AD 674660

AD

Semiannual Report No. 4

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

USATECOM Project No. 9-4-0013-01

May 1968

US Army Tropic Test Center
Fort Clayton, Canal Zone

Sponsored by

Advanced Research Projects Agency, ARPA Order No. 740
and
Army Research Office, OCRD, Project No. 2M025001A724 01

105

Destroy this report when it is no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade names in this report does not constitute an official endorsement or approval of such commerical hardware or software. This report may not be cited for purposes of advertisement.

Distribution of this document is unlimited.

Semiannual Report No. 4

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

USATECOM Project No. 9-4-0013-01

Report Period: 1 March 1967 through 31 August 1967

This research was supported by the Advanced Research Projects Agency of the Department of Defense and by the Army Research Office, OCRD, Department of Army.

Conducted by

US Army Test and Evaluation Command
US Army Tropic Test Center, Fort Clayton, Canal Zone
with assistance of Weather Engineers of Panama Corp.
Contract DAHB01-67-C-B239

May 1968

FOREWORD

This summary report, the fourth of a series to be issued semiannually, covers the progress and status of the Environmental Data Base for Regional Studies in the Humid Tropics. The project is sponsored by the Office, Secretary of Defense, Advanced Research Projects Agency (ARPA), Directorate of Remote Area Conflict, and by the Department of Army, Office of Chief of Research and Development, Army Research Office (ARO).

The study reported herein is being conducted under the guidance and with the direct participation of the Research Division of the US Army Tropic Test Center. Commanding Officers during the report period were Colonel Pedro R. FlorCruz and Colonel John Zakel, Jr. The research program is carried out under the supervision of Dr. Guy N. Parmenter, Chief of the Division. Staff members of the Division have been responsible for the preparation of the individual study papers comprising the body of this report, as noted herein. Compilation and arrangement of the report has been done by Mr. Edward E. Garrett, Physical Environmental Scientist of the Division.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF TABLES

SUMMARY

This fourth semiannual progress report for the Environmental Data Base Project presents a review of Project objectives and scope, with descriptions of the observational sites, and summarizes Project activities during the period of March through August 1967.

The Climate section (Part IV) briefly outlines the types of micrometeorological data observed and instrumentation used. A detailed discussion is given of the problem areas encountered in acquiring such data in the humid tropics, together with those solutions that have been evolved. An analysis of the spatial and temporal frequency distributions of temperature and humidity values is presented.

The Soils and Hydrology section (Part V) contains interim data on soils parameters at one satellite site.

The Vegetation section (Part VI) consists of an analytical discussion of the floristic characteristics of the Albrook Forest site.

The section on Microbiology and Chemistry of the Atmosphere (Part VII) contains a discussion on the concentration of carbon dioxide in the tropical atmosphere, as well as a paper on the microbiological content of rainwater.

The Macrofauna subtask of the Project, covered in Part VIII, presents the preliminary results of an insect collection program, carried out at different vertical levels.

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

PART I. INTRODUCTION

Background

This fourth semiannual report covering the period of 1 March through 31 August 1967, gives a review of project activities and progress as well as selected technical data and analyses. Additional technical information will be found in the periodic Data Summaries to be issued under project auspices.

The project is sponsored jointly by the Advanced Research Projects Agency, Office of the Secretary of Defense, and by the Army Research Office, Office of the Chief of Research and Development, Hqs., Dept. of Army. The work has been carried out by the US Army Tropic Test Center, US Army Test and Evaluation Command, Army Materiel Command, with contracted support of Weather Engineers of Panama, Corp. Additional scientific support was provided through cooperative arrangements with the National Center for Atmospheric Research and with several individual scientists.

The project is an interdisciplinary investigation of the humid tropical environments of the Canal Zone and the Rio Hato military training reservation. These environments include a high rainfall region on the Caribbean slope of the Isthmus where tropical evergreen broadleaf forest prevail, a less wet region on the Pacific slope where tropical semievergreen forests predominate, and the still drier Rio Hato region where a typical savanna association is found. The latter two areas are characterized by a pronounced dry season (though the Caribbean, or Atlantic, site has a relatively dry season, it is not so well marked). These areas are analogous to environments in regions of tropical monsoon and tropical savanna climates (Koeppen Am and Aw) in southeast Asia and other parts of the tropics.

Objectives

The overall objective of the Data Base project is to provide increased knowledge concerning the militarily significant environmental factors of humid tropical environments. The project is designed to provide a bank of information and analyses derived from observations of selected physical and biological conditions at representative sites in the three natural environments mentioned above. A specific objective of the US Army Tropic Center is to obtain detailed information concerning the environments in which its tests are conducted, which information will be of direct value in the planning and accomplishment of tests as well as in the development of tropical test techniques and methods. The project will establish, at the sites chosen as representative of the three specified environmental regimes, the spatial and temporal variations of a number of natural conditions that affect the durability and operability of materiel as well as such factors as movement, communication, visibility, and the physical performance of troops.

Description of Project

Tasks

The basic program for the Data Base project provides for investigations in the following fields: (1) Climate, specifically the meteorological phenomena manifested between the ground surface and a height of approximately 50 meters; (2) Soils and hydrology, with emphasis on factors related to soil trafficability and ground water; (3) Vegetation, with emphasis currently being placed on taxonomy, foliage canopy, and the ground accumulation of forest debris (litter); (4) Microbiology, with emphasis on numbers and kinds of bacteria and fungi and their transportation and deposition; (5) Macrofauna, currently limited to selected arthropods; and (6) Atmospheric chemistry, i.e., chemical and physical contaminants of the air.

Detailed study plans providing guidance for various aspects of each project task have been prepared in the form of Project Memoranda. These memoranda are periodically reviewed and revised to accord with current practice and to reflect experience gained in operation of the project.

Observational Approach

In order to obtain as much information as possible on the interrelationships between various environmental factors, investigations are carried out simultaneously at selected sites. Manpower limitations and the cost of instrumentation have dictated that the full range of observations be limited to a few main observational sites. Two are in operation; three others are planned. "Main" sites are established where a broad range of environmental elements will be observed over a relatively long period of time. Additional "satellite" sites will be, and have been, established in the same general area, at places with different physical and biological conditions where restricted data are observed.

The project plan calls for establishing two main observational sites in each of the two major environmental types found in the Canal Zone. A fifth site is provisionally planned for the Rio Hato military reservation where the third principal local variation of the tropical environment is found. The two observational sites in the semideciduous forest environment on the Pacific side of the Canal Zone are now in operation. One is within the forest, the other in a large clearing nearby. A similar pair of sites is planned for the tropical evergreen broadleaf forest environment on the wetter Caribbean side of the Canal Zone. The paired sites are necessary in order to fully characterize conditions in each of the two environments. Both cleared land and forest are extensive throughout the humid tropics and military operations are not confined to one or the other, yet each imposes significantly different environmental conditions affecting movement, visibility, deterioration of materiel, etc.

Some of the observations are made by Tropic Test Center personnel; however, most of the routine observations are made under contract by the

Weather Engineers of Panama Corp., following guidance provided in the Project Memoranda. Project scientists on the Tropic Test Center staff monitor all work and provide additional guidance as necessary. The frequency of observation varies with the nature of the parameter, ranging from the continuous reading of some meteorological instruments to the one-time observation of some soil factors. The high frequency of many observations requires manning of the main sites on a 24-hour basis.

PART II. OBSERVATION SITES

Site Locations

Established Sites

Two main observational sites are in use. These are located on the Pacific side of the Canal Zone, which is characterized by an average annual rainfall of approximately 70 inches, with a pronounced wet and dry season, and semievergreen forest vegetation. The two sites are located in the Albrook Forest and at Chiva Chiva (see Figure II-1). The latter is in an open grass-covered area, four kilometers (2-1/2 miles) from the former, which is located within a forest with a relatively dense canopy and an understory of shrubs and vines.

One satellite site, on the Pacific side, is currently being utilized for observation of soils and limited meteorological data. The soil satellite sites described in previous reports have been discontinued.

Proposed Sites

The establishment of correlative sites is planned for the Atlantic side of the Canal Zone, where the significantly higher annual rainfall (130 in. average) with a less pronounced dry season produces vegetation with evergreen characteristics and forests with higher and denser canopies. Two areas are under consideration: one in the vicinity of Fort Sherman, (military grid PV 144324), and the other in the former Coco Solo Naval Ordnance Annex (military grid PV 245365).

The fifth main observational site has been planned for location on the Rio Hato Military reservation (approximate grid location, NV 970283) about 80 kilometers southwest of the Albrook sites (see Figure II-1). This is within a savanna (grassland) area with an annual rainfall of approximately 40 in., appreciably less than at the Albrook area.

Site Descriptions

Albrook Forest Site

This site is located in the northeastern portion of the Albrook Air Force Base immediately adjacent to the Fort Clayton Military Reservation (military grid PV 602964). Elevations at the site range from 30 to 33 meters above sea level. The ground slopes gently, approximately 4%, to the southeast. The nearly-level surface is broken only by a one-half to two-meter deep channel of an ephemeral stream running southerly across the eastern side of the test site. The regional topography is characterized by rounded hills, with elevations up to 130 meters. The nearest lie about 400 meters to the east, and others 600 meters to the northwest, the

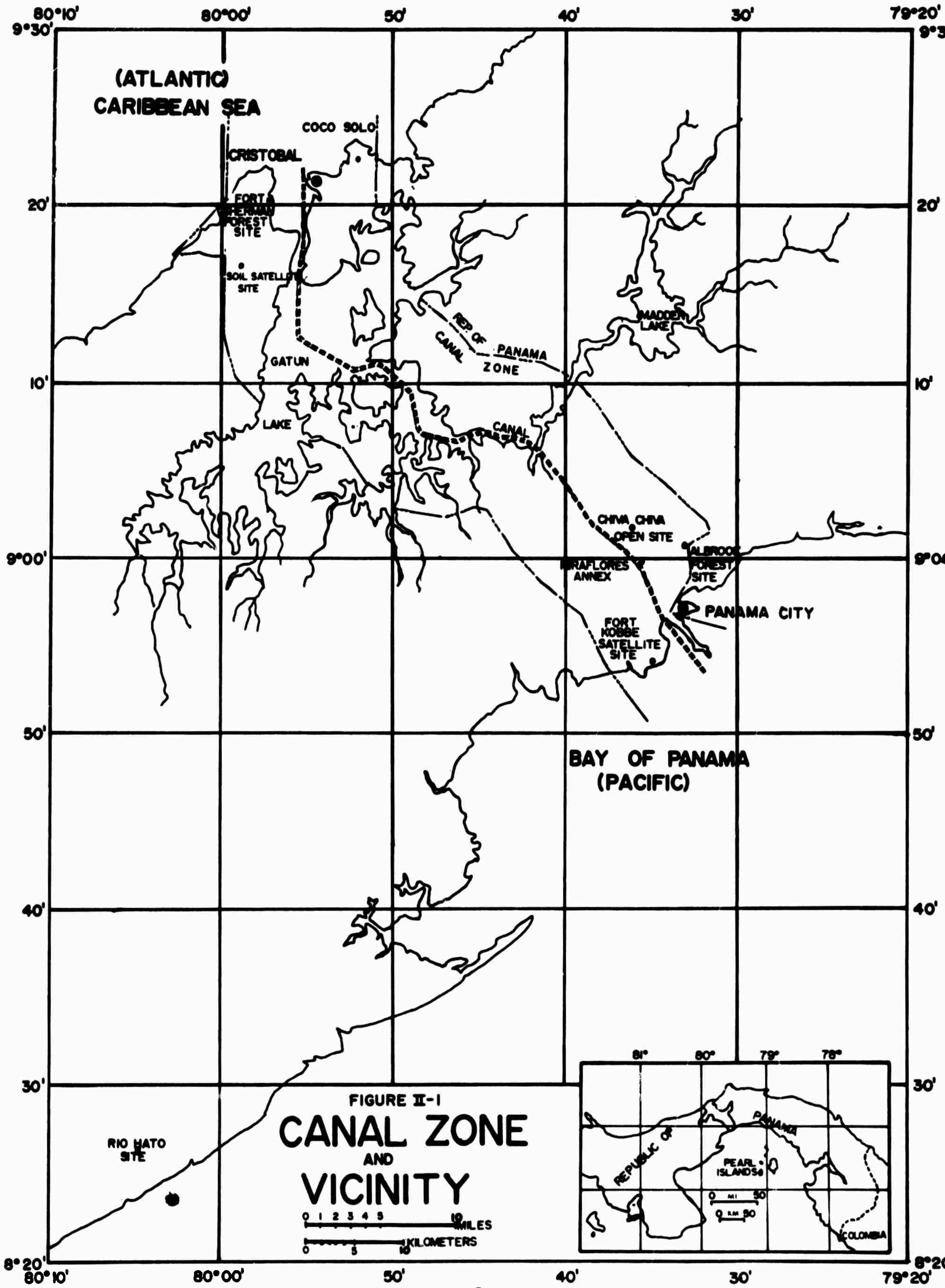


FIGURE II-1
CANAL ZONE AND VICINITY

latter being part of a generally northeast-southwest trending line, with slopes ranging from about 10% to 50%. The site is located on a low, erosional terrace. The soil is a residual clay oxisol with a light-textured surface rich in organic matter. The parent material is an agglomeratic tuff.

The vegetation consists of many species of trees, shrubs, and vines, many of which are deciduous. The top of the tree canopy is 26 to 28 meters above the surface. The forest extends for several kilometers on all sides except to the east, where the large vegetation has been cleared. A gravel road provides access to a paved highway three kilometers distant. Figure II-2 is a view over the forest as seen from 30 meters above ground.

A walk-up tower, 46 meters high, fabricated from aluminum tubing, is located at the center of the site. Figure II-3 is a diagrammatic sketch of the towers showing the instrumentation array as generally followed at both main sites. Figure II-4 is a photographic view of the below-canopy portion of the tower.

FIGURE II-2. ALBROOK FOREST FROM TOWER, 30 M LEVEL

Two generators of 30 kw capacity provide the power required to operate the electrical instrumentation (see Figure II-5). A concrete, air conditioned building for use of the observers, and in which the central components of the data acquisition and recording systems are located, is positioned on the perimeter of the site. (Figure II-5).

Figure II-6 shows the relative locations of the principal installations of the site, including the meteorological, soils, and biological instruments and devices. To minimize disturbance of the existing vegetation and soil surfaces, wooden walk-ways have been installed.

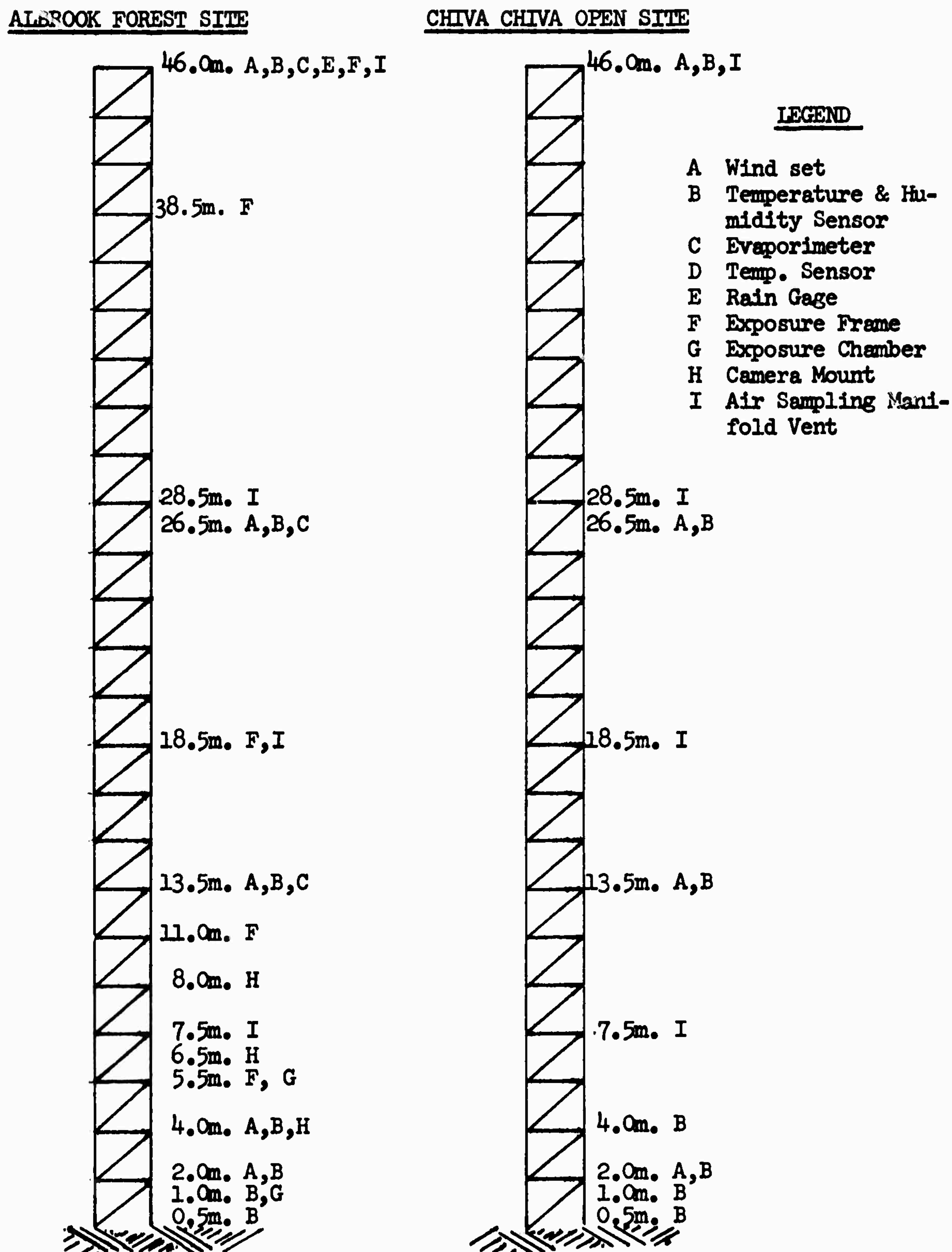
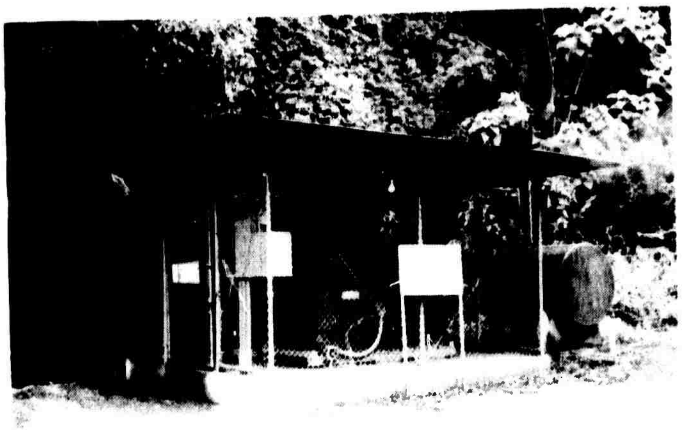


FIGURE II-3. INSTRUMENTATION ARRAY ON OBSERVATION TOWERS

FIGURE II-4. TOWER AT ALBROOK FOREST SITE



Generator Shelter
at Entrance to Site

Observer and Recording
System Building

FIGURE II-5. INSTALLATIONS AT THE ALBROOK FOREST SITE

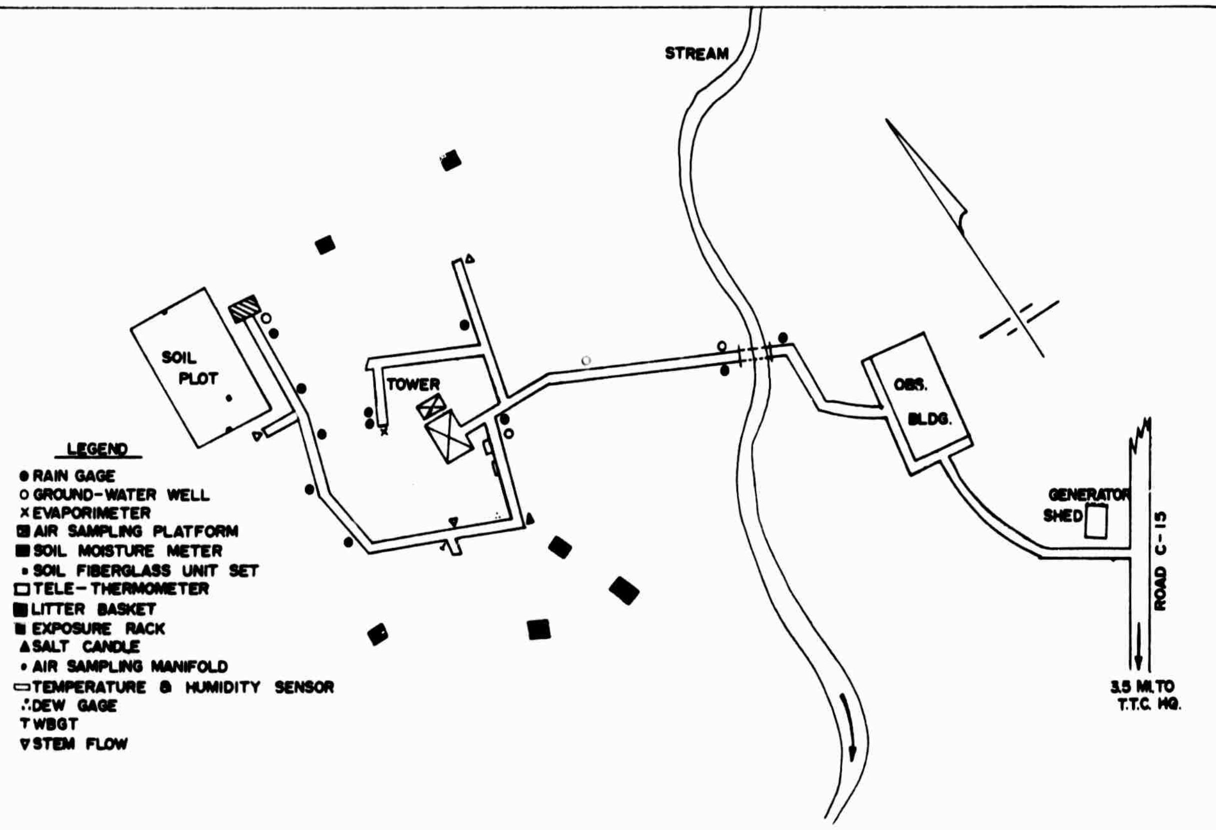


FIGURE II-6. ALBROOK FOREST SITE, GENERALIZED PLOT

Chiva Chiva Open Site

This site is located in the northwestern section of the Fort Clayton Army Reservation (at PV 562979) approximately four kilometers west-northwest of the Albrook Forest Site. The location is in an open grass-covered area at approximately 30 meters elevation. The clearing extends about one-half kilometer to the northeast and in other directions for nearly one kilometer. Beyond the cleared area, a forest, like that at the Albrook site, prevails. The surface is nearly level, with a slight incline toward the southwest. Clay, oxisolic, residual soils, very sticky and plastic, comprise the surface mantle. The parent material, an agglomerate, is generally similar to that at the forest site. A tower, identical in structure to that at Albrook, is centrally positioned on the site. This tower carries a somewhat smaller number of instruments than the one at the Albrook Forest site (see Figure II-3). Two air conditioned vans are provided for the observers and the central components of intrumental recording systems. Electricity is supplied to the site by commercial line power. Figure II-7 is a plot of the principal installations at the site. Figure II-8 shows views of the tower and the vans at Chiva Chiva. Due to the open nature of the site, biological observations are not carried out as extensively as at the Albrook site.

Fort Kobbe Soil Satellite Site II

A new satellite site for soil observations, located at PV 565851 was established in August 1967 near the previous site. Three separate soil plots are located on sloping terrain, with slope varying from 7 to 22%, in order to determine the effect of topographic position on the measured soil parameters. Plot A, in the highest position, lies under a thin deciduous forest with the top of the canopy at about 15 meters. Plot B, at a slightly lower position, lies on the steeper segment of the slope and is covered by more widely spaced trees and shrubs. Plot C is on grass-covered flat ground below the slope. The latter plot is frequently under several centimeters of water during the rainy season. At all plots the soil is a dark clay, very sticky and plastic. Figure II-9 shows views of each plot.

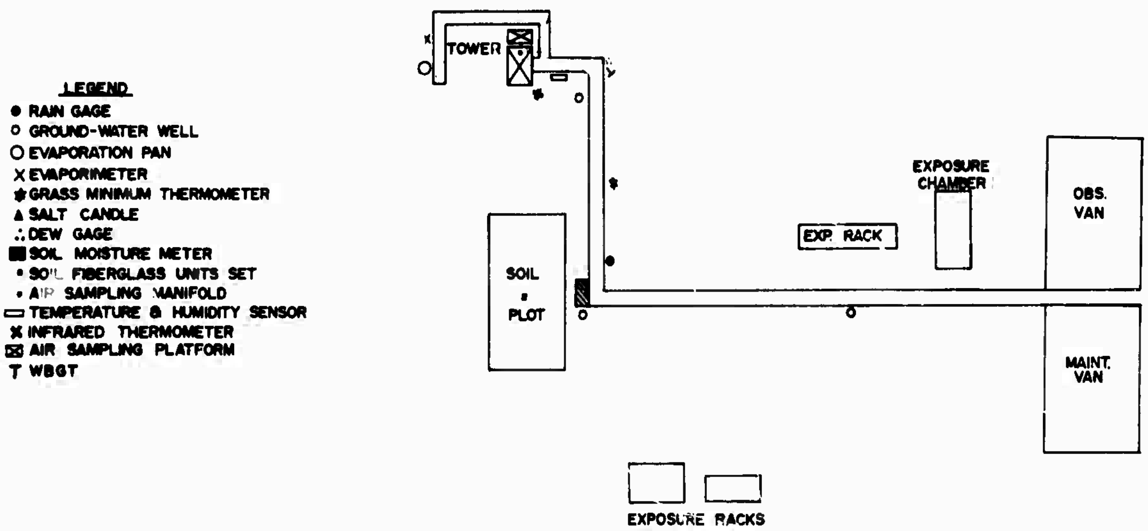
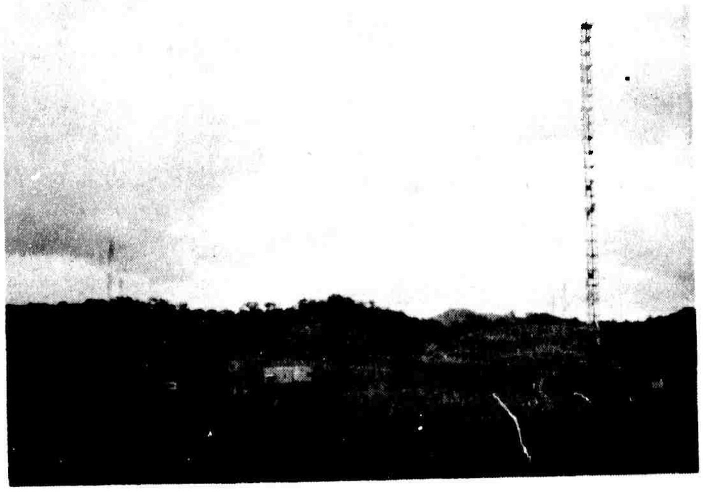


FIGURE II-7. CHIVA CHIVA SITE, GENERALIZED PLOT



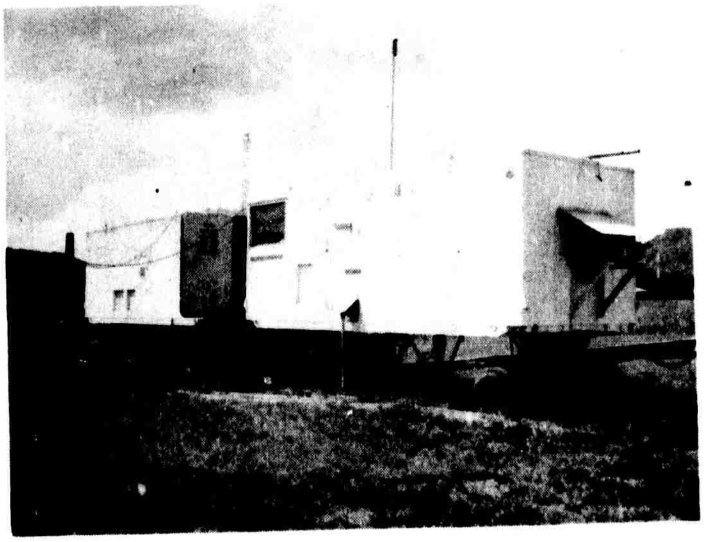


FIGURE II-8. CHIVA CHIVA SITE, OBSERVATION TOWER AND VANS

PLOT A. WELL-DRAINED SOIL

PLOT B.

PLOT C. POORLY-DRAINED SOIL

FIGURE II-9. FORT KOBBE SOIL SATELLITE SITE II

PART III. PROJECT ACCOMPLISHMENTS

General

Observations have continued on the component tasks of the project. As heretofore, the microclimatic observations, which are basic to all the studies, provide the larger proportion of the data. A reduced schedule of observations on soils and hydrology continued, though staff vacancies have precluded any detailed analysis. Systematic vegetation and animal (mainly insect) collection as well as atmospheric sampling for microbial forms and trace chemicals was continued throughout the report period. Collection will continue for some time to come and until the data can be assumed to reveal most of the significant variations which may be encountered.

Dissemination of Data

Publication of the Monthly Microclimatic Summaries continues. Table III-1 lists the meteorological elements presented in this publication. Figure III-1 shows an example of one of the data sheets, contained in the pamphlet.

TABLE III-1. ELEMENTS REPORTED IN MONTHLY MICROCLIMATIC SUMMARY

Monthly Means of Air Temperature by Hour
Monthly Ranges of Air Temperature by Hour
Monthly Means of Relative Humidity by Hour
Monthly Ranges of Relative Humidity by Hour
Monthly Means of Wet Bulb Temperature by Hour
Monthly Means of Barometric Pressure by Hour
Monthly Means of Precipitation by Hour
Monthly Totals of Precipitation
Monthly Ranges of Wet Bulb Temperature by Hour
Monthly Ranges of Barometric Pressure by Hour
Monthly Ranges of Precipitation by Hour
Monthly Means of Wind Speed by Hour
Monthly Ranges of Wind Speed by Hour
Relative Frequencies of Wind Directions (46 meters, Albrook)
Relative Frequencies of Wind Directions (26.5 meters, Albrook)
Relative Frequencies of Wind Directions (4 meters, Albrook)
Relative Frequencies of Wind Directions (46 meters, Chiva Chiva)
Relative Frequencies of Wind Directions (26.5 meters, Chiva Chiva)
Relative Frequencies of Wind Directions (4 meters, Chiva Chiva)
WBGT (Albrook)
Evaporation (Albrook)
Precipitation (Manual gauge network, Albrook)
Precipitation (Stem Flow, Albrook)
WBGT (Chiva Chiva)
Minimum Grass Temperature, Chiva Chiva

ALBROOK (Forest site) APRIL 1967

Relative Frequencies * of Wind Directions by Hour at 26.5 m. (%)

Dir. \ Hr.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N		6.7				6.7		3.3	6.7	10.0	13.3	10.0	3.4	10.3	13.3	20.0	13.3	3.3	6.7	3.3	3.3	6.7		
NNE								3.3	10.0	3.3	3.3	10.0	6.9		6.7	6.7	3.3	3.3	6.7					
NE										3.3		10.0	6.9	10.3	6.7	3.3	3.3	3.3	3.3					
ENE									3.3	13.3	3.3			6.9	6.7	3.3		3.3						
E									6.7	10.0	13.3	3.3	20.6	3.4	10.0		10.0							
ESE										3.3		3.3				3.3	3.3			3.3				
SE									3.3		3.3	10.0	6.9		3.3	3.3		3.3						
SSE											10.0	3.3	10.3	3.4	3.3	3.3								
S									10.0	10.0	3.3	10.0	10.3	17.2	13.3	10.0	13.3		3.3					
SSW									3.3	13.3	3.3	3.3					3.3							
SW			3.3					3.3	3.3			6.7	3.4					3.3		6.7				
WSW			3.3			3.3	3.3	6.7	3.3	3.3	3.3	6.7	3.4					3.3	3.3				6.7	
W	16.7	20.0	13.3	20.0	16.7	3.3	13.3	16.7		6.7	6.7	6.7	3.4	6.9		6.7	3.3	6.7	6.7	3.3	13.3	6.7	20.0	20.0
WNW	20.0	20.0	16.7	13.3	6.7	30.0	20.0	30.0	6.7	6.7	10.0	6.7	6.9			3.3	6.7	16.7	16.7	23.3	26.7	33.3	36.7	30.0
NW	40.0	26.7	23.3	23.3	26.7	6.7	23.3	10.0	30.0	3.3	10.0	3.3	10.3	20.6	13.3	10.0	16.7	30.0	30.0	26.7	33.3	20.0	16.7	26.7
NNW	3.3	3.3	3.3		3.3	3.3		3.3	3.3	3.3	10.0	6.7	6.9	10.3	6.7	13.3	10.0	10.0	6.7	10.0	6.7	10.0		
CALM	20.0	23.3	36.7	43.3	46.7	46.7	40.0	23.3	10.0	10.0	6.7		23.3	10.3	16.7	13.3	13.3	13.3	16.7	23.3	16.7	23.3	20.0	23.3

* Note: Due to rounding, percentage totals do not equal 100%.

FIGURE III-1. EXAMPLE OF TABULATED METEOROLOGICAL DATA IN MONTHLY MICROCLIMATIC SUMMARY

PART IV. CLIMATE

Introduction

The climatic task of the Data Base project is aimed at the determination of the microclimatic characteristics of the observation sites. Measurements of climatic elements through the vertical profile are made by exposing sensors at selected levels on the 46-meter towers together with an array placed at the ground level at the two main sites, Albrook Forest and Chiva Chiva (see Figures II-2, -6, and -7). All determinations are made at scheduled time intervals, and like measurements are made simultaneously, at the forest and open sites. The simultaneity and continuity of measurements at the Data Base sites makes possible the definition in precise terms of the areal and temporal variations of the humid tropical climate as exhibited at the two sites.

Observations

No significant changes have been effected in the meteorological observation regime (see previous Semiannual Report[2], p. 19). The observations were continued on a routine basis at the main sites. They were discontinued, however, at Rio Hato and at the three previous satellite soil sites.

Instrumentation

Current Instrumentation

The use of standard instrumentation continued throughout this period (see First and Second Semiannual Report[4])

Future Instrumentation

The automatic meteorological data acquisition and recording systems (see previous Semiannual Report[2], pp 21 and 25, figures IV-4 through IV-7) were delivered late in August. Installation was begun in September.

Data Reduction and Storage

Routine data reduction and storage techniques were continued (see previous Semiannual Report[2], p. 30).

Data Analysis*

Analyses of the meteorological data acquired under the project, as well as of the methodology for its acquisition, are carried out, as time permits, in order to increase the utility, significance, accuracy, and validity of the measurements. In line with this objective, the sections below are presented.

* The following sections have been prepared by Dr. Wilfried H. Portig, Research Meteorologist.

Problem Areas in Meteorological Measurements

Introduction

The use of meteorological instruments and their exposure to the ambient environment within the humid tropics imposes maintenance problems of a more serious nature than is generally realized. These problems are discussed here in order to provide some guidance to future investigation and possibly to provide some clues as to procedures which may be employed to circumvent the difficulties. The discussion may also give some insight on the limitation of accuracy to be expected on meteorological measurement made in the humid tropics.

Humidity Measurement with Hair Hygrometers

Considerable difficulties are encountered in making humidity measurements with hair hygrometers. In nearly all cases they indicate saturation at times when psychrometers show a significant spread between the dry and wet bulb thermometers. The tentative explanation is that the hair elements are rapidly covered with a hygroscopic deposition (which phenomenon occurs commonly on exposed surfaces in the tropics).

Since it is not possible to reduce a hygrometer curve which runs straight along the 100% line when the psychrometer shows variations, the moisture data were estimated in such cases. This estimate was based on two features of the observation program: 1) The hourly observations at the 0.5-, 2-, and 4-meter levels were made with psychrometers, those at the 1-, 13.5-, 26.5-, and 46-meter levels with hair hygrometers. 2) Every five hours (except when raining) the observer climbed the tower and made a calibration check of the recording instruments by means of a psychron or similar psychrometer.

The latter measurements permit relating the moisture conditions at the hygrometer levels statistically to those at the psychrometer levels. Curves can be drawn that present the most likely distribution of the moisture with height when it is known at one level. From these curves one can estimate values that are more probable than the recorded 100%. Though this procedure does not yield the precise moisture values at the hygrometer heights, the arithmetic mean of these adjusted values will not be far from the true mean. The dispersion around the adjusted means, however, may be substantially smaller than the true dispersion.

The adjustment of the hygrometer-recorded 100% values was accomplished in either of two ways, according to the height of the instruments. The 1-meter level was interpolated between the 0.5- and the 2-meter levels. The 13.5-, 26.5-, and 46-meter levels were extrapolated from the 4-meter level.

Interpolation Adjustment. The adjustment of the moisture values at the 1-meter level was made in order to produce the highest correlation coefficient between the 5-hourly calibration measurements at the 1-meter level and a linear combination of the simultaneous measurements at the 0.5- and 2-meter levels.

Let the measurements taken at 0.5, 1, and 2 meter be x, y, and z, respectively. Then constants a and b should be found such that the correlation coefficient between y and the linear combination w = ax+by is at a maximum. This is equivalent to a correlation r(y,w) between y and w = (x +az)/(1+a). The arithmetic mean of w, $\bar{w}$, is found to be w = $(\bar{x}+a\bar{z})/(1+a)$, and its varience is $\sigma_w^2 = (\sigma_x^2 + a\sigma_y^2 + 2a\gamma\sigma_x\sigma_z)/(1+a)^2$. In this equation γ is the correlation coefficient between simultaneous measurements at the 0.5- and 2-meter levels: γ = r(x,z). Correspondingly we call α = r(x,y,) and β = r(y,z). These variables are inserted into the general formula for the correlation coefficient which yields r(y,w) as a function of the known numerical values, $x, y, z, \sigma_x, \sigma_y, \sigma_z$, and the unknown a. The expression dr (w,y)/da is computed and equalized to zero in order to find the best a. This turns out to be a = $(\beta-\alpha\gamma)\sigma_x/(\alpha-\beta\gamma)\sigma_z$. We use this value to eliminate w from the regression equation between y and w and obtain as the best guess y, for any moisture value at the 1-meter level:

$$\hat{y} = \frac{\sigma_y}{\sigma_x}\cdot\frac{\alpha+g\beta}{1+2g\gamma+g^2}(x-\bar{x}) + \frac{\sigma_y}{\sigma_z}\cdot\frac{\beta+h\alpha}{1+2h\gamma+h^2}(z-\bar{z}) + \bar{y}$$

where g = 1/h = $(\beta-\alpha\gamma)/(\alpha-\beta\gamma)$. By means of this formula the most probable humidity, $\hat{y}$, may be computed for the 1-meter level from measurements, x and z, made at the same time at the 0.5- and 2-meter levels. This is a generalization of the calibration measurements.

The data obtained at Albrook in April 1967 may serve as an example as to how this method works. There were 85 calibration measurements at which the relative humidity at 1 meter was 85% or more. From this set of data the parameters required by the formula were computed: α = 0.917, β = 0.908, γ = 0.880, σ_x = 4.285, σ_y = 4.516, σ_z = 4.915, which yielded the formula y = 0.551z + 0.411z + 0.7.

How well this formula represents the true moisture conditions at any time cannot be checked since it was derived for the purpose of replacing the recorded (unrealistic) 100% values by better ones. But some check may be made by using only half of the calibration checks and applying the resulting formula to the other, unused data, to see how well it fits. The reduction from 85 to 43 trios of data leads to the slightly different parameters and formula: α' = 0.918, β' = 0.891, γ' = 0.823, σ_x' = 3.979, σ_y' = 4.424, σ_z' = 4.867, $\hat{y}'$ = 0.638x + 0.380z - 0.44. The correlation coefficient of the y's which were used in the calculation is 0.949; that with the remaining y's (which were not used) is even better: 0.967. This means that, at least in this case, the adjusted values are much more realistic than a repeated 100.

It was soon found that the calculation can be substantially simplified if a slightly lower accuracy is acceptable. Since the relative humidity is recorded only to the next full percent the simplification may be used.

The simplified adjusted y, $\check{y}$, is the arithmetic mean of x and z, rounded toward the z when the mean ends in 0.5. For example:

x = 94% and z = 88% gives $\check{y}$ = 91%
x = 94% and z = 89% gives $\check{y}$ = 91% (instead of 91.5%)
x = 95% and z = 88% gives $\check{y}$ = 91% (instead of 91.5%)

When we do so with all 85 values, the $\check{y}$'s form with the y's a correlation coefficient of 0.938 which is so high that the simplified interpolation is justified.

Extrapolation Adjustment. The adjustment of the higher levels by means of extrapolation from the 4-meter level is less gratifying, especially in Albrook where the meteorological parameters may change substantially at the boundary between the treetops and the open air. These relationships between different levels are not linear. The moisture conditions coincide fairly well at very high and very low percentages, but substantial differences exist in between. This means that regression curves are not straight lines and do not follow any curve readily described by a mathematical formula.

Again, the April 1967 calibrations for Albrook may serve to illustrate the method. The calibration checks, made with a psychron (motor-aspirated psychrometer) by an observer while he was climbing the tower, were arranged in numerical order according to the humidities measured at 4 meters. Generally all measurements were used to derive regression curves. In order to estimate the errors involved in the method, in this special case only, every other value was used for regression and the others were used to check the results. The measured values of the "working sample" were plotted in three graphs with the relative humidities at 13.5, 26.5 and 46 meters, respectively, as functions of the relative humidity at 4 meters. Free-hand curves were drawn for best fit. From these curves the moisture profiles shown in the tabulations below have been derived. Since the hair hygrometers normally function properly up to at least 85%, values below 85% are not pertinent to this discussion.

Height	Relative Humidity											
46 m	98	93	91	89	88	87	86	85	84	83	82	81
26.5 m	99	96	94	92	91	90	88	87	86	85	84	84
13.5 m	99	96	95	93	92	91	90	89	88	87	86	85
4 m	100	99	98	97	96	95	94	93	92	91	90	89

The values derived from the above tabulations were compared with the values actually measured. The following correlation coefficient between actual observation and data taken from the regression curves were obtained:

	13.5 meters	26.5 meters	46 meters
Working sample	0.743 (31)	0.769 (29)	0.709 (25)
Test sample	0.628 (32)	0.495 (29)	0.712 (25)

The correlation coefficients are substantially smaller than those for the 1-meter level discussed above. The actual errors are not so great as one might expect from these coefficients because the samples comprise only the small range from 85 to 100%. Frequencies of the actual errors at the 26.5 meter level are listed below. (**Error is estimated minus true value**)

Percent Rel. Hum.	0	±1	±2	±3	±4	±5	±6	±7	±8	±9	±10	±11	±12
Working sample	2	8	6	5	1	3	1	-	2	-	-	-	1
Test sample	4	4	4	4	2	4	1	2	-	2	1	1	-

These numbers (which include unidentified errors of the observers) are reduced drastically when the limit at which the hair begins to fail is higher than 85 percent. The errors are also smaller at the open site because the correlation between different levels is not impaired by the effects of vegetation.

These estimated corrections will become unnecessary with the replacement of hygrometers by aspirated telepsychrometers.

Temperature Measurement

Measurement of air temperature is accomplished, basically, by equalizing the temperature of the sensing device with that of the air, then reading the indication of the sensor. This would work well if the temperature of the sensor were governed only by the temperature of the surrounding air. However, the sensor is affected by other factors: radiation from any source and heat conduction of any wave length through the physical support of the sensor; heat transfer through evaporation or condensation; and the frictional heat of wind. The last factor may be disregarded for the current project since winds of sufficient speed to produce frictional heat occur too infrequently to be significant. Heat produced by evaporation or condensation is controlled by keeping the thermometers either completely dry or completely wet. While it is no real problem to keep thermometer sensors dry, it is difficult to keep them uniformly wet when they are continuously working and, as on towers, not easily accessible. This problem will not be considered since these difficulties are well known and are discussed in literature on meteorological instruments, and since experience has added no new knowledge.

The heat transfer from the supporting structure of the sensor to the sensor itself is proportional to the temperature difference between both. Such undesirable heat transfer can be avoided by keeping sensor and support at the same temperature.

Two real problems in measuring the air temperature remain: Heat transfer through radiation; and definition of air temperature.

Radiational Transfer. The extreme susceptibility of most temperature sensors to radiation has been known for some three-hundred years. Hence, at the very beginning of metrical meteorology, thermometers were sheltered against direct sunlight. In the course of time the shelter has been standardized in the form of the "Stevenson screen" which shields the thermometer from any sky or ground radiation, and whose louvered walls allow some exchange of the air inside and outside the shelter. The Stevenson screen is used in all climates, and practically all published temperature data have been obtained by means of thermometers sheltered within it.

However, there are strong indications that the measurements taken in the Stevenson screen do not always coincide with the ambient air temperature. In the tropics there are two sources of error: 1) The physical structure of the shelter is heated by sun, sky, and ground radiation to a temperature higher than that of the ambient air. Although the heat conductivity of the material (wood and paint) is low, the inside walls of the screen will be warmer than the outside air and will give off excess heat. This occurs through long-wave (infrared) radiation and through contact with the air within the shelter. In both ways heat is transferred to the sensor. 2) If the exchange of outside and inside air is rapid enough, both effects will be significantly reduced though not eliminated. However, the wind at tropical stations is frequently not sufficient to effect the necessary interchange.

Measurements made during the reporting period at the open site (Chiva Chiva) showed that there are considerable differences between the temperature of the ambient air and the temperatures of certain sensors. Since discrepancies of this type had been foreseen, the exposure of the sensors from the onset was modified to enhance their ventilation. By omitting one side of the shelter completely in some locations, and by using thermometers with a bare minimum of shielding in other locations, a reduction of the errors due to radiation was attempted.

Introduction of the much more accurate telethermometers showed, however, that the preventive measures had not been sufficient. The telethermometers are not shielded against radiation by wood but by fiberglass which is more effective. Also, they are not "ventilated" by the natural wind (which may drop to zero) but "aspirated" at a constant rate produced by a continuously running fan.

Differences between telethermometers and sensors in relatively open shelters (psychron, hygrothermograph, Taylor mercury-in-glass thermometers) are considerable (up to 8 F). A special study is planned to investigate these differences. The differences depend strongly on the wind speed, and their sign during the day is opposite from that at night. The greatest difference appears to occur in the forenoon when the solid material surrounding the sensors is heated rapidly while the air gets warmer only slowly. Preliminary measurements also showed that the difference between a psychron and a hygrothermograph, both in the same shelter, depends on the temperature and the time of the day. This, if confirmed, would mean that the sensor of the hygrothermograph is noticeably influenced by radiation emanating from the material around it.

Temperature Definition. Assuming that it is possible to accurately. measure the temperature of the air that touches the thermometer sensor, we recognize that the question remains of just how representative this air parcel is. Does it represent "the" temperature of a well defined layer, or does the temperature vary with space and time rather arbitrarily, or is measuring over a certain time period sufficient to obtain a mean value that may readily be compared with other, similarly obtained, mean values? Attempts to answer these questions are currently being made in several parts of the world. We acknowledge the problem, but are not attempting its solution.

Wind Measurement.

The problem of the measurement of air motions in the tropical forest is not yet solved. Again, as in the measurement of temperature, the problem has two parts: How is air motion measured, and what does a measurement actually mean?

In higher latitudes the difficulties are less severe. The wind speed, in general is higher there than it is in the tropics and consequently is easier to measure. The forests are generally more homogeneous, with fewer species, and with less undergrowth (which inhibits air movement). For this reason "typical" observation sites can be selected and valid generalizations may be made. In the tropical forest, on the other hand, the physical structure is so diverse that "type" situations cannot be identified with certainty.

These obstacles to a meaningful assessment of air motion in a tropical forest do not alter its importance. It is through air motion that the air within the forest is exchanged with air from the outside. Spores and small insects are carried by the air, and air pollutants are dispersed. It must be assumed that the vertical component of air movement within a forest is more significant, relatively, than in open terrain. Possibly the winds above the forest induce vertical movement between the trees, as a type of "chimney" effect. But while chimneys have simple, well defined contours which permit some systematic measurement and generalization of results, the "chimneys" in the forest are not amenable to such treatment. Added to the basic difficulties in measurement of three-dimensional air movement are the inherent problems in measuring small-scale air motion within a tropical forest. The sturdy cup-anemometer simply does not move, and even the more sensitive light-weight cup anemometer usually has too high a threshold velocity to react to slight air movements readily detected by an observer. Hot-wire anemometers have two disadvantages that preclude their use. They are mechanically too sensitive for the severe conditions in the tropical forest, and their inherent heat produces buoyant air currents disturbing the natural conditions.

There is some hope that the Hastings-Raydist thermocouple anemometer may solve the problem of measuring the air motion at a given location. This would not eliminate the other problem of identifying representative locations from which valid generalizations could be drawn.

Evaporation Measurement.

This parameter is dubious primarily because of the interpretation of the measurements rather than because of the technique of measurement. Outside of forests, where the great bulk of evaporation measurements are made, two systems compete: the big pan with a relatively large surface, and the atmometers and Piche evaporimeters which evaporate from a much smaller porous surface. Within either group there are differences, but we may consider one group as representative of open water surfaces such as water bodies, and the other for porous surfaces such as the human skin, leaves, etc.

Only a few investigations have been made concerning performance of the Piche evaporimeter with which most observations have been made in the past. The more recent pan has undergone more study and has become the standard instrument in the last decade. Unfortunately, this instrument cannot be used in a forest because a great quantity of litter is collected by the large open water-surface of the instrument. In the forest the only usable instruments are those which can easily be cleaned and are of simple construction and readily maintained. Consequently, only the Piche evaporimeter appears practical for use in the tropical forest.

In order to "reduce" Piche data to pan data some comparisons were carried out at the Chiva Chiva open site. The first series of measurements made it clear that readings taken once daily do not lead to meaningful correlations. The second series of measurements was made at 4-hour intervals. Some good correlations showed up, with marked differences between forenoon and afternoon. Throughout the day the Piche showed the same relationship between evaporation and wind speed; and between evaporation and temperature (which has generally very high correlations with the saturation deficit and with radiation). The pan, however, showed such correlations only in the afternoon, while the evaporation in the forenoon was almost equal for all days regardless of wind and temperature conditions. The reason for the different performance seems to be that the temperature variations within the large water-mass of the pan lag behind the changes in the air temperature, so that the water temperature is lower than the air temperature before noon, and higher later in the day.

A short but very detailed series of hourly measurements is planned to ascertain the validity of this hypothesis and to help understand the different performance of different types of evaporimeters and to establish a basis for the better understanding of the different types of evaporation (also different types of potential evaporation!) that actually exist in nature.

Radiation Measurement.

Radiation may be considered from the standpoint of quantity as well as quality. Meteorologists customarily look only at the quantity, and they measure the energy transferred in various types of flux. Occasionally they distinguish between different frequency bands, e.g., when they explain the greenhouse effect. They also make such distinctions when this helps in the analysis of the composition of the atmosphere. Water vapor, for example, has very distinct absorption bands, and comparison of these with other bands provides a good estimate of the amount of water vapor in the atmosphere.

Few measurements so far, however, have been made that aim at establishing the geographical and seasonal distribution of the occurrence of certain wave lengths. For purposes of material testing as well as for the understanding of biological processes it is imperative to know the spectral composition of natural light, especially in the ultraviolet range. The heat energy which is generally measured by meteorologists is, for most of the mentioned applications, well enough represented by temperatures, either of the air, soil, or the surface of material objects. Actually the radiation is generally measured by its heating effect on specially defined and designed surfaces.

The instrumentation for the measurement of solar and sky radiation is more or less standardized. Yet it poses some problems that are more difficult to overcome than those of more conventional instruments. In addition to the well-known difficulties found in the humid tropics is the rapid coating of all objects with biotic matter. Such a coating, especially strong under trees, changes the amount of radiation permitted to reach the sensor, for each wave length in a different degree. It is hoped that spectroradiational measurements may be included in the Data Base program in the future, with special emphasis on the short wave end of the light spectrum. Attempts are being made to find adequate instrumentation. The first review indicates that there is certainly no abundance of instruments suitable for this purpose.

Temperature and Humidity Frequencies

Introduction

Climatic summaries normally provide mean values, as well as maxima and minima. Such information is given in the monthly summaries published under the auspices of the Data Base project.[1] However, the frequency of occurrence of certain temperatures and relative humidities (or significant ranges of these values) must also be known for some purposes. Consequently, a series of such frequency distributions representing dry season and rainy season conditions at the two Data Base sites is presented here.

Analytical Method

Figures IV-1 through -9 are graphs representing percentage of occurrence of temperatures and relative humidities at selected tower heights in the Albrook Forest and Chiva Chiva open sites. They were prepared from a summarization of the data collected during the dry season month of March 1967 (Figures IV-1 through -5) and the rainy season month of October 1966 (Figures IV-6 through -9). These figures have been calculated on the basis of increments of one degree (F) and 5% relative humidity (thus the values 71.0 - 71.9 F are taken as 71 F). The data recorded were hourly means taken on a 24-hour basis. The calculation was applied to data at the 2-meter level for both elements, and at the 46-meter level for temperature only. The somewhat jagged frequency distributions were slightly modified by drawing a smooth line through the plot of accumulated frequencies. Approximately half of all original counts of accumulated frequencies remained unchanged, and the unchanged values were evenly distributed over the entire range. It may be assumed that this kind of smoothing comes closest to typical conditions.

It must, however, be borne in mind what has been said in the previous section (on Problem Areas) about the measured values from which the frequency distributions were derived. The temperatures at 46-meters, though measured within shelters, may have been too high during hours of little wind. The data at both stations were taken from Belfort hygrothermographs at the 46-meter level, while the data at the 2-meter level were taken with a stationary Taylor thermometer at the open site, and with a movable Psychron at the forest site.

Discussion

Temperatures as well as humidities have bimodal frequency distributions at either site during the dry season (Figures IV-1 to -4). This distribution derives from the fact that the daytime conditions differ essentially from the night time, with only short transition periods. Therefore both meteorological parameters show a secondary frequency minimum near the mean value. The forest influence is indicated by slightly less rugged frequency distributions. At 46 meters the maxima are closer together than at 2 meters. Generally, however, the differences between the four curves are not as great

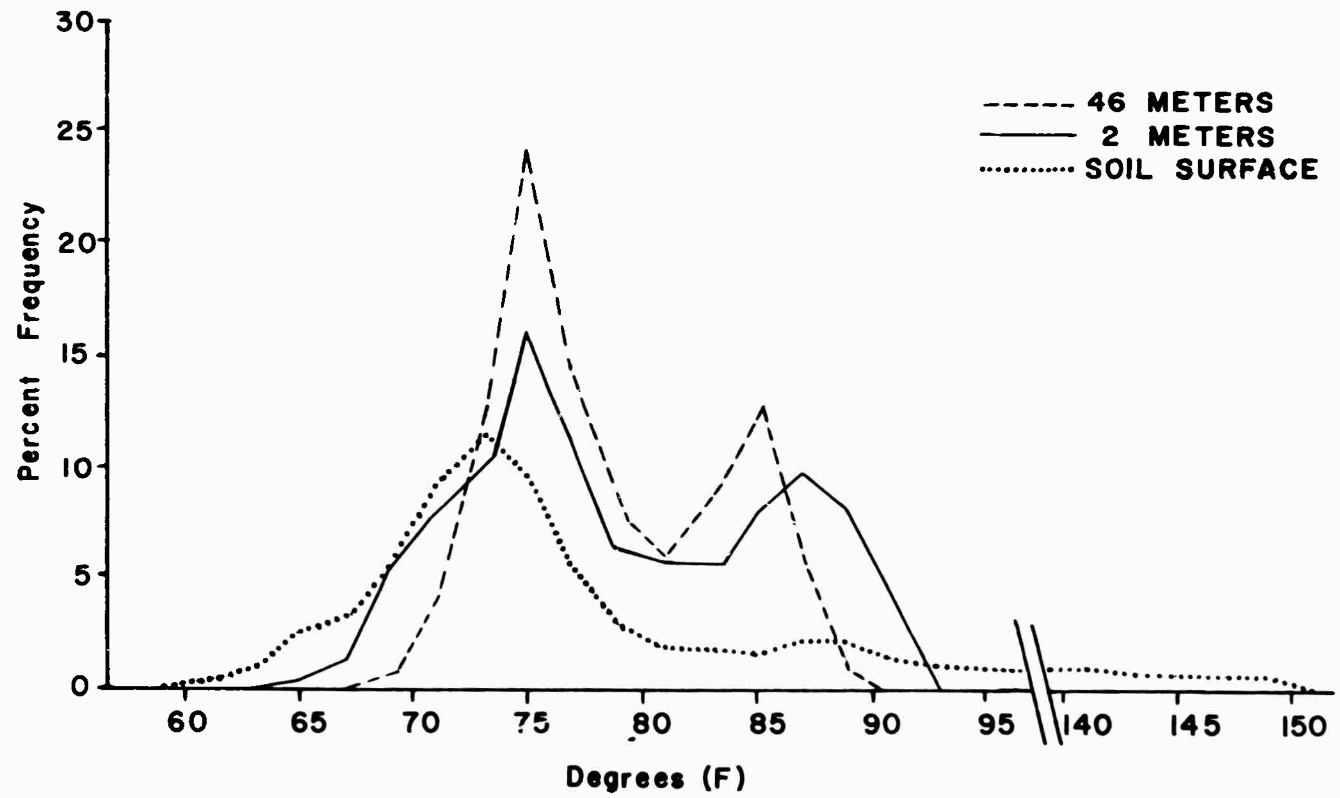


FIGURE IV-1. FREQUENCY DISTRIBUTION OF TEMPERATURE, CHIVA CHIVA OPEN SITE, MARCH 1967, DRY SEASON

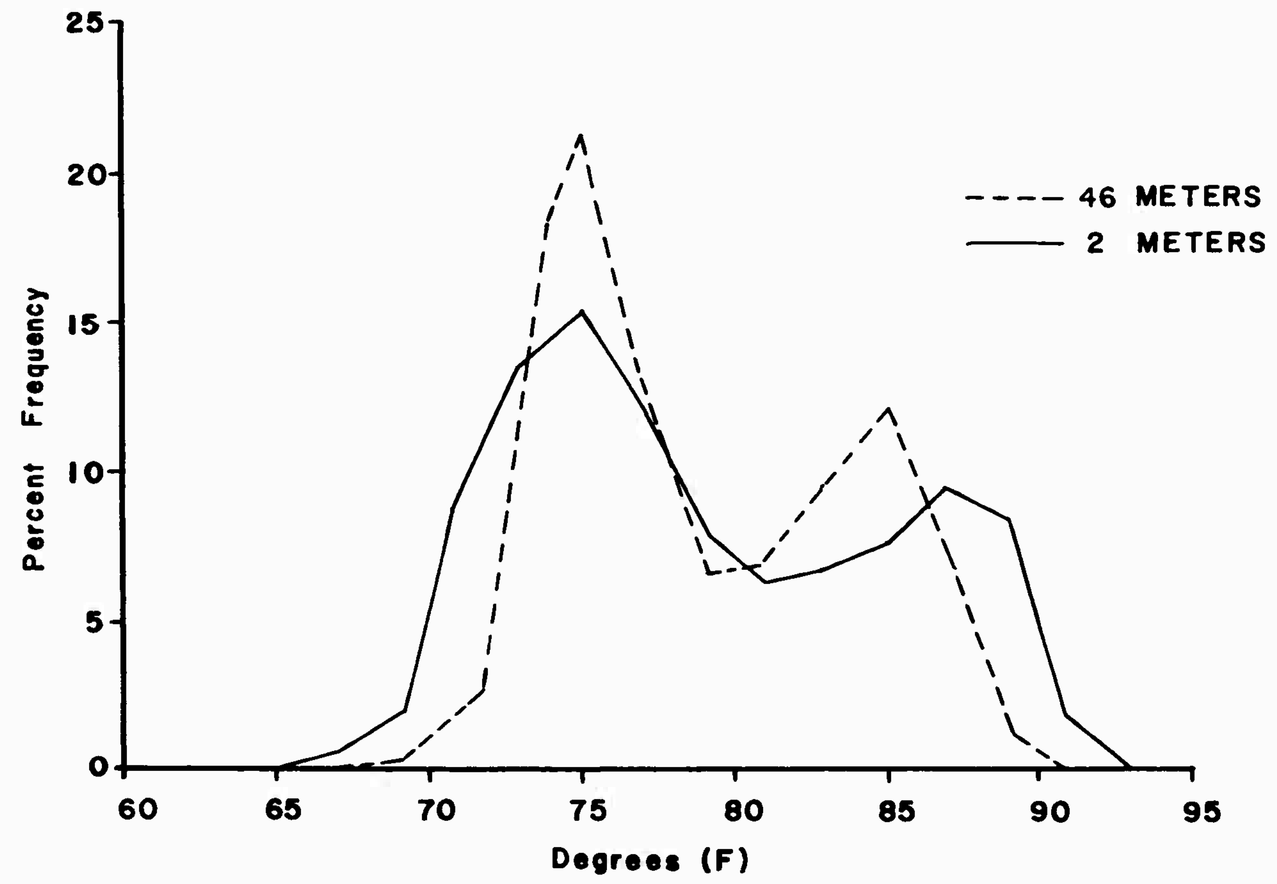


FIGURE IV-2. FREQUENCY DISTRIBUTION OF TEMPERATURE, ALBROOK FOREST, MARCH 1967, DRY SEASON

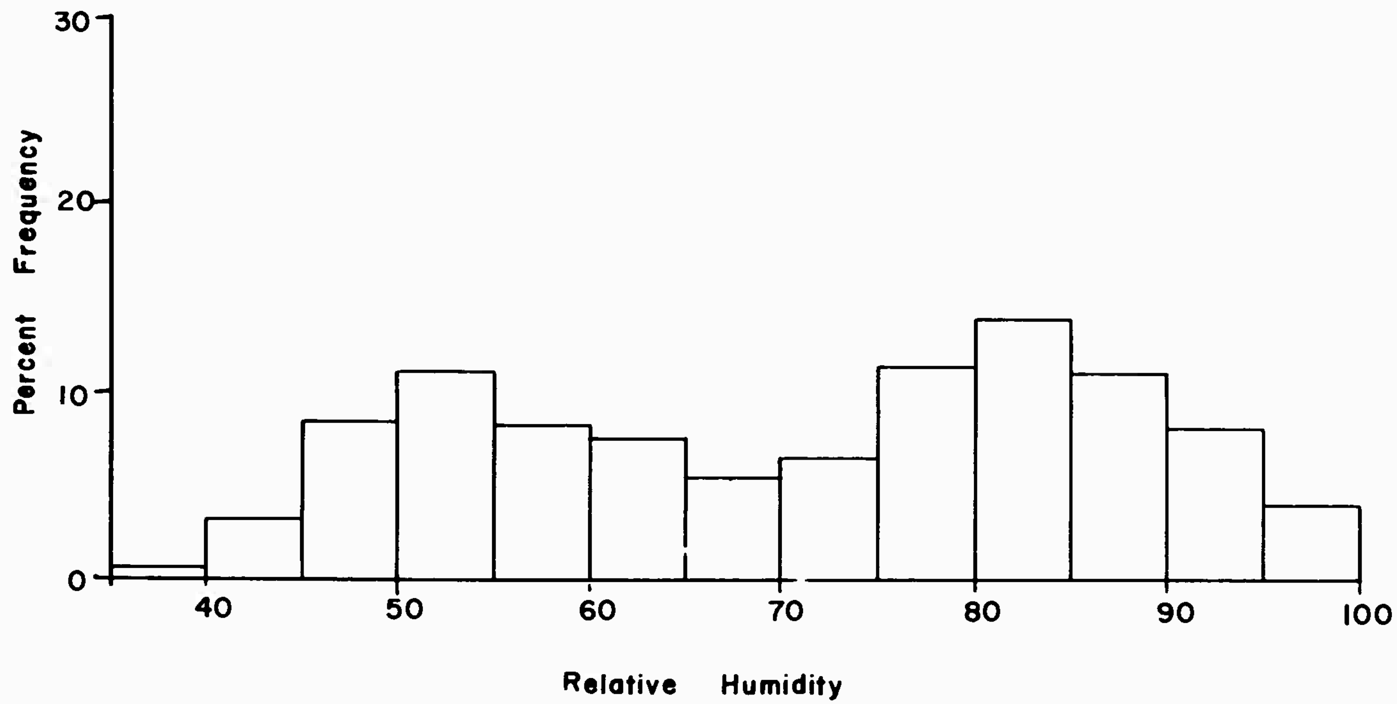


FIGURE IV-3 FREQUENCY DISTRIBUTION OF RELATIVE HUMIDITY, CHIVA CHIVA OPEN SITE, MARCH 1967, DRY SEASON (2 Meters)

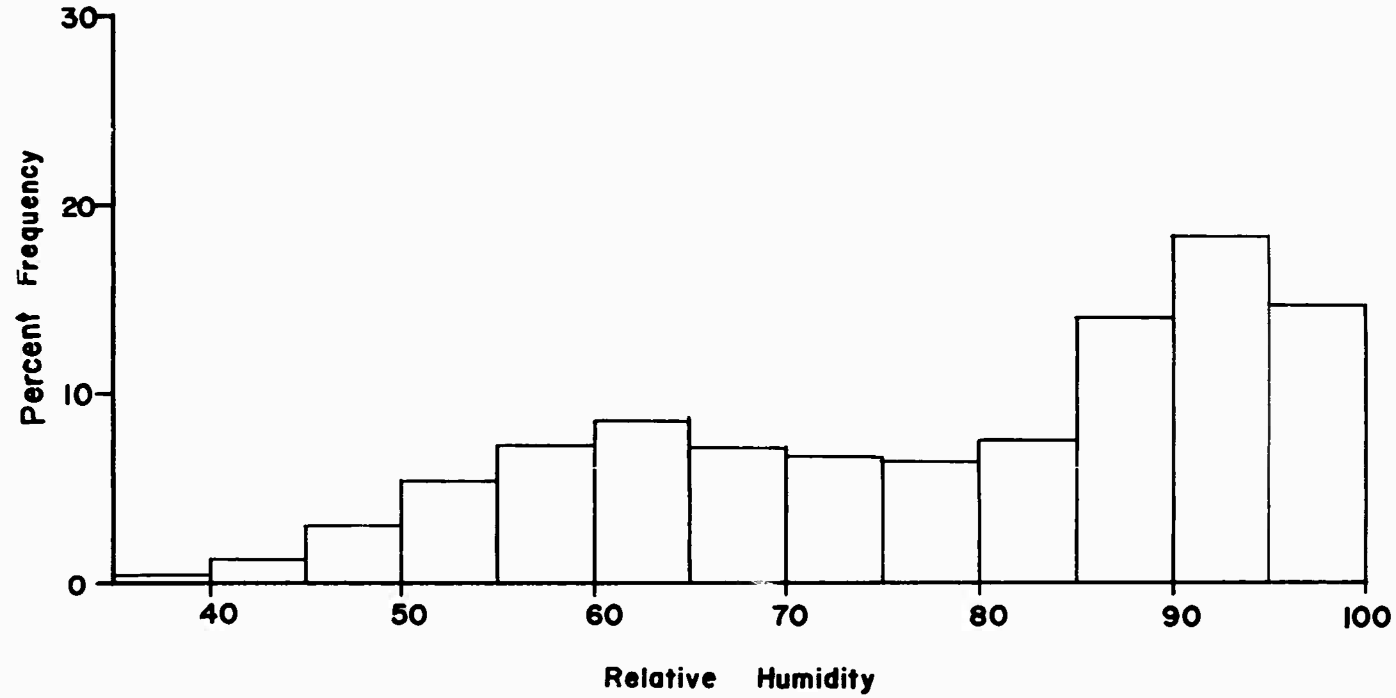


FIGURE IV-4. FREQUENCY DISTRIBUTION OF RELATIVE HUMIDITY, ALBROOK FOREST, MARCH 1967, DRY SEASON (2 Meters)

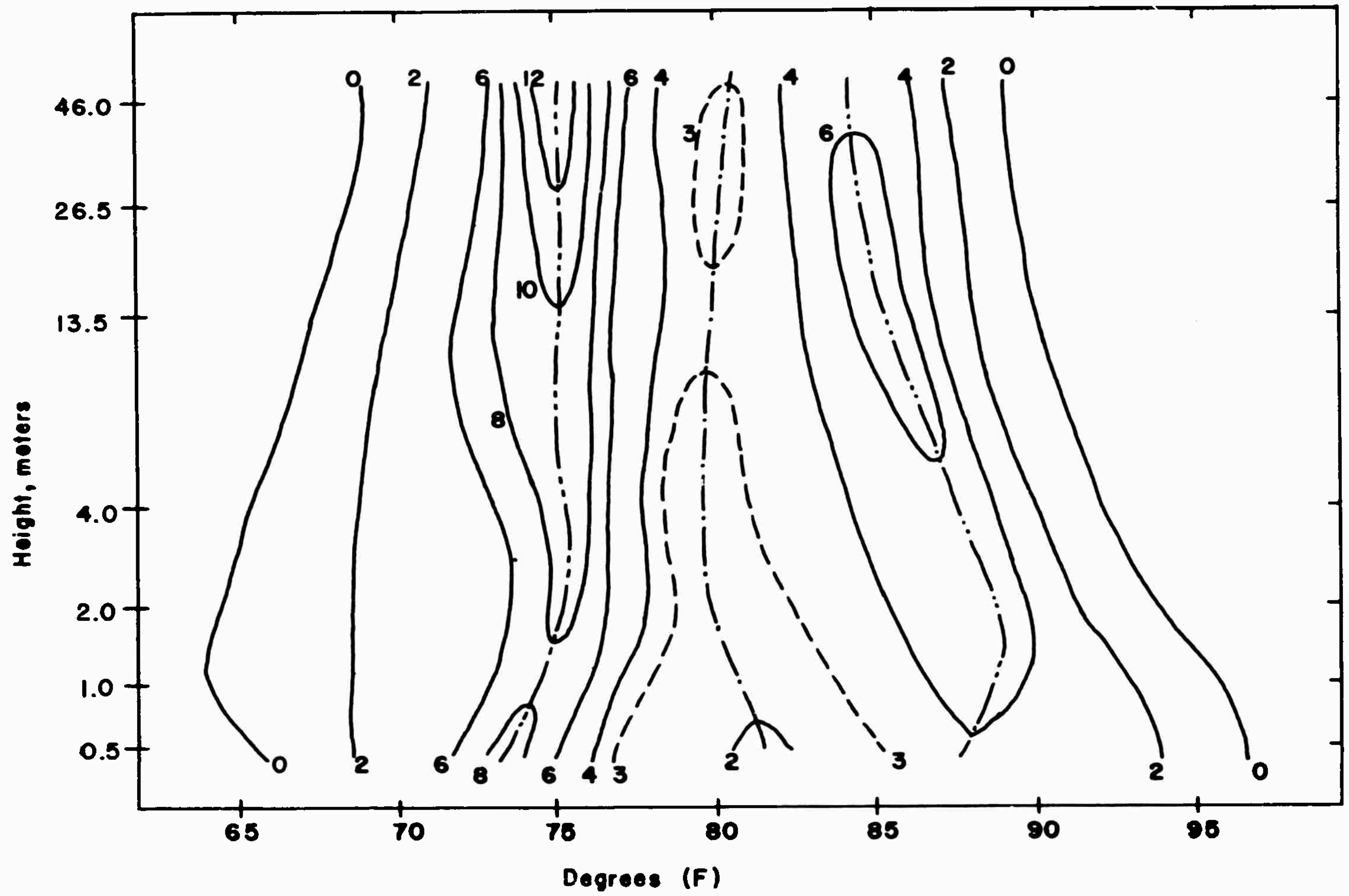


FIGURE IV-5. LINES OF EQUAL PERCENTAGE FREQUENCY DISTRIBUTION OF MARCH TEMPERATURES AS A FUNCTION OF HEIGHT.

(Frequencies refer to one-degree F intervals, slightly smoothed)

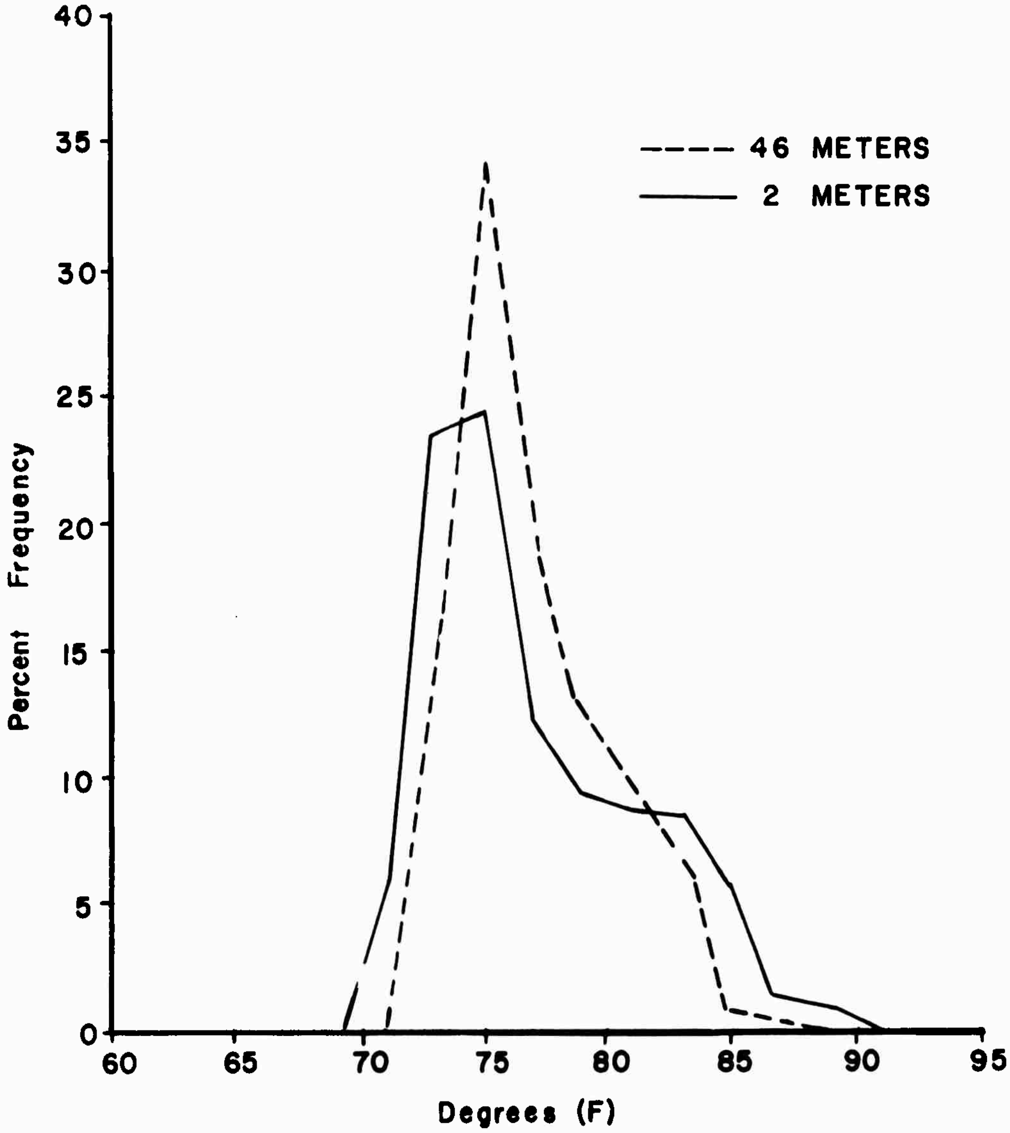


FIGURE IV-6. FREQUENCY DISTRIBUTION OF TEMPERATURE, CHIVA CHIVA OPEN SITE, OCTOBER 1966, RAINY SEASON

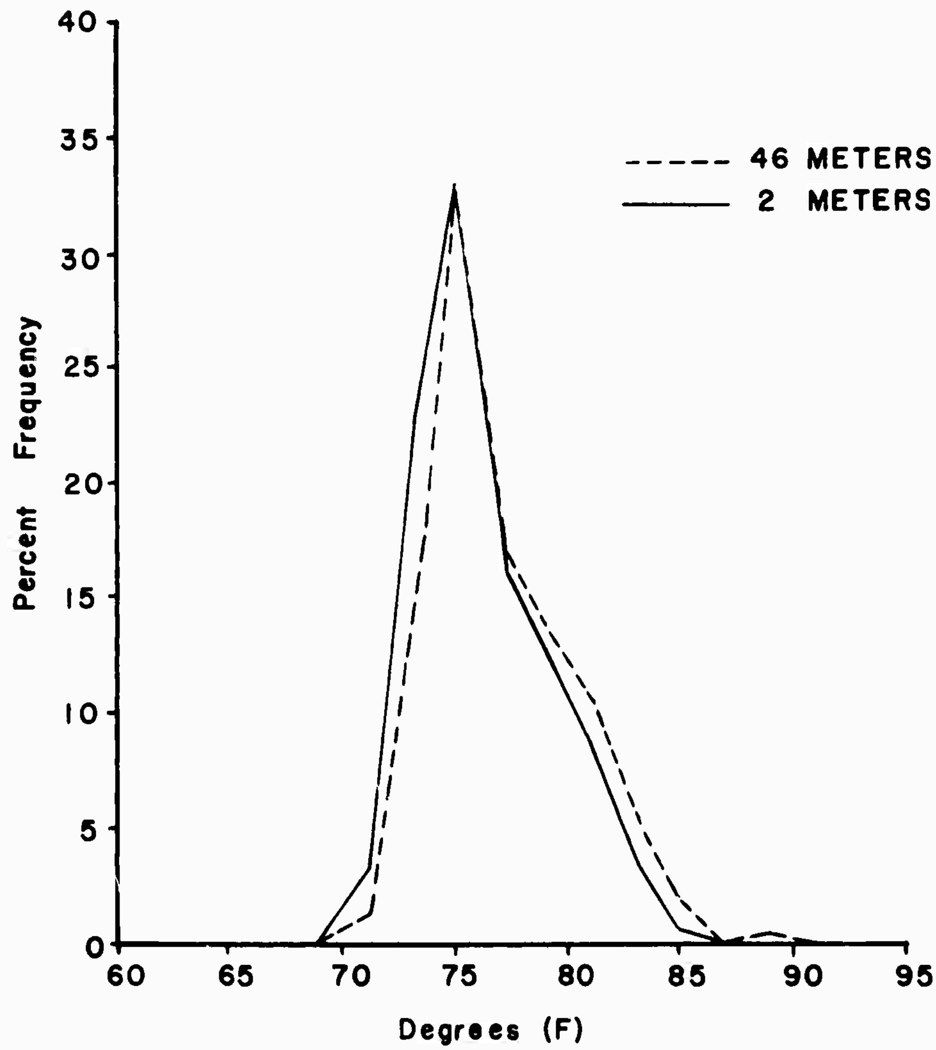


FIGURE IV-7. FREQUENCY DISTRIBUTION OF TEMPERATURE, ALBROOK FOREST, OCTOBER 1966, RAINY SEASON

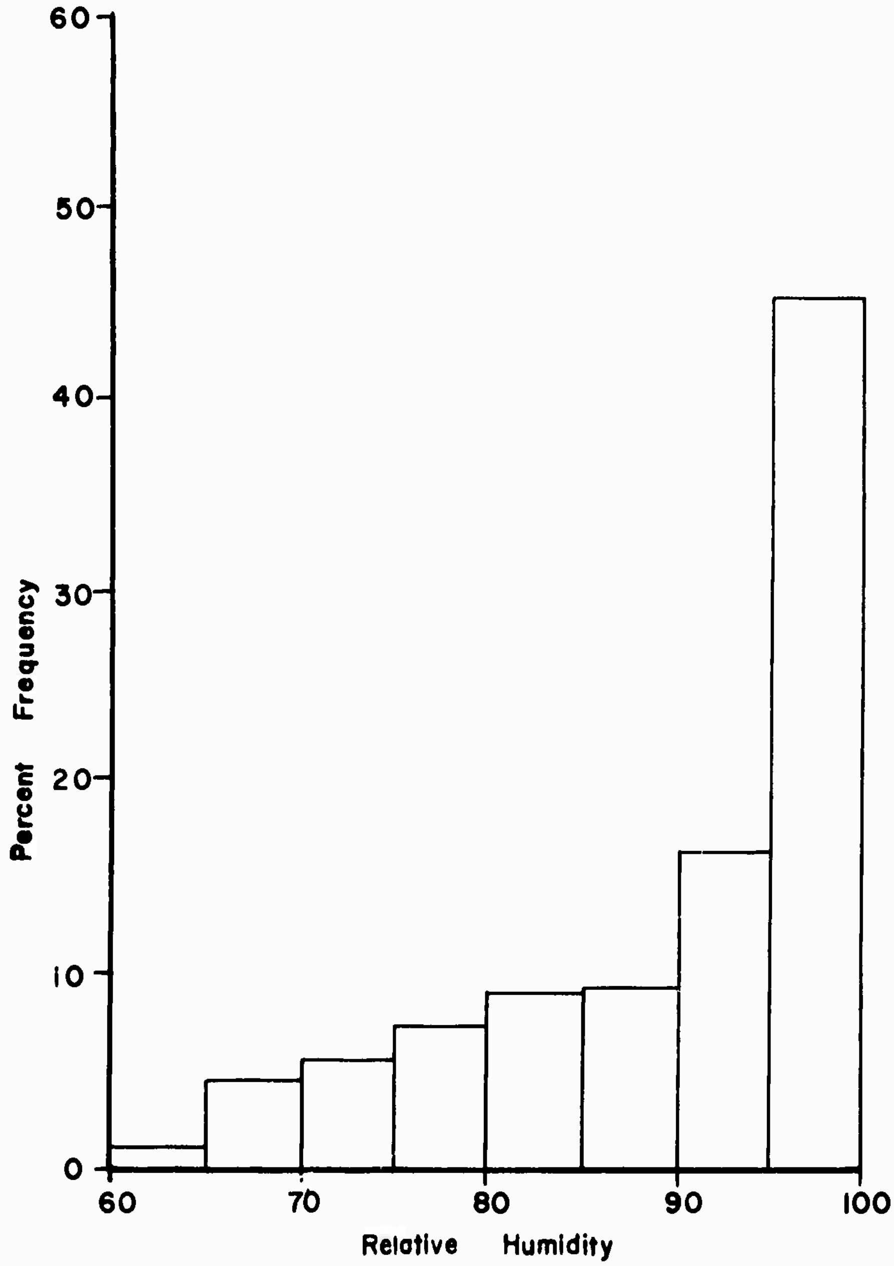


FIGURE IV-8. FREQUENCY DISTRIBUTION OF RELATIVE HUMIDITY, CHIVA CHIVA OPEN SITE, OCTOBER 1966, RAINY SEASON (2 Meters)

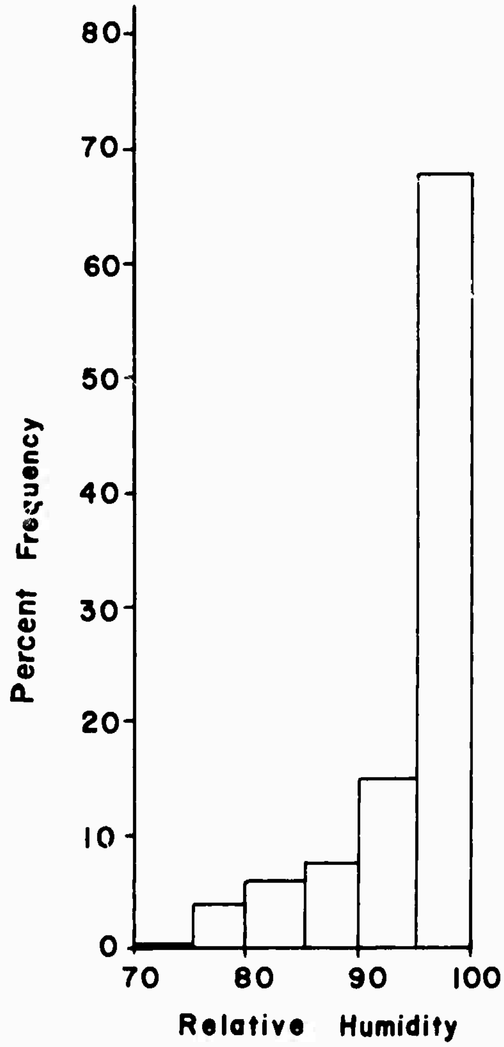


FIGURE IV-9. FREQUENCY DISTRIBUTION OF RELATIVE HUMIDITY, ALBROOK FOREST, OCTOBER 1966, RAINY SEASON (2 Meters) as might be expected.

Figure IV-1 shows, in addition to the discussed curves, the frequency distribution of the soil surface temperatures as measured with a stationary infrared thermometer (see third Semiannual Report, p. 46)[2], at Chiva Chiva. As Williams found at Yuma, Arizona[3], any temperature up to a certain value (150 F in this case) has the same chance to occur in the warmest part of the day, while the air temperature is characterized by a steady decline of probability of occurrence toward the extremes. The lowest soil surface temperatures are, of course, lower than any air temperature. The lower minimum temperatures and the higher maximum temperatures of the soil surface flatten the frequency curve, the maximum of which is 1 F lower than those of the air temperatures at 2 and 46 meters.

This displacement raises the question of how the frequency distribution of the temperature may change with height. Figure IV-5 displays lines of equal percentage frequency as a function of temperature and height, for Chiva Chiva, March 1967. (The values for the soil surface have been omitted because they would have spread the figure too much). The vertical scale of Figure IV-5 is logarithmic, as in similar figures in previous reports.

Figure IV-5 shows that the absolute extremes as well as the two frequency maxima approach each other with increasing height. There is no way to determine at what height the two maxima will merge, but there is reason to believe that this will not occur below the lowest cloud level. Details of Figure IV-5 , especially at the two lowest levels, cannot yet be explained; and no conjecture should be made before data covering a longer time span have been analyzed in the same manner.

Data for the rainy season (Figures IV-6 to -9) exhibit only one frequency maximum for both temperature as well as relative humidity. The frequency curves for temperature show a decrease of slope just where a second maximum might be expected (esp. in Figure IV-6). Actually such a second maximum does exist on days without rain, but the rainy days predominate, and they are characterized by a sharp drop in temperature when the rain begins (which occurs at irregular hours).

The frequency distributions of the relative humidity show one big maximum for the 96-100% interval which comprises 68 percent of all hourly observations at the 2-meter level in the forest. It is regretted that the observations of the relative humidity at higher levels were not good enough for preparation of frequency distributions. Due to the higher quality of recently collected data this subject will be developed in forthcoming reports.

PART V. SOILS AND HYDROLOGY

General

The soils and hydrology task of the Data Base project has embraced several interrelated data collection phases, each bearing directly on the general problem of soil trafficability. This relationship to the strictly engineering aspects of pedalogic study derives from earlier work performed by personnel from the Army Engineers Waterways Experiment Station (WES) in the Canal Zone, and the operational techniques followed have been those introduced by WES. No attempt has been made to develop any areal stratification of soil types or their correlation to hydrologic elements of the environments of the Canal Zone.

The types of data collected and the procedures used have been described in some detail in the previous semiannual reports for the Project[1,2]. The data collection has been largely completed for the two main sites (Albrook and Chiva Chiva) and for the three original satellite sites. Data obtained from these sites have been summarized and have been subjected to some analytical study in the reports referenced above.

Shortly before the conclusion of the current reporting period (in August 1967) a new soil satellite site was established at Fort Kobbe near one of the earlier sites (for location and description, see Figures II-1 and II-9 and p.11 , above). This site, subdivided into three separate plots, was located on a slope profile in order to determine the effects of varying topographic position on the measured soils parameters. Two plots, designated A and B. are positioned on pronounced slopes, under a low, sparse forest. The third plot, C, is on flat land a few meters above sea level. It is covered with dense, tall grass and, during the rainy season, is generally inundated with (fresh) water. This flooded condition precludes a full schedule of sampling during most of the year. Raingages and waterwells with automatic recorders are maintained at the sample plots, and soil sampling is carried out at least once each week to determine shear strength, moisture content, and density variations.

Data

No further analysis of the data taken from the previous sites is presented at this time, since a staff vacancy in the soils science field has severely curtailed Research Division capability in that area. A summarization of data collected from the three plots of the new site (and extending beyond the report period) is given in Tables V-1, -2, and -3. These data will be completed and analyzed in future reports.

In view of the near completion of the current phase of data collection it is anticipated that the future line of research on the soils and hydrology task of the Data Base project will be modified to some extent.

TABLE V-1. MOISTURE - STRENGTH, DENSITY SUMMARY,
FORT KOBBE SATELLITE SITE 2, PLOT A (UPPER SLOPE)

Date	Cone Index			Remolding Index	Rating Cone Index (average)	Soil Moisture Percent Dry Weight			Dry Density (pounds per cu.ft.)		
	0-6"	6"-12"	12"-18"	6"-12"	6"-12"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"
1 Aug 67	71	150	351	1.08	161	28.2	26.6	30.9	84.7	86.1	78.2
8 Aug 67	114	170	282	-	-	25.3	25.0	29.7	81.2	92.3	84.5
16 Aug 67	93	173	308	-	-	28.4	26.9	30.6	82.7	89.1	87.9
22 Aug 67	70	155	333	0.97	150	29.2	25.8	33.1	84.4	92.5	85.5
29 Aug 67	146		419	1.24	103	24.4	24.1	27.8	84.7	86.2	-
5 Sep 67	87	160	309	1.11	179	26.8	24.9	29.3	84.8	91.3	-
6 Sep 67	121	138	146	0.83	116	24.7	27.9	31.4	88.0	88.9	88.9
12 Sep 67	68	115	266	0.99	122	27.2	26.8	31.7	87.4	91.8	95.2
20 Sep 67	77	184	362	1.02	185	28.8	28.5	32.2	83.7	87.5	91.9
26 Sep 67	158	281	382	0.89	251	23.5	23.4	26.5	85.3	88.7	97.6
3 Oct 67	120	227	367	1.01	219	26.3	23.7	29.0	87.5	92.6	90.2
10 Oct 67	51	124	311	2.67	300	29.7	39.0	28.4	79.7	90.2	84.3
11 Oct 67	85	144	208	0.69	203	30.1	31.4	35.4	82.9	82.0	82.6
17 Oct 67	176	280	362	-	-	22.4	25.3	28.4	84.0	85.5	90.1
24 Oct 67	157	280	412	1.06	294	22.8	21.4	24.0	76.9	92.0	94.0
31 Oct 67	67	125	272	0.95	113	28.6	25.9	30.3	83.7	90.6	84.7
1 Nov 67	66	103	159	-	-	25.6	28.4	32.8	90.3	92.3	92.5
7 Nov 67	82	183	398	0.92	447	29.9	26.5	29.6	83.6	-	-
14 Nov 67	65	165	348	0.98	159	31.1	29.6	40.6	86.6	91.0	75.5
21 Nov 67	103	198	308	1.02	113	27.4	23.2	26.0	82.9	93.7	93.2
29 Nov 67	72	121	321	1.01	120	30.1	26.4	28.0	83.1	92.3	92.9
5 Dec 67	104	217	336	0.92	177	28.3	25.8	30.4	87.3	90.9	86.1
12 Dec 67	57	125	266	1.01	129	30.5	30.5	40.5	88.0	85.5	74.2
19 Dec 67	119	227	357	-	-	28.4	27.9	33.0	82.1	92.0	86.3
26 Dec 67	97	159	229	0.91	153	27.6	26.2	27.7	83.9	94.9	92.1
3 Jan 68	152	296	518	-	-	25.8	25.2	29.0	83.9	89.5	-
9 Jan 68	264	378	458	-	-	21.4	22.4	23.2	81.3	88.6	83.0
17 Jan 68	404	634	666	-	-	17.0	18.8	24.7	83.4	-	-
23 Jan 68	472	700	750	-	-	16.4	20.2	22.7	-	-	-
30 Jan 68	421	724	750	-	-	15.8	17.7	19.2	-	-	-

TABLE V-2. MOISTURE - STRENGTH, DENSITY SUMMARY, FORT KOBBE SATELLITE SITE 2, PLOT B (MIDDLE SLOPE)

Date	Cone Index			Remolding Index	Rating Cone Index (average)	Soil Moisture Percent Dry Weight			Dry Density (pounds per cu.ft.)		
	0-6"	6"-12"	12"-18"	6"-12"	6"-12"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"
9 Aug 67	64	99	132	-	-	30.1	29.5	29.9	85.3	90.7	88.1
16 Aug 67	72	94	143	-	-	29.7	31.6	32.9	83.1	83.7	86.3
17 Aug 67	42	38	40	-	-	40.6	44.1	52.4	70.9	74.2	69.1
21 Aug 67	89	119	161	-	-	29.0	30.7	30.0	88.0	84.3	85.6
23 Aug 67	116	159	209	1.32	207	28.5	30.0	32.8	86.1	86.6	81.7
30 Aug 67	230	300	360	0.94	280	19.1	21.4	27.4	84.3	91.6	87.1
7 Sep 67	35	31	22	-	-	37.9	49.7	55.5	78.0	68.4	66.4
13 Sep 67	61	145	245	0.98	377	31.7	31.3	32.7	80.4	81.0	81.8
21 Sep 67	80	137	253	1.03	140	28.0	29.5	30.6	83.0	80.0	69.9
27 Sep 67	192	281	299	-	-	21.0	22.4	24.8	78.3	82.7	-
4 Oct 67	109	222	228	-	-	32.1	29.6	31.6	78.4	86.2	-
18 Oct 67	236	262	223	-	-	19.5	24.1	31.0	86.8	89.0	84.3
25 Oct 67	297	439	388	-	-	20.6	22.0	26.5	80.7	84.2	88.1
8 Nov 67	75	135	155	-	-	29.8	30.3	36.1	86.8	86.1	80.8
15 Nov 67	84	126	157	1.49	194	31.9	32.2	31.4	82.9	85.0	84.3
30 Nov 67	61	116	148	1.08	127	31.6	30.5	32.3	85.1	86.1	85.1
6 Dec 67	63	122	203	0.99	144	29.8	32.3	33.4	85.1	85.0	83.7
13 Dec 67	55	99	223	0.80	82	33.3	30.9	30.3	82.2	87.0	85.1
20 Dec 67	63	105	149	0.92	95	29.3	29.2	31.3	84.4	90.2	90.4
27 Dec 67	105	142	178	0.98	140	27.7	31.6	33.5	86.6	81.1	80.4
4 Jan 68	148	165	178	-	-	25.7	28.8	32.1	80.4	82.5	82.9
10 Jan 68	289	378	390	-	-	19.0	23.9	26.4	80.8	79.0	83.2
18 Jan 68	405+	589+	619+	-	-	19.5	23.5	26.8	-	-	-

TABLE V-3. MOISTURE - STRENGTH, DENSITY SUMMARY, FORT KOBBE SATELLITE SITE 2, PLOT C (LOWER FLAT)

Date	Cone Index			Remolding Index	Rating Cone Index (average)	Soil Moisture Percent Dry Weight			Dry Density (pounds per cu.ft.)		
	0-6"	6"-12"	12"-18"	6"-12"	6"-12"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"
5 Aug 67	55	69	57	-	-	33.3	39.1	49.9	77.9	77.2	72.4
24 Aug 67	53	55	32	-	-	36.8	46.5	51.1	77.2	71.2	65.1
1 Sep 67	33	26	25	-	-	43.9	53.2	51.4	74.0	66.3	68.7
8 Sep 67	16	12	11	-	-	-	-	-	-	-	-
22 Sep 67	41	41	23	-	-	37.7	50.3	55.7	76.7	71.7	68.5
5 Oct 67	36	29	23	-	-	38.9	48.0	56.3	75.3	71.5	64.9
12 Oct 67	37	34	30	-	-	46.5	55.8	64.5	69.6	68.1	73.5
27 Oct 67	9	11	10	-	-	-	-	-	-	-	-
11 Jan 68	40	37	30	-	-	43.5	40.7	51.1	70.3	76.4	70.1
25 Jan 68	58	39	35	-	-	37.7	48.4	52.0	77.2	72.3	77.3
16 Feb 68	43.9	35.3	26.7	0.53	19.2	50.3	63.4	60.6	-	-	-
21 Feb 68	38	28	21	0.85	24.0	44.7	59.0	55.2	72.1	-	-
28 Feb 68	34	22	18	1.59	34.9	41.1	55.6	59.6	74.1	-	-
6 Mar 68	48	38	35	1.12	41.9	39.6	48.4	59.6	75.2	-	-
20 Mar 68	60.3	63.9	57.8	1.70	108.6	36.5	40.1	48.4	78.8	73.7	-
22 Mar 68	57.2	52.8	51.6	1.11	58.6	37.3	40.1	57.3	78.3	75.4	-
27 Mar 68	58.4	46.6	33.3	1.25	58.3	39.2	45.6	54.2	76.1	74.4	-
29 Mar 68	64.0	53.0	32.5	1.31	82.3	39.3	43.9	52.3	75.3	73.9	-

PART VI. VEGETATION*

Floristic Characteristics of the Albrook Forest Research Site

Introduction

Previous semiannual Data Base reports[1,2] have contained descriptions of the vegetation at the Albrook forest site in the form of vegetation inventories of a 3,600-square-meter gridded area. The descriptions were mainly concerned with locating, identifying, and measuring the vegetative components in the area. This paper contains information gathered from several sources which will allow some specific statements to be made about the floristic characteristics of this forest site.

Background and Discussion

In 1903, Schimper[4] suggested a division of lowland tropical "climatic formations" into four types: rain forest, monsoon forest or seasonal deciduous forest, savanna forest, and thorn forest. He defined the monsoon forest as "more or less leafless during the dry season, especially towards its termination, is tropophilous in character, usually less lofty than the rain forest, rich in woody lianes, rich in herbaceous, but poor in woody epiphytes." The Albrook forest site demonstrates several vegetative characteristics which conform with Schimper's definition of a monsoon forest.

The upper layer of the forest canopy extends to 28 meters. The principal species in this layer are deciduous trees which drop a significant amount of their foliage at the beginning of the dry season and renew their leaves at the advent of the rainy season. Some species represented here do not lose their foliage when more than normal rain falls during the dry season, and not all deciduous species lose their leaves at the same time. Nevertheless, the increase of leaf litter on the forest floor (Figure VI-1) and the appearance of denuded trees such as Cavanillesia platanifolia (Humb & Bonpl.) HBK (Bombacaceae) during the dry season emphasize the deciduous nature of the forest. Other species in the upper stratum which can be considered deciduous are: Guazuma ulmifolia Lam., (Sterculiaceae), Luehea seemanii Triana & Planch. Tiliaceae), Spondias mombin L. (Anacardiaceae), Tabebuia pentaphylla (L) Hemsl. (Bignoniaceae), Lafoensia punicifolia DC (Lythraceae), and Trichospermum mexicanum (DC.) Baill (Tiliaceae). Evergreen species that also occur in the upper layer are: Phoebe (Lauraceae), Ficus (Moraceae), and Anacardium excelsum (Bert. & Balbis) Skeels (Anacardiaceae). A few individuals of Cecropia are found in the upper canopy. Trees of this genus lose their leaves only if the dry season is a prolonged one. (Figures VI-1 to -4). Approximately 55% of the canopy species are deciduous in nature.

* This section has been prepared by Miss Mireya D. Correa, Botanist, Dr. Thomas C. Crebbs, Jr., Biologist, and Dr. Robert S. Hutton, Biological Scientist

FIGURE VI-1. ALBROOK FOREST LITTER DURING THE DRY SEASON (APRIL).

FIGURE VI-2. "EDGE" FOREST WITH SEVERAL CECROPIAS. THESE BARE-LIMBED INDIVIDUALS HAVE LOST MOST OF THEIR LEAVES (APRIL).

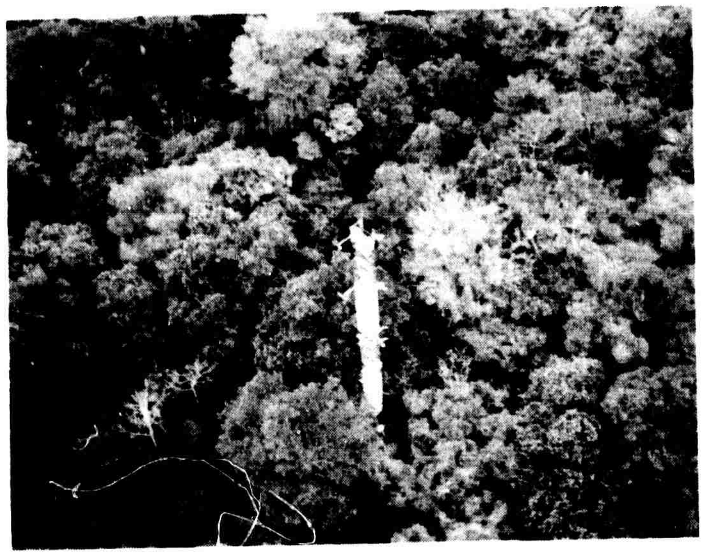


FIGURE VI-3. ALBROOK FOREST SITE (FROM 120 M, ABOVE CANOPY). BARE TREES TO LEFT ARE CECROPIA. TOWER IS 46 METERS IN HEIGHT (APRIL).

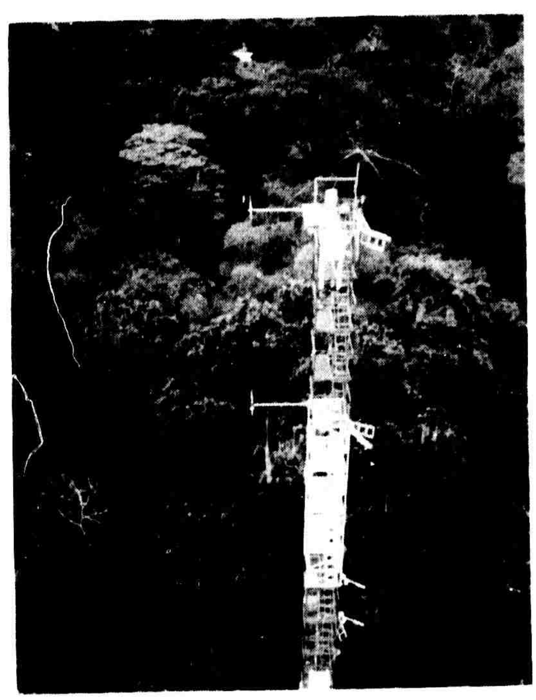


FIGURE VI-4. ALBROOK FOREST SITE (FROM 35 M ABOVE CANOPY). LARGE TREE BEHIND TOWER IS ANACARDIUM EXCELSUM. CECROPIA SHOWS BARE LIMBS AT LEFT (APRIL).

The second stratum also shows mixed evergreen and deciduous components. The taller trees in this layer are deciduous trees of Luehea, Spondias, Guazuma, and Trichospermum, which are younger representatives of species present in the upper layer. Other deciduous species in this level are Andira inermis H.B.K. (Fabaceae) Annona purpurea Moc, & Sessi (Annonaceae), and Bursera simaruba Sarg. (Burseraceae). This level, extending to approximately 20 meters, has a component of evergreen species belonging to the genera Inga, Phoebe, and Anacardium. Annona hyeccii Suff., an evergreen member of the annonaceae, also occurs in this level. Woody lianes form a conspicuous part of the vegetation at this level, as seen in Figure VI-5. Few epiphytes are present, and those few are principally herbaceous.

Understory vegetation rarely exceeds 10 meters in height and, though not as open as a temperate deciduous forest, can be quite easily passed through on foot. A minor component of the understory is made up of seedling trees belonging to overstory species. The major component of the understory is composed of shrubs belonging to the Rubiaceae and the Melastomaceae. The family Rubiaceae is represented by species from the genera Psychotria, Alibertia, Posoqueria, Palicourea, and Randia; Melastomaceae by Conostegia, Heterotrichon, and Miconia. Other understory shrubs are: Hirtella (Rosaceae), Nectandra (Lauraceae), and Croton (Euphorbiaceae).

Palms are represented by small clumps of the armed palm Bactris (could be Astrocaryum) and young plants belonging to the genus Scheelea. The ground layer has sparse grasses, seedling trees, and ferns of the genus Adiatum (Figure VI-6). Vines such as Passiflora and the climbing bamboo, probably Arthrostylidium, are quite common.

Difficulties often arise when describing tropical forests in terminology which is more often used to describe temperate forests. For example, the terms "deciduous" and "evergreen" connote an all-or-none situation in the temperate North American forest, but cannot be used in the same way in the humid tropics. Williams[5], faced with the same problem in describing forests in Southeast Asia, defined deciduous forests "as those in which some or all the trees shed their leaves, either entirely or in part, and usually during some period of the dry season". The individual trees in such a forest may lose all their leaves, may lose some of their leaves, may produce new foliage and then lose their leaves thus preserving an evergreen appearance, yet properly be termed deciduous. The aspect of the forest is, on the whole, one of constant greenery, instead of the sudden transition to a leafless state characteristic of temperate zone deciduous forests. The critical point is that the aspect of such a forest type changes with season. The seasonal forest (monsoon forest) exhibits the effect of the changing seasons without a sudden and striking loss of foliage. Figure VI-7 shows the generally open aspect of the Albrook Forest at the culmination of the dry season.

If, as is the case at the Albrook Forest site, there is a mixture of both evergreen and deciduous species, the classification of the formation could logically be either semievergreen or semideciduous. To decide which

FIGURE VI-5. VIEW OF ALBROOK FOREST SHOWING WOODY LIANES (APRIL).

FIGURE VI-6. THE MOST COMMON GROUND COVER PLANT. GENUS ADIANTUM.

FIGURE VI-7. OPEN ASPECT OF ALBROOK FOREST SITE NEAR END OF DRY SEASON (APRIL). LARGE TREE ON TRAIL IS LAFOENSIA.

terminology to use, the authors searched the literature for descriptions of similar formations. Dr. J. S. Beard[6] has suggested that there are twenty-eight recognizable and discrete vegetational formations in tropical America. Based upon his descriptions, the Albrook Forest site is an example of a Semievergreen Seasonal Forest. The term, Semideciduous, has been used by several authors to describe a forest formation occuring in the Southeast Asian region. The description of such a forest type is not consistent with the floristics of the Albrook Forest site; in fact, the only terminology consistent with ecological literature is Semievergreen Seasonal Forest. It is interesting to compare this formation with the description given by Williams[5] of a Semievergreen forest in Thailand: "The trees are of medium stature, ranging from 15 to 20 m., although some emergent species may attain 30 m. Usually they have straight trunks, with a diameter of 30 to 60 cm. The majority of the trees shed their leaves at some period of the year, but in general this subtype has a Semievergreen appearance...Woody vines are abundant, but herbaceous ground cover is somewhat sparse." What is significant is that the majority of tree species making up this formation are deciduous, but the formation is evergreen in appearance, and is so designated.

If, by the foregoing description, the Albrook forest site can be regarded as a monsoon forest according to Schimper[4] a full description has not yet been made. Forests are never static, but pass through seral stages from some original time base when there was no forest. Secondary succession is a process by which natural processes create a more stable ecosystem from an unstable one. When lands are cleared and abandoned, or when they are burned, new vegetation soon appears. The nature of the vegetation changes until, over many years, it reaches the climax or stable form. Secondary forests can be distinguished more readily by floristics rather than by physiognomy. Cecropia is a tree which is typical of secondary succession in tropical America. In West Africa the most important tree indicative of secondary succession is in the genus Musanga (Urtieaceae). This genus is very close taxonomically and in appearance to the new world genus Cecropia. In Malaysia, Macaranga (Euphoribiaceae) is a genus of tree species characteristic of secondary growth. Richards[7] in a compilation of studies from tropical forests the world over, has indicated that it is extremely doubtful if any truly virgin forest remains in the Central American tropics. Many observers have noted that the forest at the Albrook site is a secondary forest, having developed from some form of disturbed land in recent time, but none have defined its age in terms of seral succession. There are studies however, that provide some clues for analysis of the expected successional pattern of Pacific slope flora in Panama. Principally, the work of Kenoyer[8] on Barro Colorado Island (1929), and of Johnston[9] on San Jose Island (1949), added to the notes on succession taken in the Canal Zone by Standley[10] in 1924, give a basis for comparison. The authors of this paper are not only familiar with Panamanian flora, but have visited the areas where both Kenoyer and Johnston worked. With these guidelines, the floristics of any given forest site can be compared to not only what plants occur there, but to what plants do not occur there that would be expected to occur during a given seral stage. An often-noted phenomenon in monsoon forests (see Richards[7]) is that the initial stages of succession are dominated by short-lived herbs. These succulent ephemerals rarely persist beyond the first growing season after land has been disturbed. Unlike succession in other parts of the world, the next propagules to become established are of tree species, or woody species which can and do reach tree size. These species tend to possess certain characteristics which, though not unique, form a unique set of standards for evaluation. For example, the following characteristics have been suggested as applicable to the woody species which first invade disturbed land in this area: 1) The species, or at least the seedlings, are extremely intolerant of shade. 2) They are rapid growing, in comparison with other endemic tree species. 3) The wood is very light, brittle, or both. 4) The species produces many seeds, or demonstrates a very efficient mechanism for seed dispersal. 5) They possess large leaves. 6) They possess light-colored leaves. (it is possible, though not suggested here, that tree species which occupy a climax position in monsoon forests demonstrate the opposite extreme of these characteristics.)

An examination of many disturbed areas on the Pacific slope of Panama, including several quite close to the Albrook site, has shown that even-aged stands of tree species do occur. These stands are often quite dense, even if composed of several species. Accordingly, nine genera which have been observed in early successional stages have been subjected to a check of the characteristics suggested above. The results are shown in Table VI-1. Most significant is the almost perfect fit of the genera Cecropia, Trema, Ochroma, Apeiba, and Cochlospermum to the assumed necessary characteristics for initial invading woody species. Species belonging to all of these genera are found, in large numbers, all along the roadside leading to the Albrook Forest site, occupying land that was disturbed during construction of various facilities. It is suggested, then, that these genera can be used as indicators of initial stages of succession by examining the position that they occupy in any surrounding forest type. By reference to the Vegetation Inventory, (see previous semiannual reports[1,2]) and to the foregoing description, the place of the indicator genera in the flora of the Albrook site can be examined:

1. Cecropia, though represented by numerous individuals, and by three species, is not represented except in the canopy and sub-canopy. It is not reproducing itself, as it does not occur below the 18-meter level. It may, in a short period of time, cease to be a significant part of the flora.

2. Trema: The single specimen present in 1965 is now dead. There are no known seedlings.

3. Ochroma is not represented.

4. Apeiba is not represented.

5. Cochlospermum is not represented.

TABLE VI-1. SELECTED CHARACTERISTICS OF CERTAIN GENERA OF WOODY PLANTS

C H A R A C T E R I S T I C S

Genus	Shade Intolerant	Rapid Growing	Light Wood	Produce Many Seeds	Large Leaves	Leaves Light-Colored
Cecropia	xx	xx	xx	xx	xx	xx
Trema	xx	xx	xx	xx	x	x
Ochroma	xx	xx	xx	xx	xx	x
Apeiba	x	xx	xx	xx	x	x
Cochlospermum	xx	xx	xx	xx	xx	xx
Cordia	x	x	x	x	x	0
Annona	x	x	xx	x	x	0
Spondias	x	xx	xx	xx	0	0
Byrsonima	x	x	0	xx	x	0

KEY: xx = characteristic markedly manifest.
x = characteristic shown.
0 = characteristic not shown, or not in all species.

On San Jose Island, where all of the above genera are represented, and where collections were made in 1967 on areas known to have been disturbed in 1944, all five genera were found to contribute significantly to the flora. The site at Albrook, therefore, must have been forested for at least the last 23 years.

More assumptions must be made to arrive at an upper limit for the age of Albrook forest. These assumptions must be made on the vegetation that presently occurs there. Kenoyer[8], after listing Trema, Cecropia, Luehea, and Ochroma as early invaders, states that these persist "in large proportion....in the older pioneer forest, fifteen to fifty years after clearing." The key indicator genus here is Luehea, which is still well represented at the Albrook site. Seeds of Luehea are produced abundantly. In 1966 some seeds were produced each month of the year with peaks of seed drop occurring in February and June. In the rainy season seeds of Luehea germinated readily but did not live more than a few days. Seed removed from the forest and placed in trays germinated readily, and there was little if any seedling death in a ten-week period of observation (personal observation). This indicates that, while viable seeds are still being produced, they are not able to survive at this stage. This, plus the fact that Cecropia is going out, Trema has disappeared, and Ochroma never occurred, indicates that Albrook site is past the stage that Kenoyer was describing.

To proceed further, Standley[10] has stated that palms of the genera described herein as being common at the Albrook site are found largely under the shade of the forest canopy. Not only is this the case, but the shade intolerant Carludovica (Cyclanthaceae) and Heliconia (Musaceae) which are common elements of the younger forest nearby (Figures VI-8 and -9) are represented by remnants only at Albrook site proper.

Lastly, some consideration should be given to the established tree species which are known to develop into dominants in a typical monsoon forest. These are: Anacardium excelsum, Chrysophyllum cainito L., Ficus aff. hemsleyana Standl., and Cavanillesia platanifolia. The last named species has been described by Pittier[11] as "the typical, ever prominent tree of the monsoon-forest of Darien and the eastern Pacific coast". The presence of this species, especially of a large size, (Figure VI-10) indicates that the succession is well along toward the establishment of a climax forest at Albrook site. Estimates of from one to several centuries are given in Richards[7] as the time necessary for a monsoon forest to become re-established, assuming that radical changes in climate and in soil conditions do not occur. If the Albrook site has not been cleared or disturbed during the predicted time span, which would impart another regression in successional stage, it must have been forested for at least 60 years, but not more than 100 years.

FIGURE VI-8. REMNANT OF GENUS CARLUDOVICA AT ALBROOK FOREST SITE (APRIL).

FIGURE VI-9. _HELICONIA_ STAND IN CLEARED LAND NEAR ALBROOK FOREST SITE (APRIL).

FIGURE VI-10. REPRESENTATIVE OF DECIDUOUS _CAVANILLESIA PLATANIFOLIA_ AT ALBROOK FOREST SITE (APRIL).

Summary and Conclusions

1. From the floristic description given of the vegetation on the Albrook Forest site, it is determined that this vegetation may be designated as a "Semievergreen Seasonal Forest."

2. From the generic composition of the site, as well as nearby areas, this site supports, at the present time, a secondary stage in monsoon forest succession.

3. From perusal of the available literature on forest succession in the humid tropics, there is sufficient evidence to determine that the vegetation on the Albrook Forest site must be at least 60 years old, and perhaps as much as 100 years of age.

4. There is sufficient data to determine that this forest is rapidly becoming a true climax forest.

PART VII. MICROBIOLOGY AND CHEMISTRY OF ATMOSPHERE

The Concentration of Carbon Dioxide in the Tropical Atmosphere*

Introduction and Background

This is a report of carbon dioxide (CO_2) content of atmosphere at two sites in the Canal Zone, one in a cleared area near the Miraflores Annex, and the other in the Albrook Forest site. The observations contribute to the atmospheric chemicals subtask carried out as a part of Tropic Test Center's efforts to define the environment within which its testing activities are conducted. Carbon dioxide dissolved in water is a mild acid and this fact may, particularly when high relative humidity is the rule, be an important co-factor acting with other environmental phenomena to bring about accelerated deterioration and degradation of materials and military materiel. The experiments reported here were included as a part of the work done in the Data Base Project for two reasons: 1) to determine whether or not a direct relationship exists between atmospheric CO_2 level and the deteriorative and degradative processes known to be active in the tropical environment, and 2) to respond to what appears to be a world-wide interest in the subject on the part of scientists in many disciplines.

Because we do not know precisely how the observations are to be related to practical problems we elected to review what other workers have observed about atmospheric carbon dioxide. A brief review of the product of a search through existing reports is included below as background material.

The average concentration of CO_2 in the free atmosphere (approximately 0.03% by volume or 300 ppm) appears to be sub-optimal for the photosynthetic activity of green plants. Since seedling and tree growth may be directly influenced by variations in this component of the environment, the distribution of this gas within the forest is of interest (Wiant,1966)

Inasmuch as the process of photosynthesis is basic to life as we know it, and since carbon dioxide is an essential ingredient for this process, the macrocycle of carbon dioxide in the world is of interest. Also, it is of value to compare the macrocycle of carbon dioxide in the world with the microcycle of this gas within a forest.

The average concentration of carbon dioxide in the free atmosphere represents a balance between that used in photosynthesis, that removed from circulation by the formation of new coal beds and other organic deposits, and that released by decay of organic materials, respiration of plants and animals, and the activity of hot springs and volcanoes. Sudden changes in the amount of atmospheric carbon dioxide are buffered to an undetermined

---

* This section has been prepared by Mr. Alfredo Gonzalez, Chemist, and Dr. Robert S. Hutton, Biological Scientist.

extent by the absorption and release of this gas by the seas (Fonselius et al, 1955), which are the major reservoirs of the supplies of carbon dioxide in the world.

There is a relatively large quantity of carbon dioxide added to the atmosphere by the combustion product of our industrial age. It has long been debated whether the increase of carbon dioxide might induce a gradual warming of the climate of the earth due to the ability of this gas to selectively absorb long-wave radiation.

Perhaps the most important part to be emphasized is that the carbon dioxide released by decay and respiration of plants and animals balances that used by photosynthesis. If this were not, photosynthesis would have ceased long ago (Voigt, 1962). However, it will be found that this annual equilibrium may not be maintained in the microcycle of carbon dioxide in a specific forest ecosystem.

Within a forest, the microcycle of carbon dioxide, from the time of its incorporation into an organic compound by photosynthesis to its release back into the atmosphere, involves complex and diverse routes. The product of photosynthesis can be fractured to liberate carbon dioxide through the decomposition of organic matter in the soil, or through the respiration of roots and associated microorganisms and above-ground plant tissues.

Most of the carbon dioxide used in photosynthesis by a forest tree is taken into the leaves from the surrounding atmosphere, although an undetermined amount, variously estimated as 8 to 20 percent of the total utilized, comes through the roots and moves up with the transpiration stream.

Carbon dioxide concentration is usually high in soils, with values reported ranging from 0.03 to 13 percent by volume. (Voigt, 1962). Much of the carbon dioxide in the soil is the product of the decay of organic matter, although there is some indication that root respiration may contribute more than has usually been suspected. This gas diffuses out of the soil and into the relatively calm air found under forest stands, often increasing the concentration of carbon dioxide within a few centimeters of the soil by 50 ppm or more above ambient atmosphere.

An important distinction should be made between the world-wide macrocycle of carbon dioxide, where the carbon dioxide released by decay and respiration of plants and animals balances that used in photosynthesis, and the microcycle of carbon dioxide in a small area, where this equilibrium may not be maintained for a given year, specially if such large perennial plants as trees are involved. Large quantities of carbon may be tied up for long periods of time in the wood of a young, rapidly growing forest. Eventually, however, this carbon too, will be returned to the cycle.

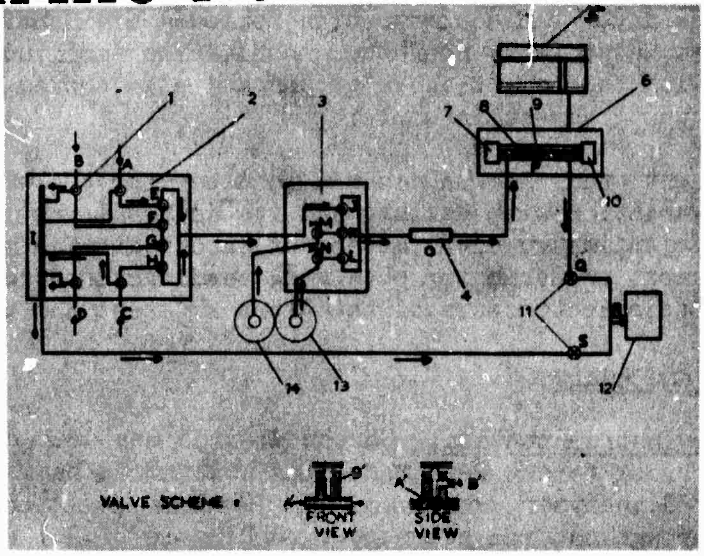
Previous work in temperate zone forests has shown that the carbon dioxide concentration varies from 300 to 400 ppm at a single level above ground during the day. The concentration followed a diurnal pattern, increasing at night, especially near the ground. The amplitude of the variation decreased with the height above ground and also showed a seasonal variation which was greatest in winter.

In the present study it was desired to determine the amplitude of the variation, its variation with height, and its seasonal variation for the tropical forest. An instrumental method of carbon dioxide measurements was found to be the most suitable for obtaining readings on a continuous basis. The sampling sites selected were at the Albrook forest and the Miraflores Annex area.

Data Collection and Analysis

Sample Site Instrumentation. Carbon dioxide measurements under the canopy at the Albrook forest were made on a continuous basis using a Beckman IR215 Infrared analyzer coupled with a Beckman potentiometric recorder. Air was drawn through natural gum rubber tubbing ($\frac{1}{4}$" I.D.) with a Gelman Little Giant Pump at a flow rate of 1.2 liters/min. The same system was used at the Miraflores sampling site. The instrument layout (Figure VII-1) consisted of a voltage regulator (not shown), infrared analyzer, potentiometric recorder, flowmeters, particulate filter tube (glass wool), nitrogen and CO_2 standard cylinders with regulators, pump, and sampling and calibration control panels. The complete analyzer section was housed on a metal box equipped with silica gel dehydrating bags, and a re-circulating fan to avoid heat gradients and maintain the temperature inside the box between 90-95 F (the limit operating of the I. R. detector is 105 F). This metal box rested on a smaller wooden box which contained the voltage regulator and the pump. The infrared analyzer was calibrated twice a day depending on the drift registered in the previous calibrations. A log was kept of the gain and detector-oscillator tuning output to give an indication of the sensitivity of the instrument and cell performance.

Instrument Calibration. Calibration was performed with two gases. Nitrogen (N_2) was used to set the zero end point of the detector, and a carbon dioxide secondary standard was used to set the gain of the instrument to obtain true upscale values. The carbon dioxide secondary standard was a mixture of CO_2 and N_2 prepared in the laboratory with a ppm-by-volume content of 400-500. It was made by delivering, under pressure, a few liters of CO_2 into a gas cylinder and diluting with nitrogen until the ppm by-volume-content of CO_2 was close to the operating value. The secondary standard was then analyzed for its exact CO_2 concentration in ppm using the infrared analyzer already calibrated with a factory analyzed primary standard. This method was adopted because of the high cost of factory analyzed standard and the vast amounts needed for continuous operation of the instrument. Figure VII-2 shows the calibration curve used for converting infrared recorder units into corresponding values in ppm of CO_2.



1. Sampling Valve
2. Sampling Control Panel
3. Calibration Control Panel
4. Filter tube (glass wool)
5. Potentiometric recorder
6. Infrared analyzer
7. Detector housing
8. Reference cell
9. Sampling cell
10. I.R. Source
11. Flowmeters
12. Pump
13. CO_2 Standard tank with regulator
14. Nitrogen tank with regulator

NOTE: All connecting lines are ¼" rubber or tygon tubing.

Valve Scheme: When the sampling valve is closed air flows through A' only.
When the sampling valve is open air flows through A' and B'.

FIGURE VII-1. INFRARED ANALYZER AND SAMPLING EQUIPMENT

GRAPHIC NOT REPRODUCIBLE

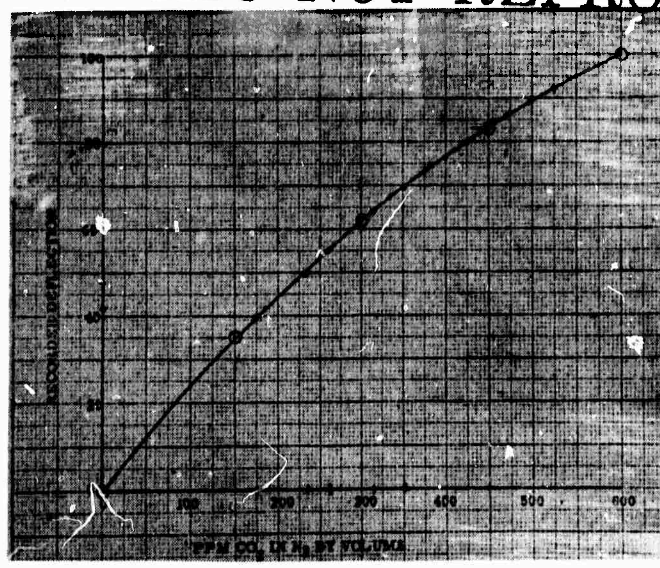


FIGURE VII-2. CALIBRATION CHART. PPM CO_2 IN N_2 BY VOLUME VS. RECORDER DEFLECTION UNITS

Sampling. The equipment is designed to sample at four different levels, without having to wait for equilibration when changing from one level to the other. This is achieved by a continuous flow of air through flowmeters Q and S (Diagram 1) so that when one port is used for sampling, the other sampling ports not in use have a similar air flow.

Carbon Dioxide Fluctuation. The measurements of carbon dioxide concentration taken at Miraflores during the first days of sampling varied widely particularly at the near ground sampling level. Before any valid data could be obtained, it was necessary to find out whether or not this fluctuation was real, or if it was caused by mechanical or electronic phenomena in the sampling system. The possible sources of error were: 1) Differences in the relative humidity of the air being sampled; 2) Sampling line length and valve positions; 3) Malfunction of the infrared analyzer detector.

Each possible source of error was checked carefully for possibility of occurrence*. Since they were conclusively eliminated, it was concluded that the indications are valid, and the fluctuations in CO_2 concentration at near-ground levels at the two sites are real.

Method of Data Analysis. With the exception of the Miraflores and Albrook all level data, which was recorded by hand (at 10 second intervals), the rest of the data was analyzed from the output of a Beckman potentiometric recorder coupled to the infrared analyzer. The recorder-chart speed was 15 cm per hour, and the 0.3-m readings showed well defined fluctuations as can be seen on Figure VII-3.

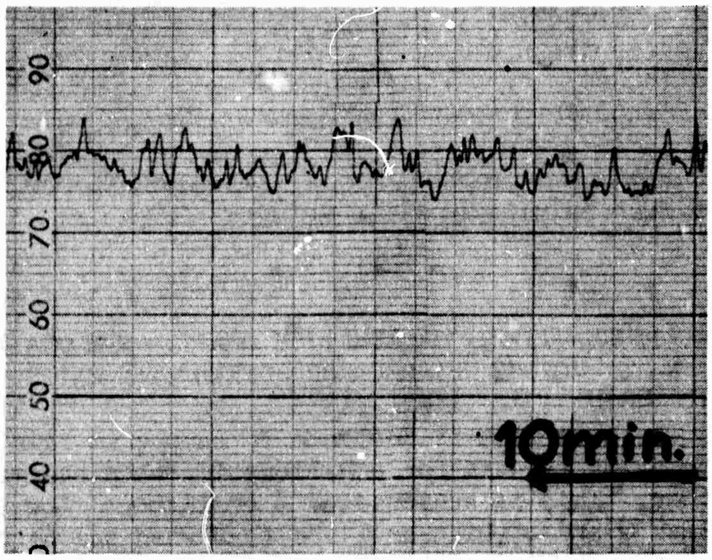


FIGURE VII-3. STRIP OF RECORDER CHART, SHOWING THE CARBON DIOXIDE FLUCTUATIONS

---

* To determine the effect that differences in the relative humidity of the sampled air had on the carbon dioxide fluctuations, the air was passed through a dessicant to absorb the moisture. This procedure had no effect on the readings, and the fluctuations still prevailed. The air being sampled was also bubbled through water to insure complete saturation; this also showed no effect on the readings. To determine the effect of sampling line length and valve positions on the fluctuations, the sampling tube was lengthened from one to fifty feet, and connected directly to the infrared analyzer without regulating valves. No change in fluctuations occurred. To determine if the fluctuations were caused by a detector malfunction the sampling air was passed through a mixing bottle and then into the analyzer. When this was done, all fluctuations disappeared.

The high CO_2 fluctuations occurring during certain hours of the day presented a problem for data tabulation and analysis. There were several variables to keep in mind: Frequency and magnitude of the fluctuations, and the average CO_2 concentration during the sampling time. After careful evaluation of the data, it was concluded that the best way to tabulate it was to analyze the data by the hour and to record the"average" CO_2 concentration, the highest and lowest fluctuations, and the frequency with which fluctuations appeared during this period. Definition and derivation of these terms are as follows:

1. The average CO_2 concentration is the one that would be obtained if the total air sampled during the hour were thoroughly mixed in a closed vessel and then analyzed for CO_2 content. To obtain this value from the data, a fine line is drawn across the chart paper so that the peak areas above and below it are approximately equivalent. In Figure VII-3 the value obtained is 78.5 recorder units or 415 ppm of CO_2 by volume.

2. The fluctuations representing the absolute maxima and minima may not be the most meaningful. To yield greater significance, the average values of the three highest and of the three lowest points, occurring during the sample period, are used as the highest and lowest fluctuation values.

3. The fluctuation frequency is defined as the percentage of time that changes in concentration occur during a sampling period. In Figure VII-2 this value is close to 100 percent.

The method of tabulation and data analysis described above is relatively crude. However, considering the existing variables and the time involved in calculating by a more precise method, it was the simplest, acceptably accurate, solution to the problem. An individual quickly learns to produce acceptably good analyses.

Results

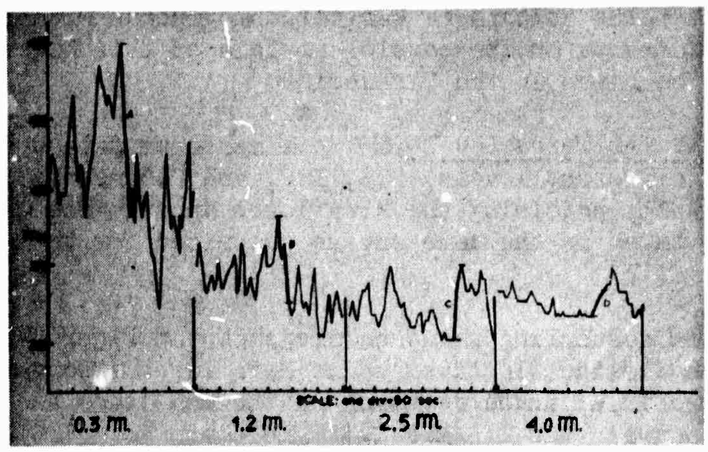
Albrook Data at Four Levels. The Albrook forest data were obtained by sampling at four different levels (0.3, 1.2, 2.5, and 4 meters) approximately 10 meters from the Albrook tower. This area was surrounded by high trees and contained a considerable amount of litter.

The carbon dioxide measurements were obtained by hand, recording every ten seconds, the meter readings in the infrared analyzer for a period of ten minutes at each level. After one sequence was completed, a second sequence was immediately started to compare results, and to verify that the indicated carbon dioxide fluctuations at the different levels were significant. This type of sequential sampling was done at different hours during the day and under different meteorological conditions. The results of a sampling sequence are shown in Table VII-1 and the curves of Figure VII-4. The curves demonstrate the marked decrease in the magnitude and frequency of CO_2 fluctuations from the lower to higher levels, as well as the decrease in the "average"carbon dioxide concentration.

TABLE VII-1. CARBON DIOXIDE MEASUREMENTS AT THE ALBROOK FOREST.
1030 to 1100, NOVEMBER 6, 1967

L E V E L S

0.3 m		1.2 m		2.5 m		4 m	
76.5	80.0	73.0	73.8	71.0	70.3	72.0	71.0
75.3	80.9	74.0	73.0	71.6	70.8	72.0	71.0
76.5	81.0	73.0	73.0	71.0	70.8	72.0	71.0
77.5	80.0	72.1	73.1	70.8	71.2	71.8	71.0
77.3	78.5	71.9	73.7	71.6	71.2	71.8	71.3
76.9	77.3	72.4	75.0	72.0	70.9	72.0	71.0
75.5	75.0	72.6	73.8	72.0	70.5	72.5	71.1
76.0	76.0	72.0	73.3	72.3	70.3	72.0	71.0
75.9	74.8	72.4	73.9	71.5	70.0	71.6	71.0
76.0	77.6	73.2	72.8	71.0	70.3	71.6	71.0
78.0	75.8	72.1	71.5	71.0	70.0	71.6	71.3
79.0	75.0	72.1	71.0	70.8	70.0	71.6	71.5
79.9	75.6	72.5	71.2	70.5	70.0	71.5	71.8
77.8	76.0	72.8	72.1	71.0	70.0	71.8	72.0
76.5	74.5	73.0	73.0	71.3	72.0	72.0	72.1
77.1	73.5	73.4	71.5	72.3	72.8	71.8	72.3
76.8	73.3	73.0	71.3	73.0	73.0	71.5	72.3
75.0	72.0	71.9	71.5	72.8	72.5	71.5	73.0
76.1	71.3	72.0	71.0	72.0	72.0	71.5	72.8
77.0	73.0	73.0	72.0	71.9	72.0	71.3	72.5
77.5	75.0	73.9	72.8	71.5	72.3	71.1	72.0
78.4	77.5	73.5	71.2	71.3	72.0	71.1	72.0
79.9	76.0	71.8	70.1	71.5	71.8	71.3	72.0
81.1	74.5	72.0	70.2	71.0	72.0	71.8	72.0
80.5	75.0	72.5	70.1	70.8	72.8	71.0	71.5
80.1	74.4	72.0	70.8	70.5	72.5	71.1	71.5
79.5	75.0	71.7	71.8	70.5	72.5	71.0	71.0
79.9	73.5	72.6	70.7	70.5	71.5	71.2	71.0
79.5	75.0	72.9	71.6	71.0	71.0	71.0	71.3
79.0	76.0	73.5	72.0	71.1	70.5	71.0	71.1



ATMOSPHERIC CO_2 AT FOUR LEVELS

FIGURE VII-4. ALBROOK FOREST - CARBON DIOXIDE MEASUREMENT AT FOUR LEVELS

DATA TAKEN FROM 1030 TO 1100 HOURS ON NOVEMBER 6, 1967

The measurements at the 0.3 m level show a high frequency of fluctuations with well defined peaks. These peaks have a maximum ppm value of 450 and a minimum of 365. The highest variation in ppm during a 50-second period is 80 units in magnitude (A, Figure VII-4) and the average carbon dioxide concentration for the ten minute period is 410 ppm.

A high frequency of fluctuations with sharp peaks still prevails at the 1.2 m level, but their magnitude has decreased by half. The fluctuation range is from 388 to 360 ppm. The highest variation in ppm's during a 50 second reading is 44 ppm (B, Figure VII-4), and the average carbon dioxide concentration for the ten minute sampling period is 370 ppm.

The 2.5 m level shows broadened peaks with more plateaus. The fluctuation frequency is much lower, with a CO_2 concentration range span from 350 to 373 ppm. The highest change during a fifty second period is 25 ppm (C, Figure VII-4), and the average carbon dioxide concentration is 368 ppm.

The 4 m level shows still fewer peaks with more plateaus, and the fluctuations are much less prominent. The highest change in concentration during a ten second reading is 12 ppm, (D, Figure VII-4) and the average carbon dioxide concentration is of 365 ppm.

The frequency and magnitude of the fluctuations together with the average carbon dioxide concentrations existing at these four levels indicated that below 4 m the atmosphere was not homogeneous with respect to carbon dioxide. Comments on the possible origin of this heterogeneity at these levels will be given in the Discussion.

Miraflores Data at Three Levels. The Miraflores data was obtained by sampling at three different levels (0.3, 1.2, and 2.5 meters) in a field with grass 2.5 m tall, adjoining the Miraflores Annex. The carbon dioxide measurements were taken in the same way as described for the Albrook forest site.

The results of a sampling sequence are shown on Figure VII-5 and Table VII-2. The carbon dioxide fluctuations at Miraflores also vary from level to level, and there is a marked decrease in the magnitude and frequency of the fluctuations between the 0.3 and 2.5 m levels.

The measurements show at the 0.3 m level a high fluctuation frequency with sharp peaks. These peaks show a maximum value of 540 and a minimum of 470 ppm. The greatest change in carbon dioxide concentration during a 50 second period is 60 ppm (A, Figure VII-5), and the average carbon dioxide ppm concentration for the ten minute period is 485 units.

A high fluctuation frequency with sharp peaks still prevails at the 1.2 m level. The range of fluctuation is reduced, however, and varies between 485 and 450 ppm. The highest carbon dioxide concentration change during a 50 second period is 45 ppm (B, Figure VII-5), and the average carbon dioxide concentration during the 10 minute sampling period is 470 ppm.

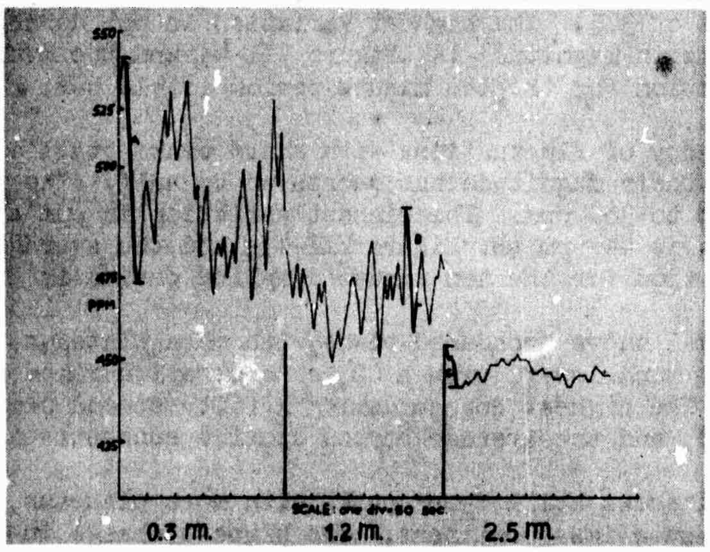


FIGURE VII-5. MIRAFLORES - CARBON DIOXIDE MEASUREMENT AT THREE LEVELS

DATA TAKEN FROM 0700 TO 0730 HOURS ON DECEMBER 6, 1967

TABLE VII-2. CARBON DIOXIDE MEASUREMENTS AT THE MIRAFLORES ANNEX
0700 to 0730, DECEMBER 6, 1967

LEVELS

0.3 m		1.2 m		2.5 m	
92.0	86.8	86.9	85.8	83.5	82.8
93.5	88.9	86.2	86.9	83.0	82.7
94.1	89.3	85.3	87.3	83.1	82.7
93.8	86.7	86.0	86.5	82.8	82.5
92.8	85.4	86.5	84.8	82.0	82.5
89.1	86.9	85.3	83.1	82.0	82.6
86.2	87.2	86.3	84.3	82.0	82.7
85.8	86.8	85.0	86.0	82.2	82.5
86.8	87.3	85.5	85.2	82.1	82.5
89.0	86.0	85.0	86.0	82.2	82.5
89.5	89.3	84.1	85.2	82.3	82.3
89.0	87.2	84.0	86.0	82.5	82.3
87.9	86.5	85.8	86.5	82.5	82.3
87.3	87.8	85.1	85.3	82.3	82.4
89.8	88.9	85.8	85.0	82.3	82.2
90.3	89.8	84.5	88.5	82.5	82.0
91.0	88.6	83.2	88.0	82.8	82.0
92.1	87.9	82.9	86.0	82.8	82.2
91.2	85.2	83.4	84.0	82.8	82.3
92.8	86.3	84.0	85.0	82.8	82.5
91.7	89.3	83.5	86.3	83.0	82.5
90.3	90.2	83.8	86.9	83.0	82.5
90.8	88.8	84.5	85.5	82.8	82.3
91.7	86.3	85.0	85.2	82.8	82.3
92.3	88.2	85.9	84.3	83.0	82.6
93.1	89.3	86.0	85.0	83.0	82.8
91.3	92.4	85.5	86.0	83.2	82.8
89.8	90.3	85.0	86.0	83.0	82.8
88.9	89.4	84.0	86.8	83.0	82.7
89.3	91.2	84.5	86.3	83.0	82.7

The 2.5-m level shows few fluctuations with broad peaks and many plateaus. The carbon dioxide concentrations range spans from 450 to 425 ppm. The highest change in CO_2 concentration during a 50 second period is 10 ppm (C, Figure VII-5), and the average concentration for the ten minute period is 446 ppm.

The Miraflores data shows heterogeneity of the atmosphere below the 2.5 m level, above this no carbon dioxide fluctuations exist and a straight line is obtained on the recorder chart. A comparison of the Albrook and Miraflores data is given in the Discussion.

Albrook Data - 0.3-Meter Level. Measurements were taken at the 0.3-m level on a continuous basis for one week. The data were analyzed by the hour (i.e. from 0000 to 0100 hours, etc.) and 24 carbon dioxide concentration values were obtained for each day. These concentration values consisted of an average value of the carbon dioxide concentration, and the highest and lowest fluctuations during the hour. The week's data were tabulated and analyzed, and an average weekly value of the carbon dioxide concentration with its high and low fluctuation was obtained for each hour. A total of eighty-four feet of recorder chart paper were analyzed to obtain these results.

The average hourly carbon dioxide concentrations for one week are shown on Figure VII-6 and Table VII-3. The average value of the concentrations is given by plot A on the figure.

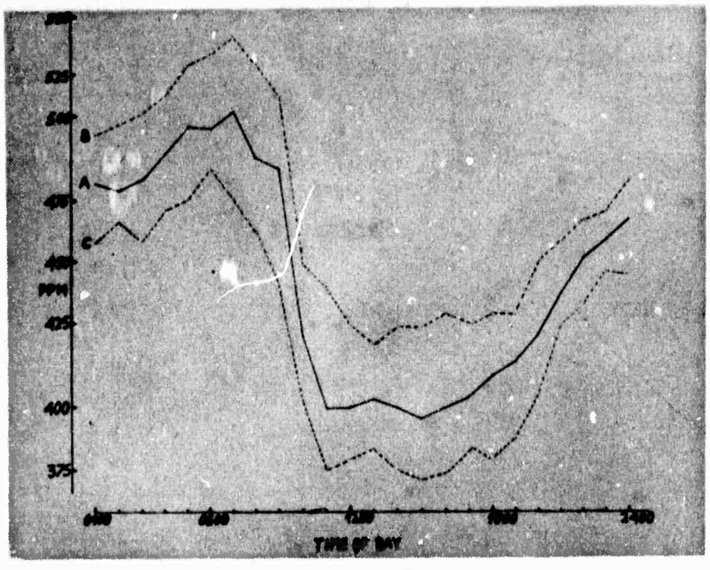


FIGURE VII-6. ALBROOK FOREST - AVERAGE OF ONE WEEK OF DATA SAMPLING 24 HOURS A DAY AT THE 0.3 M LEVEL. DATA WERE ANALYZED BY THE HOUR AND REPRESENT THE WEEK OF NOVEMBER 6-12, 1967

TABLE VII-3. ALBROOK FOREST. AVERAGE OF ONE WEEK OF DATA SAMPLING, 24 HOURS A DAY, AT THE 0.3-M LEVEL. DATA WAS ANALYZED BY THE HOUR AND WAS TAKEN THE WEEK OF NOVEMBER 6-12, 1967

Time	Average carbon Dioxide Concentration	High Fluctuation	Low Fluctuation
0100 hours	86.8	91.0	84.0
0200	86.5	90.1	85.0
0300	87.0	91.0	84.0
0400	88.0	92.0	85.5
0500	89.5	92.5	86.0
0600	89.5	93.0	87.5
0700	90.3	94.0	86.0
0800	88.0	92.5	84.5
0900	87.5	91.0	82.0
1000	79.5	84.0	76.0
1100	76.0	82.0	73.0
1200	76.0	80.0	73.5
1300	76.5	79.0	74.0
1400	76.0	80.0	73.0
1500	75.5	80.0	72.5
1600	76.0	80.5	73.0
1700	76.5	80.0	74.0
1800	77.5	80.0	73.4
1900	78.0	80.5	74.5
2000	79.5	83.0	76.5
2100	81.5	84.0	80.0
2200	83.0	87.0	79.5
2300	84.0	88.0	82.5
2400	85.0	88.0	82.5

NOTE: All values are given in recorder deflection units.

The diurnal variation in CO_2 concentration approximates the following: Starting at midnight with a concentration of about 470 ppm, the value rises to a maximum of ± 500 ppm at 0700 hours, then falls sharply to a minimum of ± 400 ppm at about 1100 hours, varies only moderately until about 1700 to 1800 hours, then increases throughout the nighttime hours. The short-time fluctuations (B and C, Figure VII-6) during the 24-hour period are less frequent and of lower magnitude during the night than the daytime hours.

<u>Miraflores Data - 0.3-Meter Level.</u> Data were collected and analyzed in the same manner as for the Albrook site.

The hourly carbon dioxide concentrations, as averaged for one week, are shown on Figure VII-7 and Table VII-4. The average value of the concentrations is shown on plot A. The amplitude of the average concentration throughout the day varies from a maximum of 480 ppm at 0800 hours to a minimum of 385 ppm at 1500 hours.

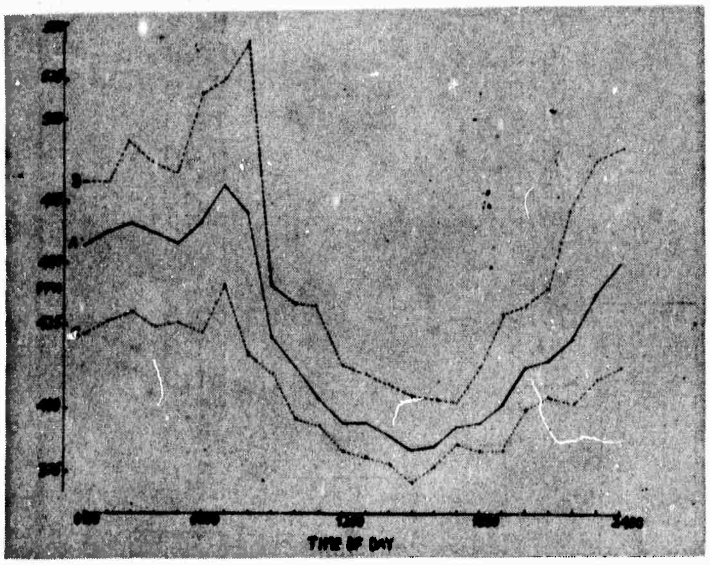


FIGURE VII-7. MIRAFLORES - AVERAGE OF ONE WEEK OF DATA SAMPLING 24 HOURS A DAY AT THE 0.3M LEVEL. DATA WAS ANALYZED BY THE HOUR AND WAS TAKEN THE WEEK OF DECEMBER 4-10, 1967

The diurnal pattern of variation in average CO_2 concentration is very similar to that exhibited at the Albrook Forest site, i.e., the maximum concentration occurs shortly after sunrise, with a sharp drop in the early daytime hours and continued low level in the afternoon, followed by a gradual increase during the nighttime hours. The short-time fluctuations

TABLE VII-4. MIRAFLORES SITE. AVERAGE OF ONE WEEK OF DATA SAMPLING, 24 HOURS A DAY AT THE ONE FOOT LEVEL. DATA WAS ANALYZED BY THE HOUR AND WAS TAKEN THE WEEK OF DECEMBER 4-10, 1967

Time	Average Carbon Dioxide Concentration	High Fluctuation	Low Fluctuation
0100 hours	84.00	87.00	79.75
0200	84.5	87.00	80.25
0300	85.0	89.00	80.75
0400	84.50	88.00	80.00
0500	84.00	87.50	80.25
0600	85.00	91.30	79.75
0700	86.75	92.00	82.00
0800	85.50	94.00	78.50
0900	79.50	82.00	77.50
1000	78.00	81.20	75.75
1100	76.50	81.00	75.25
1200	75.50	78.00	74.00
1300	75.50	77.75	73.75
1400	74.75	77.25	73.50
1500	74.00	76.75	72.50
1600	74.20	76.50	73.25
1700	75.00	76.33	74.33
1800	75.33	78.00	74.00
1900	76.33	80.66	74.00
2000	78.00	81.00	76.00
2100	78.33	81.50	76.66
2200	79.66	85.50	76.33
2300	81.66	88.00	77.66
2400	83.00	88.50	78.00

NOTE: All values are given in recorder deflection units.

(shown on curves B and C in Figure VII-7), on the other hand, are greater during the hours of darkness and show a decreased amplitude of variation during the daytime.

An analysis of the Albrook and Miraflores data will be given in the Discussion.

Discussion

Marked fluctuations in concentration of the CO_2 content of the atmosphere during sampling were observed at both the Albrook and Miraflores sites. In comparing the Albrook and Miraflores data, as presented in Figures VII-4 and -5, one may note: a) that these fluctuations take place below the 4-m level at Albrook and below the 2.5-m level at Miraflores, and b) that the most intense fluctuations in both areas occur near the ground.

Although levels of concentration at the sites differ, the distribution of the fluctuations at the 0.3 and 1.2-m levels are very similar. The differences at the 2.5 m level could be explained on the basis of wind mixing at the relatively open Miraflores site. There is little or no wind and presumably little air movement in the lower atmosphere of the forest. The indicated difference in concentration of carbon dioxide present at the two sites is a transient phenomenon. The Miraflores samples were taken beginning at 0700 hours when the average carbon dioxide concentration, as well as the magnitude of the observed fluctuations was highest (Figure VII-7). The Albrook observations were begun at 1030 hours when both the content and magnitude of fluctuation had decreased from the normal early morning maximum. (Figure VII-6).

Diurnal variations at both sites occur but there are striking differences in the two sites as well. The average carbon dioxide concentration measurements for the week at both sites follow similar patterns. (Figures VII-6 and -7). In comparing the data at both places one may note: a) that the amplitude of the average carbon dioxide concentration varies from a maximum at 0700-0800 hours to a minimum at 1500 hours, b) that there is an increase in carbon dioxide concentration from midnight until 0730 hours followed by a considerable drop in concentration to reach a plateau at 1100 hours, and c) that the concentration then remains constant until 1830 hours when it increases again throughout the night. This pattern of low carbon dioxide concentration values in the daytime with increase at nighttime is fairly common in carbon dioxide studies. (Wiant, 1966).

One of the striking differences observed in the two sites is the high and low fluctuation periods present. The Albrook data show a high fluctuation period that spans from 0700 hours until 1700 hours and disappears after sunset, and the Miraflores data shows a high fluctuation period between 2000 and 0900 hours, with extremely high values at 0700-0800 hours. One sampling site gives high-fluctuation data which are almost the inverse of the other site.

The cause of these variations in fluctuation at the Albrook and Miraflores sites is not known with certainty. However, it is known that microbial activity and plant root breathing can cause increases in carbon dioxide concentrations at near and below ground level. Microorganism activity on the surface is dependent upon the amount of litter present (food supply), the humidity of the soil (water supply), and the ambient temperature. The two sites differ in several respects. For example: 1) the Miraflores site has less litter than the Albrook site, 2) the humidity of the soil at the Albrook site is much higher than at Miraflores, 3) the amount of radiation reaching the soil is higher at the Miraflores tall grass field than in the Albrook forest where the soil is shielded from radiation by the tree canopy, and 4) the ambient temperature at low levels is higher at Albrook than in Miraflores because of the steady state existing in the first and the wind that blows accross the Miraflores tall grass field. It is possible then that a greater degree of microorganism activity at the surface of Albrook forest causes the high magnitude of the fluctuations seen during the day.

The amount of carbon dioxide that the plant roots release to the atmosphere is dependent upon: 1) how deep in the ground the roots are located, and 2) the humidity of the soil through which the carbon dioxide gas must diffuse to reach the surface. (CO_2 is soluble in water at certain pH values). Examining both sampling sites it could be noted that: 1) the Albrook sampling area is surrounded strictly by high trees with deep-set roots and the soil humidity is high, and 2) the Miraflores sampling area is covered with tall grass with roots located close to the surface, and the humidity of the soil was lower than at Albrook. It is possible then that the amount of carbon dioxide diffusing through the soil was much higher at the Miraflores site during the night, causing the high magnitude of the fluctuations observed.

The above explanations for the high fluctuations observed are assumptions. With the data available at the present time they cannot be proven. One item of note is that in the Albrook forest when the sampling line was located in an area next to the tower, where no litter was present, no carbon dioxide fluctuations were observed during the daytime.

Future Work

To achieve a better understanding of the carbon dioxide fluctuations at the different levels it is necessary to obtain data for a period of one week at each of the sampling levels at Albrook and Miraflores. (At the present time we have data at the 0.3-m level only. It is also necessary to secure carbon dioxide data at and above the canopy level in the Albrook site to correlate it with the data at low levels. Samples taken at several levels high above the sites also would be desirable.

To study the causes of the high fluctuations in carbon dioxide concentration at low levels it is necessary to do some sampling at areas that contain no litter, to correlate with the rest of the data. Carbon dioxide measurement underground are also desirable to study the carbon dioxide concentration liberated by roots.

MICROBIOLOGY OF RAIN WATER*

Introduction

Airborne microbes may be deposited on surfaces directly or they may be washed out of the air in raindrops. Therefore, a complete study of airborne and surface deposited microorganisms should include attention to the effects of rain. The observations on microbial content of rain water described below have been made as a part of the broader investigation of air and surface microbial populations in a tropical region. The purpose of this investigation is to determine the number of microorganisms which appear in rain water samples collected in the Canal Zone.

Background

Over the last three centuries about a score of people are known to have studied the occurrence of microbes in rain water. Collecting the samples requires certain precautions, however. The vessel must be obviously clean, but the danger of contamination by rain-splashed soil has not always been anticipated, though, with current knowledge of the magnitude of splash and its part in soil erosion, the danger may be avoided (Laws [15]).

The only systematic study of precipitation microbiology comes from Miquel[16] at the Parc Montsouris, Paris. Miquel caught rain in a metal funnel fixed at 1.7 meters above ground-level on a pillar, well away from trees and buildings. Rain falling into the funnel was collected in a platinum crucible with a cover, both funnel and crucible having been heated to redness just before sampling. The sample was then sown, by drops, in 50 to 100 flasks of beef broth. The largest catches of bacteria occurred in the warmer months, when numbers varied from 0 to 8.3 per ml. with a general mean of 4.3 per ml., but these figures excluded the first rain after several dry days when up to 200 bacteria per ml. might be recorded. During prolonged rainfall the numbers fluctuated instead of continuing to diminish, suggesting to Miquel that the rain clouds themselves had a characteristic bacterial content. Molds fluctuated in the same manner as bacteria and averaged 4 per ml. Miquel estimated the annual precipitation of bacteria and molds at Monsouris at over 4 million per square meter - a figure that was obviously too low as he excluded the contribution of the first rain after dry days.

In the present century various workers have cultured microbes from rain. Minervini[17] collected numerous rain samples on ships in the North Atlantic. Bacteria were abundant, half the samples yielded pink yeasts, and a quarter of them Penicillium.

---

* This section was prepared by Mr. George W. Gauger, Microbiologist, and Dr. Robert S. Hutton, Biological Scientist.

Rain water collected over the ocean at considerable distances off-shore by ZoBell[18] averaged 1 to 10 bacteria per ml., with few or no mold fungi. Rain water collected on land at the Scripps Institution of Oceanography, in California, contained from 10 to 150 microbes per ml. As usual, the highest counts were obtained during the first rain and were associated with a predominance of mold spores.

Puschkarew[19] collected ten samples of rain water in a sterile funnel at Heidelberg and added nutrient solutions. At the start of rain he found large numbers of fungi and bacteria.

Observations on microorganisms in rain were made at Rothamsted Experimental Station in 1951 by Gregory, Hirst, and Last (See Hirst,[20]) while they were comparing various spore-trapping techniques. Two conical glass funnels 20 cm in diameter were exposed on a wooden structure at a height of 2 meters above ground level. One funnel was open to rain (rain trap), while the other (dry-trap) was protected by a flat asbestos-cement disk held 25 cm. above the mouth of the funnel - to keep off rain but still allow dry deposition. Washings from both funnel were collected daily and the fungus spores separated by sedimentation onto a glass cover-slip. On dry days the fully exposed rain-trap consistently caught fewer microbes than the dry-trap; but, as might be expected, this was reversed during rain - especially in the first rain after dry weather.

Rain falling during one thunderstorm was studied in detail (Gregory,[21] and Hirst[20]), and a detailed account of changes in the air-spora during this period, observed with the aid of the Hirst automatic volumetric spore-trap, has already been published (Hirst[22]). A seven-day spell of warm, dry weather ended in a thunderstorm in the afternoon on 22 July 1951. The rain-trap was cleared immediately before the rain started, and the first mm of rain which fell in the first half-hour of the storm was collected separately from the suceeding 3.75 mm., which contained many fewer spores.

As Hirst[20] remarks in discussing this series of observations: "Spores released during rain are presumably removed from the air as readily as spores already there when rain starts to fall, so that concentrations of airborne spores measured during rain represent, not the total released, but the excess of those released over those removed." Rain-scrubbing seems an ideal method of deposition for air-dispersed soil fungi. For foliage pathogens its biological significance is far from clear. Many spores may be lost in runoff unless they can attach temselves to the leaf surface or penetrate into crevices they would be unlikely to reach through deposition from dry air.

In contrast Asai[23], who introduced the useful method of filtering rain through membrane filters under reduced pressure, failed to obtain uredospores of Puccinia graminis, although they were known to be in suspension in the air at the time the rain samples were collected.

Visser[24] has determined the microbial content of tropical rain water by cultural studies and has found a wide variety of microorganisms, algae, fungi, and bacteria, which generally resemble those found in soil. The average value of the seven determinations made was 2.1 x 10^4 fungi per ml. The average total microbial count on nutrient agar was 32 x 10^5 per ml.

The data mentioned above clearly show that the microbial content of rain water varies greatly, that rain-scrubbing seems an ideal way of deposition for air-dispersed fungi, and that rain water may contain a wide variety of microorganisms.

Data Collection Methods

Rain water samples were collected in sterile, 400-ml beakers placed 1 meter above ground in an area open to the sky, well away from buildings at the Miraflores Annex. At the start of rainfall, aluminum foil protective dust covers on the beakers were manually removed. Samples were collected each 15 minutes and analyzed separately during heavy rain; collection of a usable sample required 30 to 60 minutes, or more when rains were light.

Processing of the rain samples was accomplished by drawing the entire contents of the sample through a Millipore* 0.45 U pore-size membrane filter field monitor (Figure VII-8). During filtration, the microbes contained in the rain water are trapped and held on the surface of the membrane. After filtration the rain water was measured to determine sample size, and then discarded.

Double strength nutrient broth was drawn through the monitor to infuse the filter pad, and the excess broth was drawn off. The resulting moist pad contained enough nutrient to enable the trapped microbes to develop into colonies large enough to be seen. The capped monitor was incubated at 28 C for three days, after which colonies appearing were counted and the number recorded.

Results

Table VII-5 presents microbial contents of rain water collected between 9 May 1966 and 8 December 1966. Though there is no evidence that season, time of day, or the duration of rain over a given period has any effect on the microbial content of rain samples, there is definite indication that heavy rainfall reduces the microbial contamination. Since no records of precipitation are available for the sampling point, rainfall figures at the times samples were collected are given for the two Data Base sites nearby. Table VII-6 is a summary of the data contained in Table VII-5 , in which small, medium, and large collections of rain were

---

*Millipore Filter Corporation, Bedford, Massachusetts

TABLE VII-5. MICROORGANISMS IN RAIN WATER COLLECTED NEAR MIRAFLORES ANNEX.

DATE		MICROOGANISMS/100 MLS.			RAINFALL AT COLLECTION TIME		24-HOUR RAINFALL	
1966	HOUR	BACTERIA	FUNGI	MLS. COLLECTED	CHIVA	ALBROOK	CHIVA	ALBROOK
9 May		40	170	50				
		44	136	70				
		400	1,060	10			.87	.09
13 Jun		160	0	86				
		100	50	14				
		80	0	12			.43	.02
12 Jul		1,714	1,685	7			1.46	.91
18		28	400	25			1.02	.58
20		268	1,250	12				
		84	85	115			.15	.11
29		362	129	21			.39	.59
4 Aug		159	172	34			.12	.03
18		1,150	388	8			.06	.30
23		264	928	11			1.97	.05
26		114	10	143			.16	.02
6 Sep		414	256	57			.44	.60
9	0800-0840	122	1,222	8	.08	.00		
	1005-1020	53	36	36	.02	.05		
	1020-1030	422	147	19	.02	.05		
	1030-1050	282	154	11	.02	.05	.57	.33
13	1410-1420	127	58	29	.00	.12		
	1420-1430	67	4	55	.06	.12		
	1430-1445	122	2	108	.06	.13		
	1445-1500	322	19	32	.07	.13	.93	1.04
22	1305-1325	300	12	116	.15	.12		
	1325-1405	300	5	103	.20	.25		
	1405-1430	650	100	7	Trace	.00	.51	1.39
26	1135-1235	220	700	19	.05	.30		
	1335-1540	300	130	22	.30	.12	.53	.66

TABLE VII-5. MICROORGANISMS IN RAIN WATER COLLECTED NEAR MIRAFLORES ANNEX (cont'd)

DATE		MICROORGANISMS/100MLS.			RAINFALL AT COLLECTION TIME		24-HOUR RAINFALL	
1966	HOUR	BACTERIA	FUNGI	MLS. COLLECTED	CHIVA	ALBROOK	CHIVA	ALBROOK
6 Oct	0800-0830	200	6	61	.10	.08		
	0830-0930	240	15	22	.14	.14		
	0930-1030	320	40	18	.06	.08		
	1030-1135	380	0	4	.02	.03		
	1135-1335	930	130	3	.00	.04	1.40	1.34
10	1210-1225	95	0	124	.00	.00		
	1225-1255	1,300	570	7	.00	.00		
	1335-1350	675	30	42	.00	.00		
	1350-1405	40	315	64	.00	.00	.83	1.21
12	0730-0830	120	25	28	1.11	.73		
	0900-0930	185	30	165	.76	.28		
	0930-1000	530	6	36	.73	.27		
	1000-1030	55	0	13	.20	.13		
	1030-1130	2,600	0	11.5	.25	.15		
	1145-1315	145	0	3.5	.11	.07	4.49	2.60
18	1245-1300	60	0	87	.03	.00		
	1300-1315	60	30	100	Trace	.30		
	1315-1330	70	10	134	.01	.45		
	1330-1345	210	40	74	.01	.54	.27	2.12
21	1335-1405	0	80	14	.10	.00		
	1415-1430	0		22	.08	.00		
	1430-1445	285	7	29	.10	.00	.47	.00
24	1355-1410	85	6	46	.10	.00	.16	.01
25	1315-1345	230	120	51	Trace	.00		
	1345-1400	3	3	64	Trace	.00		
	1400-1415	6	80	17	.16	.05	1.48	1.15
26	1200-1215	200	5	81	.02	.00	.10	.00
1 Nov	1525-1535	100	220	6	.07	.02	.19	.08
2	1030-1135	2,400	7,440	5	.00	.06		
	1217-1317	960	385	13	.01	.00	.05	.10

TABLE VII-5. MICROORGANISMS IN RAIN WATER COLLECTED NEAR MIRAFLORES ANNEX (cont'd)

DATE		MICROORGANISMS/100 MLS		MLS.	RAINFALL AT COLLECTION TIME		24-HOUR RAINFALL	
1966	HOUR	BACTERIA	FUNGI	COLLECTED	CHIVA	ALBROOK	CHIVA	ALBROOK
7 Nov	1143-1158	280	5	82	.25	1.47		
	1159-1259	170	10	36	.06	.06		
9	1115-1125	1,070	335	3	.00	.00	.31	1.53
	1245-1315	305	30	85	2.04	.08		
	1315-1340	885	200	31	.00	.06		
10	1225-1240	345	155	142	.11	.11	2.04	.14
	1240-1255	140	130	13	.12	.12		
15	1525-1540	625	650	48	.08	.07	.23	.32
21	1330-1350	3,335	1,090	9	.05	.03	.61	.77
23	1200-1230	32,000	1,240	5	Trace	.00	.05	.04
25	1100-1130	80,000	1,050	2	.00	.00	.15	.01
29	1030-1045	1,470	150	32	.00	.00	.02	.04
	1045-1115	420	320	90	.00	.00		
	1115-1130	1,200	340	27	.04	.00	.14	.02
1967								
1 Dec	0735-0835	1,000	400	13.5	.09	.13		
	1315-1415	500	100	37	.47	.51		
	1415-1445	900	40	52.5	.18	.15		
	1445-1515	4,100	300	11	.08	.13		
5	1355-1455	50	70	6	.16	.03	1.67	1.86
6	1310-1325			86	.01	.40	.26	.09
	1325-1340			18.5	.00	.05		
8	0945-1045	700	0	45	.55	.25	.44	.70
	1045-1115	300	0	66	.15	.01		
	1115-1140	400	0	16	.04	.02	.85	.63

TABLE VII-6. MICROBES FOUND IN SMALL, MEDIUM, AND LARGE SAMPLES OF RAIN WATER COLLECTED IN THE CANAL ZONE

Sample Size MLS	No. Samples	Maximum No. 100 MLS		Minimum No. 100 MLS		Average & Standard Deviation/100 MLS	
		Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
Less than 50	54	80,000	1,700	5	6	820 (1310)	313(413)
50 - 100	16	900	320	3	3	240 (75)	82(111)
over 100	9	345	155	70	2	180 (101)	34(49)

compared for both bacterial and fungal contamination. In spite of the fact that numbers appearing in samples varied between extremely wide limits, it is clear that small samples tended to have greater numbers of both bacteria and fungi than did the large samples.

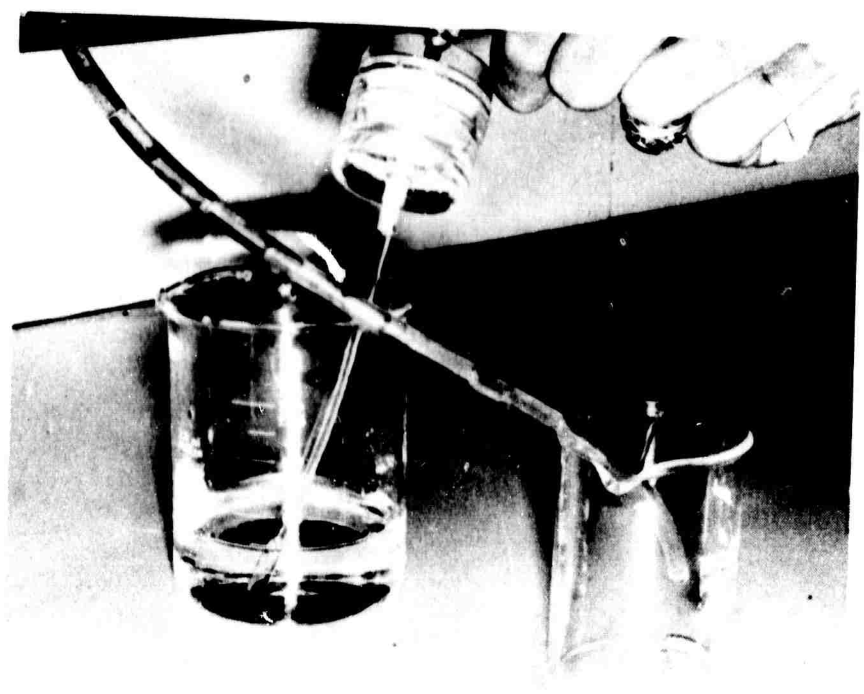


FIGURE VII-8. FILTERING A RAIN WATER SAMPLE THROUGH A FIELD MONITOR

Discussion and Conclusions

The tendency for smaller samples to contain more microbial forms could be explained in any of several ways. If, as might be expected, the rainfall making up the small samples fell in the form of mist or very small droplets, one could assume that they would more effectively filter the microorganisms from the air. On the other hand, the vessels used to collect small samples of rain were exposed to the atmosphere for longer periods than those used to collect larger samples. Since moisture surfaces are effective traps for particles floating in turbulent air, we would expect rain water relatively free of microbial forms to become increasingly contaminated through air contact throughout the period of collection. Hirst[20] tested this possibility by using a pair of collectors - one open to rain, one open to air but sheltered from rain. With this system, Hirst was able to observe that rain falling after several dry days did not contain more microbes than rain falling during a season of heavy rains.

The utility, as well as the approach, of subjecting the data given in Table VII-5 to more detailed analysis and interpretation remains to be determined.

PART VIII. MACROFAUNA

Insect Collections at Albrook Forest Site*

Introduction

The order Insecta contributes significantly to the biomass of any area, and often plays an important role in reduction and decay of vegetation. The authors decided to investigate the numbers and distribution of insects at the Albrook Forest site by using black-light traps. The traps would be set at two levels: at 30 meters on the tower, and at ground level. A comparison could then be made between numbers and groups of insects captured at the two levels.

Methods

The two black-light traps were constructed and sent to Panama in May of 1967. See Figure VIII-1 for details of black light trap. Both traps were in operation one night a week, between 6 P.M. and 6 A.M., except during occasional electrical failures. The traps have been in operation since May 25, 1967. The collected insects were preserved in alcohol and sent to the University of Arkansas for segregation and identification. The material has been segregated to insect orders, and the order Coleoptera further divided into families. During the first six-month period, collections were made on 27 nights, and 24 of these collections have been counted and separated. A complete analysis of these collections will be made at the end of a full year sampling period.

Results

Analysis of total insects captured in light traps can lead to erroneous conclusions. Light-trapping is not a random sample; it is highly selective. Many orders of insects are over-represented in the sample because they are nocturnal and are attracted strongly to light. Other insects may be present in even larger numbers, but may be diurnal or not attracted by light. Further, it is impossible to total numbers by month, as both traps were not in operation for all of the sampling nights of the month, due to mechanical failure. To obtain meaningful numbers, the monthly catch at each level was totaled, then divided by the number of complete trap-nights, which gives an average nightly catch during that month. These data are shown in Tables VIII-1 and VIII-2. In terms of total insect activity, it is apparent that more insects were taken at the 30-meter level than at the ground level. Some orders seemed to fluctuate widely in numbers, while others contributed regularly and consistently to the total catch.

---

* This section has been prepared by Dr. Robert T. Allen, Entomologist, University of Arkansas and by Dr. Thomas C. Crebbs, Jr., Biologist, and Dr. Robert S. Hutton, Biological Scientist.

TABLE VIII-1. AVERAGE NUMBER OF INSECTS CAUGHT PER TRAP NIGHT - GROUND LEVEL

	MAY (1)	JUN (4)	JUL (3)	AUG (4)	SEP (4)	OCT (4)	NOV (5)
Coleoptera	1219	314	290	584	174	133	1009
Dermaptera	0	1 T	1 T	0	0	1 T	2 T
Plecoptera	0	0	0	22	118	151	506
Ephemeroptera	26	18	27	99	12	7	171
Hemiptera	166	33	35	123	37	23	111
Homoptera	226	56	69	407	576	544	798
Hymenoptera	754	446	563	445	153	100	348
Isoptera	0	1 T	1	2 T	1 T	1 T	1 T
Lepidoptera	790	266	347	156	10	10	26
Neuroptera	0	1	0	2	1	2 T	2
Orthoptera	58	39	25	15	1 T	1 T	2 T
Psicoptera	12	2	2 T	2	12	13	49
Odonata	0	0	0	0	1 T	1	2 T
Embioptera	0	0	1 T	2 T	0	0	1 T
Thysanoptera	0	1 T	0	0	0	0	0
Trichoptera	39	39	22	10	0	0	0
Collembola	0	0	0	0	0	0	1 T

NOTE: T indicates total number.
Number of trap nights per month in parenthesis.

TABLE VIII-2. AVERAGE NUMBER OF INSECTS CAUGHT PER TRAP NIGHT - 30 METER LEVEL

	MAY (1)	JUN (3)	JUL ([illegible])	AUG (5)	SEP (4)	OCT (4)	NOV (4)
Coleoptera	873	4491	1370	1099	1383	1249	1547
Dermaptera	5	4	2	2 T	1 T	0	2 T
Ephemeroptera	7	1	2	5	6	7	356
Hemiptera	1122	206	149	114	92	37	76
Homoptera	695	390	395	175	131	84	90
Hymenoptera	574	869	477	291	308	129	625
Lepidoptera	1410	1659	883	650	478	238	241
Neuroptera	10	12	3	2	1	1	3 T
Orthoptera	58	43	21	12	10	4	10
Psocoptera	23	6	4	2	4	3	3 T
Thysanoptera	0	2 T	0	0	0	1 T	1
Trichoptera	49	14	16	9	13	3	32
Isoptera	0	6	0	0	0	2 T	2 T
Odonata	0	1 T	0	1 T	0	1 T	0
Pseudoscorpion	0	6	0	0	0	0	0
Embioptera	0	0	0	0	0	0	0
Plecoptera	0	0	0	0	1 T	0	0

NOTE: T indicates total number.
Number of trap nights per month in parenthesis.

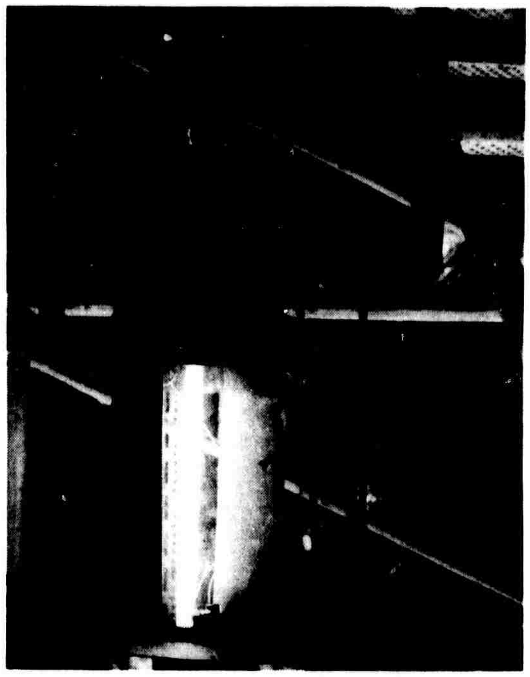


FIGURE VIII-1. BLACK LIGHT INSECT TRAP IN OPERATION.
JAR AT BOTTOM OF CONE CONTAINS ALCOHOL.

These data were collected during the wet season, which begins in early May, and lasts through November. When insects have been collected during the dry season, more meaningful trends in insect population can be compiled.

Though no detailed analysis has been carried out, reference to Tables VIII-1 and -2 indicates that of the orders of Insecta captured, some groups are represented more often, and in larger numbers, than others. In an attempt to demonstrate the possible significance of these groups of insects, included here are short comments on their life cycles, food habits, and economic importance, where applicable.

Characteristics of Insect Orders

Orthoptera: Grasshoppers, Locusts, Roaches, Mantids, and their kin.
This order contains some of the largest and best-known insects. Most, with exception of the Mantids, are plant feeders. The destructive locusts and grasshoppers of the temperate latitudes do not occur in swarms in the Tropics, but may still play a significant role in destroying vegetation, and are known to carry Chagas' disease. They are winged or wingless, and the winged forms usually have four wings. The fore-wings are thickened,

many-veined, and narrow, and form a cover for the larger hindwings when the insect is at rest. The mouth parts are of the chewing type. The metamorphosis is simple. The following families of insects are among commonly known members of this order:

- Pygmy Mole Crickets
- Mole Crickets
- Crickets
- Cockroaches
- Short-horned Grasshoppers
- Wingless Short-horned Grasshoppers
- Grouse Locusts
- Long-horned Grasshoppers
- Wingless Long-horned Grasshoppers
- Walking Sticks
- Mantids

Orthoptera did not appear in large numbers in either trap, but did show a decrease in numbers during the six-month sampling period. This is possibly due to the removal of territorial individuals which are not speedily replaced in the immediate area of the traps.

Hemiptera: True bugs.

This widely distributed group of insects is very adaptable, and is found in many habitats. Most are terrestrial, but many are aquatic. All are identifiable as true bugs by the wing structure. The forewings have a thickened and leathery basal portion, which becomes membraneous toward the rear; this type of wing is called a hemelytron. The hindwings are entirely membraneous, and both pairs of wings are held flat over the abdomen at rest. All true bugs have piercing and sucking mouthparts, whether they feed on plants or are predators. The majority are plant feeders, sucking out the juices of living plants. Some bugs are predaceous on other insects, and a few bite man, transmitting diseases such as Trypanosomiasis. The metamorphosis is simple, and the nymphs usually exhibit the same food habits as the parents. The most serious pests of cultivated plants are in this order, as well as many of the insect vectors of plant diseases.

True bugs were represented in the catch at both levels during each month. Both levels show a peak catch in May, with over six times as many caught at the higher level.

Homoptera: Cicadas, Hoppers, Scale Insects, and Aphids.

All of the members of this order are plant feeders. They have, for the most part, four membraneous wings which are held slanted (tentlike) over the abdomen when at rest. Life histories are quite variable in the families and species, including some that give birth to living young and some forms that reproduce asexually. Most are voracious feeders on living plant tissues, and cause losses in agricultural crops and forest trees. Many carry plant diseases, and the cicadas can stunt and kill trees by mutilation while laying eggs. Two species are of commercial value; both shellac and the red dye, cochineal, are made from scale insects. The seventeen-year locust (a cicada) belongs to this order.

Homoptera caught at the 30-meter level showed a gradual decline in numbers from May until November. Oddly, the ground-level trap showed the reverse; increasing to a high in November. Though this analysis has not yet been made, this trend is probably the result of different species being caught at the two levels.

Ephemeroptera: Mayflies.

Mayflies are small to medium-sized, elongate, very soft-bodied insects with two or three long threadlike tails. They are often very common around ponds or streams, and their nymphs are entirely aquatic. The adult stage is short-lived, and does not feed. Nymphal mayflies feed on organic detritus in streams, and may take two to four years to develop. Adults have membranous wings with numerous veins; the front wings are large and triangular, and the hindwings are small and rounded. The wings at rest are held together above the body. Metamorphosis is simple.

Mayflies did not show up in significant numbers until November, when traps from both levels recorded highs. This probably indicates that the local hatch of mayflies occurs at that season.

Plecoptera: Stoneflies.

These insects are mostly medium-sized or small, somewhat flattened, soft-bodied, rather drab-colored and are found near water. They are poor fliers, and are not very active as adults. Like mayflies, the nymph is the long-lived stage, and is aquatic. Adults do not feed, and nymphs feed on both animal and plant material in the water. Metamorphosis is simple. The four membraneous wings of the adult are held flat over the abdomen when at rest. Mouthparts are of the chewing type, but are often quite reduced. The economic importance of both stoneflies and mayflies is that they are important links in aquatic food chains leading to fishes and turtles.

Only one stonefly was caught at the 30-meter level, and very few at the ground level until August. Plecoptera increased in number through September and October, with the largest catch recorded in November. This looks like a slowly growing hatch of adults of a species or group of species which is weak-flying and does not reach the higher level.

Hymenoptera: Bees, Ants, and Wasps.

This order is probably the most beneficial in the entire insect class, as it contains a great many insects that are of value as parasites or predators of insect pests. In addition, the bees and solitary wasps are most important as plant pollinators. Many hymenopterans exhibit a strongly developed social behavior, and care for their eggs and young. The metamorphosis is complete, with the larvae feeding on a wide variety of foods; many are parasitic on the larvae of other insects. The many species of tropical ants are important as defoliators, as predators, and as pests of some import to persons working in the jungle.

Hymenopterans were caught in numbers, at both levels, during the entire sampling period. No strong trends were noted, save that lower numbers were caught in September and October than in other months.

Psocoptera: Psocids.
The psocids are small, soft-bodied insects, less than one-quarter inch in length. When winged, there are four membraneous wings which are held rooflike over the abdomen when at rest. Some forms are wingless. The mouth parts are of the chewing type, the antennae are generally long, and the metamorphosis is simple. Psocids feed on molds, fungi, cereals, pollen, dead insects, and similar detritus. They are mostly terrestrial, living under bark or stones, or in foliage. A few species are gregarious, and spin webs on tree trunks and branches.

Psocids made up a small part of the total catch, but built up from lows in June, July, and August to a peak in November. Very few of these small insects appeared at the 100-foot level.

Neuroptera: Nerve-winged Insects.
Some of the insects of this group are known as Lacewings, because all four wings are intricately veined. Ant lions and Dobson flies are also found in this order. All of the larvae of this group are predaceous upon other insects, and some are aquatic. Many adults do not feed, but those who have functional mouthparts are predaceous. Metamorphosis is complete, with an exarate pupa. Neuroptera appear infrequently at both levels, and make up a very small part of the sample.

Trichoptera: Caddisflies.
The caddisflies are small to medium-sized insects very similar to moths in appearance. The four membraneous wings are covered with hairs, instead of the fine scales of moths. The chewing-type mouth parts of the adult are rarely used, as the adult lives a short time and feeds only on liquids. The larvae are caterpillarlike, living in elaborate cases constructed of silk cemented to debris from stream and pond bottoms. Each species builds a different type of case, from which the jaws protrude to feed on plants or small insects in the water. Adults are attracted to lights from great distances, so make up an inordinately large percentage of the catch in light traps. The larvae are an important food source for fresh-water fish and other aquatic animals.

Caddisflies were caught at the ground level during May-July, then were not represented in later samples. At the 30-meter level, they appeared in all samples, with a peak in May and another in November. This appears to be another example of differential sampling, in that the species caught at 30 meters is different in habits from those caught at ground level.

Lepidoptera: Butterflies and Moths.
These well-known insects need no description. They can be distinguished from other insecta by the very fine scales on the wings. The

metamorphosis is complete, and the larvae or caterpillar is the stage of greatest economic importance. Many are serious pests of agricultural crops, defoliating and carrying plant diseases to a wide variety of plants.

Butterflies and moths were caught in the ground level trap during the period May through August, then fell off to a trace during September-November. The upper-level trap showed the same trend in numbers caught, but were still represented by hundreds of individuals during the September-November period.

Coleoptera: Beetles.
This is the largest order of insects, containing about 40 percent of the known species in the class insecta. Over a quarter-million species of beetle have been described. As is to be expected, there is considerable variation in a group of this size. The distinctive feature of beetles is the wing structure. The forewings are tough, even hard, and serve as only a cover for the rear wings. This cover, called the elytron, is not functional in flying, so most beetles fly slowly and somewhat clumsily, compared with other insects. The metamorphosis is complete, most larvae being equipped with chewing mouth parts as are the adults. Beetles are found in almost all possible habitats, and feed on a variety of foods. More beetles were caught than any other order of insecta. Consistently, more were caught at 30 meters than at ground level. The ground-trap catch peaked in May and in November, while at the 30-meter level catches were consistently uniform, except for a four-fold increase recorded in June. Beetles caught at the Albrook Forest site have been separated into families, some of which have definite importance in testing programs. The families of beetle which have been recorded in largest numbers, with a synopsis of each, are as follows:

Anthicidae. Antlike Flower beetles. These beetles usually occur on flowers or foliage and are somewhat antlike in appearance; some occur under stones or logs or in debris. Their larvae may contribute to breakdown of woody material.

Orthoperidae. Minute fungus beetles. These beetles are quite small, usually less than 1 mm in length. They occur in and presumably feed upon, decaying vegetable matter and debris.

Cantharidae. Soldier beetles. These are soft-bodied beetles that look much like lightningbugs. Adults are found on flowers and the larvae are predaceous on other insects.

Cerambycidae. Long-horned wood-boring beetles. The adults of this family are largely flower-feeders. The larvae, however, feed almost exclusively on wood. They bore into dead and decaying wood, and some feed on living plant tissues. Many feed on stored lumber and wood products. Some species are vectors of plant diseases.

Chrysomelidae. Leaf beetles. Many leaf beetles are serious pests of cultivated plants. Larvae can be leaf feeders, leaf miners, root borers, or bore in stems. Adults feed on flowers and foliage. Many of these beetles are vectors of plant diseases.

Cucujidae. Flat Bark beetles. Though these beetles are most often found under bark, especially of freshly cut logs, they are almost entirely predaceous on other insects.

Curculionidae. Snout beetles (Weevils). The members of this family, both as adults and larvae, feed on plant materials. They feed on fruit, buds, seeds, nuts, and stems. Some do considerable damage to stored grains and seeds.

Dytiscidae. Predaceous Diving beetles. A large group of entirely predaceous insects that live in streams and pools. They often leave the water at night and are attracted to light.

Elateridae. Click beetles. The adult click beetle feeds on plant materials, and is found on flowers, under bark, or on vegetation. The larvae, called wireworms, are very destructive, feeding on seeds in the soil and the roots of beans, cotton, potatoes, corn, and cereals. Many elaterid larvae occur in rotting logs, under bark or in dead wood, where they may be predaceous.

Elmidae. Riffle beetles. These usually occur on the stones or debris in stream riffles. A few species occur in ponds and swamps, and a few are terrestrial. Their food habits are not mentioned in the literature.

Hydrophilidae. Water Scavenger beetles. These aquatic beetles are entirely predaceous as larvae, and scavenge organic detritus as adults.

Anobiidae. Powder-post beetles. These tiny beetles are excellent borers. Some are able to bore through lead cables, and have been called "short-circuit" beetles. Others in this family are pests of stored foods and products of many kinds. Among the materials they attack are: cereals, tobacco, drugs, spices, meats, dairy products, furniture, fabrics, and furs.

Nitidulidae. Sap beetles. These small (less than 12 mm) beetles are found where plant fluids are fermenting or souring. They feed on decaying fruits, sap, and on some types of fungi. Some feed on decaying animal tissue, and a few on molding wood.

Platypodidae. Pin-hole borers. The beetles in this group are elongate, slender, and cylindrical; brownish in color and 4 to 6 mm long. They are wood-borers that feed on both living and dead wood. Larvae feed on a fungus that develops in the galleries left by the adults.

Pselaphidae. Short-winged Mold beetles. These are small (0.5 to 5.5 mm) beetles that are found under stones and logs, in decaying wood, and in termite nests. They have no economic importance, save in the decay and breakdown of woody material.

Ptilodactylidae. These beetles feed on plant material, chiefly in wet and swampy places. Their larvae are aquatic, or occur in plant roots.

Scarabaeidae. Scarab beetles. This is one of the largest and varied families of the Insecta. There are many species, and their size and habits vary considerably. Many are dung feeders, or feed on carrion, decaying plant materials, and detritus. A few feed on fungi, and many are serious pests of lawns and agricultural crops.

Scolytidae. Engraver beetles. These are rarely over 8 mm in length, and both adults and larvae feed under the bark of both living and dead trees. They feed on a fungus that grows in their borings, not on the wood itself, but do considerable damage in the process. Trees are often girdled and killed by the borings of these insects.

Staphylinidae. Rove beetles. These large (up to 2 cm) insects are almost entirely predaceous. They are quite active, running or flying, and feed in large part on insects that feed in carrion and dung. They are entirely beneficial.

Tenebrionidae. Darkling beetles. This is a large and varied group. Some feed on fungi, some on decaying plant material and detritus, and some are scavengers or predators. A few can become pests of stored plant materials.

REFERENCES

1. US Army Tropic Test Center, Semiannual Report No. 1 and 2, Environmental Data Base for Regional Studies in the Humid Tropics, Fort Clayton, Canal Zone, (1966) 173 pages.

2. US Army Tropic Test Center, Semiannual Report No. 3, Environmental Data Base for Regional Studies in the Humid Tropics, Fort Clayton, Canal Zone, (1967) 173 pages.

3. Williams, Llewellyn, Climatological Conditions Favoring Occurrence of High Temperatures at Yuma Proving Ground, Arizona, US Army Natick Laboratories, Technical Report 67-42-ES, 1967.

4. Schimper, A. F. W., Plant Geography upon a Physiological Basis. Trans. by W. R. Fisher, Edited by P. Groom and I. B. Balfour, Oxford, 1903.

5. Williams, L. Vegetation of Southeast Asia. Studies of Forest Types. 1963-1965. Agricultural Research Service Pub. (Under ARPA order number 424) 1965.

6. Beard, J. S. "The Classification of Tropical American Vegetation-Types", 1955, Ecology 36(1), 89-100.

7. Richards, P. W. The Tropical Rain Forest. Cambridge University Press, 1964.

8. Kenoyer, L. A. General and Successional Ecology of the Lower Tropical Rain-Forest at Barro Colorado Island, Panama. 1929, Ecology 10(2): 201-221.

9. Johnston, I. M. The Botany of San Jose Island. 1949, Sargentia vii: 1-306.

10. Standley, P. C. Flora of the Panama Canal Zone. 1928. Contr. US Nat. Herb. 27: 1-416.

11. Pittier, H. Our Present Knowledge of the Forest Formations of the Isthmus of Panama. 1917, Journal of Forestry 16: 76-84.

12. Wiant, Harry V. The Concentration of Carbon Dioxide near the Ground under Eastern White Pine and Black Spruce Trees. 1966, Advancing Frontiers of Plant Sciences Vol. 16: 197-204.

13. Fonselus, S. F. Koroleff, and K. Buck. Micro-Determination of CO_2 in the Air - with Current Data for Scandinavia. 1955, Tellus 7: 258-265.

14. Voigt, G. K. The Role of Carbon Dioxide in Soil. In Tree Growth. T. T. Koslowski (ed) The Ronald Press Co., New York, 1962, 205-220.

REFERENCES (Cont'd)

15. Laws, J. O. "Recent Studies in Raindrops and Erosion", Agric. Engr., St. Joseph, Michigan, 1940, 21, 431-433.

16. Miquel, P. Les Organismes Virantes de L'Atmosphere. Gauthier-Villars, Paris.

17. Minervini, R. Einige bakteriologische Untersuchungen uber Luft und Wasser inmitten des Nord-Atlantischen Ozeans. 1900, Z. Hyg. InfektKr. 35, 165-94.

18. ZoBell, C. E. Marine Microbiology. 1946, Chronica Botanica, Waltham, Mass.

19. Puschkarew, B. N. "Ueber die Verbreitung der Susswasserprotozoen durch die Luft." 1913, Arch. Protistenk.

20. Hirst, J. M. "Spore Liberation and Dispersal". In Plant Pathology: Problems and Progress, 1908-1958 (Edited by C. S. Holton). University of Wisconsin Press, Madison, 1959.

21. Gregory, P. H. "Fungus Spores". 1952, Trans Brit. Mycol. Soc. 35.

22. Hirst, J. M. "Changes in Atmospheric Spore Content: Diurnal Periodicity and the Effects of Weather". 1953, Trans. Brit. Mycol. Soc. 36.

23. Asai, G. N. "Intra and Inter-Regional Movement of Uredospores of Black Stem Rust in the Upper Mississippi Valley". 1960, Phytopathology, 50.

24. Visser, S. A. "Origin of Nitrates in Tropical Rainwater". 1964, Nature 201.

BLANK PAGE

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

US Army Tropic Test Center
Fort Clayton, Canal Zone

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

Semiannual Report No. 4, Environmental Data Base for Regional Studies in the Humid Tropics

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Semiannual Technical Report: March through August 1967

5. AUTHOR(S) *(First name, middle initial, last name)*

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1968	106	24

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. USATECOM No. 9-4-0013-01

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

No. 4

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Advanced Research Projects Agency
Army Research Office, OCRD

13. ABSTRACT

This fourth semiannual progress report for the Environmental Data Base Project presents a review of Project objectives and scope, with descriptions of the observational sites, and summarizes Project activities during the period of March through August 1967.

The Climate section (Part IV) briefly outlines the types of micrometeorological data observed and instrumentation used. A detailed discussion is given of the problem areas encountered in acquiring such data in the humid tropics, together with those solutions that have been evolved. An analysis of the spatial and temporal frequency distributions of temperature and humidity values is presented.

The Soils and Hydrology section (Part V) contains interim data on Soils parameters at one satellite site.

The Vegetation section (Part VI) consists of an analytical discussion of the floristic characteristics of the Albrook Forest site.

The section on Microbiology and Chemistry of the Atmosphere (Part VII) contains a discussion on the concentration of carbon dioxide in the tropical atmosphere, as well as a paper on the microbiological content of rainwater.

The Macrofauna subtask of the Project, covered in Part VIII, presents the preliminary results of an insect collection program, carried out at different levels.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Humid Tropics						
Tropic Environment						
Climate						
Microclimatology						
Micrometeorology						
Soil Trafficability						
Tropic vegetation						
Microbiology						
Atmospheric contaminants						
Data Base						