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TROPICAL VEGETATION MEASUREMENTS

Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland

10 April 1973

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13. ABSTRACT

Describes a technique for predicting the number of trees in large areas of tropical forests from small samples. Also describes a method for estimating tree height from tree diameter.

The techniques described have applications in evaluating the effects of vehicular mobility, weapons and/or munitions, electromagnetic propagation, surveillance systems, and air-delivered items in tropical forests.

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TROPICAL VEGETATION MEASUREMENTS

SECTION I
GENERAL

1. Purpose and Scope.

a. This document establishes procedures for:

(1) Predicting the vegetation stem density of large areas of tropical forests based on field measurements from small sample sites.

(2) Predicting vegetation canopy height based on vegetation stem diameter data.

b. These predictions can be useful in support of tests of ground mobility and weapons lethality. Other applications include tests of electromagnetic propagation, surveillance systems, and air-delivered items.

c. The vegetation stem density sampling and prediction techniques described herein have been validated in mature tropical wet, and mature and immature tropical moist forests located within the Canal Zone (reference 2). The techniques described for predicting canopy height as a function of stem diameter were found to be applicable in these same forest types, with the exception of the palm swamp trees in tropical forests where the vegetation is characterized by atypical growth patterns. These procedures are believed to have equal applicability in similar tropical forest associations located in wet-warm and wet-hot climates as defined in AR 70-38 (reference 1). If attempts are made to use the techniques described herein in temperate forests, they should first be validated.

2. **Basic Information**.

a. The parameters of vegetation significant for tropic testing are numerous, and include type, structure, height, and population density. For example, to determine the performance of a vehicle traveling cross-country, it is necessary to know the diameter of tree stems encountered and the population density of the stand. Data of this nature are required for vehicular studies because vegetation is a collection of objects distributed in such a way that they must be either overridden or avoided. If a vehicle cannot override a stem of a given diameter, then it probably cannot override a stem of greater diameter and, therefore, these stems must be avoided. The spacing of these stems will also influence immobilization. Similarly, the lethality of a weapon is also dependent upon the density of vegetation. The "killing" radius of a warhead is influenced by the amount of degrading material or vegetation density that is available to attenuate the shrapnel dispersion. These performances must not be overestimated or underestimated significantly by poor sampling techniques.

b. Collection of adequate data on such parameters in order to quantify the environmental conditions under which tests are conducted can become a complex, time-consuming, and expensive task. However, the simplified method for collection of vegetation data described herein has proven to be satisfactory when used in tropical forests in the Canal Zone.

SECTION II
TECHNICAL PRESENTATION

3. **Selection of Sampling Sites**. The procedures described herein are used to determine whether an area selected for conduct of tests meets the requirements of the test plan, i.e., the test plan may call for conduct of tests within areas having a certain stem density or canopy height. The only requirement for selection of the location(s) of the sampling site(s) is that each site selected in a tropical forest must contain only one vegetation type for each set of sampling points taken. If the area to be characterized is extremely large, as might be the case for cross-country mobility tests, and it contains more than one vegetation type, a separate set of data must be collected for each.

a. Typical major tropical vegetation types existing within the Canal Zone are shown in figures 1 through 6 and are described in the following subparagraphs:

(1) Mangrove Swamp—A general view of a typical mangrove swamp is shown in figure 1. This type of forest is a complex of plant communities that covers large areas fringing sheltered tropical shores. The dark green, shiny foliage and the apparently

Figure 1. Mangrove Swamp Trees

impenetrable tangle of roots (figure 2) are the most characteristic features of this type of forest. Typically, mangroves are found on sheltered muddy shores where the land is encroaching on the sea; they also grow on coral reefs and on sandy shores where there is little accretion.

(2) Palm Swamp–Figure 3 illustrates the characteristics of a typical palm swamp. The dominant vegetation in most tropical American fresh water swamps is palms varying in size from 2 to 60 centimeters DBH (diameter of tree stem at breast height–1.37 meters) and 3 to 12 meters in height. Generally, the palm swamp forest does not have any understory vegetation except for small shrubs and/or succulent plants that occur on islands or hammocks where the ground surface is slightly elevated. Extremely wet conditions prevail during approximately 10 months of the year within this type forest and pools of fresh water stand throughout the swamp.

(3) Immature Tropical Moist Forest–An immature tropical moist forest (figure 4) occurs where the land has recently been cleared and young jungle tangle has appeared. The general characteristics by which the test officer can recognize an immature tropical moist forest are as follows: (a) the canopy consists of small trees, shrubs, vines, and succulent plants with an average height of 5 to 12 meters; (b) the average DBH of the canopy species is 4 to 8 centimeters; (c) the canopy is extremely irregular with a total coverage of 40 to 60 percent; and (d) the understory is extremely dense making movement through the area difficult. The ragged canopy allows many sun flecks on the jungle floor; ambient illumination is generally high, averaging 30 to 50 footcandles during the wet season.

(4) Mature Tropical Moist Forest–Mature tropical moist forests as shown in figure 5 occur widely where land has been allowed to remain fallow. The general characteristics of such forests are: (a) the canopy is extremely irregular with an average height of 16 to 20 meters, (b) the average DBH of the canopy species is 20 to 35 centimeters, (c) the canopy coverage is 60 to 80 percent, and (d) the understory is dense. Ambient illumination is low.

(5) Mature Tropical Wet Forest–There are several different types of mature tropical wet forests, however it is not necessary for the test officer to be able to distinguish between these different types as far as population density is concerned. The general characteristics of this type forest (figure 6) are as follows: (a) the average canopy height is 20 to 30 meters, (b) the average DBH is 30 to 60 centimeters, (c) the canopy coverage is 75 to 100 percent, (d) the understory is generally sparse providing ease of movement, and (e) numerous epiphytes (air plants such as orchids) are usually found in the larger trees. Ambient illumination is very frequently measured at only one footcandle.

b. In order for the test officer to determine the total number of sampling sites that must be used in order to adequately characterize the test area, he must be able to determine how many of the above major tropical vegetation types exist within the area. This can be accomplished by one of the following methods:

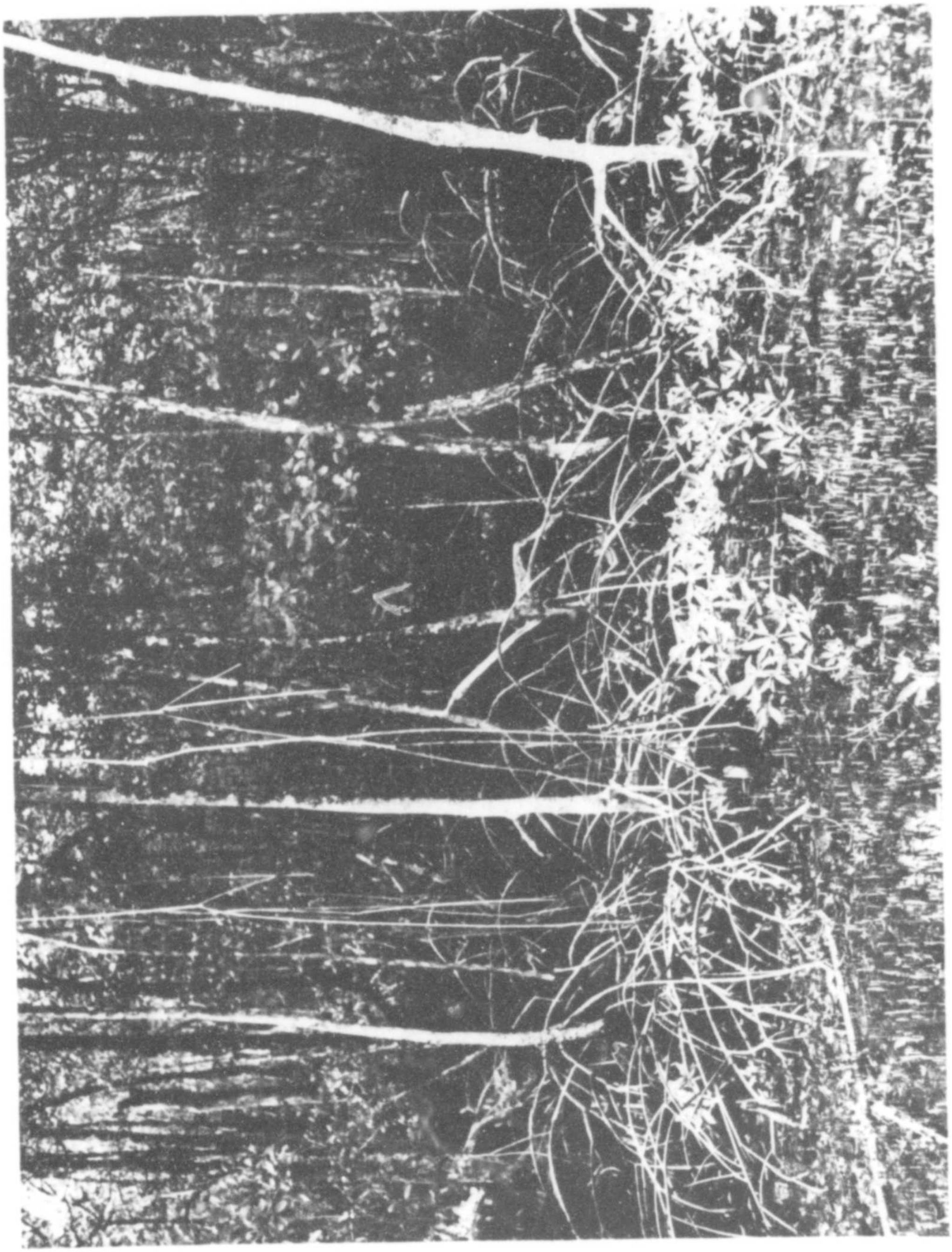


Figure 2. Typical Root Structure of Mangrove Swamp Trees

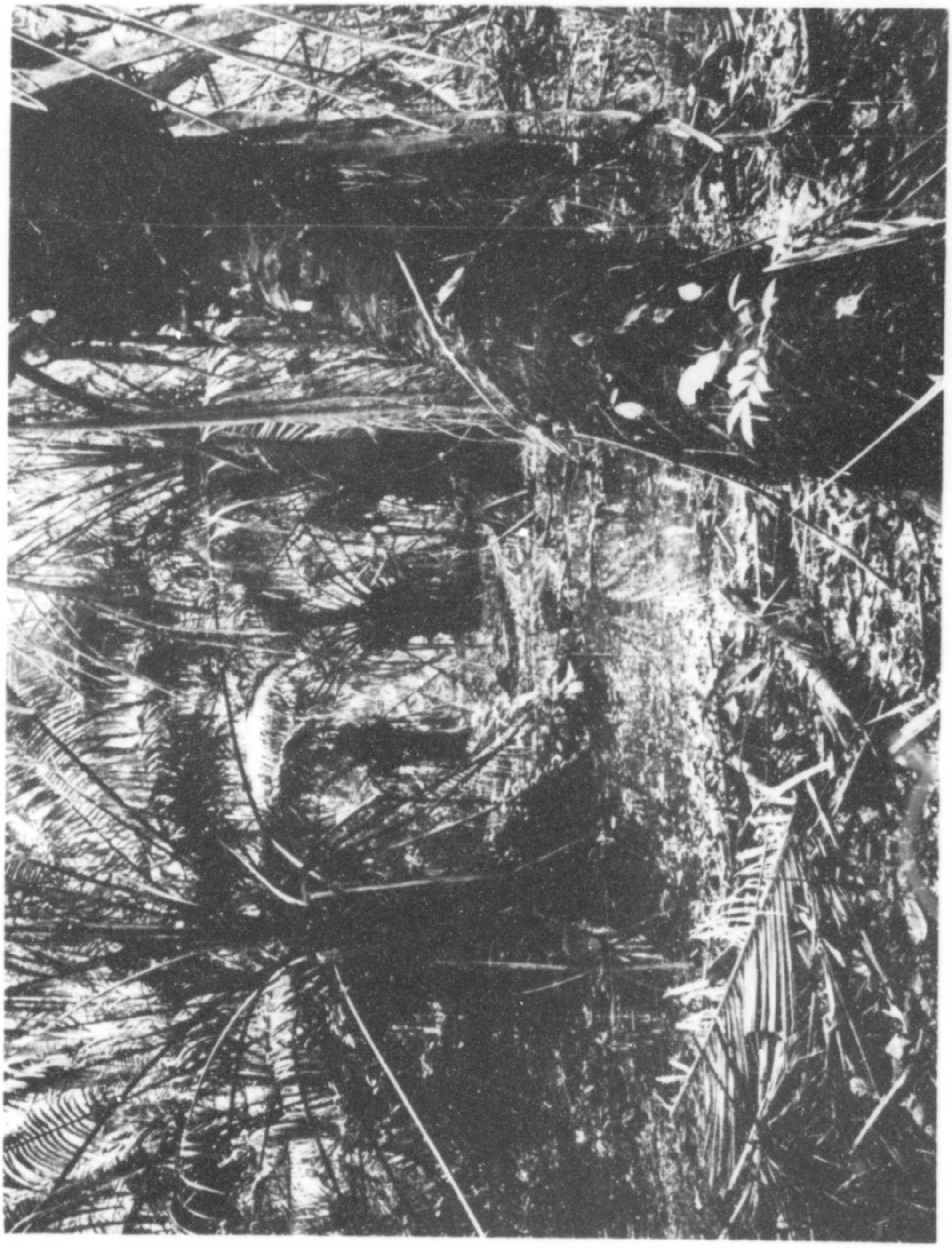


Figure 3. Palm Swamp Trees

Figure 4. Immature Tropical Moist Forest

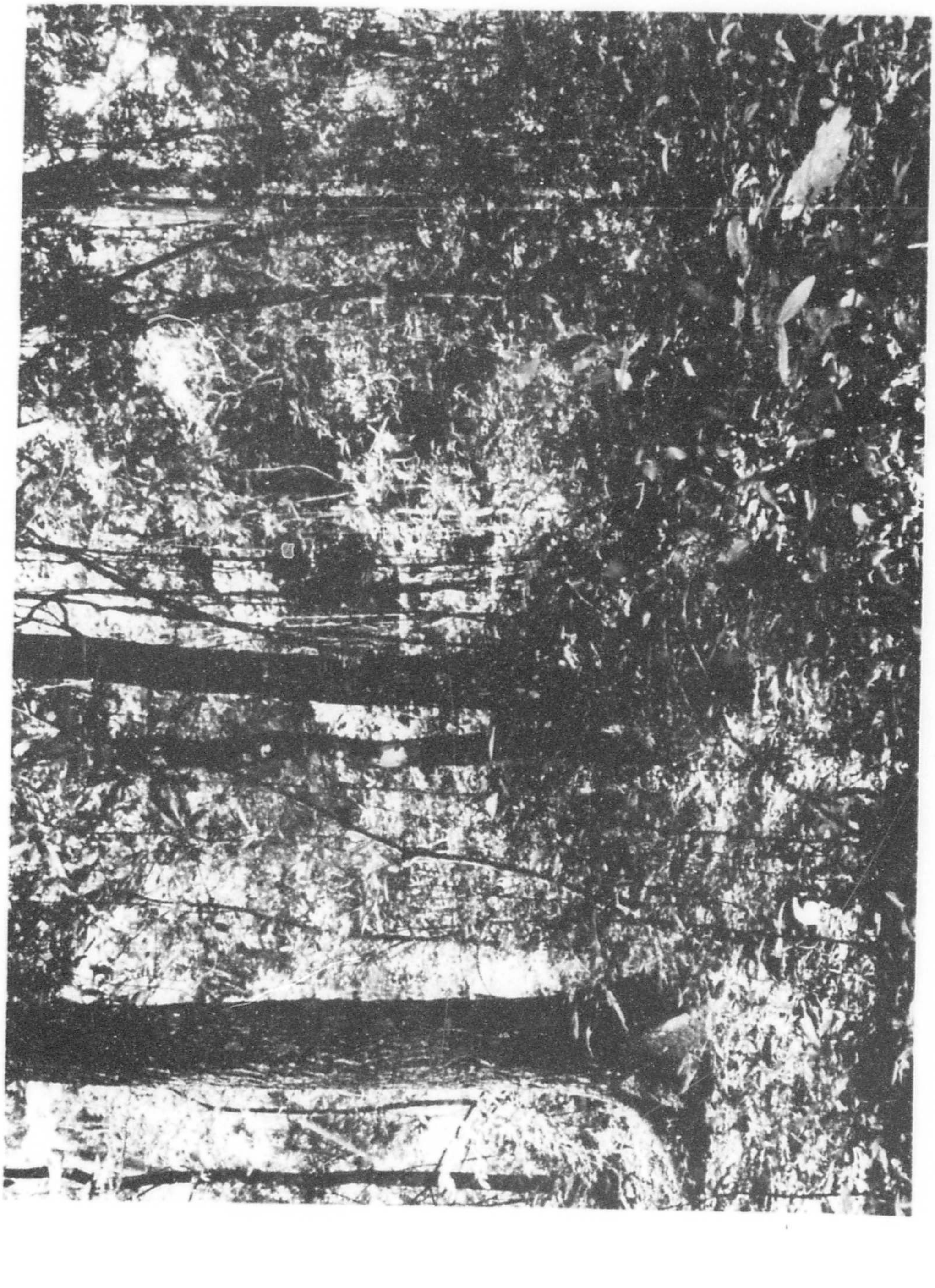


Figure 5. Mature Tropical Moist Forest

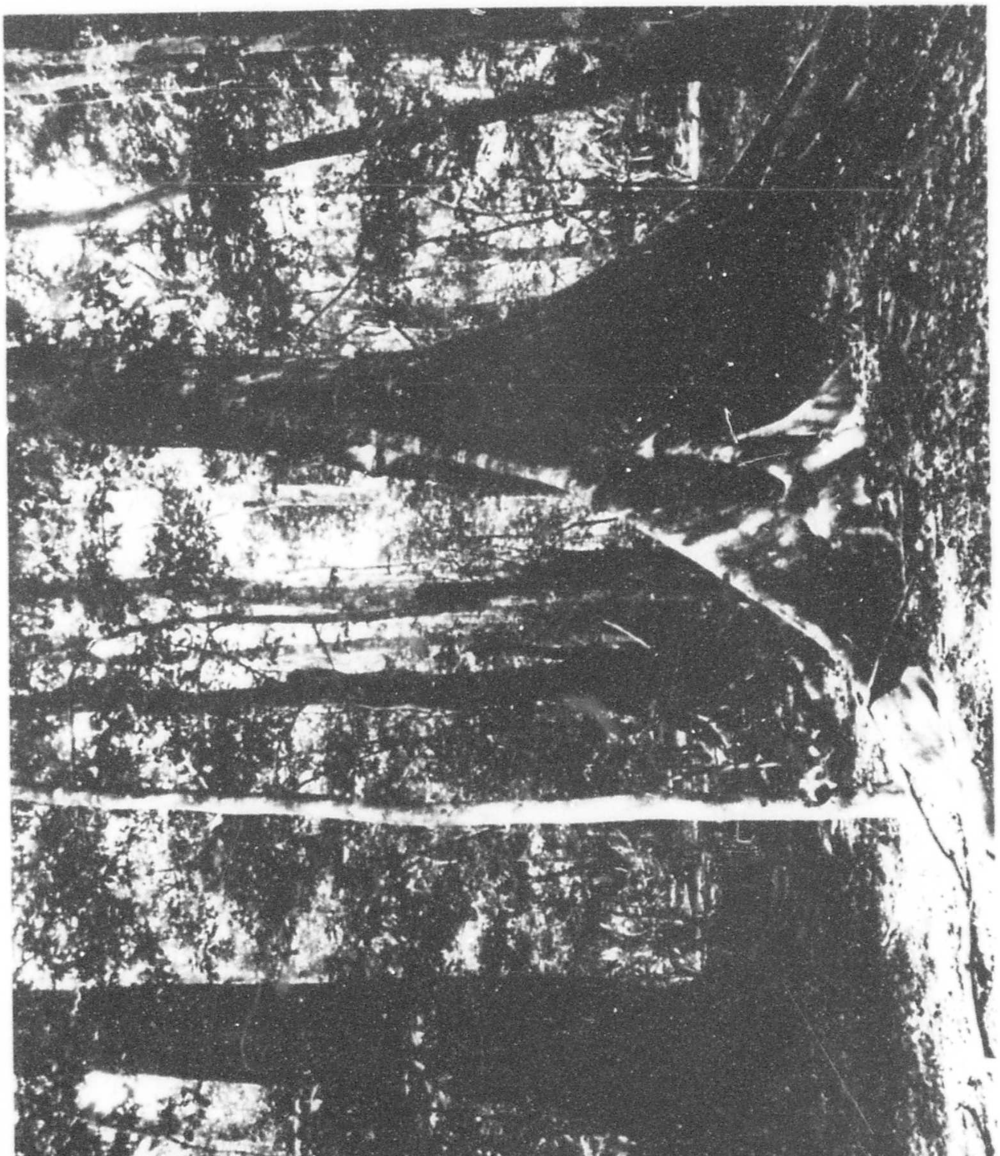


Figure 6. Mature Tropical Wet Forest

(1) The most advisable method for determing the variety of vegetation types present is to seek technical assistance from a botanist, forester, or other scientific personnel knowledgeable in this field.

(2) In the event technical assistance is not available, the test officer should examine a vegetation factor map of the area of interest. A typical map of this type is shown in figure 7. Such factor maps readily differentiate the boundaries of the various vegetation types existing in the test area. In addition, data collection and preparation of such maps normally will have been accomplished by environmentalists who have expertise in the classification of vegetation types; i.e., foresters, botanists, or ecologists; and the resulting maps can be considered highly reliable.

(3) Another conventional method for determining the number of sampling points required to adequately characterize an area is through examination of aerial photographs of the area such as shown in figure 8. This, however, requires the services of experts in the field of image interpretation which may not be available to the test officer.

(4) The least desirable technique for determining the number of sampling points required is for the test officer physically to walk through the proposed test area to determine if vegetation changes occur. Using the descriptions given in paragraph 3a, above, the test officer can determine readily if there is a change in major vegetation types within his area of interest. If there is a doubt in his mind concerning vegetation changes, he should take another set of sampling data. The greater the number of sampling sites used, the more reliable the data.

4. Equipment Needed. The equipment needed for collection of data is as follows:

a. A 30-meter measuring tape—used to measure distance between trees.

b. A 3-meter stem diameter tape—used to measure diameter of tree stems without the need for applying mathematics to compute stem diameter from circumference of stem; if this type of measuring tape is not available, a regular measuring tape can be used to measure the circumferences of tree stems and stem diameters computed using the following formula:

Equation 1

$$d = \frac{c}{\pi}$$

where d = diameter of tree stem
c = circumference of tree stem
π = constant, 3.14

c. Stem height tables—tables that show the relationship between the stem diameter and stem height of trees, and thus permit determination of the height of a tree merely by measurement of the diameter of the tree stem at breast height. Typical stem heights for tropical vegetation types found in the Canal Zone are shown in tables 1 and 2. If these tables are not applicable, a *haga* altimeter may be used to measure stem heights.

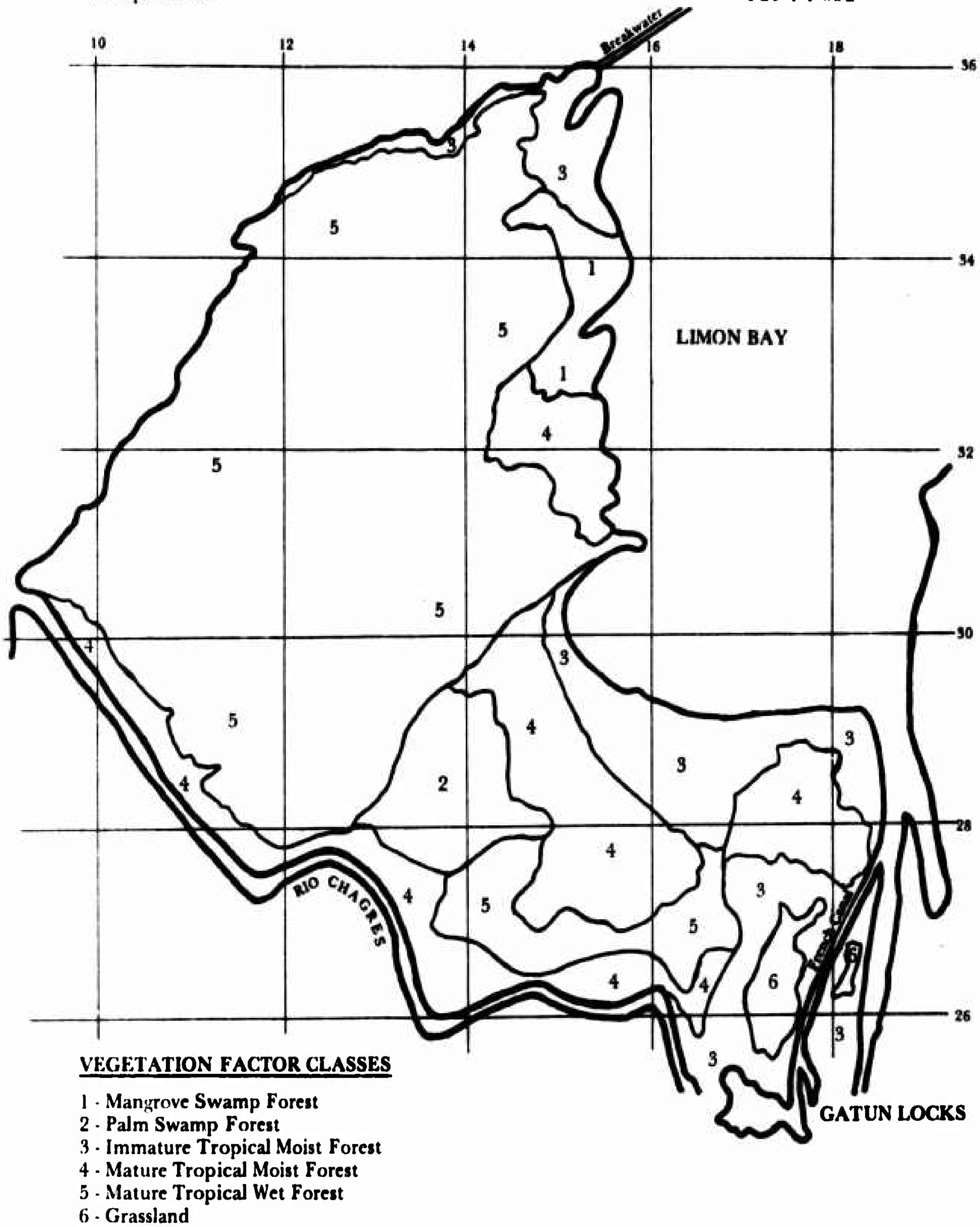


Figure 7. Vegetation Type Factor Map, Fort Sherman Military Reservation, Canal Zone

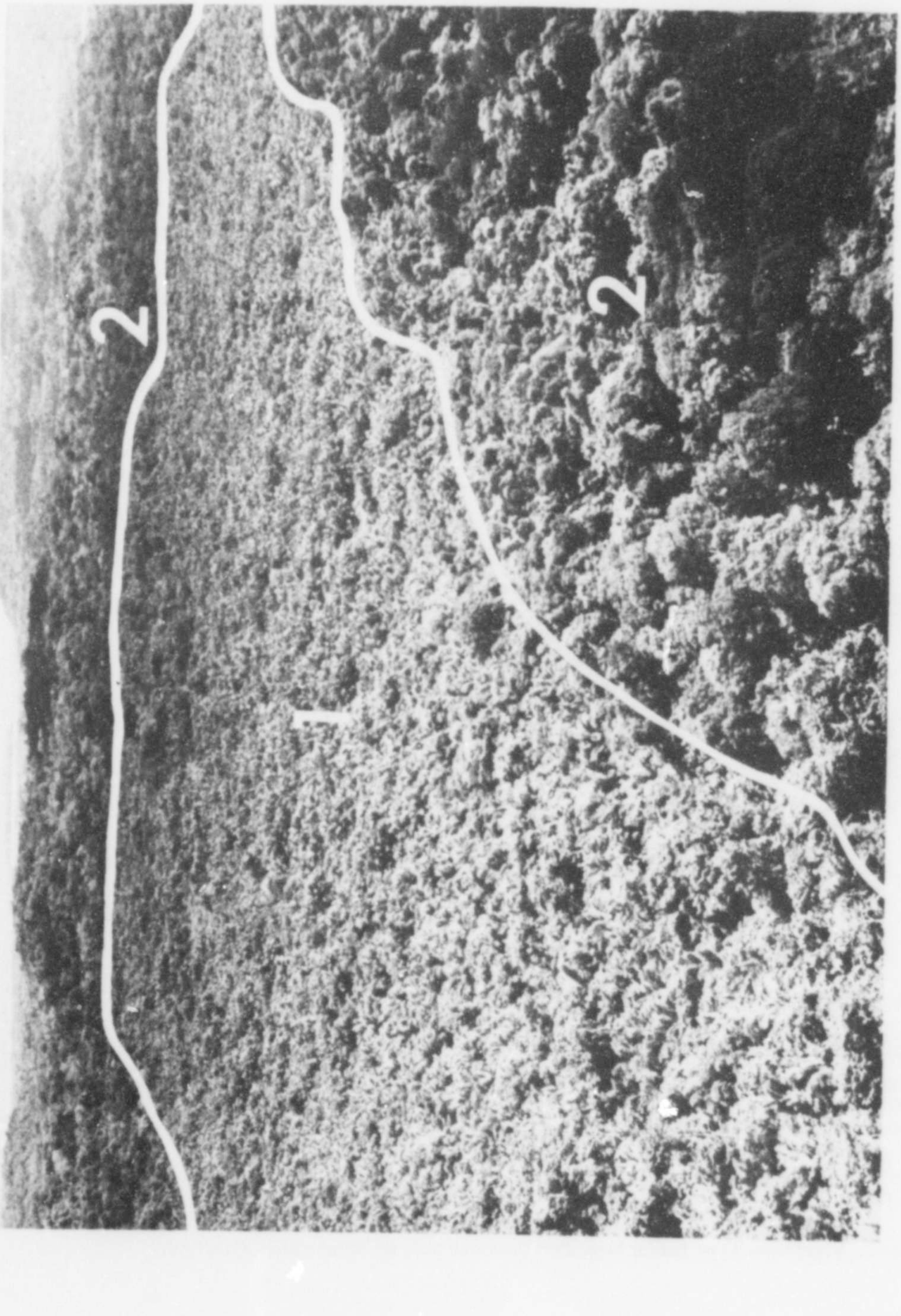


Figure 8. Aerial View of Tropical Vegetation Depicting Differences in Vegetation Types with (1) Being a Palm Swamp and (2) Being a Tropical Wet Forest

Table 1. Relation between Stem Diameter and Tree Height of Mature Tropical Wet and Mature and Immature Tropical Moist Forests

X	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0
Y_c	3.9	6.0	7.7	9.0	10.1	11.1	12.0	12.7	13.4	14.0
X	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0
Y_c	14.6	15.2	15.7	16.1	16.6	17.0	17.4	17.8	18.1	18.5
X	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0		
Y_c	18.8	19.1	19.4	19.7	20.0	20.2	20.5	20.7		

where: X = Stem Diameter (centimeters)
Y_c = Computed Tree Height (meters)

Table 2. Relation between Stem Diameter and Tree Height of Mangrove Swamp Trees

X	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0
Y_c	6.9	8.7	10.2	11.3	12.3	13.1	13.9	14.5	15.1	15.7
X	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0
Y_c	16.2	16.6	17.1	17.5	17.9	18.2	18.6	18.9	19.2	19.5
X	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0		
Y_c	19.8	20.0	20.3	20.5	20.8	21.0	21.2	21.4		

where: X = Stem Diameter (centimeters)
Y_c = Computed Tree Height (meters)

d. Surveyor's flagging tape or paint—used to mark trees selected as sampling centers.

e. Compass—used to select sampling quadrants around trees picked as sampling centers.

f. Data sheets—used to record data.

5. **Data Collection Procedures**. Once the location(s) of the sampling site(s) has been determined, data collection procedures can be initiated using the following techniques:

a. Ten trees should be selected randomly at each sampling site and the tree stems marked, using either a surveyor's flagging tape or paint. The trees selected should not be clustered in one small section of the sampling site but should cover a large representative section of the total area.

b. Each of the 10 trees selected will serve as the center of a sampling point. The immediate area surrounding each tree stem selected is subdivided into four quarters (quadrants) as shown in figure 9, with orientation of these quarters being determined by a compass.

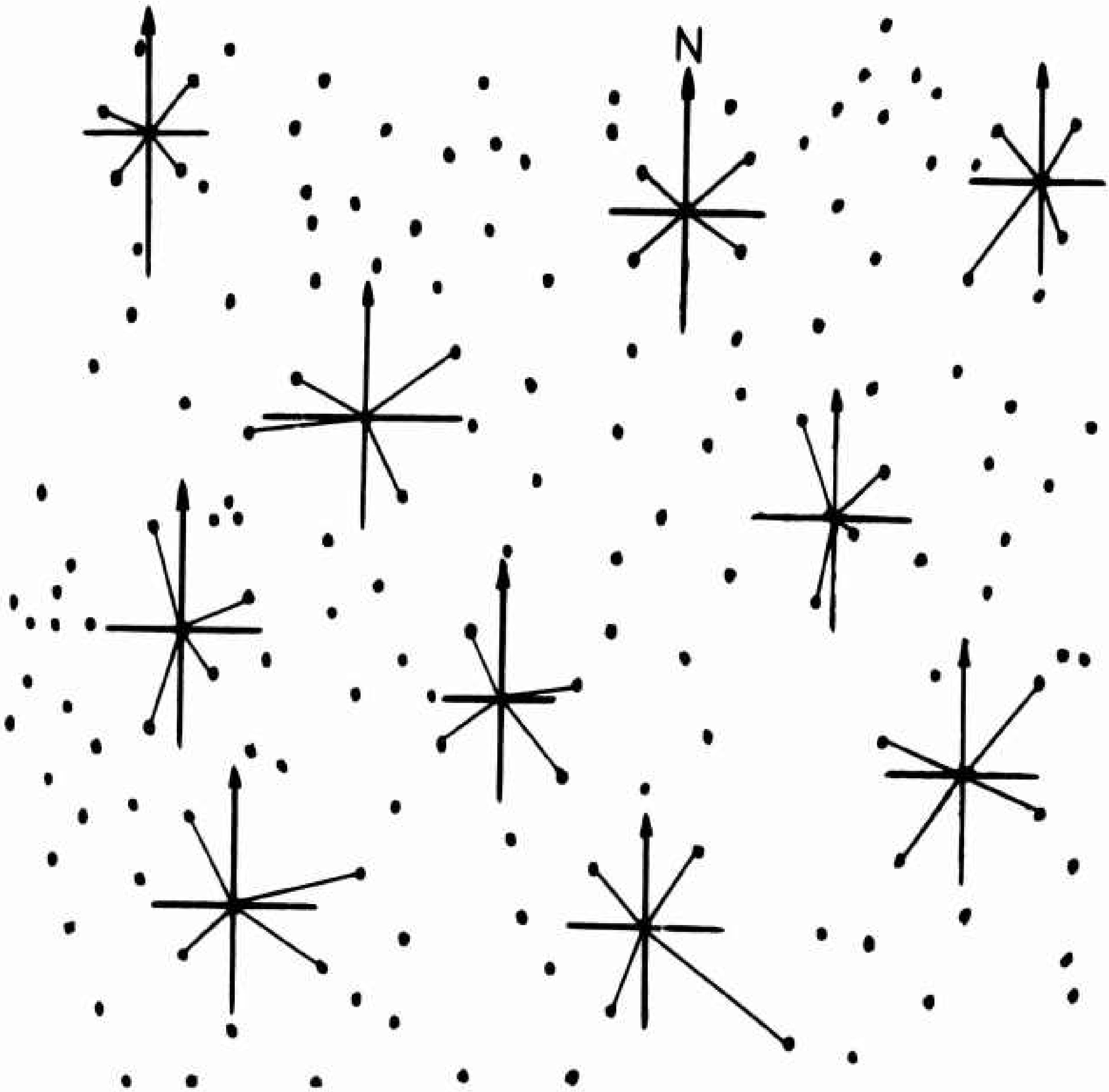
c. At each of these 10 sampling points, the distance [this distance is termed the Nearest Neighbor Distance (NND)] between the nearest tree in each of the quadrants and the tree randomly selected as the center of the sampling point is measured using the 30-meter measuring tape, and the distance recorded using the Data Form shown in appendix B.

d. The stem diameter of the nearest tree in each quadrant is then measured at breast height, i.e., DBH 1.37 meters, using the stem diameter tape and the diameter is recorded on the Data Form.

e. Using the stem diameter measurements obtained in paragraph d, above, and stem height tables as shown in tables 1 and 2 (paragraph 4, above), the stem height of the nearest neighbor in each quadrant can be determined and recorded on the Data Form. An alternate method for determining stem height is the use of a *haga* altimeter; however, this method is more time consuming, sometimes impossible with dense canopies, and leads only to marginal accuracy gains.

6. **Method of Analysis for Determining Stem Density**.

a. As indicated in paragraph 5a, the sample size at each sampling site is 10 random points and at each point four NNDs are measured. Therefore, 40 NND measurements are taken to describe each sampling site within the test area. To determine the population density the following formulas are used:



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• Denotes location of tree stems within sampling site

Denotes location of 10 trees selected as sampling points with area surrounding tree divided into four quarters (quadrants)

Denotes distance between tree selected as sampling point and the nearest tree to it in each of the four quadrants

Figure 9. Diagram of Method for Measuring Vegetation Stem Density

Equation 2 <u>Computation of Mean Nearest Neighbor Distance ($\overline{NND}$)</u>

$$\overline{NND} = \frac{\Sigma D}{40}$$

where ΣD = The sum of the measured distances in meters of the 40 nearest trees in the four quadrants around each of the 10 randomly selected trees.

Equation 3 <u>Computation of Population Density (stems per hectare*)</u>

$$\text{Number of Stems per Hectare} = \frac{A}{(\overline{NND})^2}$$

where A = number of square meters per hectare
$\overline{NND}$ = mean nearest neighbor distance, in meters

An example of the above calculations is as follows: Assume that the sum of the NNDs measured between the 10 sampling centers and each of their four nearest neighbors (total of 40 NNDs) equalled 160 meters. First, equation 2 is used to compute $\overline{NND}$ as follows:

$$\overline{NND} = \frac{160}{40} = 4.0 \text{ meters}$$

Once the computation of $\overline{NND}$ has been accomplished, the population density (stems per hectare) can be computed by applying equation 3 as follows:

$$\text{Number of stems per hectare} = \frac{10{,}000}{(4.0)^2}$$

Number of stems per hectare = 625 stems/hectare

b. The techniques for determining the stem density described thus far yield relatively accurate results for all types of tropic forests where verification tests were conducted within the Canal Zone. Because of the homogeneous characteristics of palm swamp vegetation (figure 3), there is another method for determining stem density characteristics of forests called the structural cell method (reference 3) which yields slightly higher accuracies for this type vegetation—8 percent error as opposed to 16 percent error for the techniques described herein. The structural cell method, however, is far more complicated to use and the data collection time is increased by as much as 300 percent. For these reasons the techniques described herein are recommended for use by test officers in characterizing all tropical vegetation, including palm swamps.

* 1 hectare equals 2.47 acres or 10,000 square meters

7. **Method of Analysis for Determining Stem Height.** Techniques for determining stem height were developed through establishment of a correlation between stem diameter and height. This analysis revealed a high correlation coefficient for all tropic forest types except palm swamp. This latter type vegetation shows little correlation because of its atypical growth pattern (the stem of the tree grows parallel to the ground before vertical growth occurs).

a. Tables 1 and 2 show the relation between stem diameter and tree height as computed using the following equations:

Equation 4. Mature Wet and Mature and Immature Moist Tropical Forests (Table 1)

$$Y_C = 16.79 \log X - 9.13$$

Equation 5. Mangrove Swamp Trees (Table 2)

$$Y_C = 14.53 \log X - 4.36$$

where: Y_C = Calculated Tree Height

X = Measured Stem Diameter

b. In order to determine tree height, one takes the stem diameter measurements obtained as outlined in paragraph 5d and, using either table 1 or 2, determines tree height. For example, if the test officer is characterizing a mangrove swamp and measures a stem diameter of 26.0 centimeters, the corresponding height of that tree would be 16.2 meters (table 2). This latter value (16.2) was determined for table 2 using equation 5 as follows:

$$Y_C = 14.53 \log X - 4.36$$
$$Y_C = 14.53 \log 26.0 - 4.36$$
$$Y_C = (14.53)(1.4150) - 4.36$$
$$Y_C = 16.2$$

This same procedure is used for all 40 trees sampled with the mean tree height of the entire sampling site being obtained by summing up all the tree heights and dividing by the total number of trees sampled, i.e., 40.

c. Figures 10 and 11 show the best fit curve and the 95 percent confidence band for the field data, demonstrating the accuracy to be expected from this established relation between stem diameter and tree height (reference 4).

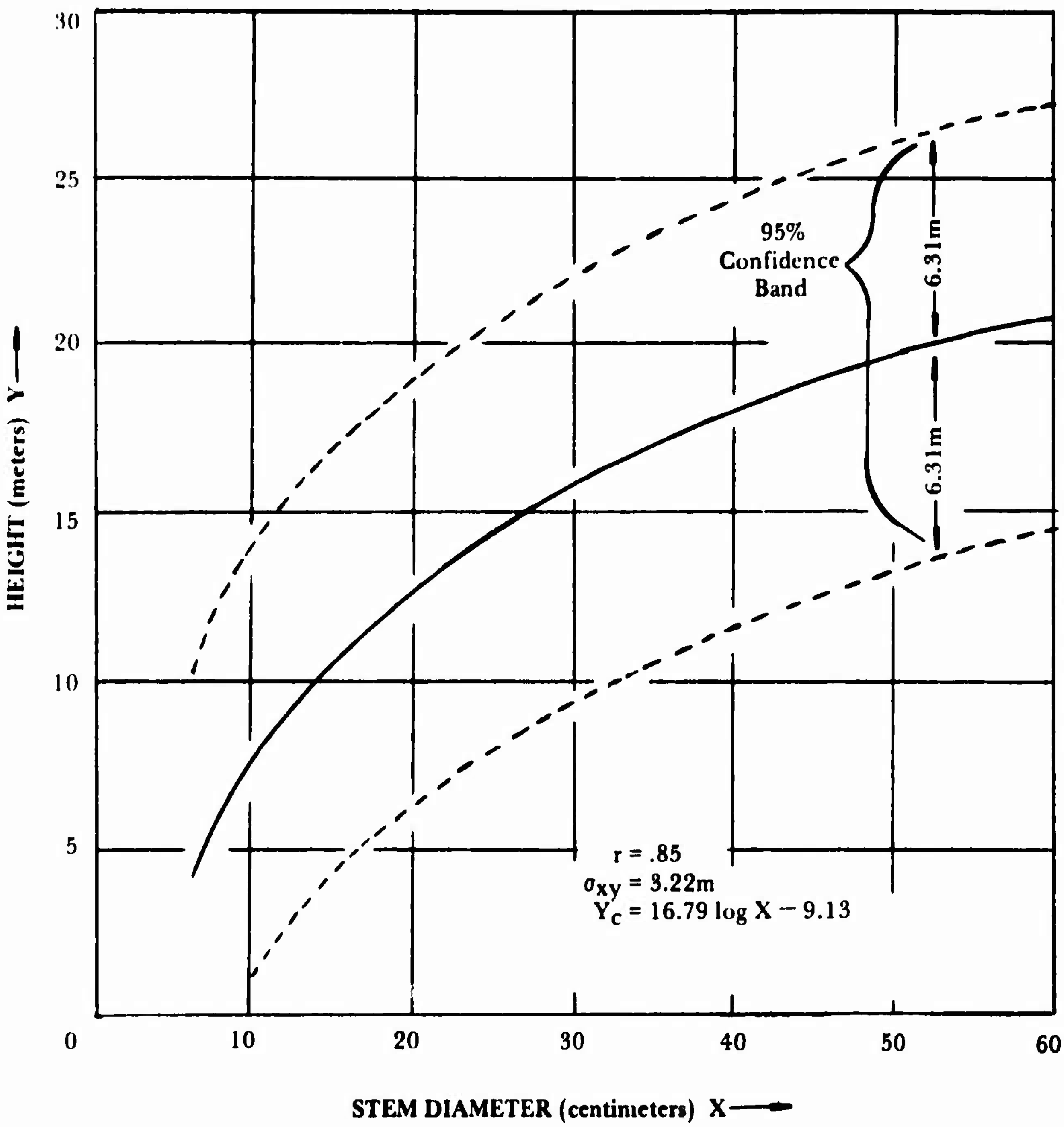

Figure 10. Regression of Tree Height on Tree Diameter in Mature Tropical Wet and Mature and Immature Tropical Moist Forests.

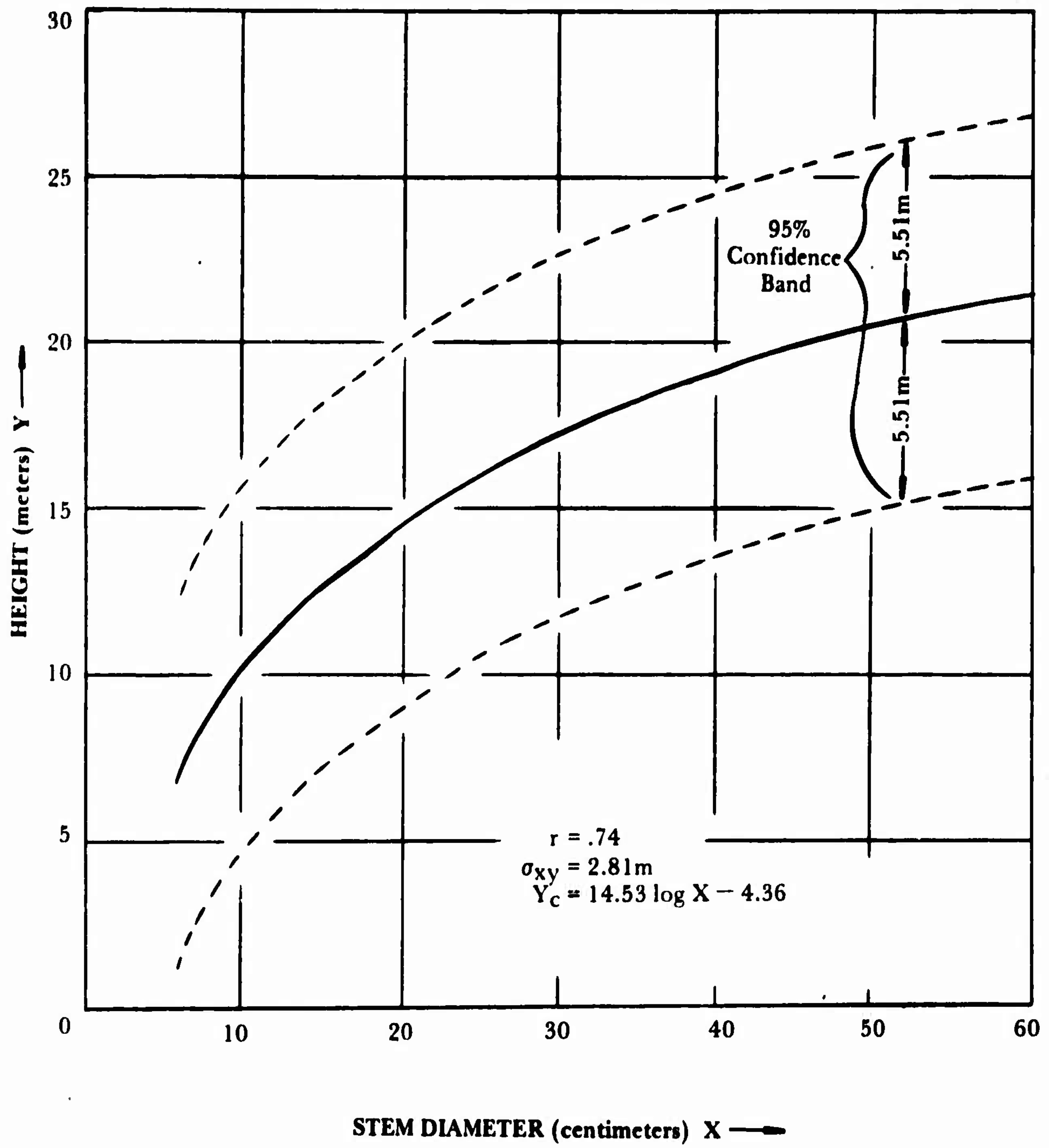

Figure 11. Regression of Tree Height on Tree Diameter in Mangrove Swamp Trees

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APPENDIX A
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APPENDIX B
DATA FORM

VEGETATION STEM DENSITY/HEIGHT FIELD DATA

Date: ____________________

Test Area: ____________________ Grid Coordinates: ____________________

Test Site: ____________________ Forest Type: ____________________

Sampling Center Tree Number	Quadrant	NND (meters)	DBH (centimeters)	Tree Height (meters)
1	1			
	2			
	3			
	4			
2	1			
	2			
	3			
	4			
3	1			
	2			
	3			
	4			
4	1			
	2			
	3			
	4			
5	1			
	2			
	3			
	4			
6	1			
	2			
	3			
	4			
7	1			
	2			
	3			
	4			
8	1			
	2			
	3			
	4			
9	1			
	2			
	3			
	4			
10	1			
	2			
	3			
	4			
TOTALS				22
MEANS				