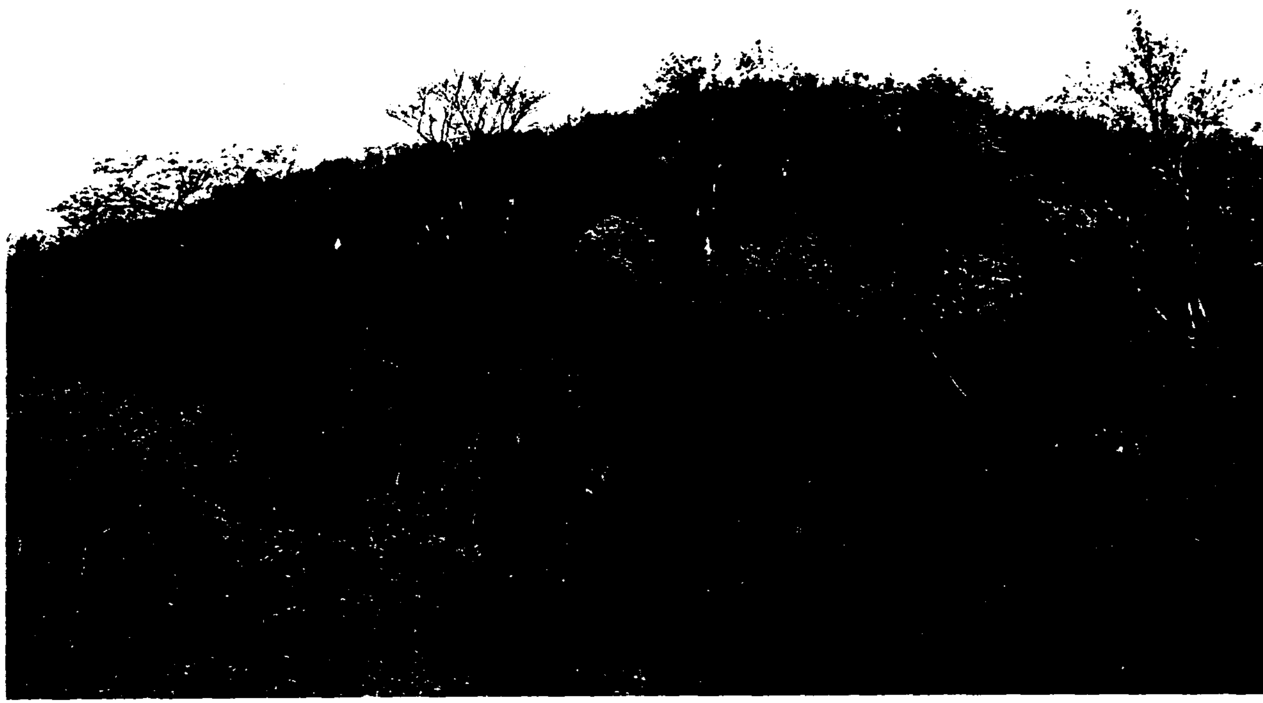


Figure 31. Monsoon Onset Photograph of Partly Leafed-out Forest. -- Trees protruding above skyline are, left to right: *Ceiba acuminata*, *Lysiloma divaricata*, *Ipomoea arborescens*, *Ceiba acuminata* and *Ipomoea arborescens*. Taken along Alamos Highway July 9, 1968. See re-photographs.

At the time of the third monitoring, July 12, the advanced stage of leafing was startling (Figures 32, 33 and 34). Most all plants now had nearly mature leaves while one week before they were almost bare. The only major plant barely coming into leaf was Lysiloma divaricata.

Near the time of the fourth and last (July 19) monitoring of this series. All vegetation, including Lysiloma divaricata, had foliage (Figures 35, 36 and 37). Most leaves were full in size but were fresh, soft and generally light green in color. Two additional weeks might be necessary for them to mature. The seeds of Jatropha platanifolia have already matured and were being dispersed.

Discussion. The harsh spring early summer drought is brought to an end in late June or early July by the monsoon. The month of May has an average annual rainfall of only 1.5 mm, June has 45.9 mm, while July, the wettest month of the year, has 187.9 mm. Average annual and average maximum temperatures peak in June and decrease slightly in July. Average minimum temperatures reach annual highs in July.

Considerable leaf development and flowering occurs weeks prior to the first summer rains. At that time maximum air temperature at 0.5 m approached 40°C while in spring it was 30°C. As in the spring nearly 90% of open light penetrated to the forest floor. Soil temperature at 50 cm was near 32°C, as compared to 26°C in the spring. Daily range of soil surface temperature was about the same but now a maximum of about 65°C was reached; in the spring it was 53°C. Soil moisture (3.5%) was about what it was in the spring (3.7%). The favorable environmental factor which could be responsible for the pre-rain triggering of leafing

Figure 32. Post-monsoon Photograph of Hecho Cactus (Pachycereus pecten-aboriginum). -- Large leaved foreground shrub is Jatropha platanifolia and upper foreground branch, Tabebuia palmeri. Taken on-plot July 14, 1968. See re-photographs.

Figure 33. Post-monsoon Photograph of Lower Portion of Air Temperature Column. -- Major tree is Conzattia sericea; tree at right, Tabebuia palmeri; and large leaved foreground shrub, Jatropha plantanifolia. Taken on-plot July 14, 1968. See re-photographs.

Figure 34. Post-monsoon Photograph of Study Area Drainage; Leafing is Nearly Complete. -- Upper left limb is Ceiba acuminata; center tree, Guazuma ulmifolia; and shrubs at right, Montanoa rosei. Taken July 14, 1968. See re-photograph.

Figure 35. Post-monsoon Photograph of Hecho Cactus (Pachycereus pecten-aboriginum), Nearly Hidden by Leafed-out Vegetation. -- Tree at right is Tabebuia palmeri and large leaved foreground shrubs are mostly Franseria cordifolia. Taken on-plot July 21, 1968. See re-photographs.

Figure 36. Post-monsoon Photograph of Leafed-out Ground-cover. -- Foreground shrubs are mostly *Franseria cordifolia*; background large leaved shrubs, *Jatropha platanifolia*; and tree trunk, *Bursera hipinnata*. Taken on-plot July 21, 1968. See re-photograph.

Figure 37. Post-monsoon Photograph of Leafed-out Forest. -- Trees protruding above the skyline are, left to right: Lysiloma divaricata, Ipomoea arborescens, Ceiba acuminata (beneath skyline), Ipomoea arborescens and Lysiloma divaricata (right edge). Taken along Alamos Highway July 21, 1968. See re-photographs.

and flowering is relative humidity. In spring it averaged 31%, and 12 days before the first on-plot summer rain it averaged 49%.

By the time of the first monitoring after the rain, July 5, 31 mm of rain had fallen on the plot. Leafing, though advanced from the time of the pre-rain monitoring, was still in an early stage. Light penetration to the substrate was now 80% of open light values. Average relative humidity was now up to 66%. Nocturnal ground-level cooling still occurred even though it was not as drastic as before. Diurnal ground-level heating remained quite strong.

A dramatic surge in leafing occurred before the July 12 monitoring. A total of 76.1 mm of on-plot rain had now fallen. Sampled directly after a heavy rain, soil moisture averaged 15.5%. This was higher than field capacity. Thirty percent of open light was now received at ground-level. Average relative humidity was up to 83%. For the first time, since the beginning of this study, diurnal air temperature profiles indicated that ground-level heating no longer occurred. Diurnally the warmest air temperatures were now near the canopy.

At the time of the final monitoring, July 19, the vegetation was almost completely foliaged. Mean soil moisture was 11%. Light penetration was 5-10%. Average relative humidity (86%) was about the same as during the earlier monitoring period. Soil temperature curves at all depths were now extremely flat and depressed toward 27°C.

Diurnal air temperature profiles were now strongly developed curves reflecting high temperatures in the canopy and lower ground-level temperatures. Since the rains began, nocturnal profiles have been noticed in nature and generally lack ground-level cooling.

Late Summer (August)

Environmental monitoring was begun 1800, August 7, 1967, and was continued for 48 hours. The first half of the period was cloudy to partly cloudy with 10.2 mm of rain falling between 1230 and 1800 hours. The second evening, night and early morning were clear and calm but clouds and slight breezes developed in the mid-morning of the second day.

Temperature. Temperature at 0.5 m and 18 m air column heights are plotted on time in Figure 38. Nocturnal temperatures at 0.5 m are slightly cooler than are temperatures at 18 m. Diurnally the relationship remains the same but the separation intensifies. Temperatures at 0.5 m become 3°C cooler on the average than at 18 m.

Figure 39 includes profiles of thermometer height on temperature. Chosen for illustration are profiles at minimum (0400, August 9) and maximum (1400, August 8) temperatures occurring at the 0.5 m height and intermediate temperatures in a transition period (2000, August 8). Concurrent surface and substrate temperatures are included with the air profiles. The minimum temperature profile is vertical, without appreciable variation. The transition profile is nearly vertical but shifted to the right. The maximum temperature profile is not vertical but reflects an increase in temperature with height.

Substrate surface and soil temperatures are plotted on time in Figure 40. All curves are quite flat. The line representing temperature at 0.5 m is consistently near 26°C. Amplitude of surface temperatures is only 8.1°C.

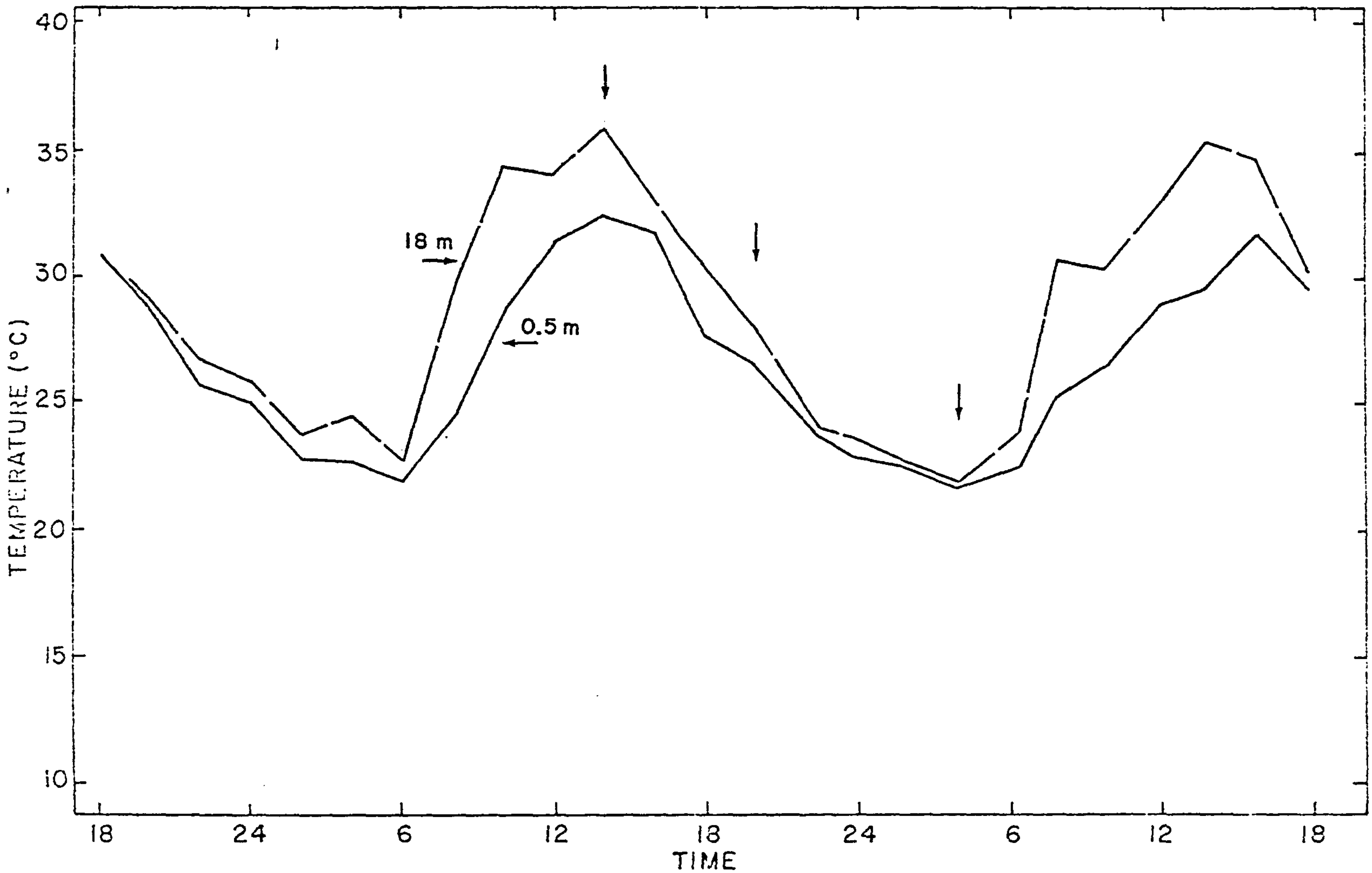



Figure 38. Late Summer March of Air Temperature Above the Forest Canopy (18 m) and Near the Ground (0.5 m). -- Monitoring commenced 1800 August 7 and continued for 48 hrs. Vertical arrows indicate times of temperature profiles shown in Figure 39.

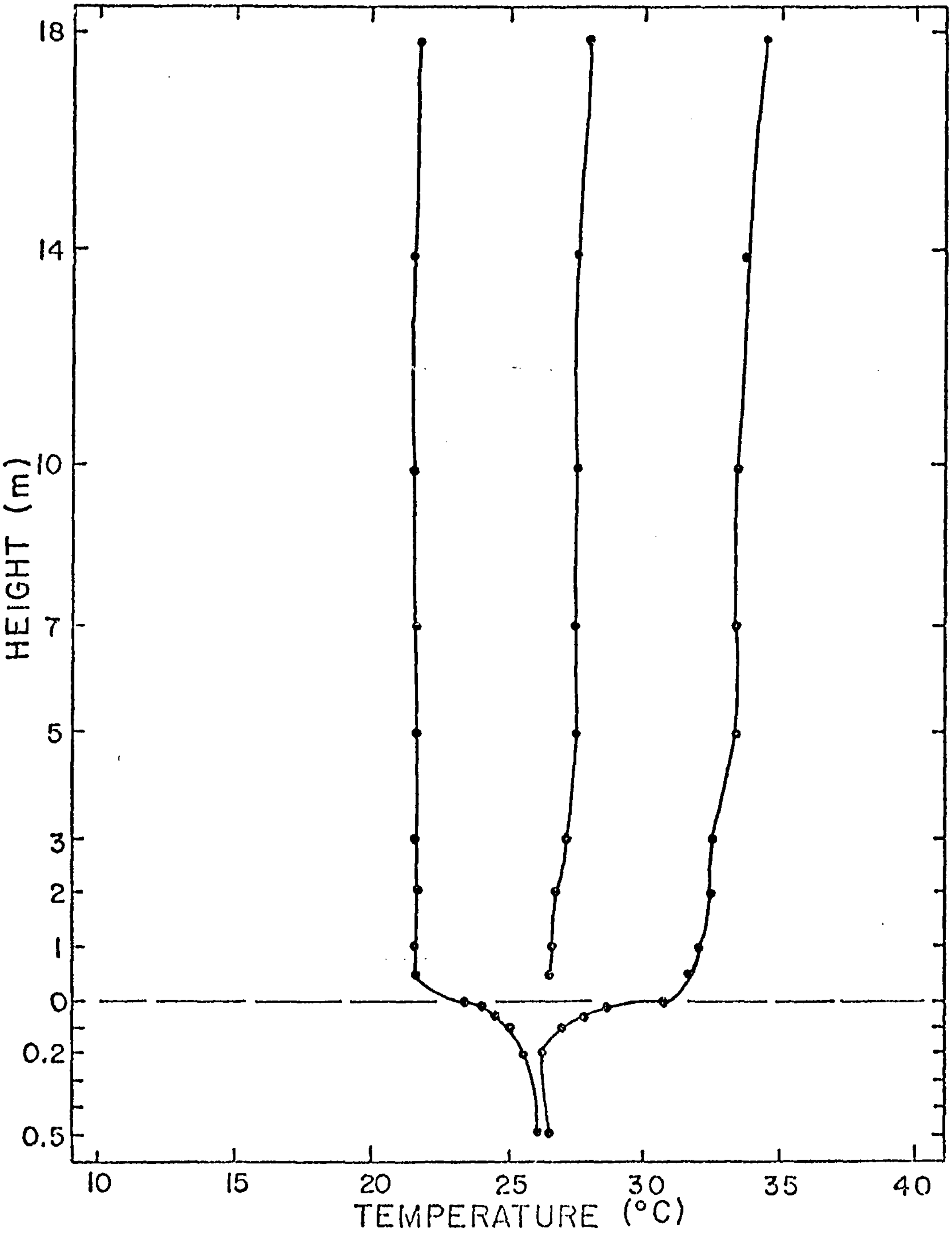



Figure 39. Late Summer Temperature Profiles. -- Left, profile at the time of lowest occurring 0.5 m temperature, 0400 August 9. Right, profile at highest occurring 0.5 m temperature 1400 August 8. Center, a transition profile, 2000 August 8. Subsurface depth scale is enlarged.

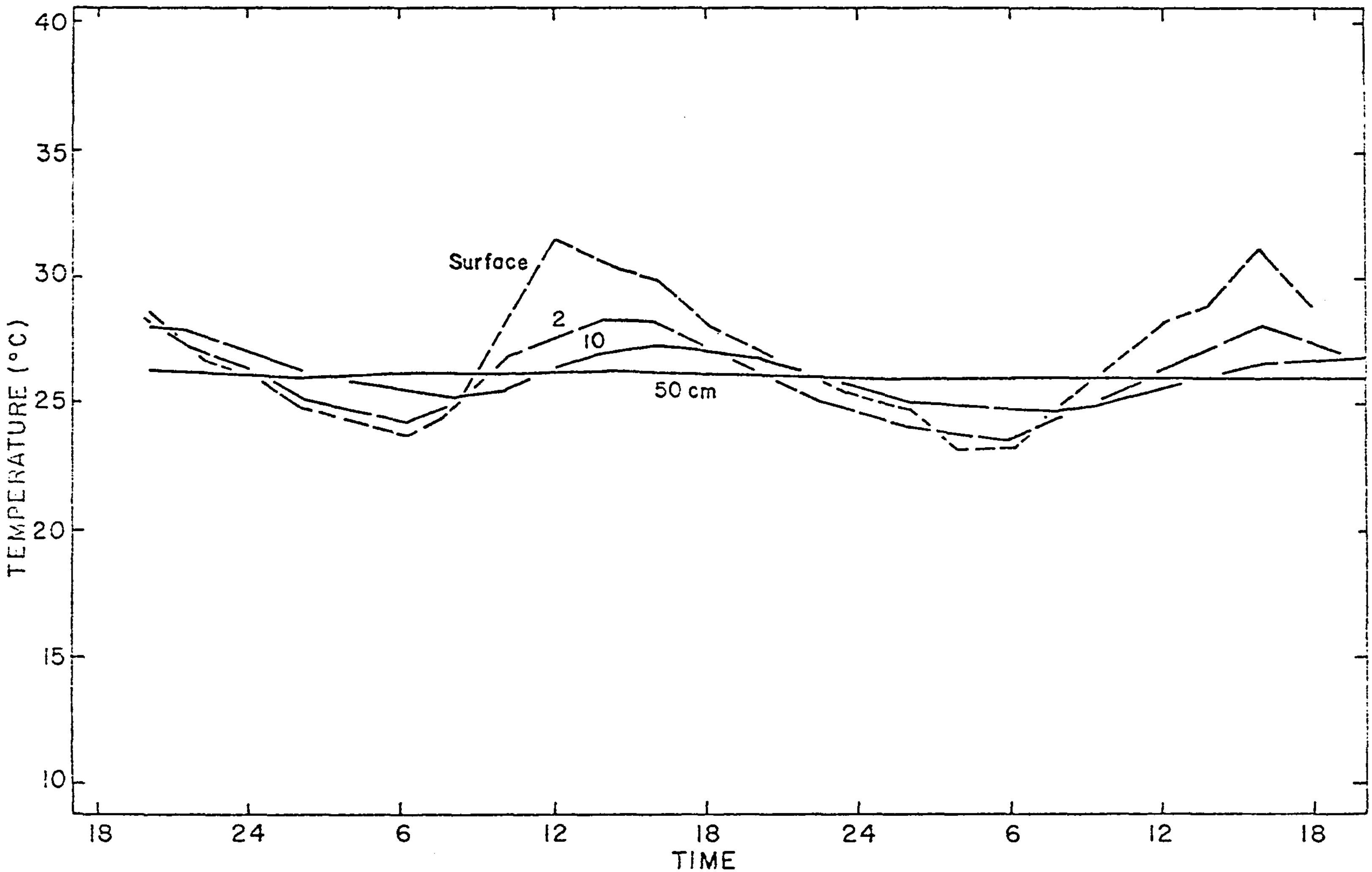



Figure 40. Late Summer March of Soil Temperatures. -- Monitoring commenced 2000 August 7 and continued for 48 hrs. Thermometer depths are indicated.

Relative Humidity. Diurnal lows drop to 51%. Nocturnal curves were broad and rose to above 95%. Vapor pressure deficit ranged between 0.6 and 17.7 mm. See Figure 41.

Light. Open light readings at noon were near 7000 foot candles. Values at ground level approached 300 fc or 4.3% of open light. At the top of the D-stratum, one meter off the ground, readings doubled to 600 fc or 8.6% of open light.

Soil Moisture. Samples collected August 10 reflected the occurrence of the August 8 rain. Moisture content was 11.9% at the 5 cm depth, 6.5% at 10 cm, 6.5% at 20 cm and 7.4% at 50 cm. The mean for all samples was 7.9%.

Phenology. Late summer is the time during which leaves mature and fruits begin to ripen. See Figures 42 and 43. No trees or shrubs were leafless and were commonly in flower. Mature seeds occurred on Brongniartia alamosana, Bursera bipinnata, Bursera confusa, Bursera laxiflora, Jatropha cordata, Heliocarous attenuatus, Willardia mexicana, Croton fragilis, and Jatropha platanifolia.

Discussion. In late summer all vegetation strata had mature foliage. Rainfall begins to decrease after July but August still ranks second in average monthly precipitation (181.5 mm). The mean temperature for August (27.3$^{o}$C) is down 1.2$^{o}$C from the preceeding month.

Light reaching the substrate in August was at its annual low (300 fc), about 3-5% of open light. Soil moisture (7.9%) and mean relative humidity (75%) were slightly down from what they were after the first summer deluges (11% and 86% R.H.). Soil temperature curves

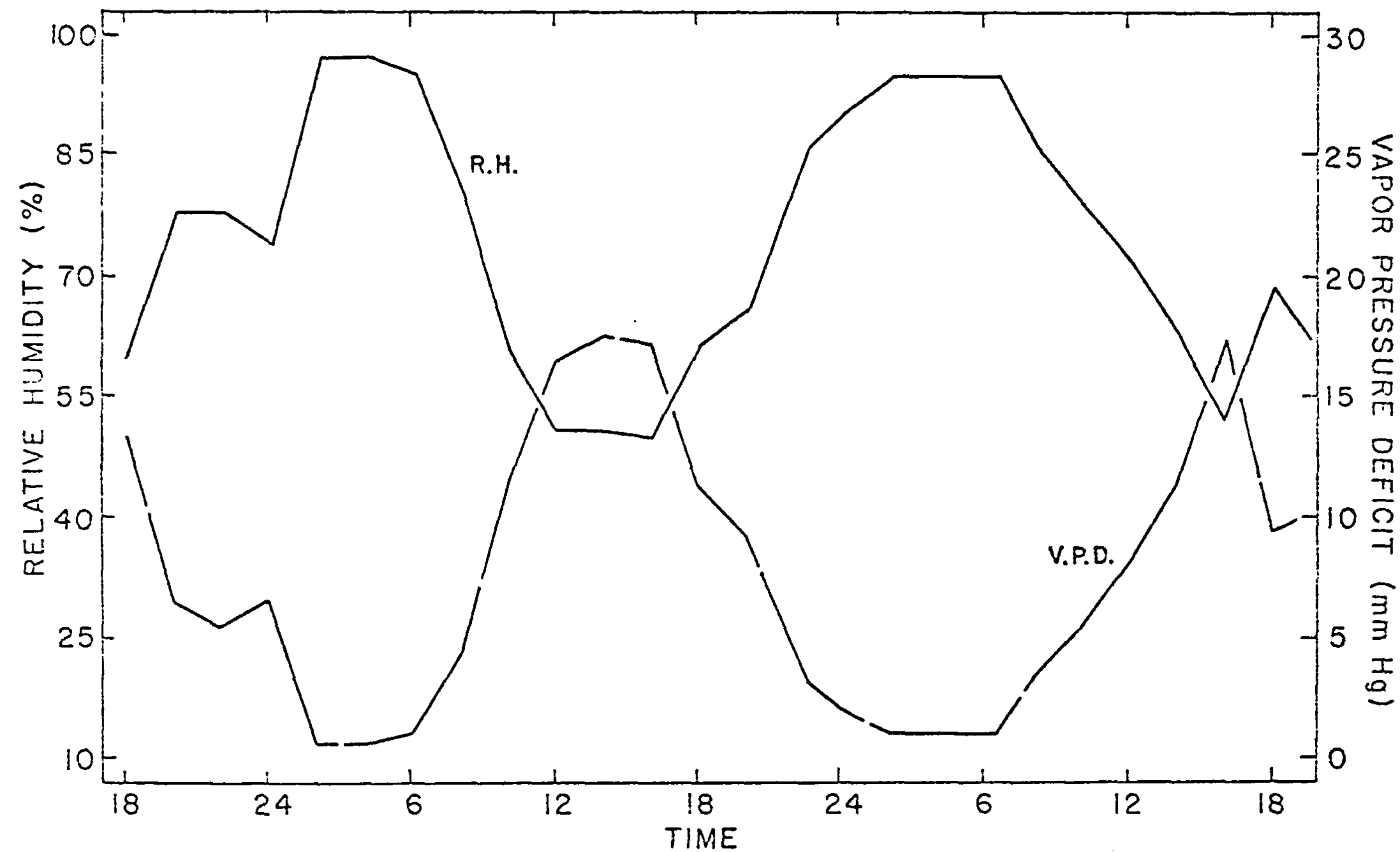



Figure 41. Late Summer March of Relative Humidity and Computed Vapor Pressure Deficit. -- Monitoring commenced 1800 August 7 and continued for 48 hrs.

Figure 42. Late Summer Photograph of Lower Portion of Air Temperature Column. -- Major tree is Conzattia sericea; large leaved shrub at left, Jatropha platanifolia; right foreground shrubs, Franseria cordifolia; and tree at right, Tabebuia palmeri. Photographed August 8, 1967. See re-photographs.

Figure 43. Late Summer Photograph of Hecho Cactus (Pachycereus pecten-aboriginum), Now Nearly Hidden by Leaves. -- Foreground shrub is Jatropha platanifolia; and upper branch, Tabebuia palmeri. Photographed August 8, 1967. See re-photographs.

are nearly identical to those observed immediately after initial leafing. Air temperature at the canopy was higher, both diurnally and nocturnally, than it was at ground-level. The nocturnal differential was slight.

Autumn (September, October, November)

Environmental monitoring commenced 1800, October 18, 1967, and continued for 48 hours. Clear and calm weather prevailed during the entire period. Figure 44 shows the range of air temperature at both the 0.5 m and 18 m heights. Temperature at 18 m was consistently higher than the temperature at 0.5 m.

All air column temperature profiles (Figure 45) display an increase in temperature with height above the ground. Diurnal heating takes place in the canopy and nocturnal cooling occurs at ground level. The sub-surface portion of these profiles illustrates a typical convergence of temperature.

Soil temperatures on time (Figure 46) reflect normal patterns with surface temperature showing the greatest variation.

Relative Humidity. Relative humidity reached nocturnal highs of nearly 80% with diurnal lows close to 20% (Figure 47). Vapor pressure deficit forms a complimentary pattern and reached a nocturnal low of 3.0 mm and a diurnal high of 27.9 mm (Figure 47).

Light. Readings taken at ground-level (3,700 fc) were about 30% of the values obtained in open light (12,000 fc). One meter above the ground the value rose to 40% (5,000 fc).

Soil Moisture. Autumn soil moisture generally increased with depth. A value of 6.1% was obtained at 5 cm, 6.6% at 10 cm, 10.1% at

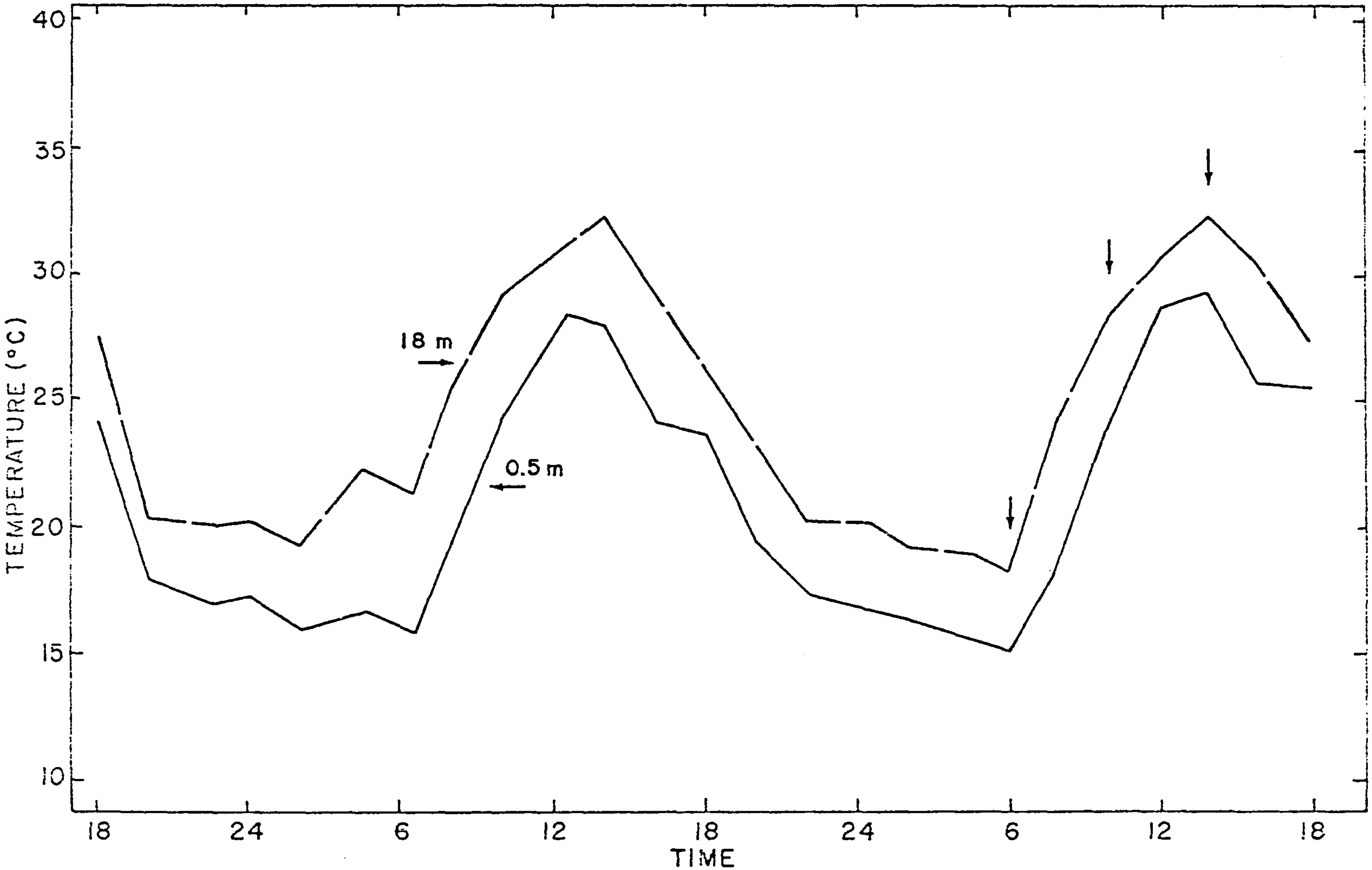



Figure 44. Autumn March of Air Temperature Above the Forest Canopy (18 m) and Near the Ground (0.5 m). -- Monitoring commenced 1800 October 18 and continued for 48 hrs. Vertical arrows indicate times of temperature profiles shown in Figure 45.

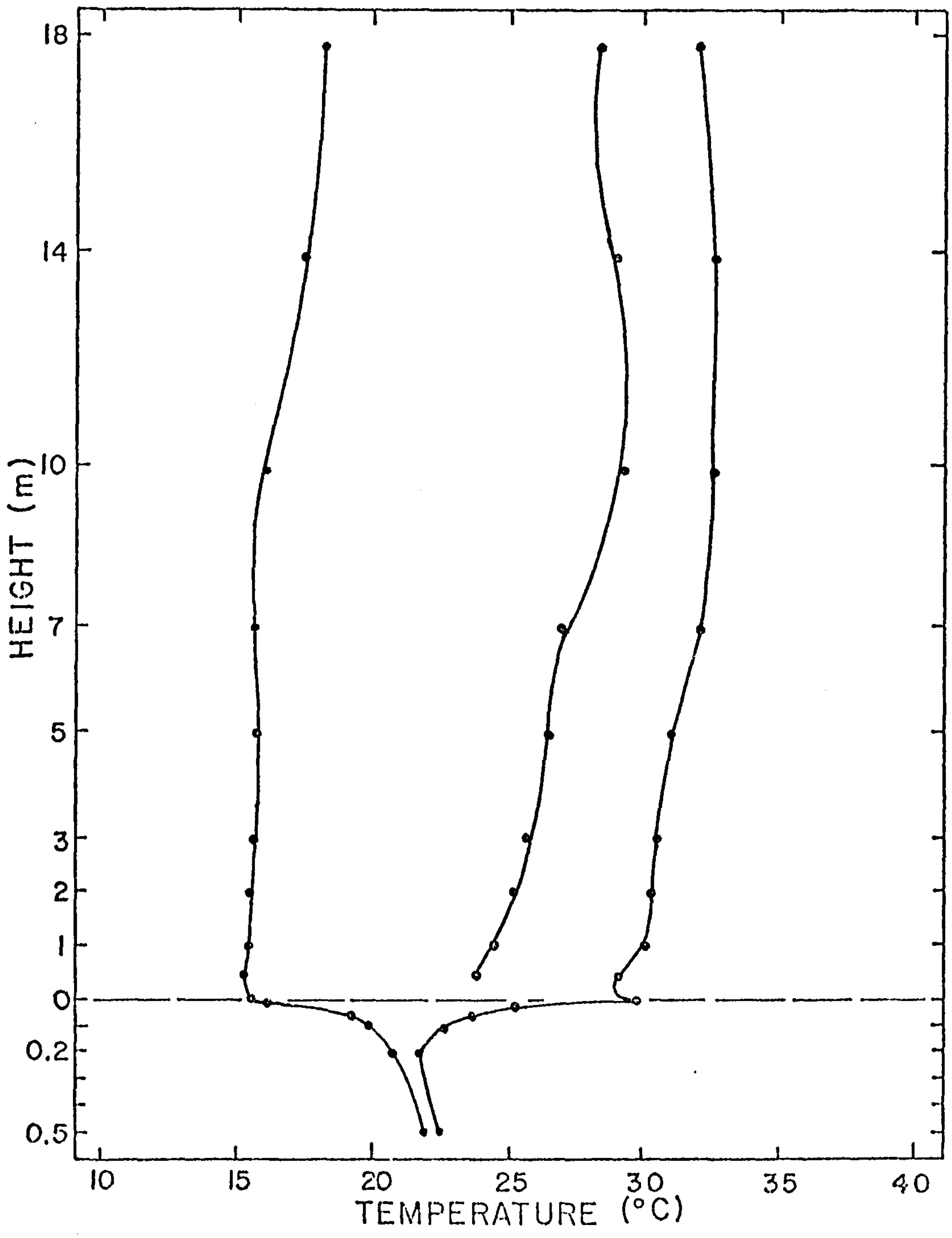



Figure 45. Autumn Temperature Profiles. -- Left, profile at time of lowest occurring 0.5 m temperature, 0600 October 20. Right, profile at highest occurring 0.5 m temperature, 1400 October 20. Center, a transition profile, 1000 October 20. Subsurface depth scale is enlarged.

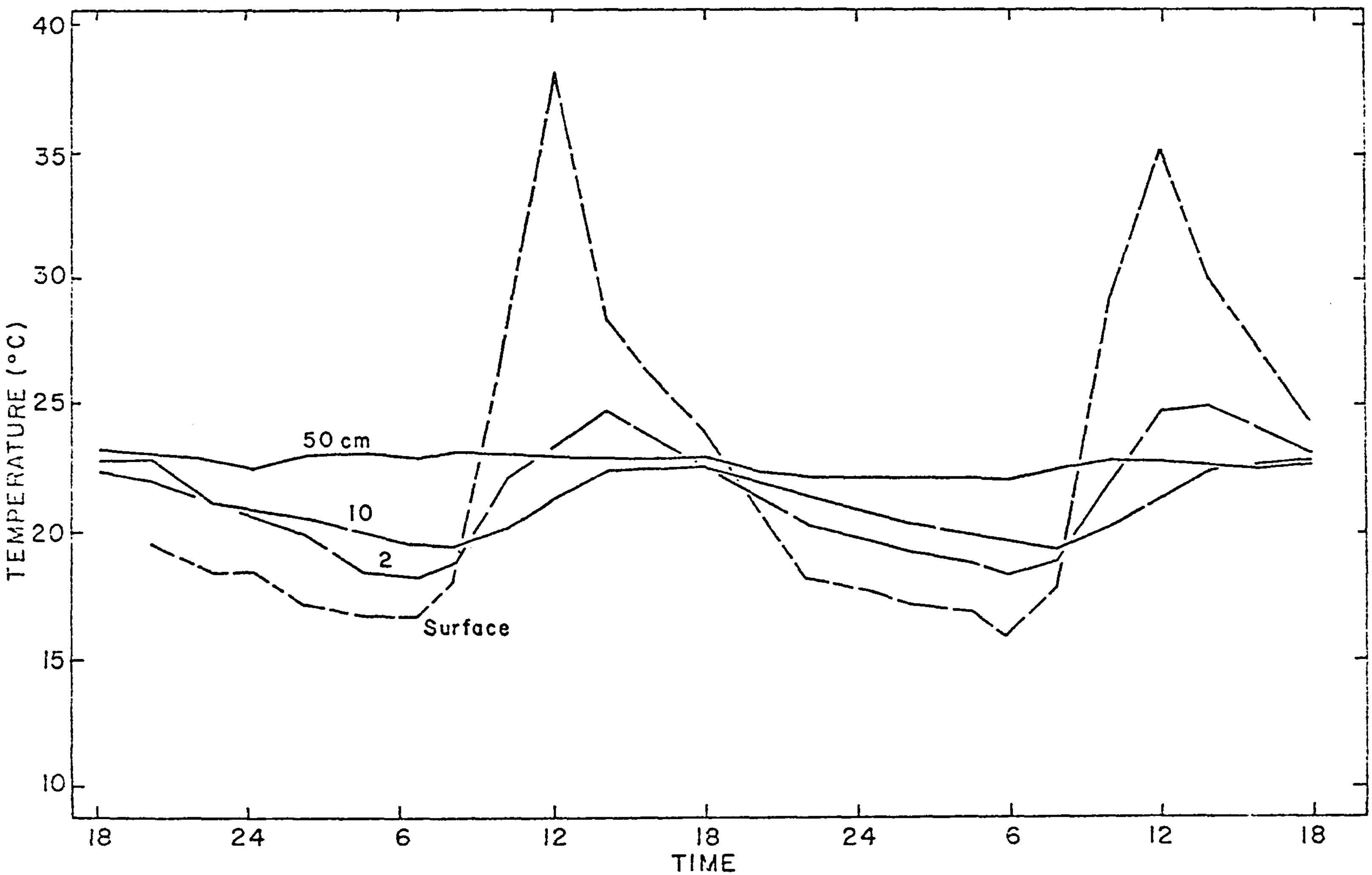



Figure 46. Autumn March of Soil Temperature. -- Monitoring commenced 1800 October 18 and continued for 48 hrs. Thermometer depths are indicated.

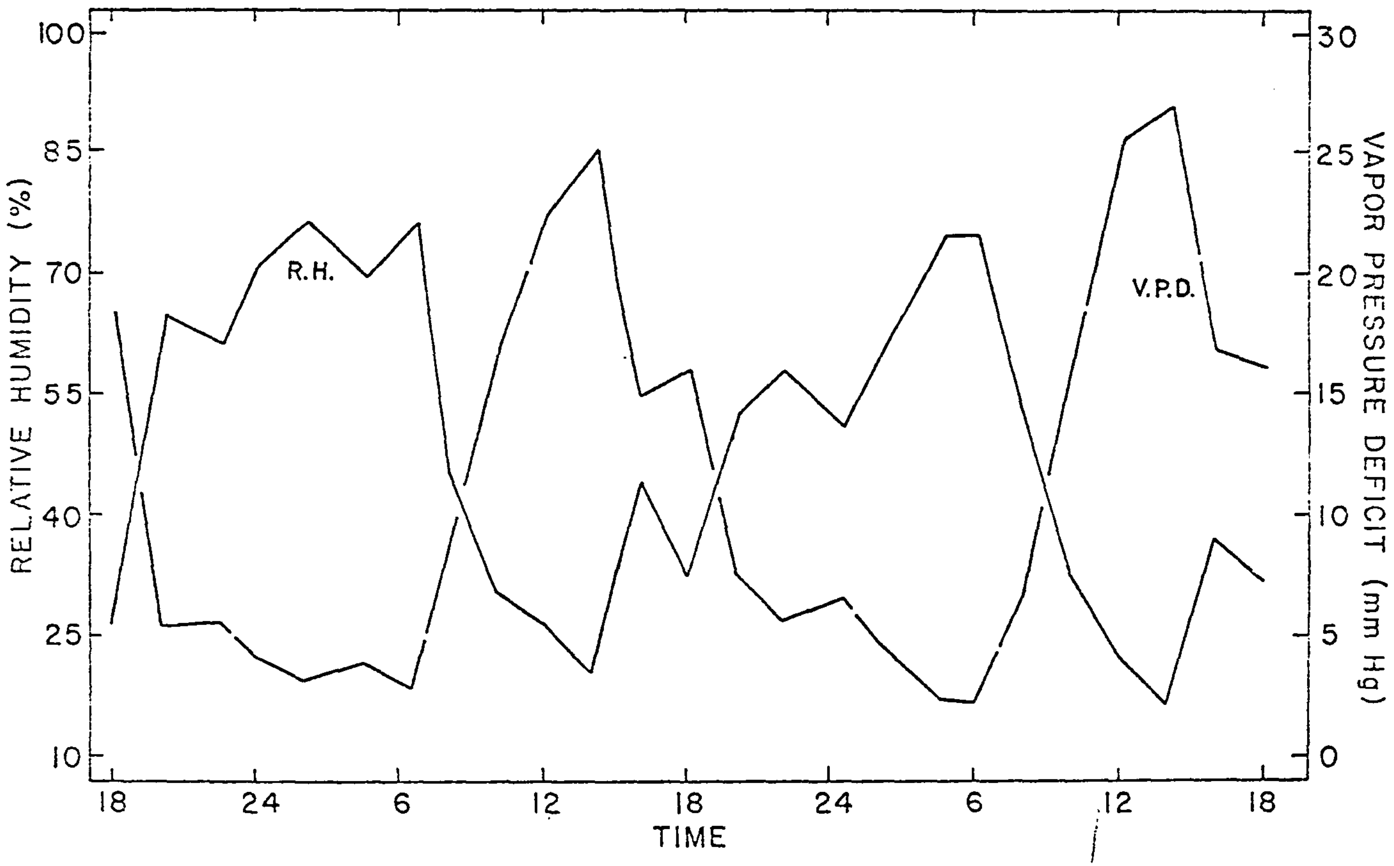



Figure 47. Autumn March of Relative Humidity and Computed Vapor Pressure Deficit. -- Monitoring commenced 1800 October 18 and continued for 48 hrs.

20 cm and 8.6% at 50 cm. Soil moisture for all samples averaged 7.8%. Samples were collected on October 22.

Phenology. Autumn is the season of increasing foliar senescence and early leaf fall (Figures 48 and 49). The seeds of many species reach maturity at this time. Autumn phenology varies considerably year to year depending upon the interplay of temperature and moisture.

The Conzattia sericea are leafless but have ripe pods. Many B-stratum trees are leafless or nearly so, e.g., Bursera, spp. (except B. grandifolia), Ceiba acuminata, Heliocarpus attenuatus, Ipomoea arborescens, and Jatropha cordata. Mature legumes are also present on Lysiloma divaricata and Pithecollobium tortum. Much of the greenness of the canopy is due to leaves still remaining on Lysiloma divaricata and Cassia emarginata. Aging leaves are present on Tabebuia palmeri, Willardia mexicana, and others. Two vines, Heteropteris palmeri and Nissolia hirsuta, are in fruit and still with leaves. Plants along the washes, especially Guazuma ulmfolia, are still in good condition.

Among the members of the C-stratum, Jatropha platanifolia is completely bare. The leaves of Montanoa rosei are beginning to turn yellow. Croton fragilis is nearly leafless. The dominant D-stratum shrub, Franseria cordifolia is noticeably dry. Cassia biflora and Lantana velutina are the only on-plot woody plants which may be in flower. Both may also have leaves and fruits.

Discussion. In autumn the forest is drying and partly bare. Soil moisture (7.8%) is approximately what it was in late summer. Mean relative humidity (49%) is considerably down from what it was in late

Figure 48. Autumn Photograph of Lower Portion of Air Temperature Column. -- Major tree is Conzattia sericea; bare left foreground shrub, Jatropha platanifolia; shrubs at left with leaves, Montanoa rosei; and tree at right, Tabebuia palmeri. Photographed on-plot October 20, 1967. See re-photographs.

Figure 49. Autumn Photograph of Hecho Cactus (*Pachycereus pecten-aboriginum*). -- Upper tree is *Tabebuia palmeri*; and small leaved tree in front of hecho, *Erythroxylon mexicana*. Photographed on-plot October 20, 1967. See re-photographs.

summer (75%). Mean vapor pressure deficit is higher (12.2 mm). Light reaching the forest floor is now 30% of open light compared to only 3-5% in late summer. Soil temperature at 50 cm has dropped to about 23°C. The amplitudes of soil temperature curves for the upper depths have increased since summer.

Air temperature at canopy height is still diurnally and nocturnally warmer than is air temperature near the ground. Temperature differences between the canopy-level and the ground-level are considerable. This suggests that in autumn the canopy still intercepts a significant amount of solar radiation but that strong nocturnal re-radiation is now occurring.

In winter a thinner canopy will intercept a less solar radiation. As a result ground-level temperatures become the warmer portion of the diurnal profile.

## Annual Patterns

Seasonal summaries of physical parameters are given in Tables 5 and 6. These reductions suggest annual patterns based upon data obtained from twelve days of monitoring. Diurnal and nocturnal divisions follow field determinations of civil twilight.

Temperature. Mean diurnal and nocturnal temperatures at both the 0.5 m and 18 m column heights are plotted on months in Figure 50. The low temperatures which occurred in July are real but may have been over emphasized by chance.

Nocturnally, during the entire year mean air temperatures near the ground (0.5 m) are cooler than those close above the canopy (18 m).

Table 5. Reduced Air Temperature and Soil Temperature Data. -- Diurnal-nocturnal divisions follow field determinations of civil twilight. Selected data are graphed in Figures 50 and 51.

| Parameter | Winter | Spring | Monsoon 1 | Monsoon 2 | Monsoon 3 | Monsoon 4 | Summer Late | Autumn |
|---|---|---|---|---|---|---|---|---|
| Air Temperature (°C) | | | | | | | | |
| 0.5 m diurnal $\bar{x}$ | 20.4 | 25.0 | 33.8 | 29.5 | 26.8 | 25.8 | 28.1 | 24.3 |
| 0.5 m nocturnal $\bar{x}$ | 14.7 | 15.4 | 25.3 | 25.0 | 21.8 | 22.8 | 24.2 | 16.9 |
| 0.5 m overall $\bar{x}$ | 17.0 | 20.8 | 30.5 | 27.8 | 24.9 | 24.7 | 26.6 | 21.0 |
| 0.5 m range | 12.6 | 19.0 | 16.9 | 12.1 | 8.4 | 7.6 | 10.6 | 14.2 |
| 0.5 m extremes | 12.6-25.2 | 11.7-30.7 | 22.5-39.4 | 22.5-34.6 | 20.4-28.4 | 21.8-29.4 | 21.7-32.3 | 15.1-29.3 |
| 18 m diurnal $\bar{x}$ | 20.9 | 24.3 | 31.8 | 29.1 | 27.6 | 27.5 | 31.2 | 28.3 |
| 18 m nocturnal $\bar{x}$ | 16.5 | 16.9 | 26.1 | 25.5 | 22.0 | 23.6 | 24.9 | 20.2 |
| 18 m overall $\bar{x}$ | 18.2 | 21.0 | 29.6 | 27.7 | 25.5 | 26.0 | 28.7 | 24.7 |
| 18 m range | 8.8 | 14.7 | 11.8 | 9.9 | 9.7 | 9.7 | 14.0 | 14.0 |
| 18 m extremes | 14.7-23.5 | 14.2-28.9 | 23.9-35.7 | 22.7-32.6 | 20.1-29.8 | 22.2-31.9 | 21.8-35.8 | 18.2-32.2 |
| Soil Temperature (°C) | | | | | | | | |
| Surface diurnal $\bar{x}$ | 22.4 | 34.8 | 43.8 | 33.2 | 27.9 | 27.7 | 26.0 | 26.3 |
| Surface nocturnal $\bar{x}$ | 15.5 | 17.2 | 27.0 | 25.6 | 23.5 | 24.5 | 25.4 | 18.0 |
| Surface overall $\bar{x}$ | 18.3 | 27.0 | 37.3 | 30.3 | 26.2 | 26.5 | 25.8 | 22.5 |
| Surface range | 15.6 | 40.5 | 40.7 | 29.7 | 8.5 | 8.7 | 8.1 | 22.0 |
| Surface extremes | 13.4-29 | 12.5-53 | 23.8-64.5 | 23.8-53.5 | 22.5-31.0 | 23.8-32.5 | 23.4-31.5 | 16.0-38.0 |
| 50 cm overall $\bar{x}$ | 19.2 | 25.9 | 31.6 | 30.0 | 28.0 | 26.8 | 26.2 | 22.7 |

Table 6. Reduced Relative Humidity, Vapor Pressure Deficite, Light Reaching Substrate and Soil Moisture Data. -- Diurnal-nocturnal divisions follow field determinations of civil twilight. Selected data graphed in Figure 52.

| Parameter | Winter | Spring | Monsoon 1 | Monsoon 2 | Monsoon 3 | Monsoon 4 | Summer Late | Autumn |
|---|---|---|---|---|---|---|---|---|
| Relative Humidity (%) | | | | | | | | |
| Diurnal $\bar{x}$ | 53 | 23 | 43 | 62 | 76 | 80 | 68 | 37 |
| Nocturnal $\bar{x}$ | 79 | 41 | 58 | 72 | 93 | 95 | 83 | 66 |
| Overall $\bar{x}$ | 68 | 31 | 49 | 66 | 83 | 86 | 75 | 49 |
| Range | 50 | 31 | 41 | 52 | 33 | 40 | 46 | 58 |
| Extremes | 40-90 | 15-46 | 28-69 | 38-90 | 67-100 | 57-97 | 51-97 | 19-77 |
| Vapor Pressure Deficit (mm Hg) | | | | | | | | |
| Diurnal $\bar{x}$ | 8.9 | 18.0 | 21.1 | 13.0 | 6.7 | 6.1 | 10.0 | 17.5 |
| Nocturnal $\bar{x}$ | 2.8 | 8.2 | 11.2 | 7.4 | 1.3 | 1.2 | 4.2 | 5.1 |
| Overall $\bar{x}$ | 5.2 | 13.7 | 17.4 | 10.8 | 4.6 | 4.2 | 7.6 | 12.2 |
| Range | 12.1 | 21.8 | 26.9 | 22.5 | 9.5 | 13.5 | 17.1 | 24.9 |
| Extremes | 1.2-13.3 | 6.2-28 | 6.4-33.3 | 2.1-24.6 | 0.3-9.8 | 0.6-14.1 | 0.6-17.7 | 3.0-27.9 |
| Light Reaching Substrate (% of open) | 50 | 90 | 90 | 80 | 30 | 5-10 | 3-5 | 30 |
| Soil Moisture $\bar{x}$ (%) | 6.7 | 3.5 | 3.5 | 7.7 | 15.5 | 11.0 | 7.9 | 7.8 |

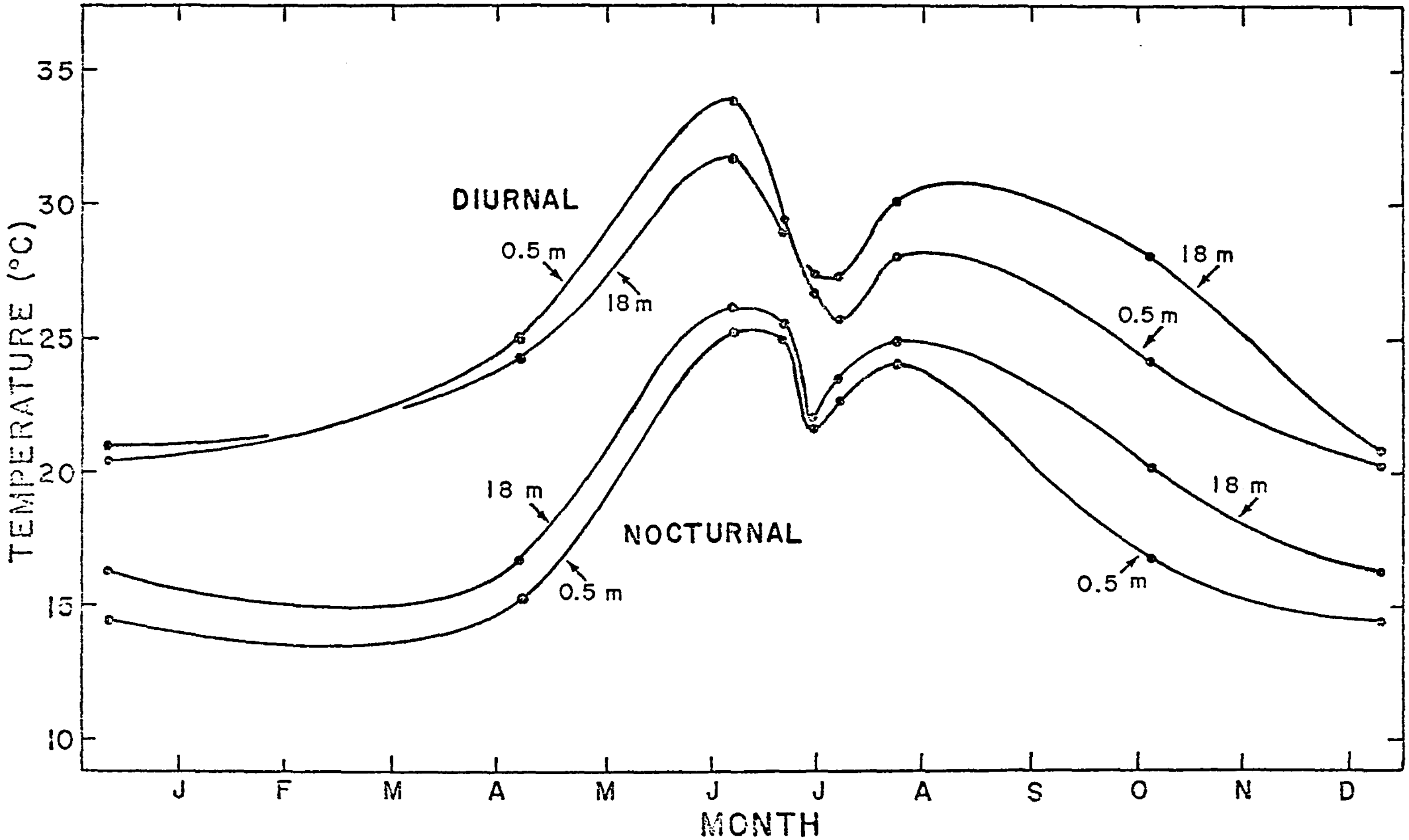



Figure 50. Mean Microclimatic Air Temperatures on Months. -- Upper two lines are diurnal means at the 0.5 m and 18 m heights. The lower two lines are mean nocturnal temperatures at the same heights. Smoothed curves are illustrated. Mid-summer depressions are perhaps over-emphasized by chance. Data in Table 5.

The difference between these two nocturnal means is the least in summer. Some monitoring in summer showed air near the canopy to be cooler at night than the air at ground-level.

Diurnal mean temperatures at the level of the canopy are higher than those near the ground from mid-summer through autumn and winter. At that time a switch takes place with ground-level air becoming increasingly warmer in late spring and early summer.

All air temperatures reach their maxima just prior to the onset of the monsoon. There is a clumping of temperatures once the vegetation has leafed out. In winter, spring and early summer the range of air temperature near the ground is greater than at the canopy-level. During summer and autumn, after the vegetation is fully foliaged, the air temperatures near the canopy tend to have a greater range.

Extreme and mean soil surface temperatures are plotted on months in Figure 51. The annual pattern is suggested by eight points of data. As with air temperatures all soil temperatures peak just prior to the onset of the monsoon. With the first rains a sharp decline in extreme maximum soil temperature occurs. In mid- and late-summer there is little variation in the range of surface soil temperature extremes. In autumn there is an expansion of this range. Mean surface temperature decreases until winter then increases again through spring and early summer. Mean soil temperatures at a depth of 50 cm follow a pattern similar to that of the surface means.

Relative Humidity. Mean relative humidity reaches its annual low in the spring (Figure 52). Prior to the onset of the monsoon

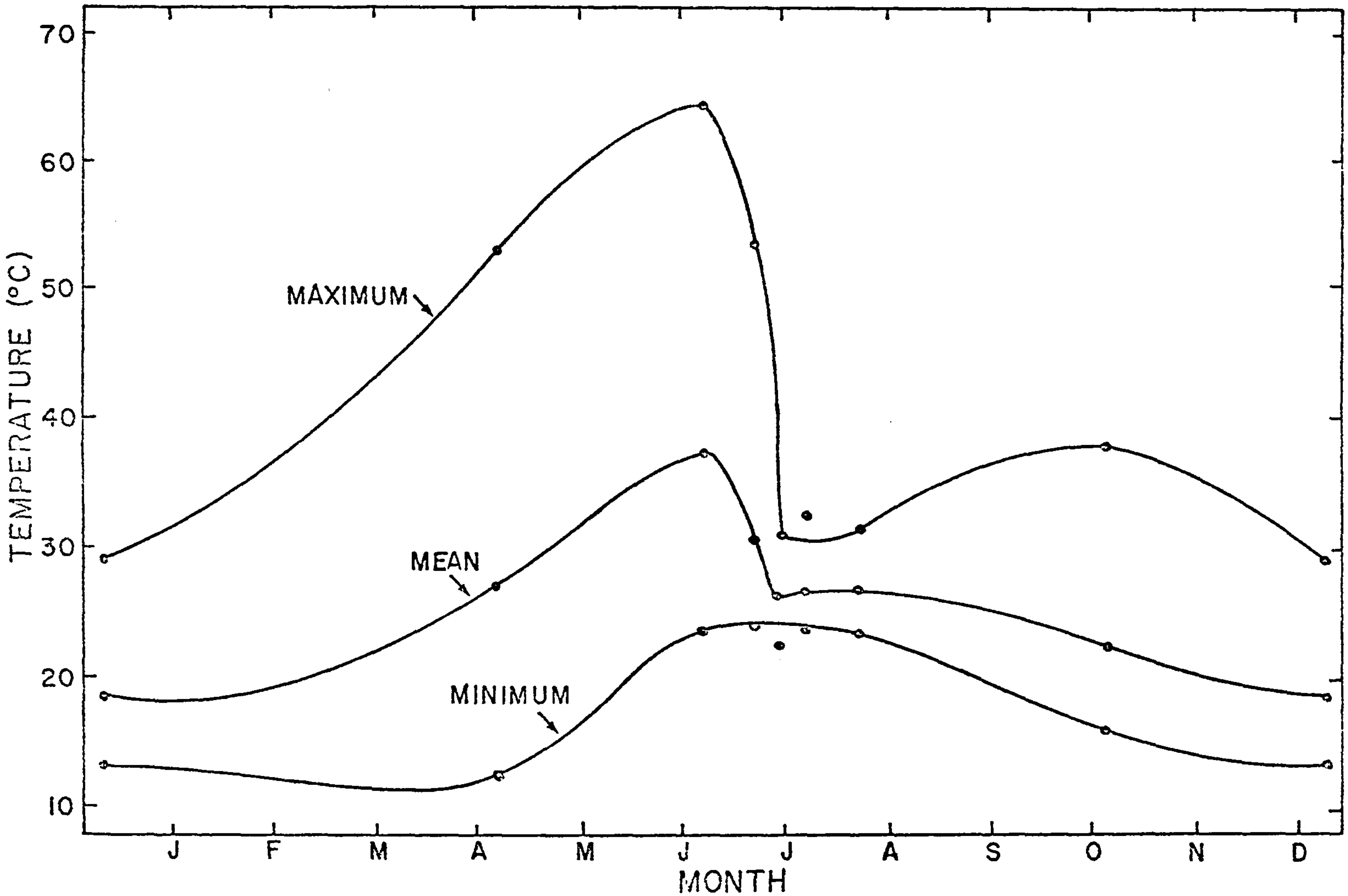


Figure 51. Soil Surface Temperatures on Months. -- Upper dots are extreme maximum, lower dots are extreme minimum, middle dots are mean surface temperature during periods monitored. Smoothed curves are illustrated. Data in Table 5.

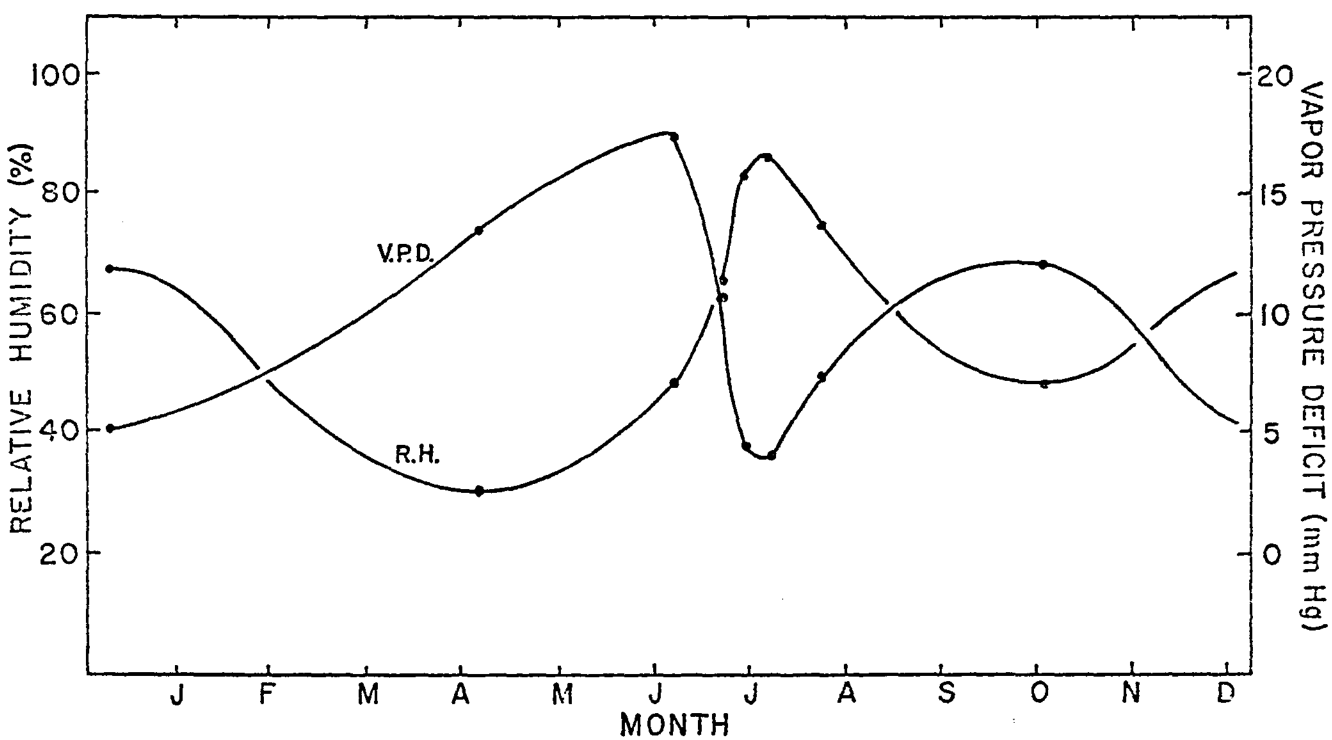



Figure 52. Mean Relative Humidity and Vapor Pressure Deficit on Months. -- Means are computed from all determinations made at each period monitored. Smoothed curves are illustrated. Data in Table 6.

relative humidity begins to increase. It peaks in mid-summer at the height of the monsoon season. There is a moderate decrease in autumn and a corresponding increase in winter. Vapor pressure deficit follows a nearly complementary curve to relative humidity except that a continual increase occurs from spring to early summer. These curves reflect the biseasonal precipitation pattern of the region.

Light. The percent of open light reaching the substrate is presented in Table 6. These data follow a pattern of high light penetration in the spring and early summer, a mid-summer crash concurrent with leafing and a late-summer low at leaf maturity. This is followed by a gradual increase in light intensity as leaves are dropped in autumn, winter and spring.

Soil Moisture. Mean soil moisture is given by season in Table 6. Low values occur with the spring and early-summer drought and extremely high values coincide with the monsoon. Increases in moisture probably occur in winter but are not shown by the data presented.

Phenology. An annual summary of major phenological events is presented in Table 7. This table is designed to indicate the major season(s) for the presence of leaves, flowers and mature seeds of each of the on-plot species. In some instances particular events are variable and seasonal placement is difficult to determine.

In late spring and early summer no on-plot plants are in leaf. Soon after the onset of the monsoon all species quickly develop foliage. In autumn about two-thirds of the species still have their leaves but in winter the volume of the foliage is reduced to half. In general, the shrubs retain their leaves better than do the trees.

Table 7. Annual Summary of Major Phenological Events. -- Presence of leaves, flowers and mature seeds are indicated by season. Variable events often makes seasonal placement difficult. On-plot species only. Species are grouped by stratum.

| STRATUM | | SPECIES | WINTER<br>L F S | SPRING<br>L F S | SUMMER<br>L F S | AUTUMN<br>L F S |
|---|---|---|---|---|---|---|
| A | 1. | Conzattia sericea | 0 0 + | 0 0 0 | + + 0 | 0 0 + |
| B | 2. | Brongniartia alamosana | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 3. | Bursera bipinnata | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 4. | Bursera confusa | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 5. | Bursera grandifolia | 0 0 + | 0 0 + | + + 0 | 0 0 0 |
| | 6. | Bursera laxiflora | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 7. | Cassia emarginata | + 0 + | 0 + 0 | + + 0 | + 0 + |
| | 8. | Ceiba acuminata | 0 0 + | 0 0 + | + + 0 | 0 0 0 |
| | 9. | Erythroxylon mexicana | + 0 0 | 0 0 0 | + + ? | + 0 ? |
| | 10. | Exogonium bracteatum | 0 0 0 | 0 + + | + 0 0 | + 0 0 |
| | 11. | Guazuma ulmifolia | + 0 + | 0 0 + | + + 0 | + 0 0 |
| | 12. | Heliocarous attenuatus | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 13. | Heteropteris palmeri | + 0 0 | 0 0 0 | + + 0 | + + + |
| | 14. | Hintonia latiflora | 0 0 + | 0 0 + | + + 0 | + 0 0 |
| | 15. | Ipomoea arborescens | 0 + + | 0 0 0 | + 0 0 | 0 0 0 |
| | 16. | Jatropha cordata | 0 0 0 | 0 0 0 | + + + | 0 0 + |
| | 17. | Lysiloma divaricata | + 0 + | 0 0 0 | + + 0 | + 0 + |
| | 18. | Nissolia hirsuta | + 0 0 | 0 0 0 | + + 0 | + 0 + |
| | 19. | Pachycereus pecten-aboriginum | + 0 | 0 0 | 0 + | 0 0 |
| | 20. | Pithecollobium tortum | + 0 + | 0 0 + | + + 0 | + 0 + |
| | 21. | Tabebuia palmeri | 0 + 0 | 0 0 + | + 0 0 | + 0 0 |
| | 22. | Willardia mexicana | + 0 0 | 0 0 0 | + + + | + 0 + |
| | 23. | Wimmeria confusa | + 0 0 | 0 0 0 | + 0 0 | + + + |
| C | 24. | Acacia cymbispina | + 0 0 | 0 0 0 | + + 0 | + 0 + |
| | 25. | Croton fragilis | + 0 0 | 0 0 0 | + + + | + 0 0 |
| | 26. | Jatropha platanifolia | 0 0 0 | 0 0 0 | + + + | 0 0 0 |
| | 27. | Karwinskia humboldtiana | + 0 0 | 0 0 0 | + 0 0 | + + + |
| | 28. | Montanoa rosei | + + 0 | 0 0 + | + 0 0 | + 0 0 |
| | 29. | Opuntia kleiniae | 0 0 | + 0 | 0 + | 0 0 |
| | 30. | Randia echinocarpa | + 0 + | 0 0 0 | + + 0 | + 0 + |
| D | 31. | Cassia biflora | + + + | 0 + 0 | + + + | + + + |
| | 32. | Franseria cordifolia | + + 0 | 0 0 + | + 0 0 | + 0 0 |
| | 33. | Lantana velutina | + + + | 0 + + | + + 0 | + + + |
| | 34. | Opuntia fuliginosa | 0 0 | + 0 | 0 + | 0 0 |

The flowering activities of trees reach a peak in the summer but flowering by shrubs is more evenly distributed throughout the year. Seed maturation for both trees and shrubs is at its height in autumn.

Discussion. An interesting aspect of this study was the seasonal change in air temperature profiles. During the dry leafless portion of the year, from spring through early summer, diurnal air temperatures produce incoming radiation type profiles and nocturnal temperatures yield outgoing radiation type profiles. Curves of these types are typical for areas with minimal vegetation cover and are especially evident in deserts (Sinclair 1922, Hadley 1970). Nocturnal outgoing temperature curves also occur in coniferous forests (Geiger 1961).

Air temperature profiles quickly change in character with the summer rains. Diurnal curves now place the highest temperatures at the forest canopy and the lowest temperatures at ground-level. Diurnal patterns of this type are typical of; temperate forests (Geiger 1961, Heckert 1959); semi-evergreen tropical forests, during both wet and dry seasons (Hopkins 1965); and tropical evergreen forests (Richards 1952).

Nocturnal profiles observed during the in-leaf seasons, midsummer through early spring, are similar to those occurring in the leafless seasons. These are typical terrestrial radiation type curves. In July, the wettest month, these profiles are nearly vertical and upon occasion show canopy-level air to be cooler than ground-level air. Strongly developed curves of this type are suggestive of tropical rain forests (Evans 1939, Hales 1949) and semi-evergreen tropical forests in the wet season (Hopkins 1965).

Some solar radiation is absorbed and converted to heat by the leaves of the forest canopy. When the forest is leafless this energy passes through to heat the ground. Nocturnally, long wave length radiation from the ground escapes through the canopy and results in ground-level cooling. When the forest is in-leaf it is possible that cooling occurs at the canopy-sky interface and that the colder air then settles to the ground.

In mid-summer, with high relative humidity, terrestrial long wave radiation is absorbed by water vapor and the typical nocturnal outgoing curve is destroyed. When this occurs long wave radiation from the canopy may result in cooling at the canopy, apparently without significant settling.

Baynton et al. (1965), working from a 200 ft (61 m) tower in a 125 ft (38 m) tall Columbian tropical rain forest, observed that the maximum temperature in the diurnal profile was not reached at the canopy but was above it; temperature was low near the ground and increased to canopy height, was then constant for some height but increased again near the top of the tower. It was suggested that the evaporation of dew at the canopy lowers temperature at that level. His nocturnal profiles showed decreasing temperatures from ground-level upward. He explained this by saying that the temperature profile took the shape of the dew-point profile. From a 32 m tower in a 16 m tall temperate forest 85 km north of Moscow (Russia), Rauner (1958) observed daytime temperatures to decrease with height above the canopy and nighttime temperatures to increase.

When the tropical deciduous forest of northwestern Mexico is leafless in late spring and early summer soil surface temperatures display extremes and ranges suggestive of desert conditions (Sinclair 1922, Hadley 1970). But after heavy precipitation and leafing soil temperature aplitudes are lessened and nearly flat curves result.

In the spring relative humidity and vapor pressure deficit also follow patterns which are suggestive of deserts but the summer monsoons bring patterns which are almost tropical (Geiger 1961, Richards 1952).

Light reaching the substrate at the period of full foliage in late-summer was 3-5% of open light. Richards (1952) suggests that ground-level values of 0.5-1% are typical in tropical rain forests.

Soil moisture at the time of the monsoon was generally near field capacity. In late summer, autumn and winter, it dropped to the permanent wilting point. In spring and pre-monsoon summer it was well below permanent wilting.

# SUMMARY AND CONCLUSIONS

Seasonal monitoring of instruments was used to obtain the following descriptions of micro-environmental parameters.

1. Diurnal temperature inversions are evident during the in-leaf seasons.
2. Diurnal ground-level air warms intensely in the leafless seasons.
3. Nocturnal temperature inversions are normal throughout the year but are weakly defined in mid-summer.
4. Maxima soil surface temperatures are high (60+$^\circ$C) and daily amplitudes are broad (40$^\circ$C) in the leafless seasons; maxima (30$^\circ$C) and amplitudes (10$^\circ$C) decrease in the in-leaf seasons.
5. Mean relative humidity is at its lowest in the spring (30%) and highest in the summer (85%); secondary lows and highs occur in autumn (50%) and winter (70%).
6. Mean vapor pressure deficit peaks in early summer (17 mm) but generally follows a pattern complementary to relative humidity.
7. Ninety percent of open light reaches the substrate in early summer, but by late summer this drops to only 3-5%.
8. Soil moisture approached or exceeded field capacity during the summer rains, was below the permanent wilting point in the spring and was near the wilting point in autumn and winter.

Quadrat analysis was used to obtain the following quantitative descriptions of the 0.1 ha study plot.

1. Thirty-one species of drought deciduous trees, shrubs and woody vines, and three species of cacti were present.
2. Seven growth-forms were present; 52% of species were broad-leaved deciduous trees; 21% of species were broad-leaved deciduous shrubs.
3. Stratification included a discontinuous A-stratum, a nearly continuous B-canopy forest, C- and D-shrub strata and an ephemeral herbaceous stratum.
4. A species density of 1917/0.1 ha included 92 trees.
5. Coverage by A- through D-strata totaled 238%.
6. Relative diameter at breast height indicated *Lysiloma divaricata*, *Brongniartia alamosana*, *Pachycereus pecten-aboriginum*, and *Tabebuia palmeri* to be dominant.
7. Relative crown coverage indicated the dominant shrubs to be *Franseria cordifolia*, *Jatropha platanifolia* and *Montanoa rosei*.
8. Leafing in the tropical deciduous forest of northwestern Mexico follows an annual cycle in which spring and early summer are characterized by bareness, mid-summer by leafing, late-summer by leaf maturing, autumn by leaf drying and winter by leaf dropping. The dominant shrubs *Franseria cordifolia* and *Montanoa rosei* leaf in the summer but re-leaf, flower and fruit during favorable winters and springs. Another dominant shrub, *Jatropha platanifolia*, very rapidly gains leaves, flowers and fruits at the onset of the summer rains.

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