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TRAINING MANUAL FOR FORESTRY TECHNICIANS IN THE CARIBBEAN

AN INSTITUTE OF TROPICAL FORESTRY PUBLICATION

1985

PREFACE

As part of the U.S. Government's contribution to the Caribbean Environmental Action Plan, the U.S. Agency for International Development funded two training courses for Caribbean Islands junior foresters. The training was conducted at the U.S. Forest Service, Southern Forest Experiment Station, Institute of Tropical Forestry in Puerto Rico. This training was a direct response to the concern expressed by many island governments in a Caribbean foresters meeting held in St. Lucia, that lack of forest training was one of the main limiting factors to forest development in the eastern Caribbean. Both training courses lasted three months and graduated a total of 27 junior staff officers from seven islands. Diplomas were awarded by the Forest Service and by the Caribbean Management Institute of the University of Puerto Rico, co-sponsors of the activity. The training staff and students are listed in the introduction. Case studies prepared by students under staff guidance are published separately. Course coordination was made possible through the effort of Edwin Maldonado of the State and Private Forestry staff of the U.S. Forest Service, Region 8, Caribbean National Forest. Nilda Echevarria acted as course secretary. I am grateful to all these people for the supurb job they did.

This document summarizes the lecture and field materials used in the training. Because of the diversity of staff and the emphasis on field training (50% of the course was outdoors), the manual is not in book-form narrative. Each topic is presented in a three section format: a list of activities, formal narrative and references (if available), and handouts used for illustration purposes. In addition, the manual contains course outlines and other related materials.

ARIEL E. LUGO
December 1984

INTRODUCTION TO THE MANUAL AND SUMMARY OF THE COURSE

Ariel E. Lugo
Project Leader

This introduction has the purpose of highlighting aspects of the course that will help the reader understand the contents of the manual and gain an idea of the major topics covered by the two training courses.

Students were all civil servants (Table 1) and had the equivalent of a high school education. Island governments requested that the courses be as practical and field oriented as possible. The Caribbean Environmental Action Plan required that attention be given to issues on environmental quality and ecology. The outlines of the courses (Appendices 1 and 2) incorporated both requests. Half of the time was outdoors. Staff from federal and commonwealth agencies contributed time as instructors (Table 2). The instructors developed several units or course modules that deserve special attention. I will discuss them in the order they appear in the manual and refer to materials in the manual in support of the description of a particular module.

Ecological Principles

This course module provided a general introduction to ecological concepts (see the list of terms), an introduction to tropical forests and the forests of Puerto Rico, an experience with sampling of soil and plant parts, and a laboratory exercise on the analysis of samples. The introduction to tropical and Puerto Rican forests was through slides including a slide-program developed for this course (enclosed in the manual). Also, the climate and geology of Puerto Rico was discussed in some detail. In addition, students visited most state forests and conducted field exercises designed to familiarize them with the diversity of forests in a Caribbean island. The field exercises and introduction to the forests of Puerto Rico are included in the manual. Finally, students visited the El Verde forest where a radiation experiment had been conducted in 1963-1967, and they sampled soils from disturbed, natural, and plantation environments. They also sampled leaves from different levels in the canopy using a tower available at the site. A day was spent in the laboratory doing chemical and textural analyses of soils, and extracting chlorophyll, phosphorus and potassium from leaf tissue. This exercise was followed by a class meeting where each group reported and discussed the results of their experiments. At the end of this module the students took the same quiz they were given at the beginning. Grades were significantly higher than those obtained the first day of the week.

Air photo interpretation

Students were introduced to the theory and practice of air photo interpretation for a two day period of intensive instruction. Activities included use of stereopairs, interpretation of air photographs of areas

visited by the class, and uses of scales. The material used in this module could not be reproduced for enclosure in this manual.

Land surveying

This part of the course included practical and theoretical exercises. Concepts are outlined in the course handouts. Practice took place first in the parking lot of the Institute and then in the forest. Each student learned the use of such surveying equipment as compasses, chains, levels, protractors, graph paper, scales, etc. Quizzes and constant oral questioning were used to verify progress and understanding.

Dendrology

The emphasis of this unit was to teach the families of trees found in the vicinity of the Institute of Tropical Forestry (the Botanical Garden of the University of Puerto Rico). Students were taught how to identify tree species with a key prepared especially for this course. Learning was verified by having each student key-out unknown specimens. Use of the herbarium, collection of specimens, and their care were also included in this segment.

Mensuration

Part of this unit was conducted in a permanent forest growth plot located within walking distance of the Institute. Trees in that plot had been originally identified by species, tagged, and followed for about 40 yr. Study of past records combined with new measurements yielded information on ingrowth, mortality, and growth of the residual trees. Common log formulae for estimating volumes, standard volume tables, and standard log rules were studied. Differences between mill tally and log scale were presented along with the major types of log defect and methods for estimating cull. Biomass sampling of leaves, branches, and trunks was also done in Rio Abajo, part of the Commonwealth of Puerto Rico forest reserve system, on plantation grown Maria (Calophyllum calaba). In all instances, the data were analyzed in laboratory sessions after field work was completed.

Forest inventory

Techniques for forest inventory were taught by means of field exercises in the vicinity of the permanent forest growth plots. The types of information available from inventories were discussed as were the steps in the conduct of the inventories, among them, objectives, focus, sampling procedure, plot stratification, collection of related data, tree measurements, and summaries of data. Reasons for establishing temporary or permanent plots were also reviewed. Traditional inventory techniques including complete tallies, line plot, and strip cruising were conducted and the basic statistics associated with these techniques (in particular sample size) were studied. Finally the regional inventory of Puerto Rico's

secondary forests was outlined from beginning to end as an example.

To highlight the opportunities available to the forest manager aside from the establishment of plantations, sampling of natural regeneration in 3 different size classes was conducted. The data were again collected in field exercises and analyzed in the laboratory. In the latter exercise, dendrology of the tree species common in the vicinity of the permanent plot was reviewed.

Silviculture

The land use principles fundamental to the selection of forests for silvicultural treatment were revised. The pros and cons of natural forest vs plantations as a source of usable wood were debated. The systems of silviculture and tropical experience with them were summarized. Then, using Puerto Rico as an example, and specifically the Tabonuco Forest type of the Luquillo Experimental Forest, two universally applicable techniques for secondary forest refining were applied and assessed by the students. First was the selection of crop trees within secondary forest and second was marking the competitors to liberate the crop trees, using crown diameter to diameter at breast height ratios as a guide for adequate spacing between crop trees and their competitors. Results were assessed in term of crop trees by species and size per unit of forest area and the number and size of inferior competitors marked by the students for removal. Field crews conducted the thinnings specified by the students and the results were evaluated by the class in a subsequent visit to the forest.

Nursery management

The nursery management module included classroom slide presentations of container and bare-root forest nursery systems being used in four Caribbean countries. Field trips were made to two forest and one commercial ornamental nursery to compare propagation culture techniques, insect/disease control, and management differences between nurseries. Laboratory exercises included assessing soil textures and pH of a nursery soil in which seedlings were growing poorly. From the results, students were to determine why seedling growth was poor. A seed germination practical was also done. Students planted several species of seeds in nursery flats and maintained germination percentage records for two weeks.

Plantations and soils

Classroom lectures and slide presentations were used to discuss whether soils of tropical and temperate regions were different. Major plantation species being studied in the Caribbean were reviewed and advantages and disadvantages of plantation forestry vs natural forest management were discussed. Lectures also reviewed tree improvement techniques for plantation stands, flowering and phenology of tropical pines and hardwoods, and different methodologies to determine growth of plantation forests growing under normal conditions or damaged by hurricanes and other disturbances.

Field practicals for soils included sampling soil depth and soil texture by the feel method in natural forests and plantations. Water percolation rates were compared in heavily-grazed (compacted) and lightly-grazed (non-compacted) sandy soils planted to pines and eucalyptus. Plantation field exercises also included field layout designs for adaptability and provenance trials and a practical exercise in selecting eucalypt and pine "plus trees" in two plantings, using tree improvement grading criteria reviewed in lecture and in the field. Students were taught how to bore young pines with an increment borer to determine age and to learn how to obtain samples for wood specific gravity determinations.

Research (see "Experimentation" in the Plantations and Soils section)

A research primer was developed for this course and included as a module. This primer contains fundamental principles for establishing and monitoring experiments with trees.

Wildlife

Wildlife was introduced at the organismal level, emphasizing an animal's needs and interactions with its environment. Next, the concept of animal populations was emphasized, showing the mechanisms behind their growth and population regulation (i.e., disease, parasites, and predation). The concept of animal populations was then expanded to the community level, with an introduction into energy flow through the community. The concepts of the niche and food web in animal communities were also discussed. Finally, the ecosystem concept was presented in order to show how an organism, populations, and animal communities all interact to form ecosystems. Students were then introduced to wildlife research techniques and the steps necessary in the study of wild animals. An outline of how to plan and conduct a wildlife study was included. Topics included animal marking techniques such as tagging (fish, reptiles, bats) and banding (birds) and an insight into how to conduct animal population counts, explaining various survey and census methods for estimating animal numbers. Topics on wildlife management strategies included hunting and harvest data retrieval, predator control, artificial stocking and the concept of carrying capacity of the environment. Methods were introduced showing how to improve food production, water supply, and animal cover. Steps in treating wildlife damage, diseases and animal control methods were outlined. The unit ends with a discussion of the procedures followed in obtaining wildlife project grants, how to write a grant proposal, and a listing of grant-funding agencies. An annotated list of wildlife publications was provided.

Environmental quality

Air and water quality plus their interaction with vegetative and wildlife resources were the focus of this unit. Staff from government agencies responsible for resource management facilitated these sessions. The unit started with a two day session on environmental education. Then, students learned to perform effective problem solving techniques. They were

asked to investigate and prescribe management measures for vegetation, water, and wildlife of Caribbean ecosystems. They were also required to present the ecological situation for these resources in their home island, and how they would proceed to prescribe treatments to achieve the desired resource balance.

Watershed management

This unit had four parts i.e.,introduction, soil erosion and control, watershed planning and application, and hydrology and water quality. The emphasis was on practical methods to identify and solve soil erosion and water quality problems. In the the first two parts student learned to identify and delineate watershed boundaries on topographic maps and in the field. Causes of soil erosion, cultural techniques to control soil erosion, and the interrelationships between soil, water, timber, wildlife, and recreation were also discussed. For part three, students were assigned to teams and each team was required to develop a prescription for improving an eroded site. Each team solution was discussed in a round table which resulted in the formulation of an ideal solution. Finally, students constructed erosion check dams on the eroded site (see field assignment 1). In part four of the unit, students learned the fundamental principles of watershed hydrology and water quality. Students participated in lengthy field trips with staff of the U.S. Geological Survey who used a mobile laboratory equipped to measure water quality and discharge. Students measured water discharge an practiced various techniques of stream gauging, sampled streams for water quality analyses, and conducted the chemical analyses in the field.

Policy and legislation

Legal aspects of forest management and the doctrines of public trust were discussed during a one day seminar on these issues.

Special activities

A team of forest management specialists spent a week demonstrating under field conditions many of the techniques taught in the class. Exercises included thinning, harvesting, watershed assessments, plantings, operation of chain saws and lumber mills, among others.

Case studies

Each student had to prepare a case study of his/her choice under the supervision of an advisor. Students used the Institute library facilities for this project. Case studies were published under separate cover.

Round table discussions

Four days were dedicated to round table discussions. The idea of these

talks was to give students an opportunity to develop and communicate ideas to their peers. A staff member guided the discussion following each presentation. The subjects of these case studies were: the island and its people, the island forests, uses of the forests, and forestry needs.

Recreation and cultural activities

The Puerto Rico Department of State formally welcomed each group and hosted students at La Fortaleza (the Governor's mansion) and in tours of major attractions in the capital city. Films depicting Puerto Rican culture and other materials were used to orient students and make their stay in Puerto Rico warm. Field trips to different parts of the island were held on Saturdays and sponsored by staff and friends of the Institute. Organized sports (volleyball and basketball) were conducted on Thursday nights. Because soccer is the favorite sport of most islanders, the group was provided with a soccer ball and soon found its way to the University playing fields. Students made many friends and maintained active social calendars. No morale or disciplinary problems developed in either of the two courses. Attendance was nearly perfect.

Administration of the course and logistics

Administering the course would not have been possible without a full time course coordinator and secretary with adequate budget and administrative support. There was a cost overrun in the budget due to an unexpected increase in room and boarding costs. The need for a contingency fund was thus shown. The course also had access to a van that accommodated all course participants, one instructor, and luggage. This vehicle was critical for course success.

Table 1. List of students who participated in the training courses.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY COURSE

COURSE PARTICIPANTS

(January 31 - April 22, 1983)

A. DOMINICA

1. Egbert Bethel
2. Albert Gallion
3. Ronald Charles
4. Stephen Durand

B. ST. LUCIA

1. Augustin Charles
2. Alexander Forde
3. Vincent Ernest

C. ST. VINCENT

1. Lennox Quammie
2. Edgar Williams
3. Brenon Samuel

D. ANTIGUA

1. H.D. McRonnie Henry

E. BARBADOS

1. Roosevelt Greene

F. PUERTO RICO

1. Luis A. Vega
2. Roberto Lantigua
3. Carlos J. Pérez

Table 1. (cont'd)

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

COURSE PARTICIPANTS

(June 3 - August 25, 1983)

A. ST. LUCIA

1. Michael Jules
2. Julius George
3. Peter Vidal
4. Gloria Mortley

B. DOMINICA

1. Ashton Lugay
2. Timothy Harry
3. Randolph Winston
4. Charles Watty

C. ST. VINCENT

1. Gideon Cordice
2. George Beache
3. Kenley Shallow

D. JAMAICA

1. Llewellyn A. Hall

Table 2. Staff responsible for teaching the training courses.

U.S. Forest Service
Institute of Tropical Forestry

A.E. Lugo
J.B. Feheley
J.C. Figueroa
P.L. Weaver
C. Rivera
L.H. Liegel
F.H. Wadsworth
F. Torres
J. Jimenez

U.S. Forest Service
Caribbean National Forest

E. Maldonado
M. Maldonado
L. Santoyo
J. Bauer
J. Zambrana
J. Muñoz
I. Rivera
J. Lefebre
D. Bolinger

U.S. Forest Service
Atlanta

G. Dissmeyer

Department of Natural Resources

J. Stewart
R. Woodbury
J. Vivaldi
J. Gonzalez Liboy

U.S. Geological Survey

P. McKinley

U.S. Soil Conservation Service

A. Sierra

U.S. Fish and Wildlife Service

J. Wiley

Environmental Quality Board

M. Rivera
L. Matos
F. del Valle

Consultant

J. Rodriguez Vidal

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH JANUARY 1983

APPENDIX 1

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
	31 ORIENTATION A. Lugo, E. Maldonado J. Feheley					

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH FEBRUARY 1983

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
		1 CLIMATOLOGY (life zones) AND GEOLOGY OF PUERTO RICO Lecture and Field Trip J. Figueroa	2 Field Trip Cambalache, Río Abajo and Toro Negro	3 Field Trip Susúa, Maricao, Guánica	4 ROUND TABLE 1 A. Lugo and Staff	5
	7 ECOLOGICAL PRINCIPLES A. Lugo	8	9	10	11 NURSERY MANAGEMENT M. Maldonado	12
13	14 NURSERY MANAGEMENT M. Maldonado	15 ROUND TABLE 2 Forests of each participant's country A. Lugo and Staff	16 SURVEYING L. Santoyo	17	18	19
20	21 GEORGE WAHSINGTON'S BIRTHDAY HOLIDAY	22 SURVEYING L. Santoyo	23	24	25	26
27	28 MENSURATION P. Weaver, C. Rivera Figueroa					

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH MARCH 1983

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
		1 MENSURATION P. Weaver, C. Rivera J. Figueroa	2 AIR PHOTO INTERPRETATION John Stewart (DNR)	3	4 FOREST INVENTORY P. Weaver, C. Rivera J. Figueroa	5
	7 FOREST INVENTORY P. Weaver, C. Rivera J. Figueroa	8	9	10	11	12
	14 DENDROLOGY R. Woodbury, J. Vivaldi, C. Rivera	15	16 PLANTATION AND SOILS L. Liegel	17	18	19
	21 INTRODUCTION TO SILVICS F. Wadsworth	22 SILVICULTURE OF NATURAL FORESTS F. Wadsworth, P. Weaver, J. Bauer, J. Zambrana	23	24	25	26
	28 ROUND TABLE 3 Forest Use A. Lugo and Staff	29 FOREST MANAGEMENT F. Wadsworth	30 (AM) ROUND TABLE 4 (PM) POLICY AND LEGISLATION J. Muñoz	31 WATERSHED MANAGEMENT AND SOIL CONSERVATION J. Bauer, A. Sierra P. McKinley		

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TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH APRIL 1983

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
					1 WATERSHED MANAGEMENT AND SOIL CONSERVATION J. Bauer, A. Sierra P. McKinley	2
	4 WATERSHED MANAGEMENT AND SOIL CONSERVATION J. Bauer, A. Sierra P. McKinley	5	6	7	8	9
10	11 WILDLIFE MANAGEMENT J. Wiley	12	13	14 EDM PANEL Private Forestry DNR, SCS, ACSC, Staff	15 ROUND TABLE 5 Forestry Problems A. Lugo and Staff	16
17	18 WOOD UTILIZATION Nursery (SA Team)	19 Harvesting and Lodging (SA Team)	20 Hydrology (SA Team)	21 Silviculture Country Case Studies	22 COUNTRY CASE STUDIES AND EVALUATION	23
24	25	26	27	28	29	

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH JUNE 1983

APPENDIX 2

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3 AM - [illegible] Estate PM - ORIENTATION A. Lugo, J. [illegible], E. Maldonad	4
	6 FIRST AID AND SAFETY I. Rivera, J. Lefebre	7 ENVIRONMENTAL QUALITY INTRODUCTION D. Bolinger	8	9 WATER QUALITY, AIR QUALITY, SOLID WASTE M. Rivera, L. Matos, F. del Valle (JCA)	10 MANGROVES J. Jiménez	11
12	13 COASTAL SYSTEMS J. González-Liboy	14 CLIMATOLOTY AND GEOLOGY OF P.R. J. Figueroa	15 Field Trip El Yunque	16 Field Trip Cambalache, Río Abajo, Toro Negro	17 Field Trip Susúa, Mariana, Guánica	18
19	20 ECOLOGICAL PRINCIPLES A. Lugo	21	22	23 NURSERY MANAGEMENT L. Liegel, J. Rodríguez-Vidal	24	25
26	27 FOREST MENSURATION P. Weaver, C. Rivera F. Torres	28	29	30 ROUND TABLE 1 A. Lugo and Staff		

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

TRAINING SCHEDULE
MONTH JULY 1983

USDA FOREST SERVICE
P. O. BOX AQ
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
					1 FOREST MANAGEMENT F. Wadsworth	2
	4 INDEPENDENCE DAY HOLIDAY	5 INTRODUCTION TO SILVICS F. Wadsworth	6 SILVICULTURE OF NATURAL FORESTS F. Wadsworth, J. Bauer, J. Zambrana	7 →	8 →	9
0	11 SILVICULTURE OF NATURAL FORESTS F. Wadsworth, J. Bauer, J. Zambrana	12 FOREST INVENTORY P. Weaver, C. Rivera F. Torres	13 →	14 →	15 →	16
7	18 FOREST INVENTORY P. Weaver, C. Rivera F. Torres	19 PLANTATIONS AND SOILS L. Liegel	20 →	21 →	22 ROUND TABLE 2 A. Lugo and Staff	23
	25 WATERSHED MANAGEMENT AND SOIL CONSERVATION G. Dissmeyer	26 →	27 →	28 →	29 →	30

19

TROPICAL FORESTRY AND
ENVIRONMENTAL QUALITY SHORT COURSE

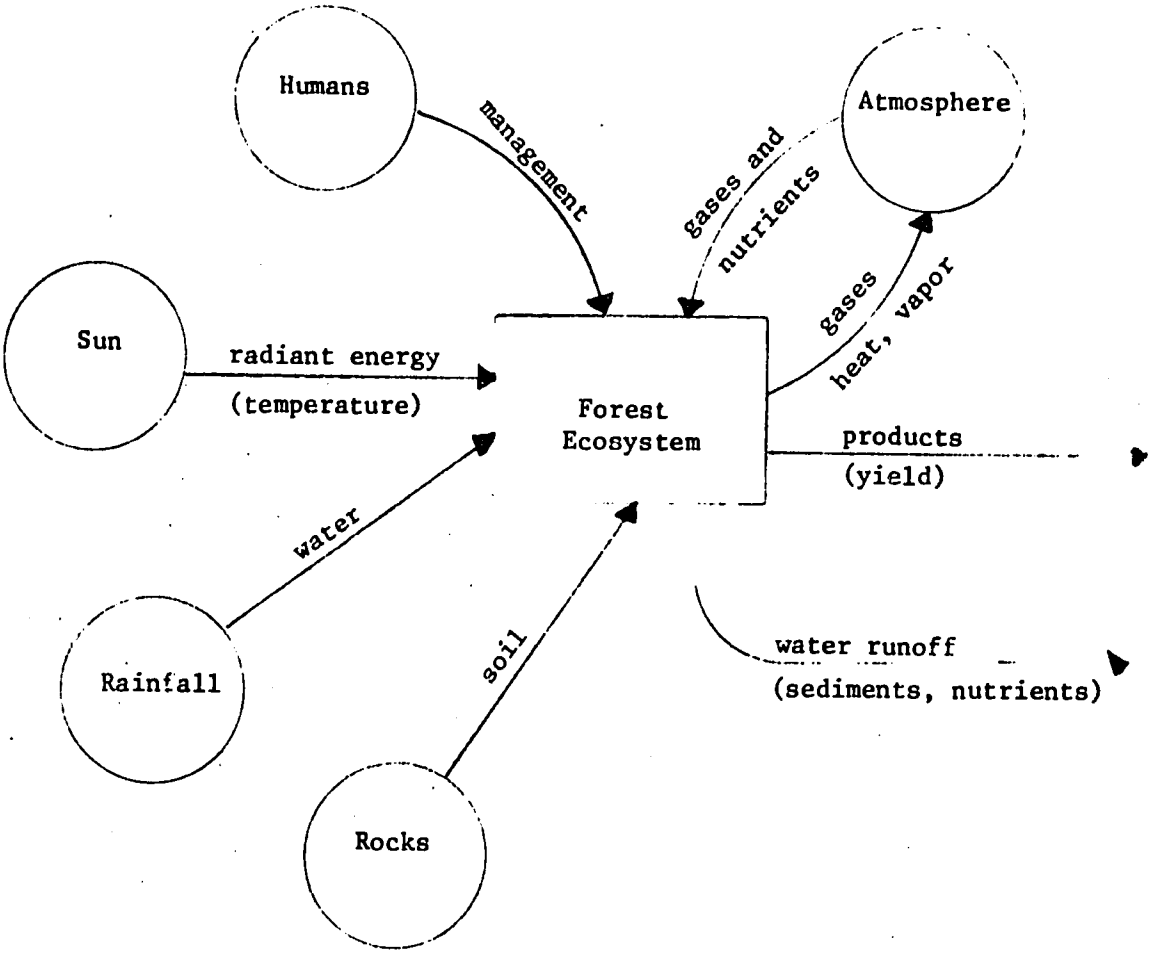
TRAINING SCHEDULE
MONTH AUGUST 1983

USDA FOREST SERVICE
P. O. BOX AO
RIO PIEDRAS, PUERTO RICO 00928
TEL. (809) 753-4335; 763-3939

SUN	MON	TUE	WED	THU	FRI	SAT
	1 WATERSHED MANAGEMENT AND SOIL CONSERVATION G. Dissmeyer, P. McKinley, A. Sierra	2	3	4 WOOD UTILIZATION E. Maldonado	5 WOOD UTILIZATION	6
7	8 SURVEYING L. Santoyo	9	10	11	12	13
14	15 SURVEYING L. Santoyo	16	17	18 AIR PHOTO INTERPRETATION J. Stewart	19	20
21	22 WILDLIFE MANAGEMENT J. Wiley	23	24	25 COUNTRY CASE STUDIES EVALUATION GRADUATION	26	27
28	29	30				

ECOLOGICAL PRINCIPLES

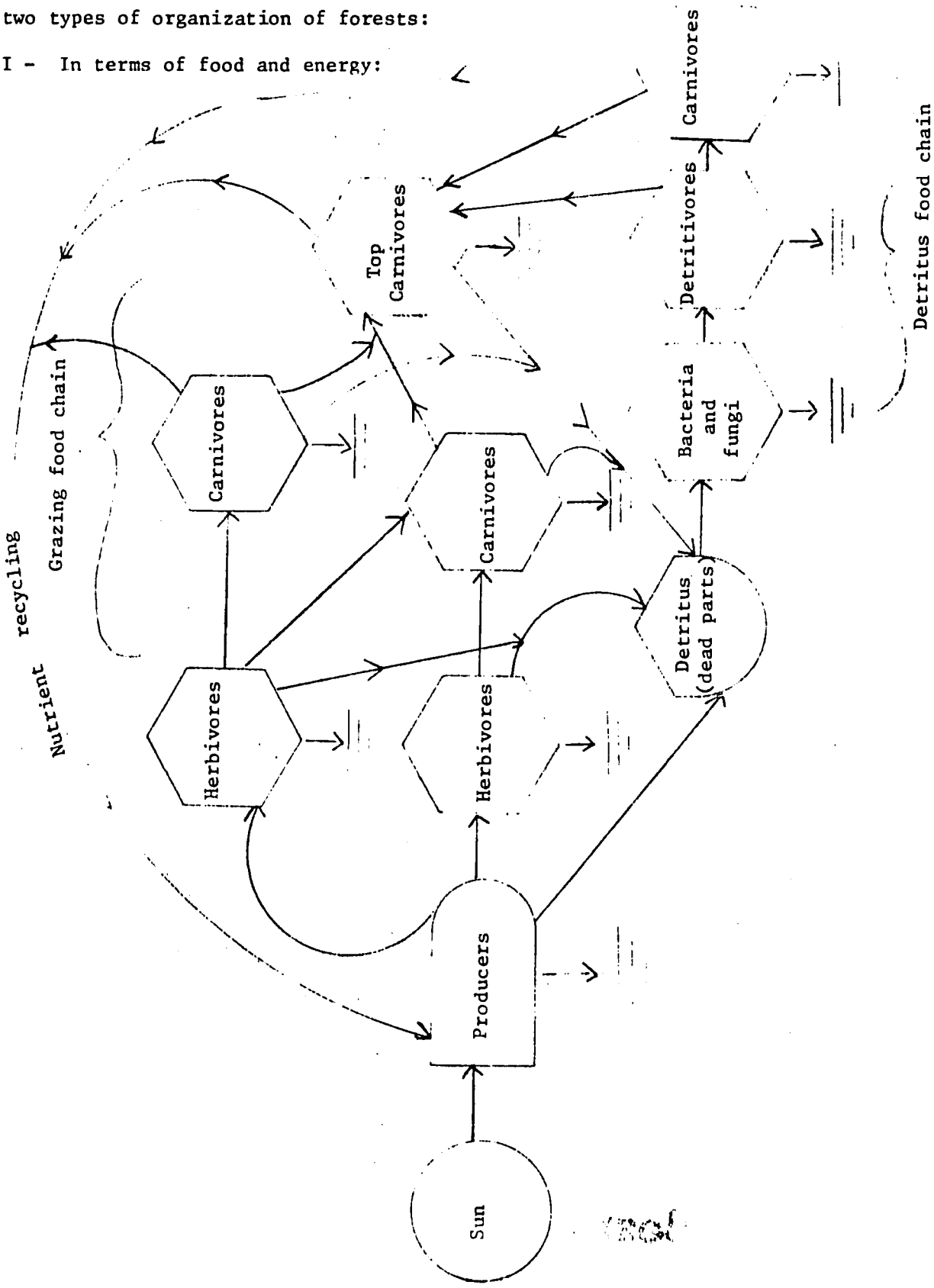
This week we are going to look at tropical forests from an ecological point of view. It is important to understand how forests are structured and how they function because it is from this understanding that enlightened management can occur. Forests are living systems subject to external environmental sources that drive them. If one can identify the critical driving force of a forest, one has a good handle on its management.



Best Available Document

Each forest is organized to take advantage of its environment. Lets look at two types of organization of forests:

I - In terms of food and energy:



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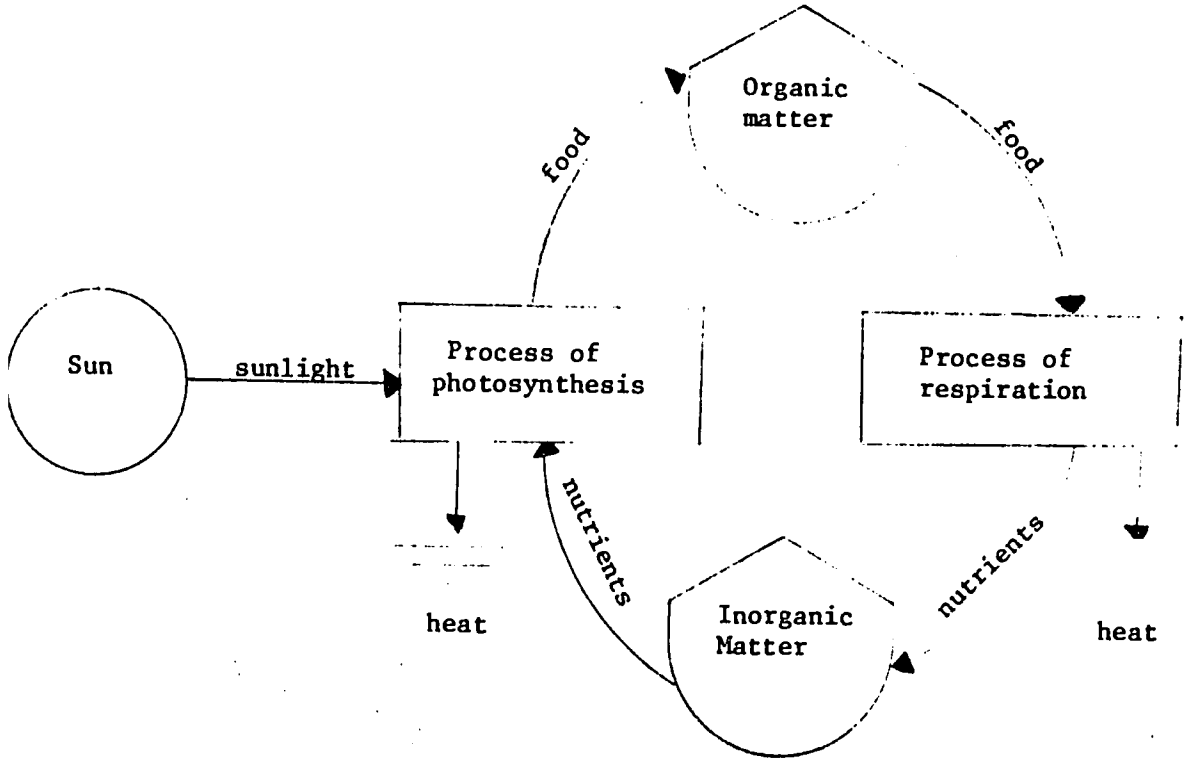
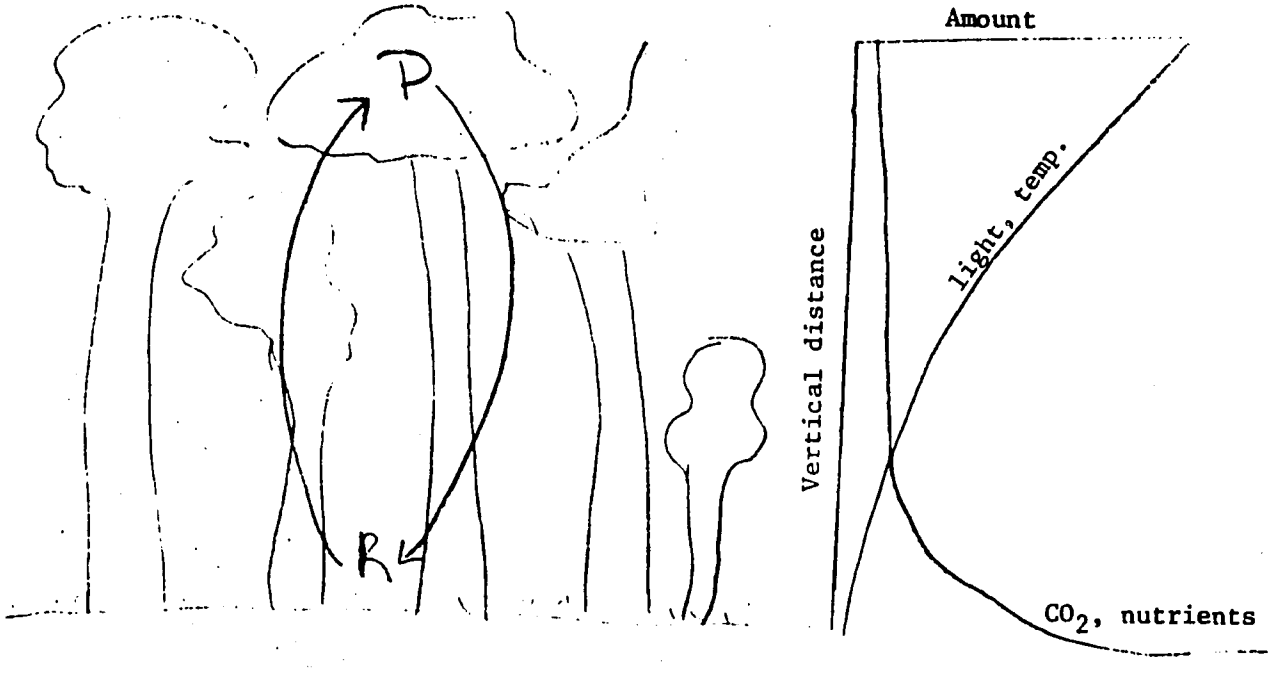


II - In terms of vertical organization:



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Terms You Should Know

1. Forest - A biological community dominated by trees and other woody vegetation.

2. Ecology - The study of ecosystems.

3. Forest ecology - Study of forest ecosystems.

4. Ecosystem - The functional unit of ecology. It includes plants, animals, microbes and their physical environment.

5. Habitat - All environmental conditions that surround a tree or organism.

6. Niche - The role a species plays in an ecosystem. It includes space, time, and species adaptation.

7. Pioneer or successional species - Species of fast growing organisms that occupy niches during the early stages of succession.

8. Succession - The changes that occur in an ecosystem over time.

9. Gap phase species - Those that grow under intermediate light conditions.

10. Climax or shade tolerant species - Those that grow under deep shade. They dominate the late stages of succession.

11. Autecology - Study of populations.

12. Albedo - Light reflection.

13. Solar constant - Solar light intensity at the top of the atmosphere (2 g cal/cm^2. min).

14. Photosynthesis - Conversion of solar energy to chemical energy by plants.

$$\text{Minerals} + CO_2 + H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + O_2$$

15. Respiration - Use of chemical energy to sustain life by all organisms.

$$C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O + \text{minerals} + \text{heat}$$

16. Gross photosynthesis - Net photosynthesis + Respiration.

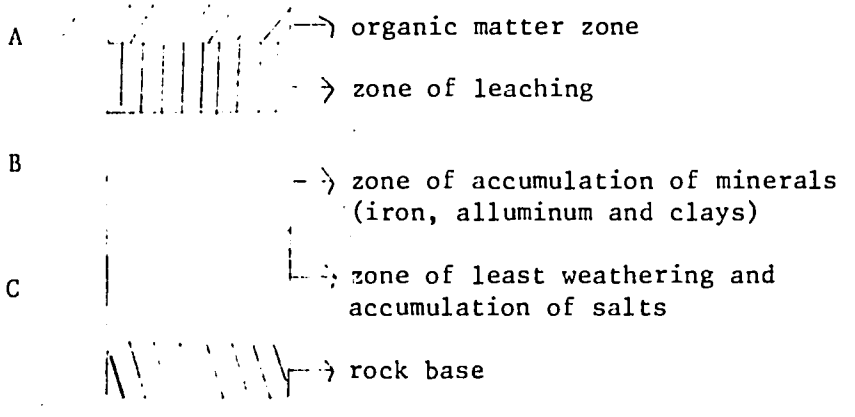
17. Stoma - Gaps on the leaf surface used for gas exchange.

18. Evapotranspiration - Total water evaporation in an ecosystem = transpiration by plants + evaporation from soil and other surfaces.

19. Soil texture - The relative proportions of mineral soil particles of various sizes in soil.

20. Soil structure - The aggregation of soil particles.

21. Soil profile - The different horizons of a soil.



22. Mycorrhizae - Symbiotic fungi that facilitate decomposition and nutrient uptake.

23. Rainfall - Wet precipitation (brings water and nutrients).

24. Dryfall - Dry particulate fall out.

25. Throughfall - Drip through the forest canopy.

26. Stemflow - Water flow over stems.

27. Grazing food chain - A food chain based in green plants.

28. Detrital food chain - A food chain based on dead plant parts.

29. Detritus - Dead organic particles.

30. Food chain or food web - Describes the feeding sequences in an ecosystem.

31. Chlorophyll - Molecule responsible for the capture of light by plants.

Exercise

- Compare the external forces acting on tropical forests vs. those acting in temperate forests.
- Write the equations for the photosynthesis and respiration processes.
- What is the difference between a detritus and a grazing food chain?
- What is the importance of animals and bacteria to the forest?
- In what part of the forest is the
    - temperature highest?
    - O_2 is lowest?
    - CO_2 is highest?
    - nutrients are highest?
    - light intensity highest?

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

ECOLOGICAL COMPONENT

DAILY SCHEDULE

Monday

AM	7:30	-	The Tropical Forests (Lecture)
	9:00	-	Break
	9:30	-	Caribbean Forests (Lecture)
	11:30	-	Lunch
PM	1:00	-	Forests of Puerto Rico (Lecture)
	2:30	-	Review of lectures
	3:00	-	Break
	3:30	-	Planning of case studies
	4:00	-	Adjourn

Tuesday

7:30 - 4:00 Field trip to El Verde to:

- study how forests are structured and how they function.
- compare natural forests and plantations.
- collect samples for laboratory analysis.

Wednesday

AM	7:30	-	Principles of Forest Ecology
	9:30	-	Break
	10:00	-	Principles of Forest Ecology
	11:30	-	Lunch
PM	12:30-4:00		Work in Laboratory

Thursday

AM	7:30-11:30		Complete laboratory work
	11:30	-	Lunch
PM	1[illegible]:30	-	Class reports on laboratory work
	3:00	-	Break
	3:30	-	Review
	4:00	-	Adjourn

Name: _____ Date: _____

Country _____

QUIZZ

Define the following ecological terms:

1. Forest -

2. Ecology -

3. Forest ecology -

4. Ecosystem -

5. Habitat -

6. Niche -

7. Pioneer or successional species -

8. Succession -

9. Gap phase species -

10. Climax or shade tolerant species -

11. Autecology -

12. Albedo -

13. Solar constant -

14. Photosynthesis -

15. Respiration -

16. Gross photosynthesis -

17. Net photosynthesis -

18. Yield -

19. Stoma -

20. Evapotranspiration -

21. Soil texture -

22. Soil structure -

23. Soil profile -

24. Mycorrhizae -

25. Rainfall -

26. Dryfall -

27. Throughfall -

28. Stemflow -

29. Grazing food chain -

30. Detrital food chain -

31. Detritus -

32. Food chain or food web -

33. Chlorophyll -

34. Producers -

35. Herbivores -

36. Carnivores -

37. Parasites -

28. Epiphytes -

29. Mineral cycle

30. Decomposer -

An Introduction to the Forests of Puerto Rico

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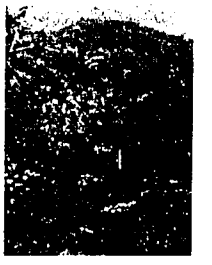

Slide 1 At the time of its discovery the island of Puerto Rico was 100% forested. Those who first saw the mountains of the island would have had a view such as this one. The palm forest in the center of the slide represents one of the major forest types on the island. Behind the palm forest one can see the smooth canopies of the lower montane forest. Towards the back one can see continuous forest cover to the tops of the mountains where the cloud forest is found. It is unusual to see the mountain tops because these areas are usually covered by clouds. (photo by A.E. Lugo).

Slide 2 Unfortunately, Puerto Rico did not stay fully forested for long. This is how the island looked during the 1940's. With intensive use of the land for agriculture and while meeting the demands of overpopulation, Puerto Rico lost over 90% of its original forest cover. Today, the island is greener (30% forested) than it was when this slide was taken because land is no longer used as before. We now import most of our food and energy. But, if we had to depend on the land again, our chances of doing better than we did before would be enhanced if we understood the forests and managed the land with care and understanding. The slides that follow serve as an introduction to the forests of Puerto Rico. It is a very general introduction and you are all encouraged to study the suggested readings where much more detail about our forests is given. (Photo by F. Wadsworth).

The presentation has the following parts: 1) a description of the factors that determine forest structure and function (7 slides), 2) a general discussion of terrestrial forests (35 slides), 3) an introduction to wetland or swamp forests (9 slides), and 4) an overview of uses, values, and management problems of forests (21 slides).

The forests of Puerto Rico have many characteristics in common with Caribbean forests in general (e.g., they share many of the same species) and with those of the American tropics. There are many ways of classifying tropical forests. We will not concern ourselves with classification in this slide presentation. The emphasis will be on forest structure and function, and the factors that regulate them.

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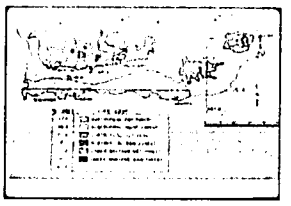
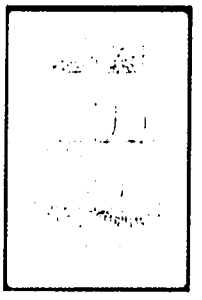
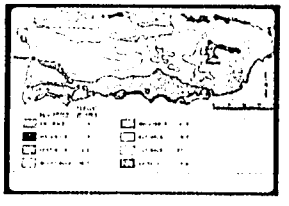
Slide 3 This map of Puerto Rico shows six life zones that support forest growth on the island. A life zone is a set of environmental conditions that support forest types not found in other life zones. The life zone is defined by rainfall, biotemperature, and evapotranspiration. There are about 120 life zones in the world. Sixty eight are in the tropics and 32 of these are forested. Because temperature varies little throughout Puerto Rico, rainfall and evapotranspiration are the main determinants of forest types. The wettest area in Puerto Rico and the one with least evapotranspiration is the East Peak in the Luquillo Experimental Forest. The driest is the southwestern region. Most of the island is moist with intermediate rainfall and evapotranspiration. The slide also gives the location of public forests. (From Birdsey and Weaver).



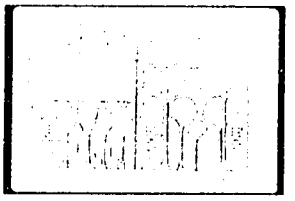
Slide 4 This diagram explains the differences that occur in the structure of tropical forests along a height gradient. The proposed causal force is the decreasing atmospheric saturation deficit with altitude. *A* has the tall forest of the warm lowlands. These are the forests that one would find at the base of the mountains where the saturation deficit and rate of evapotranspiration are high. Trees are large with platform support, and with large roots that turn inward into the soils (slide 28). *B* shows the lower montane forests such as the tabonuco forest (slides 11-15). Here all the large roots are on the surface of the forest. Trees are of intermediate height. The air is moist and saturation deficits are of intermediate value. *C* represents the cloud forest which is located above the condensation level of clouds. Here most roots are in the soil organic layer and above the soil which is waterlogged (slide 52). Cloud-laden saturated wind reduces potential evapotranspiration and sculptures the vegetation. As a result of the combined effects of waterlogged soils, high wind velocity, and the low saturation deficit, the stature of the forest is reduced. (From Odum and Pigeon).



Slide 5 Soil is another important determinant of forest type. It modifies the impact of climate and may override it. This map of soil orders in Puerto Rico shows their diversity. All but one of the major soil orders of the world are represented. These are subdivided in soil series. There are about 164 soil series in Puerto Rico. Each has a different texture, fertility, and water-holding capacity. By superimposing soil and climate maps it becomes clear that the potential number of forests types in the island is large. We know very little about this variability. However, in the Maricao State Forest, the vegetation is influenced by the unique serpentine soils. Similarly, the limestone region supports unique tree species combinations. (From Birdsey and Weaver).



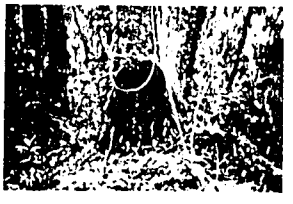
Slide 6 On the average, Puerto Rico is subject to a hurricane once every ten to twenty years. The ecological role of hurricanes is extremely important because they can destroy forests and exert strong selective pressure over plant and animal species. They affect the physiognomy or form of the surviving forests. This slide compares the structure of Puerto Rican forests (left) with tropical forests in areas not subject to hurricanes (right). Forests under the influence of hurricanes are shorter, contain many vines and lianas, have even tree canopies, and support many trees with small canopies. In contrast, forests not subject to hurricanes grow taller because emergent trees are not pruned back by hurricane winds. Individual canopies are larger and tree density is lower. The stratum of dominant umbrella type trees is missing in the forests of the Caribbean. Our trees are rarely taller than 35 m. (From Odum and Pigeon).



Slide 7 This slide illustrates the effects of hurricanes on the forest canopy. Very few trees are emergent. They all have more or less the same size as if a giant lawn mower has passed over the forest crown. Notice the different shapes and colors of crowns. They reflect the diversity of tree species that typify tropical forests. The Institute of Tropical Forestry has reported that the number of tree species reaches a peak several years after a hurricane passes over the island and then decreases progressively until the next hurricane passes by. After the hurricane, secondary and climax tree species grow together. Thirty years or so later, the successional species die out and the forest retains only its climax species. (Photo by R.F. Smith).

Slide 8 The colorado forest usually grows above 600 m elevation below the cloud forest but above the tabonuco forest. This forest is dominated by the colorado tree (*Cyrilla racemiflora*) shown here. The tree reaches impressive diameters and produces a copious number of branches. Because of the characteristics of its wood, this tree was used to make charcoal in the island. (Photo by J. Bauer).

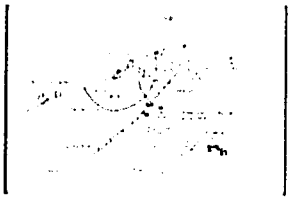
Slide 9 This colorado tree has an enormous cavity in its base. Cavity formation is another characteristic of the colorado tree and this is why the Puerto Rican parrot uses this species for its nest. The abundance of lianas in the forest is also evident in this slide. (Photo by A. E. Lugo).



Slide 10 In this colorado tree lives the Puerto Rican parrot. The scientist is climbing the tree to inspect the parrot's nest. Notice the proliferation of bromeliads of the genus *Guzmania* and the small and open canopy structure of the colorado tree. Some of the characteristics of this forest suggests that it is a swamp forest (slide 51). In Florida, the colorado tree grows only in swamps. (Photo by A.E. Lugo).

Slide 11 These are tabonuco trees (*Dacryodes excelsa*), the dominant species in one of Puerto Rico's most extensive forest types, the tabonuco forest. This particular tabonuco stand is located in the Big Tree trail in the Luquillo Experimental Forest also known as El Yunque or Caribbean National Forest. The tabonuco tree is one of Puerto Rico's finest timber trees and has many traditional uses in the Puerto Rican culture. (Photo by J. Bauer).

Slide 12 Between the years 1962 and 1969, a tabonuco forest located at El Verde in the Luquillo Experimental Forest, was subjected to one of the most intensive ecological studies of any tropical forest in the world. This slide shows a schematic of the layout of the studies conducted as part of that project. Scientists selected 2 study areas shown here as circles with radial lines following 16 compass settings. On the left circle, known as radiation center, a cesium 137 radiation source (20,000 curies) was set in place with a helicopter. This source irradiated the forest for three months so that scientists could study the effects of radiation on a tropical rain forest. The irradiated forest was compared with a south control center on the upper part of the diagram, which was identical to the radiation center but not irradiated. An area was cut and designated the north cut center in order to compare the impact of radiation with that of forest cutting. Flags were placed at the top of the canopy to identify the site in aerial photographs. The Sonadora River passed along one of the boundaries of the study forest. A giant cylinder was located in the study area to measure the transpiration, photosynthesis, and respiration rates of the forest. A suspended cable was laid between the south control center and the radiation center so that scientists could study the forest canopy. A meteorological tower was installed to measure climatic and microclimatic conditions in the forest. The El Verde Field Station received all the data from the meteorological tower and housed scientists and equipment during the study. Fences were erected to prevent people from walking into the radiation area. Patrols operated 24 hours a day to warn people about the dangers of radiation. Low and high level isotopes were used to trace the movement of minerals throughout the forest. A book was published in 1970, summarizing all the results of this significant study. (From Odum and Pigeon).



Slide 13 This is the tripod that supported the radiation source (hidden in the stainless steel container at the base of the tripod). You can appreciate the damage caused by three months of ionizing irradiation. The radiation source itself was raised or lowered through the central pipe by remote control. (Photo by J.F. McCormick).

Slide 14 After ten years of recovery, it is difficult to surmise that this is the same irradiated area seen in the previous slide. The succession, or recovery process is very fast in tropical forests such as this one at El Verde. In fact, a humid tropical forest can restore its original biomass in less than 20 years, or 2–3 times faster than moist temperate or tropical dry forests. (Photo by S. Silander).

Slide 15 This is the forest floor of the tabonuco forest. Notice the darkness of the forest. A leaf area index of 7 is responsible for the absorption of most of the incident light on the forest. Sun flecks illuminate particular areas of the forest at particular times. There is not much litter on the forest floor because the rate of decomposition is fast. Abundant surface roots are visible and are due to the rocky nature of this particular forest. In the center, there is a tabonuco seedling. In front of the tabonuco seedling there is another seedling receiving light from the sun fleck. Because of the darkness, seedlings germinate in great numbers, only to die rapidly as a result of lack of light. The half life of the seedling population in the tabonuco forest is six months. (Photo by P.G. Murphy).

Slide 16 This false color infrared photo of the south coast illustrates the sparseness of the natural vegetation during the dry season. Notice the contrast between the natural forest on the upper part of the picture, the coconut grove on the right hand side of the peninsula, and the mangrove forest on the left hand side. Among all vegetation, mangroves exhibit the most vigorous growth at this time of the year. After a rainfall, the dry forest will look just as red. This slide also shows the relation between the mangroves and the coral reefs which, by breaking the waves, protect the mangroves from excessive wave action. (Photo by NASA).

Slide 17 This is a real color slide of a similar landscape as that depicted in the previous false color slide. It is the entrance of Guanica Bay in the Guanica State Forest. (Photo by A. E. Lugo).

Slide 18 The next few slides deal with the dry forests of Puerto Rico. This is the entrance to the Guanica State Forest during the rainy season. Notice that the vegetation is lush green, and grasses are abundant on the roadsides. (Photo by A. E. Lugo).

Slide 19 This is the same forest during the dry season. Grasses along the roadsides are dead, leaves are off the trees, and the forest is shown to be scrubby and short (average height is about 5 m). (Photo by A.E. Lugo).

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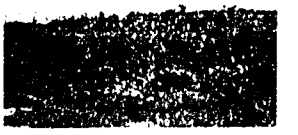
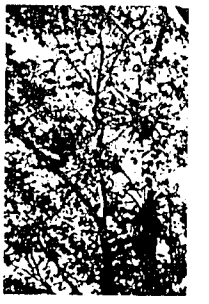
Slide 20 The Guanica Forest grows on rocky limestone soils. Roots concentrate in the upper organic horizon, but there is also significant rooting in the deeper portions of the soil profile. (Photo by A. E. Lugo).

Slide 21 The Guanica State Forest supports many types of dry forests. This particular slide shows a forest of cacti and other shrubby or herbaceous vegetation. The rainfall is in the order of 1000 mm a year and the shallow rocky soils exacerbate the water problems of the forest. It is obvious that this is a coastal forest as well. (Photo by K. Dugger).



Slide 22 In spite of its dryness, the Guanica forest has an abundance of epiphites. These plants derive moisture and nutrients from the air. They also accumulate water (particularly the tank bromeliads) and as a result, support the forest aquatic fauna and flora (e.g., frogs and algae). Bromeliads, and epiphytes in general, also accumulate soil on the branches of trees. In the Guanica forest the air acquires moisture during the evening when sea breezes blow over the forest. (Photo by A. E. Lugo).

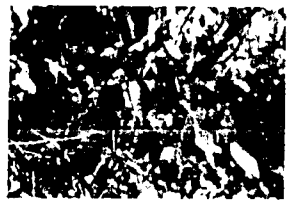


Slide 23 Trees can reach impressive sizes in Guanica as is the case of this guayacan (*Guaiacum officinale*) that grows in a ravine where soil moisture is available in greater quantities. The guayacan has one of the hardest woods in Puerto Rico, being 1.3 times heavier than water. These trees were used by the Spaniards for the construction of ship masts. (Photo by J. Bauer).

Slide 24 Termites are abundant in the dry forest and are responsible for the decomposition of dead wood. They do not kill live trees as is commonly thought. (Photo by A. E. Lugo).

Slide 25 The bark of trees in the dry forest tends to peel off easily as shown here. Mabi, one of our most popular native drinks is made out of the bark of a tree from the dry forest. Notice the many stems that emerge from the trunk of this tree (*Pictetia aculata*). This phenomena is called coppicing and is the main mechanism for forest regeneration following cutting, fire, or hurricanes. (Photo by A. E. Lugo).

Slide 26 These are the leaves of *Croton*, an understory shrub in the Guanica Forest. This slide was taken during the rainy period of the year when the forest blooms and grows. Notice that the leaves are horizontal, green, fully expanded, but small. Most leaves in dry forests are small and hairy. When water is available, water loss or transpiration, is fast, as is photosynthesis. Trees grow faster and the evaporation of water keeps leaves cool in spite of their horizontal position. (Photo by A. E. Lugo).



Slide 27 Here the Croton leaves are in a vertical position and drying. This occurs during periods of drought. The vertical position helps the leaves by preventing overheating which may occur when sunlight is intense and the forest runs out of water. By turning vertically, leaves avoid direct sunlight and maintain cooler temperatures. If drought is prolonged, leaves turn color and fall as is the case for some of the leaves in this slide. (Photo by A. E. Lugo).

Slide 28 In the south coast of Puerto Rico, on alluvial soils, one can find trees of impressive size such as this Ceiba with its buttress roots that reach over 5 m. The presence of trees such as this one suggests that at one time there was a tall forest in this part of Puerto Rico. This was taken in Cabo Rojo, one of the dryer areas of the island. (Photo by A. E. Lugo).

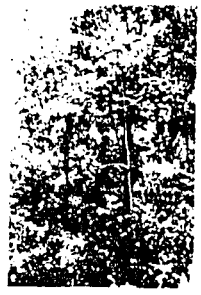
Slide 29 This is an infrared photograph of the North coast of Puerto Rico. What we see here are the forested limestone hills, urban, and agricultural flat lands. (Photo by NASA).

Slide 30 This is a color slide of an area similar to the one just shown. Limestone hills occur throughout the north coast of Puerto Rico but are most abundant in the San Sebastian area. Locally known as "Mogotes" or "Pepinos", these hills originated thousands of years ago when the region was submerged in the ocean. Because of their unique topography and geology, these hills support equally unique forest types. (Photo by A. E. Lugo).

Slide 31 In this false color infared photograph we can appreciate the relation between the limestone forest on the foreground and the Tortuguero lagoon in the center of the picture. Tortuguero lagoon is the only natural freshwater lake in Puerto Rico, even though it is located next to the ocean. The lake is fed by the underground aquifer, which is fed in turn by rain that falls over the limestone hills on the foreground. The white areas near the lake are the encroachment of developments in that region. On the left hand side one can see the valley of the Manati River. (Photo by NASA).

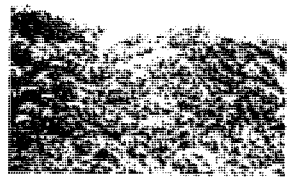
Slide 32 The condition of these limestone hills contrasts sharply with the condition observed in the previous infrared color slide. The reason is that this slide was taken when the island was deforested. The infrared photo was from the 1970's. (Photo by F. Wadsworth).

Slide 33 This is the inside of a limestone forest. Notice the high density of stems, the tall stature of trees and their small diameter. This is a well-developed stand because this particular forest (Rio Abajo State Forest) receives abundant rainfall (as much as the tabonuco forest). (Photo by A. E. Lugo).



Slide 34 Here we see that the limestone forests grow over a layer of limestone rock under which one finds unconsilidated rock. Trees of the limestone forest are not very large in diameter nor are they very tall. They are water- and nutrient-limited due to the rocky condition of the soil. (Photo by A. E. Lugo).

Slide 35 Secondary forests cover a significant area in Puerto Rico. These are forests that have grown after humans modified the original climax forest. In this particular slide, taken in the Utuado area where coffee was prevalent in the early part of the century, one can see the abundance of yagrumo tree *(Cecropia peltata)*, characterized by it's silvery leaves. The presence of this tree is clear evidence of disturbance and is an indicator of secondary forests. (Photo by A.E. Lugo).



Slide 36 This picture of a yagrumo tree illustrates why this species is such a successful successional species. The tree is a fast grower with soft wood. It has a tendency to spread its branches and its large leaves in such a way that it fills any gaps created in the forest canopy. It thus protects the forest floor from the direct impact of rainfall or sunshine and provides suitable habitat for the growth of climax tree species. (Photo by A. E. Lugo).

Slide 37 This view of the central mountains of Puerto Rico shows that secondary forests are interspersed between agricultural fields. The forests predominate on the highest peaks and along the narrow valleys between the mountains. (Photo by A. E. Lugo).

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Slide 38 Because most of our secondary forests originated with the abandonment of agriculture and coffee plantations (where trees were used for shading coffee), the composition of secondary forests such as this one is dominated by coffee shade species (eg. *Inga vera, Guarea guidonia*), fruit trees (eg. *Mangifera indica*), and other species associated with human use of the land (eg. *Citrus sinensis, Eugenia jambos*). In spite of this, there is enough diversity in these forests (189 tree species found in a survey), that many important native species are regenerating in the forest understory. As a result, there is a unique opportunity to manage these forests for the many beneficial uses that forests provide. (Photo by A. E. Lugo).

Slide 39 In areas where the topsoil has been scraped by machines (e.g. roadsides) or where erosion has been severe (e.g. abandoned pastures) the exotic tree *Albizia procera* forms monospecific forests such as this one. This species is successful in these habitats because it fixes nitrogen and contributes to the restoration of the soil profile. This is a new forest type in Puerto Rico and one with a very low species diversity, as can be seen in this slide. Trees in this forest grow fast and have short life spans. (Photo by A. E. Lugo).

Slide 40 Managed human-made forests are becoming more important in Puerto Rico because they grow so well. Yet the island imports all its wood products. If we could expand the area of plantations and use their wood, we could save the needed foreign exchange dollars. Most of the plantations in the island are of exotic tree species. This particular one is a pine forest *(Pinus caribaea)* planted for research purposes by the U.S. Forest Service. Pines grow at rates that exceed 2.5 cm in diameter and 1 m in height per year. Managed forests will be very important in the future of Puerto Rico if the island is to become self-sufficient in the production of wood products. (Photo by A.E. Lugo).

Slide 41 Teak plantations such as this one are another example of managed forests. While pines are coniferous softwoods, teak is a broad leaf hardwood that provides valuable timber for local island consumption. This particular plantation is located in the Rio Abajo State Forest. (Photo by A. E. Lugo).

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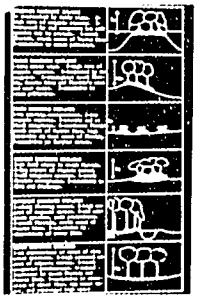
Slide 42 Natural forests can also be managed for the production of wood products without sacrificing all of their species diversity nor their multiple values. Here, Dr. Frank Wadsworth (on the right) examines the results of the management that he applied to this natural tabonuco forest at El Verde, Puerto Rico. Through judicious selection of trees and by eliminating individuals that competed with desirable trees, Dr. Wadsworth was able to develop a stand where all the species have commercial value and good forms, as can be appreciated in this picture. (Photo by A.E. Lugo).

Slide 43 This scheme shows the types of saltwater forests (mangroves) that grow in Puerto Rico. The types are determined by the hydrology and topography of the forest habitat. In general, forests are taller and more productive in areas with abundant freshwater runoff and become smaller with decreasing runoff and increasing salinity. All mangroves are tidal and estuarine forests. (From A. E. Lugo).



Slide 44 In contrast to the south coast, the north coast is a high energy coastline. This false color infrared photo shows that the mangrove forests grow inland behind sand dunes where they find protection from excessive wave action. These forests are known as basin forests because they grow in inland basins where water tends to stagnate. On the right hand side you see the largest river in Puerto Rico, the Rio Grande de Loiza. The lagoon in the center of the slide is the Piñones Lagoon. On the left, you see part of the San Juan Metropolitan Area. A runway of the International Airport can be seen on the far upper left side of the slide coming into the Torrecilla Lagoon. Just in front of the limestone hill behind the mangrove forest one can see a small forest stand. This is a freshwater swamp. The Piñones-Torrecilla-Vacia Talega mangrove complex is one of the largest mangrove forests on the island. Most of the flooded land behind the mangroves was used for agriculture in the past. (Photo by NASA).

Slide 45 This is the inside of a basin black mangrove forest. The black mangrove forest is characterized by its carpet of pneumatophores which are the pencil-like structures on the forest floor. These are adventitious roots used by the tree (*Avicennia germinans*) to exchange gases with the atmosphere. Oxygen is transported from the air to the roots and CO_2 is returned from the roots to the atmosphere. The scientist in this photo is reading a refractometer which measures the salinity of the soil solution. Black mangrove forests grow on high salinity soils (between 10–100 parts per thousand; ocean water is 35 parts per thousand). (Photo by D. J. Pool).

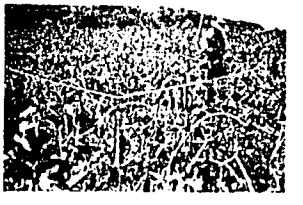
Slide 46 Two types of mangrove forests are shown: overwash island on the far left (the island in the center is not overwashed by tides), and fringe mangroves in the foreground. Notice that the trees are taller on the fringe and decrease in size towards the landward portions of the forest. Tidal flushing decreases and soil salinity increases towards the land, causing the trees to be smaller. In the lagoon inside the island in the middle of the slide, soil salinity has increased so much that trees can no longer survive. Dead trees in the foreground are indicators of the progresssive change in soil salinity beyond their tolerance. Islands, lagoons, and their mangroves are excellent refuges for wildlife. (Photo by A. E. Lugo).

Slide 47 Fringe mangroves are characterized by a maze of red mangrove prop roots such as these. The adventitious roots are necessary for gas exchange and for supporting trees growing on soft sediments. The basket in the center is used for measuring the rate of leaffall. Mangroves produce over 8 tons of leaves/ha.yr and these are an important food source for sport and commercial fisheries in the estuary and oceans. (Photo by D. J. Pool).

Slide 48 This is a riverine forest. You can see three important components of mangrove forests. The trees with the whitish bark are white mangroves, *Laguncularia racemosa*. Those with the reddish bark, such as the one toward the left, are black mangroves. The herbaceous vegetation in the background is the fern *Acrostichum*, a fern that grows in saline soils. The presence of ferns indicates that soil salinity in this stand is not very high. Trees in this stand exhibit nice form, illustrating that this forest is useful for wood production. This forest type was used extensively for charcoal production. (Photo by A. E. Lugo).

Slide 49 This is an example of a tall red mangrove forest characterized by its arching prop roots and the adventitious roots that emerge from the top of the canopy to the forest floor. In fact, this is one of the tallest mangrove forests in Puerto Rico (23m) located in Yabucoa. The vertical tree with the grayish bark on the right side of the photo is a white mangrove. The presence of red mangroves serves as an indicator of frequent water flux. (Photo by A. E. Lugo).

Slide 50 This is a dwarf red mangrove forest in Ceiba. It is dominated by the same tree species (*Rhizophora mangle*) as the one shown in the previous slide. The scientist in the photograph is preparing to do a study of the biomass of the forest, which is unique due to the small size of the trees. Notice the taller mangroves in the background. They grow by a canal. Scientists do not understand why the dwarf forest is so short. (Photo by A. E. Lugo).



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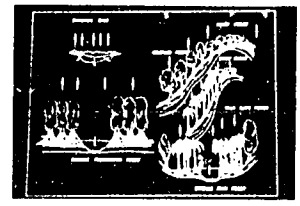
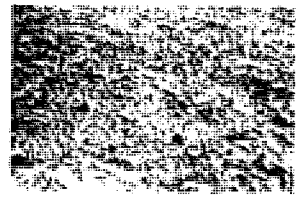
Slide 51 This slide illustrates the various types of freshwater wetlands in the moist mountains of Puerto Rico. Like the saltwater wetlands, hydrologic and topographic conditions are determinants of forest type and function. Arrows indicate the sources and flows of water in these wetland ecosystems. Because these ecosystems do not have salinity, they can support a higher diversity of plant species than saltwater wetlands can. The wetland on the upper left corner is a *Sphagnum* bog, a non-forested wetland. (From Frangi and Lugo).



Slide 52 This is a mountain peak with its typical cloud forest. You can define the cloud forest by the smoothness of its dark canopy. Notice that the foliage appears to be sculptured by the wind. This is visible on the right hand side of the slide. It may appear impossible to consider a mountain peak a wetland. However, two factors make it such. First is the abundant rainfall and low evapotranspiration. Second is the limited capacity of soils to drain excess water. The next slide illustrates the response of the vegetation. (Photo by A. E. Lugo).

Slide 53 This is the inside of the cloud forest. Notice the proliferation of roots on the surface of the forest and the abundance of epiphites or air plants on all surfaces. Air plants contribute to water condensation such that more water drains out of the cloud forest than falls as rain. Roots are on the surface because of the soil. The cloud forest is an example of a wetland forest in a mountain. Here soils are waterlogged most of the time, roots must be on the surface of the soil to obtain enough oxygen, many are adventitious, stems contain numerous lenticels, and organic matter accumulates on the forest floor. All these are characteristics of wetlands. (Photo by R. Birdsey).

Slide 54 From the top of the mountain, if one looks down, one sees the distribution of the riverine palm forests. It is clear from this slide that this type of forest grows along streambanks where soils are periodically flooded. The palm forest is another example of a mountain wetland. (Photo by P. G. Murphy)



Slide 55 This picture was taken in the Toro Negro State Forest. It shows basin type palm wetlands growing on the side of a mountain. On the ridge tops, one can see the smooth crowns of the cloud forest. The presence of such an extension of palm forest indicates water logged soils over broad areas. (Photo by A. E. Lugo).

Slide 56 Here we see the root system of the Sierra palm (*Prestoea montana*). This picture was taken in a very wet area of the Luquillo Experimental Forest.These roots are termed adventitious roots because they grow from the side of the stem. Normal roots emerge from the bottom of the stem. These adventitious roots are also known as "pneumatorhiza" and they serve a special gas exchange function. Because of the high rainfall in this area one can see the abundance of epiphites growing on the trunks of the palm and on the roots themselves. The canopy of the palm forest is open. The forest floor is not dark as in the tabonuco forest (slide 15). Thus, there is a corresponding abundance of understory plants growing on the forest floor. This plant cover is extremely important in the protection of soil from erosion. Think what would happen if raindrops impacted the soil directly on these steep slopes. (Photo by A. E. Lugo).

Slide 57 This is a study of water stemflow in a riverine palm forest wetland located in the Luquillo Experimental Forest. Stemflow water is collected in plastic drums for future measurement and analysis. Studies such as this one have demonstrated the role of this forest in maintaining water quality. (Photo by A. E. Lugo).

Slide 58 Here a student from the University of Puerto Rico High School, who is working in cooperation with the Institute of Tropical Forestry, measures the growth rates of palms. Palms are monocotyledonous trees and grow slowly in diameter but very fast in height. The rate of leaf production is constant in palms. Each leaf leaves a conspicuous scar when it falls. This student is measuring the distance between leaf scars and using that distance as a measure of growth rate of the tree. Because leaf scars are produced at a constant rate, it is possible to calculate the age of the palm by counting scars and dividing by the production rate. (Photo by A. E. Lugo).

Slide 59 This slide shows specimens of *Pterocarpus officinalis* (palo de pollo), a tree that grows in basin and riverine freshwater wetlands in wet mountains and behind the mangrove forest all around Puerto Rico except on the dry south coast. This forest type is an endangered ecosystem as there are only about 200 ha left on the island. (Photo by D. J. Pool).

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Slide 60 One of the important products of a forest is clean water. Normally, rivers such as this one are in base flow. Their water flow is very small. This particular stream is La Sonadora River in the Luquillo Experimental Forest. The boulders (rocks) that one sees are volcanic in origin. So are the soils of this region. They are fertile forest soils. The forest surrounding the river is called a "gallery forest," which means a forest that grows along stream banks. Notice that in this forest type, leaves cover the whole side of the forest, giving the impression of an impenetrable jungle. In reality, most tropical forests are not jungle-like. Instead, they have open understories that are easy to walk through. The water that flows down this river at this time is crystal clear. Notice also the logs scattered throughout the river bed. How do they get there? (Photo by B. Cintrón).

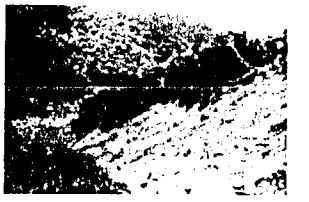
Slide 61 This is the same Sonadora River at high flow. The water is no longer crystal clear but chocolate color reflecting the high amount of organic material dissolved in it. The boulders of the river bed are not visible. The water level is as high as the lower leaves of the gallery forest. All the rivers in Puerto Rico exhibit this behavior. The logs that we saw in the previous slide find their way to the stream bed as a result of floods caused by torrential rains. The periods of time that rivers spend in flood stage are very short in comparison to the time they spend at base flow. Yet, it is during these times that the role of the river becomes clear and significant. (Photo by B. Cintrón).

Slide 62 Poor use of land is illustrated here. The sediment created by sand extraction by the river is transported downstream and fills reservoirs whose water is needed for urban and industrial uses. The watersheds of water supply reservoirs should be forested to avoid these incidents. (Photo by P. Gelabert).

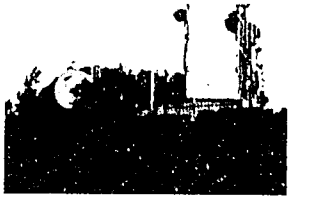
Slide 63 This is the Toro Negro State Forest swimming pool. The rain water in this swimming pool flows through the forests located just behind it. Forests provide recreation to all of us in Puerto Rico. (Photo by A. E. Lugo).

Slide 64 Landslides are a problem in the humid tropics. This is a massive landslide that ocurred in the Luquillo Experimental Forest. Landslides such as this one are typical along the roads in mountainous areas. Usually, the landslide is caused by ill-designed or poorly maintained roads. (Photo by A. E. Lugo).

Slide 65 This is a close-up of the landslide shown previously. You can see the cross section of a colorado forest with a high density of short stems and an even canopy. Observe how the landslide completely obliterated the forest, its topsoil, and exposed the bedrock underneath this stand of virgin forest. (Photo by A. E. Lugo).



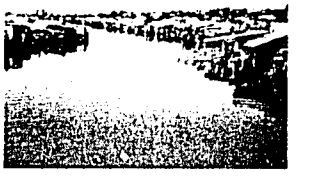
Slide 66 These transmission towers are located at the top of Cerro de Punta in Jayuya. Cerro de Punta, the tallest mountain in Puerto Rico, was shaved by at least 10 m in order to locate these transmission towers on its summit. Actions such as this one endanger cloud forests. (Photo by A. E. Lugo).



Slide 67 One of the problems in the conservation of dry forests is the tendency of Puerto Ricans to transplant the plants of the forest to their yards. Because plants in the dry forest grow slowly, this illegal harvest eventually depletes the populations of rare plants. In this example, the owner has taken cacti from the Guanica forest for display at the entrance of his/her house. However, these cacti cannot survive under the new conditions for any length of time and they will soon die, leaving the owner and the forest without the cacti. (Photo by A. E. Lugo).

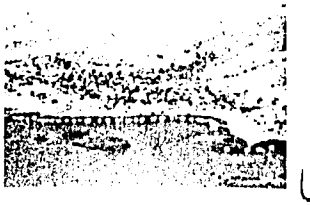
Slide 68 In Caña Gorda beach, people and the government have destroyed the dry forest to park their cars. Note that an understory does not exist but trees are valued for their shade. Unfortunately there is no opportunity for the natural regeneration of shade trees once these few survivors die. Eventually, this will be a barren parking lot. (Photo by A. E. Lugo).

Slide 69 This is El Caño Martin Peña in the San Juan metropolitan area at a time when both sides of El Caño were used for housing. (Photo by A. E. Lugo).



Slide 70 After the removal of the houses, the original mangrove forest returns to its habitat. At one time a large portion of the San Juan metropolitan area was a mangrove forest. This slide shows that upon abandonment of a mangrove area by humans, the mangroves return. (Photo by A. E. Lugo).

Slide 71 These squatters are in the fringes of the red mangroves of La Parguera. In the background you see the devastation of the dry forest in this part of the island. (Photo by P. Gelabert).



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Slide 72 The removal of the mangroves for trash disposal in the coastal zone not only ruins the aesthetic beauty of the coastal zone but it disrupts the function and services that mangroves provide. (Photo by A. E. Lugo).

Slide 73 This large black mangrove tree in Isabela is the only indication that all this area was forested at one time. In the background one can see what is left of the sand dune that once protected this forest from the ocean. If houses are built here, they will be exposed to periodic flooding by the ocean. The size of this individual tree is testimony to the impressive stature of the original forest. (Photo by A. E. Lugo).

Slide 74 The original sand dune in this coastal area was removed to fill in Torrecillas Lagoon and construct a runway for the San Juan International Airport (Slide 44). With the disappearance of the dune, the ocean flooded the mangrove forest behind it. The resulting sedimentation killed the mangroves, as is evident in this slide. (Photo by A. E. Lugo).

Slide 75 On the south coast, oil pollution endangers the health of fringe mangroves. In this slide one can see the oil spill that polluted the mangroves in the Bahia Sucia region. (Photo by G. Cintrón).

Slide 76 This is a picture of the mangrove forest of Bahia Sucia after the oil killed all the mature trees. The young trees that germinate underneath usually die after they reach about 3 m in height. This oil spill resulted in a major federal court case where the courts ruled that the responsible parties had to pay damages to the government of Puerto Rico for the destruction of valuable forest. (Photo by A. E. Lugo).

Slide 77 Sooner or later all civilizations run out of the main fuel that powers their development. Our civilization runs on fossil fuels and, as illustrated in this slide, some day we will no longer have this energy resource available to us. At that time we may be forced to go back to wood as a means of harvesting solar energy. Even today, most of the people on Earth depend on natural forests for their cooking and heating energy. (Photo by A. E. Lugo).

Slide 78 This is an energy plantation. Trees were planted close to each other for the purpose of maximizing the amount of wood biomass produced per unit area and time. The trees that are being measured are over 20 m tall and only 2 years old. This is one way to produce charcoal for fuel energy for Puerto Rico's future. However, if we planted the whole island with trees that grow as fast as these, we could not satisfy the island's current energy needs. (Photo by B. Cintrón).

Slide 79 With the end of civilization the forest always comes back, as is evident here in the Virgin Islands where a secondary forest has emerged through the ruins of an old sugar cane plantation. (Photo by A. E. Lugo).

Slide 80 The forests of Puerto Rico provide marvelous areas for human recreation and enjoyment. They also provide raw materials for the development of our culture. We must manage these forests with the proper care so that both the forests and we survive for many centuries to come.

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CLIMATE AND GEOLOGY OF PUERTO RICO

by

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The structure, appearance, and composition of the natural vegetation that develops on any given site will directly reflect the environmental conditions prevalent there. Consequently, if the prevailing environmental conditions of a given site are adequately known, then the physical and structural characteristics of the plant forms that naturally occur there could be predicted. Also, if reasonably adequate descriptions are available for the dominant natural plant formations of a given area, then, the prevailing environmental factors could be predicted.

Two environmental factors of prominent importance for their influence on plant form and structure are: climate and geological parent material. Classifications based on these two parameters, either individually or in combination, are crucial for their potential in the determination of possible management units.

Climate

The two most important climatic factors for their influence on vegetation type are rainfall and temperature.

Holdridge's Life Zone System (Fig. 1) is a comparatively simple bio-climatic classification system of wide use particularly in the tropics. The system utilizes two independent climatic parameters, mean annual rainfall and "bio-temperature". Bio-temperature differs from regular temperature in that it substitutes zero for all unit values above 30°C and below 0°C.

Though this system is not dependent on floristic relations or taxonomy, the geographic limits to species distributions often coincide with life zone boundaries.

The Life Zone system (Holdridge 1967) is a plant formation classification, hierarchial in nature, the first level of which is the life zone determined by purely climatic factors (Mean annual precipitation and biotemperature). Subsequent second and third levels of classification (associations and successional stages, respectively) are particularly useful for regional mapping of land-use capabilities and for detailed ecological mapping, watershed zoning of farm planning. Only the fourth level of classification within the system takes into account actual vegetation.

Out of the approximately 120 life zones in the world, 66 are found within the tropical latitudes. Of these 66, thirty can support forests. Six life zones occur in Puerto Rico (Fig. 2), and three of these account for over 98% of the total land area (Ewel and Whitmore 1973).

Parent Material

The geological origin of the parent material which underlies a forest will also influence its structure and development. The action of climate and vegetation on this parent material is primarily responsible for the creation of soils of differing physical and chemical characteristics.

Using Brigg's (1966) Provisional Geology map of Puerto Rico, 5 major formations can be mapped for the island (Fig. 3). These five parent material types are:

1. Volcanic - This type, the most extensive, comprises extrusive volcanic deposits. The soils that develop from these deposits

are mainly acidic clays.

2. Plutonic - This type, though also volcanic in origin is intrusive in nature. The soils derived from this type are sandy.
3. Limestone - This type is made-up of ancient exposed coral reefs. Soils on this type tend to be shallow.
4. Serpentine - This formation is the product of hidrothermic alterations. Soils derived from this parent material are the poorest known for agriculture. These soils are very low in N, P, and K as well as having a low Ca/Mg ratio.
5. Alluvial - These are ancient fluvial deposits found along the coast. Of extensive use historically as farm land, these remains very little natural forest on this type.

Use for Management

When prescribing management for forest land or considering land-use possibilities, the use of homogeneous working units (in reference to any one or combination of characteristics) are most useful in that they assure more uniform results. They also permit the use of management prescriptions over wide areas.

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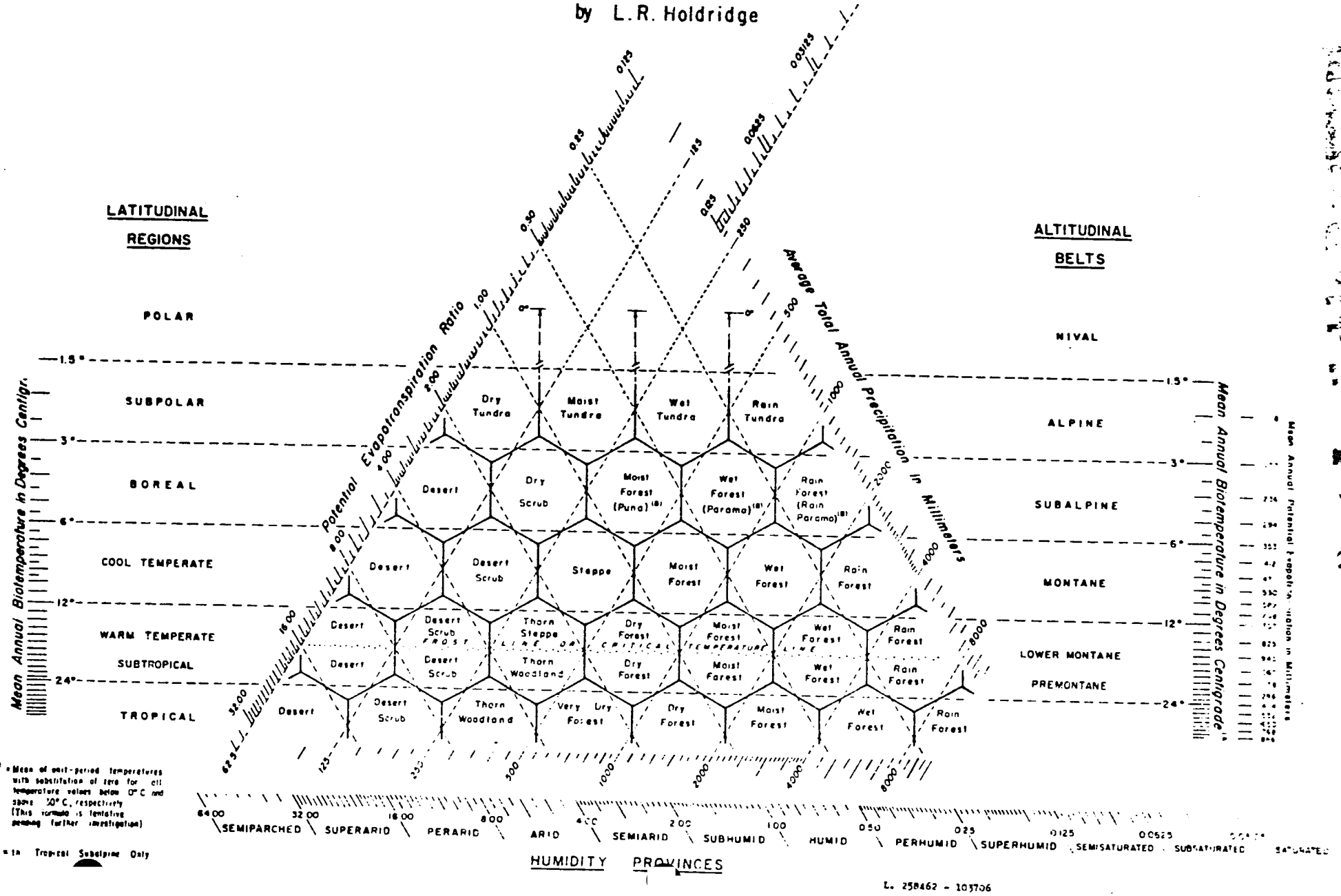
DIAGRAM FOR THE CLASSIFICATION OF WORLD LIFE ZONES OR PLANT FORMATIONS

by L.R. Holdridge



(A) t^{bio} = Mean of unit-period temperatures with substitution of zero for all temperature values below 0°C and above 30°C, respectively (This formula is tentative pending further investigation)

(B) = In Tropical Subalpine Only

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TROPICAL SCIENCE CENTER, San José C.R. May 1966

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Figure 2. Distribution of Holdridge Ecological Life Zones in Puerto Rico (adapted from Ewel and Whitmore 1973).

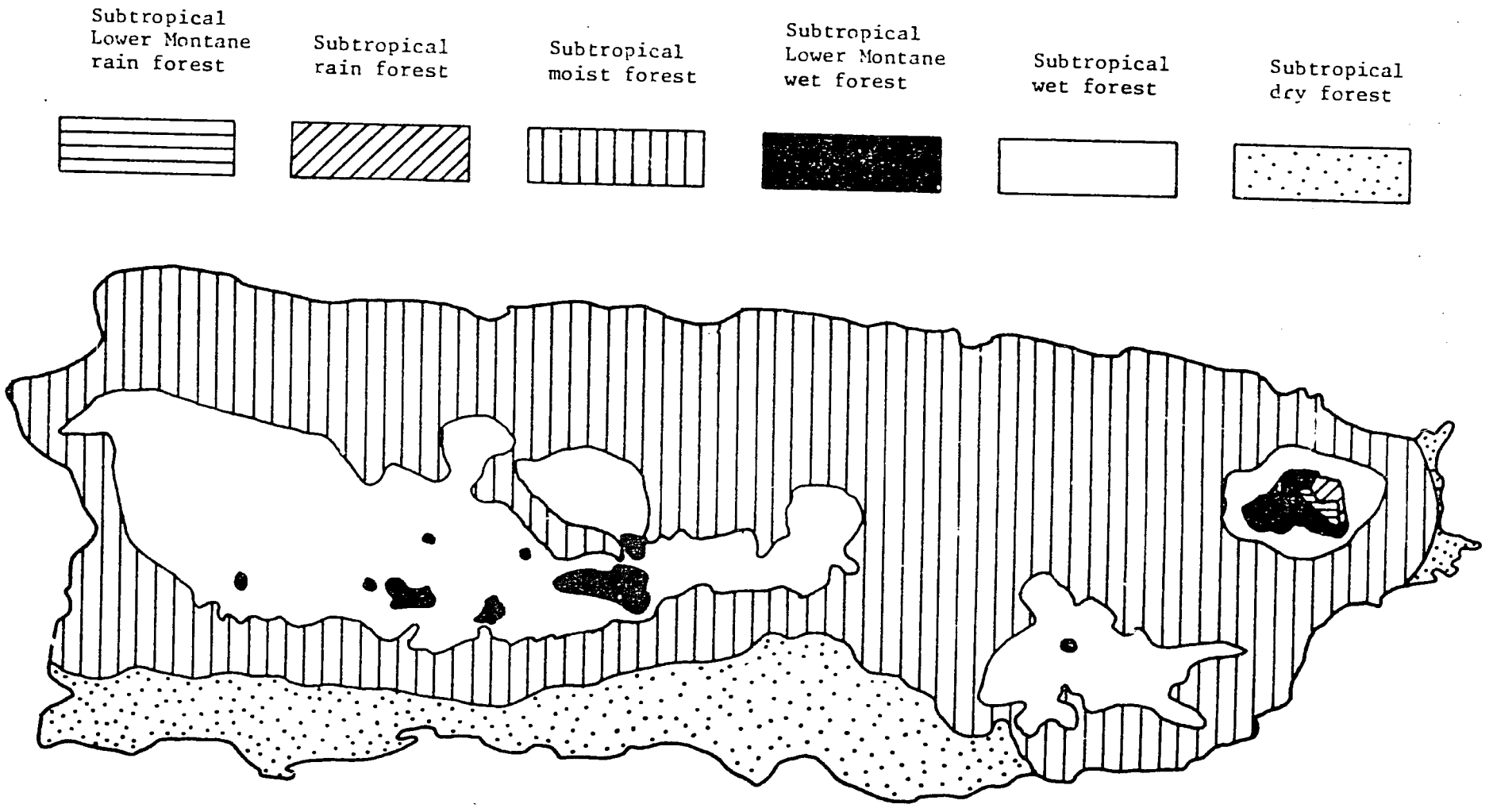

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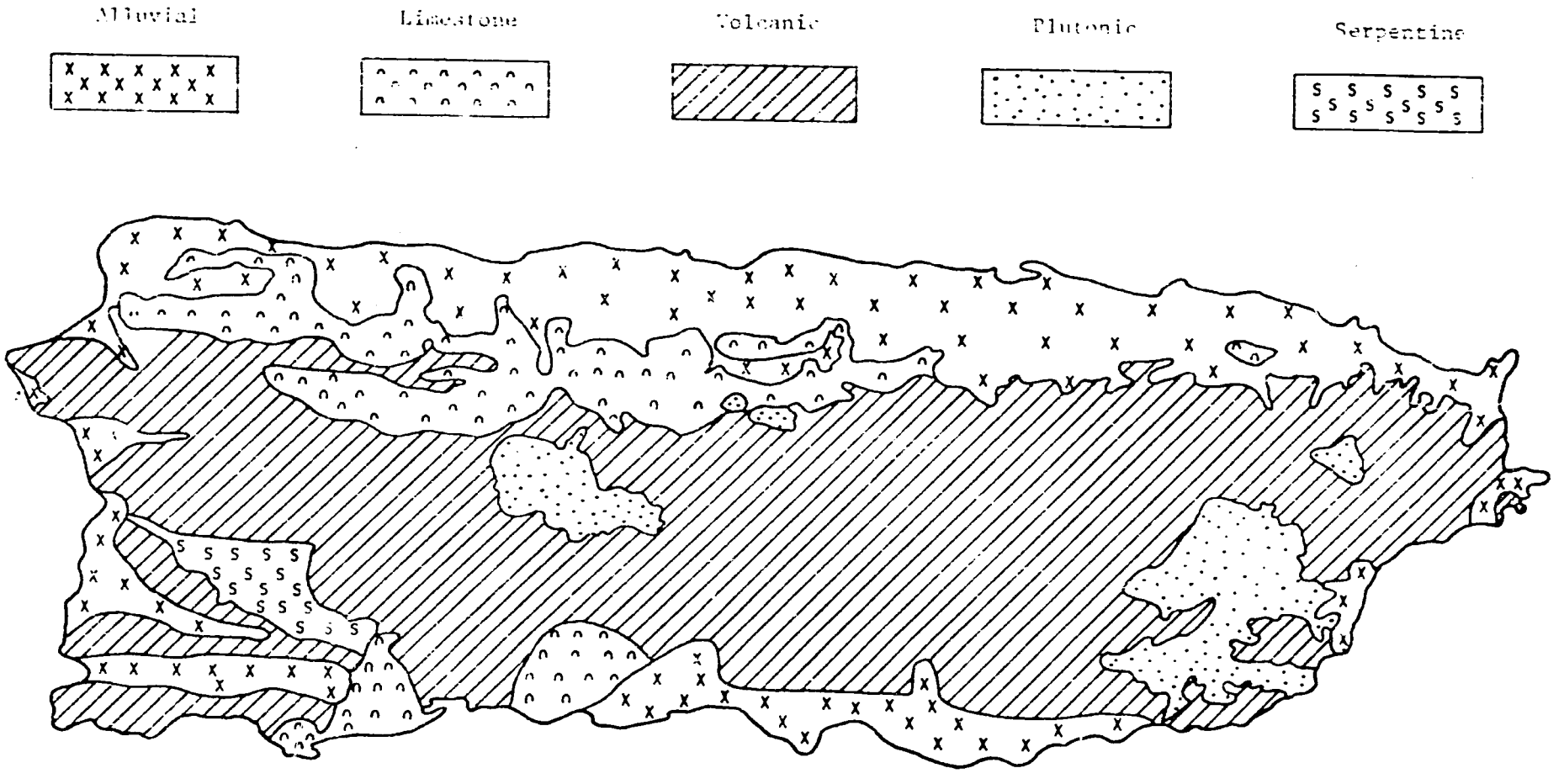
Figure 3. Distribution of major geologic formation in Puerto Rico (adapted from Briggs 1966).



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EXERCISE #1

FIELD TRIP TO THE LUQUILLO EXPERIMENTAL FOREST

Purpose: To study the influence of climatic environmental factors (rainfall and temperature) on the structure and appearance of natural vegetation.

Questions:

1. List the four forest types visited.

   a.

   b.

   c.

   d.

2. What is an edaphic association?

3. Which of the forest types visited can be considered an edaphic rather than a climatic association?

4. On an elevational gradient, enumerate factors concerning climate and vegetation structure that:

   a. Increase with elevation

      1.

      2.

      3.

      4.

Exercise #1 (Contd.)

b. Decrease with elevation

1.

2.

3.

4.

5. Enumerate main theories concerning the stunted growth of trees in the dwarf forest.

EXERCISE #2

LIMESTONE HILLS

Purpose: To study the vegetation types that occur on limestone formations on the north coast of the island.

Questions:

1. What is the origin of the limestone hills?

2. What is the chemical composition of the limestone?

3. What micro-topographical plant associations may be identified in these limestone hills?

   a.

   b.

   c.

4. Offer an explanation for the exceptionally high diversity supported by this area.

EXERCISE #3

DRY FOREST (GUANICA)
SERPENTINE FOREST (MARICAO)

Purpose: To observe morphological adaptations of plants that occur in adverse climatological and edaphic conditions.

Questions:

I. Guánica

a. What is the annual rainfall in this forest?

b. What type of rock makes up the forest substrate?

c. How tall is the forest canopy?

d. How do the leaves in this forest differ from those in the rain forest (size, shape, thickness, texture, color)?

II. Maricao

a. What is the annual rainfall in this forest?

b. What type of rock makes up the forest substrate?

Exercise #3 (Contd.)

c. What is the mineral composition of this rock and what are its physiological implications?

d. What are the general characteristics of the vegetation that develops on this substrate?

e. Though receiving similar amounts of rainfall, this forest is quite different from its counterpart in the Luquillo Experimental Forest. Enumerate reasons for these differences.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

LAND SURVEY COURSE

February 16-25, 1983

I - OBJECTIVES: TO LEARN AND PRACTICE LAND SURVEY

a. Topographic maps

b. Legal and boundaries principles

c. Tract maps

d. Scales, protractor and relate equipment

e. Aereals photos and corner's cards

II - FUNDAMENTALS OF LAND SURVEYING

a. Azimuth

b. Bearing

c. Declination

III - GENERAL USE OF SURVEY EQUIPMENT

a. Staff compass

b. Sunto compass

c. Measure tape

d. Clinometer

e. Abney level

f. Transit

g. Rod and rod level

IV - SURVEY FIELD PRACTICAL WORK

a. Short traverse

b. Computations of azimuth and distances

c. Draw a plot at scale

TROPICAL FORESTRY

Surveying Course Outline

A. OBJECTIVES - TO LEARN:

1. Fundamentals and general methods applicable to forest mapping and timber cruising

2. Use of "less precise" surveying instruments

   a. Pacing and chining (taping)
   b. Sunto compass
   c. Sunto level

3. Mapping - using tools in (2) above

   a. Distances

      1) horizontal (direction and distance)
      2) vertical (elevations and height)

   b. Map scale
   c. Interpretation of land features from topo maps.

B. THEORY AND DEFINITIONS

1. Surveying

2. Plane surveying vs. geodetic

3. Horizontal and vertical measurements (basic arithmetic)

   a. Horizontal distance
   b. Horizontal angles
   c. Vertical distance
   d. Vertical angles

4. Units of measure

   a. Feet and meters
   b. Decimal equivalents
   c. Angular units
   d. Other units (Gunter chain and links)

5. Locating points - 7 methods

6. General methods and work division

   a. Field work
   b. Office
   c. Care of equipment

7. Purpose of a survey

8. Accuracy required

9. Speed vs. accuracy - skill

10. Notekeeping

    a. Field notes
    b. General suggestions
    c. Numerical records
    d. Sketches
    e. Explanatory notes

C. PRACTICAL EXERCISES AND PROBLEMS IN USING "TOOLS OF THE TRADE"

1. Pacing vs. chaining (taping)

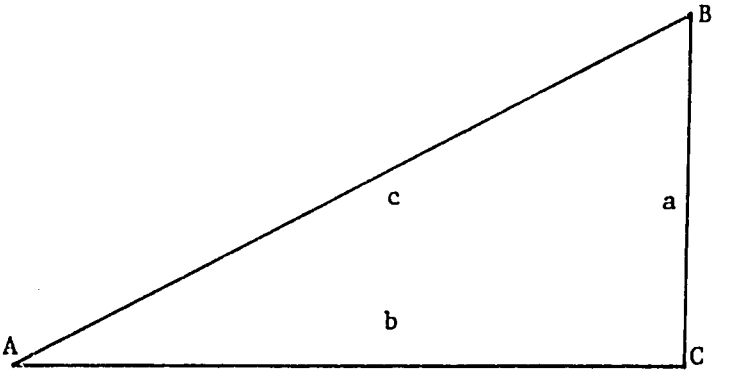
2. Use of Sunto level and chain for distance (horizontal)

3. Use of Sunto compass

4. Use of compass, level. Pace and chain for mapping.

5. Practical problems and map making.

SOLUTION OF RIGHT TRIANGLES



Sine of angle A = $\frac{\text{opposite side}}{\text{hypothenuse}} = \frac{a}{c}$ = Cosine angle B

Cosine of angle A = $\frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{b}{c}$ = Sine of angle B

Cotangent of angle A = $\frac{\text{adjacent side}}{\text{opposite side}} = \frac{b}{a}$ = Tangent of angle B

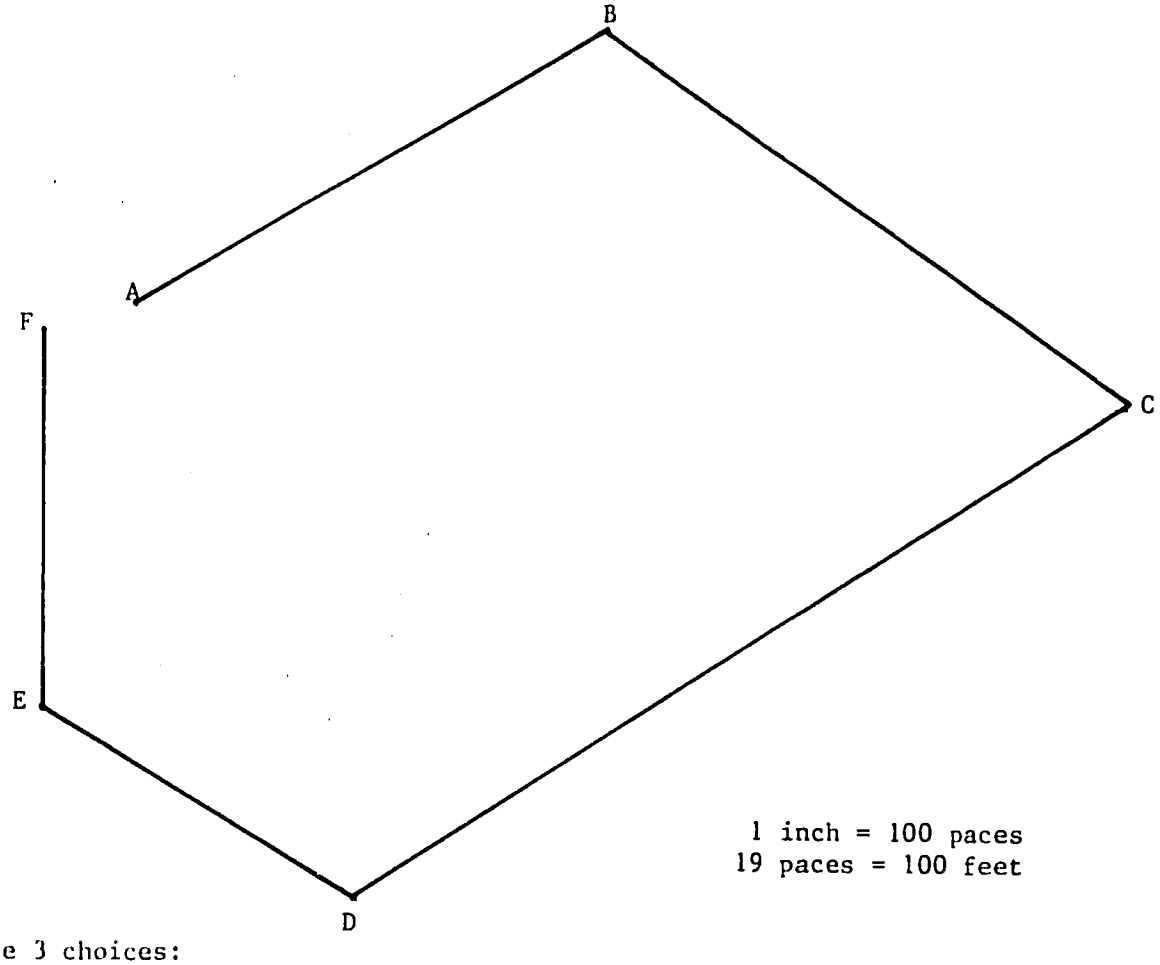
Tangent of angle A = $\frac{\text{opposite side}}{\text{adjacent side}} = \frac{a}{b}$ = contangent of angle B

In field work you should always have tables to use which give these functions of angles. Then computations can be made as the survey progress so that when finished you have all the essential data on angles, and distances. A very handy book is "Forest Surveying - (Part I)" by De Noisy, published by O.S.U. Cooperative Association, Corvalis, Oregon, U.S.A. Price is $2.50.

Best Available Document

SURVEYING
PROBLEM

One of your more intelligent workers comes to you and hands you this map he made with a hand compass and pacing. He knows that A and F are the same point on the ground, but drawing his map from his data made in the field, he finds this gap (AF).



You have 3 choices:

1. You can beat him on the head with the nearest thing handy and call him and idiot.

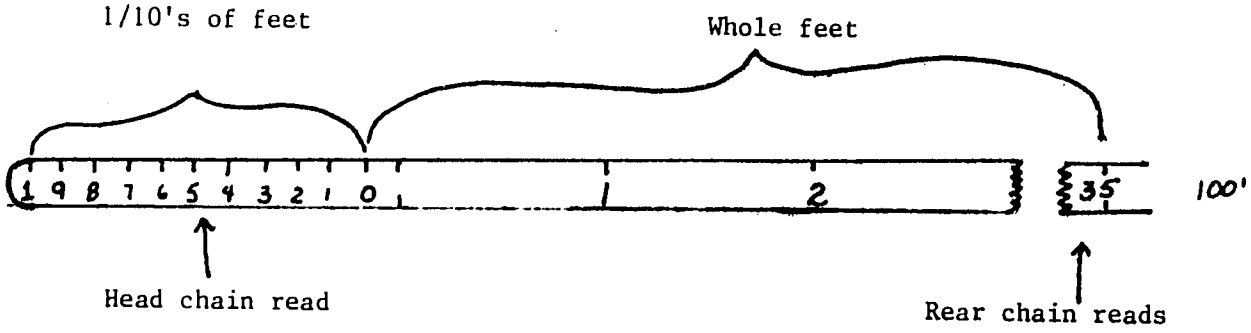
2. You can say that his job was well done and within allowable limits.

3. You can decide to put a gate at AF and let it go at that.

Which will you do? Why? On what facts do you base your choice? Correct his map for him whichever you decide to do.

COMMON TYPE TAPES

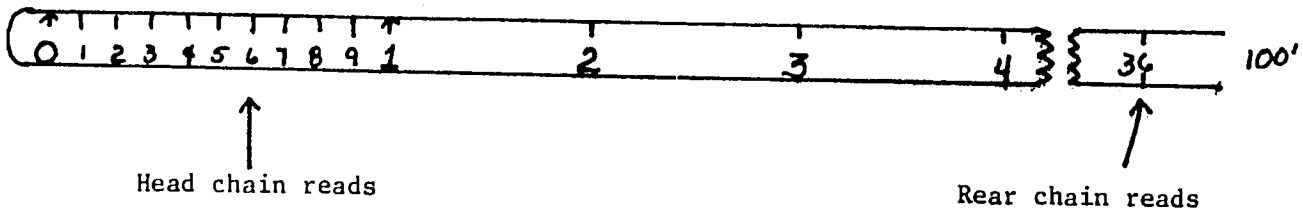
ADDING TAPES:



Distance = 35' + .4' = 35.4'

Add "thenth" number, i.e., .4, to whole No. 35

SUBTRACTING TAPE:



Distance = 36' - .6' = 35.4'

Substract "tenth" No., i.e., .6, from whole No. 36

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TAPING - CHAINING

SOURCES OF ERROR

A. Most common errors

1. not counting number of lengths correctly
2. sag: try to maintain 20 lbs. "pull" on each end
3. not horizontal, i.e. level
4. alignment bad
5. misreading or miscalling numbers (always read "right side up")
6. temperature: 15° from standard temperature (at 68°F) = .01' error per 100' linear distance
7. tape not standard length

   a. in measuring distance between 2 points A & B:

      a long tape gives a distance too short

      a short tape gives a distance too long

   b. in laying out a line of a given distance:

      a long tape gives a distance too long

      a short tape gives a distance too short

TAPING PROBLEMS

1. A line measured with a 100-foot tape is found to be 987.2 feet long. Later you discover your tape is .09 foot too long. What is the correct length of the line you found to be 987.2 feet long?

2. You have a standard 100-foot tape which you know to be .09 feet too long. You have to lay out a base line of exactly 1000 feet in length. What distance must you lay out with your tape to have the correct length?

3. You have measured a line with a 100-foot tape and found it to be 1008.7 feet long. Later you discover your tape is .17 foot too short. What is the correct length of the line?

4. With a subtracting tape you measured a distance of 72.6 feet. What number was (a) the head chairman holding? (b) the rear chairman holding? With an adding tape, what numbers were read by the two men?

IMPORTANT FORMULAE

A. HORIZONTAL DISTANCE (HD):

1. HD = (Slope distance) X (Cosine of slope angle)
2. HD = (Vertical distance) X (100) / % slope
3. HD = (Vertical distance) / (Tangent of slope angle)

B. SLOPE DISTANCE (SD):

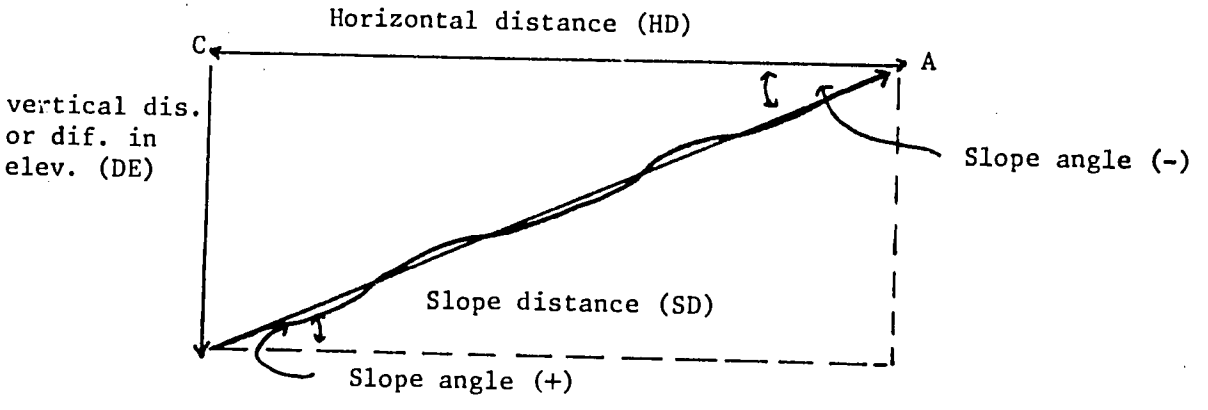
1. SD = (Vertical distance) / (Sine of slope angle)
2. SD = (Horizontal distance) / (Cosine of slope angle)

C. VERTICAL DISTANCE OR DIFFERENCE IN ELEVATION (DE):

1. DE = (Slope distance) (Sine of slope angle)
2. DE = (Horizontal distance) (Tangent of slope angle)
3. DE = (Percent slope) (Horizontal distance) /100

D. PERCENT SLOPE (%S)

1. %S = (Difference in elevation) (100) / (Horizontal distance)
2. %S = (100) (Tangent of slope angle)

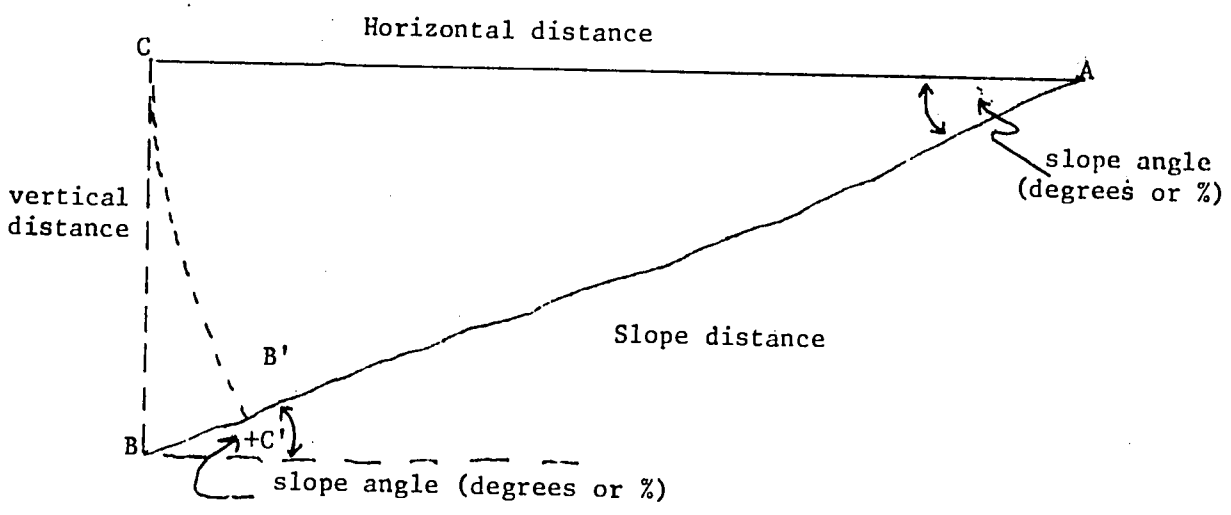


TAPING THEORY

Slope vs. Horizontal distance

and

Slope & Horizontal



1. slope distance is always longer than horizontal distance or horizontal distance is always shorter than slope distance. If tape 100' long stretches from A to C (horizontally), it would lie from A to B' on a given slope. The error in actual measurement of 100' horizontal distance on slope is the distance B to B'. Therefore A to B' on slope = length AC on horizontal. To put it another way, to obtain a horizontal distance of 100' while chaining on ground or along a slope, you must add a little to the 100' measurement on the slope to make the vertical projection (of A to C, the 100' horizontal line) be the same point (B) as the tape end at the slope point (B).

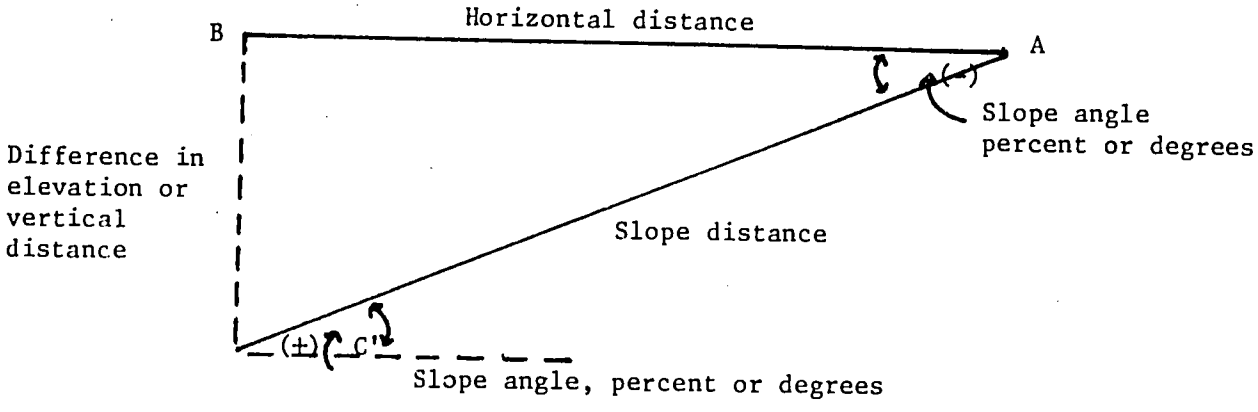
   By Formula the entire distance A to B along the ground can be "reduced" to the horizontal as in using degrees, like:

   Horizontal distance = (Slope distance)(Cosine of vertical angle)
   AC = (AB)(Cos 10°)
   AC = (190')(.98481)
   AC = 189.1'

   Note AC is shorter than AB. This is because horizontal distance is always shorter than slope distance.

TAPING THEORY

VERTICAL DISTANCES OR ELEVATION DIFFERENCES



Recall that horizontal distance = (Slope distance)(Cosine of slope angle)
or AB = (AC)(Cos angle A or C')

Vertical distance = (Slope distance)(Sin or slope angle)
or BC = (AC)(Sin angle A or C')

Example: AC slope distance = 190'
Angle A or C' slope angle = 10°
What is horizontal distance AB, & Vertical distance BC?

BC = (190')(Sin angle A or C')
BC = (190')(.17365)
BC = 18.91

BC or vertical distance is 18.91'. If elevation at A is 110.51', then elevation at C is 110.51 - 18.91 = 91.70.

Using percent instead of degrees, formula for AB horizontal distance is:

$$\frac{(\text{Difference in elevation})(100)}{\text{level reading}} \quad \text{or}$$

$$\frac{(18.91)(100)}{10} = 189'$$

Decimals of angle cosines of integral degrees

Decimales de cosenos de ángulos de grados enteros

Grado	Coseno	Grado	Coseno
1	0.9998	23	0.9205
2	0.9994	24	0.9135
3	0.9986	25	0.9063
4	0.9976	26	0.8988
5	0.9962	27	0.8910
6	0.9945	28	0.8828
7	0.9925	29	0.8746
8	0.9903	30	0.8660
9	0.9877	31	0.8572
10	0.9848	32	0.8480
11	0.9816	33	0.8387
12	0.9781	34	0.8290
13	0.9744	35	0.8192
14	0.9703	36	0.8090
15	0.9659	37	0.7986
16	0.9613	38	0.7880
17	0.9563	39	0.7771
18	0.9511	40	0.7660
19	0.9455	41	0.7547
20	0.9397	42	0.7431
21	0.9336	43	0.7314
22	0.9272	44	0.7193
		45	0.7071

(slope distance) (cosine of slope angle) = horizontal distance

(distancia de la pendiente)(coseno del ángulo) = distancia horizontal

SURVEYING PROBLEM

Measuring with the tape

Here is survey data for a map made with a compass and tape.

What is your total (horizontal) distance?

From	To	Bearing	Slope distance	Slope	Cosine	Horizontal distance
A	B		344.0	10°30'		
B	C		76.0	12°00'		
C	D		21.0	0°00'		
C	E		842.0	0°30'		
E	F		182.0	21°00'		

MEASUREMENT OF DIRECTION

General relationships: The angle a line makes with some reference line establishes the direction of that line. The reference line is usually a North-South line called a meridian, or a magnetic meridian if reference line is indicated by a magnetized compass needle.

Direction representation: Angular relationships are based o the intermingled use of azimuths and bearings. Since instruments are graduated into either one or both, it is often necessary to convert from one to the other.

BEARINGS

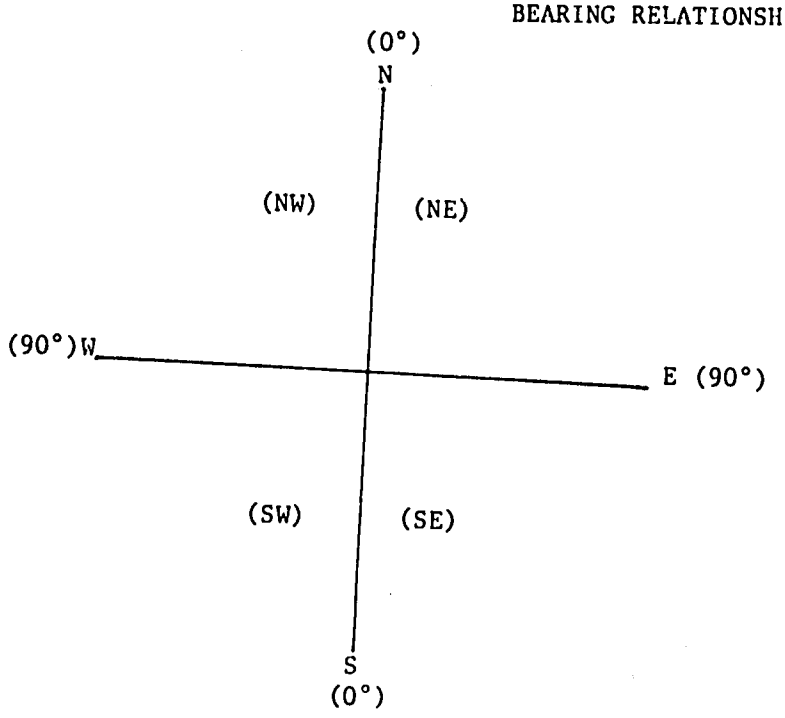
The bearing of a line is the acute angle a line makes with the meridian. Thus, bearings are measured from North or South to the East or West, dividing the circle into quadrants of 90° each. No bearing is therefore greater than 90°.

AZIMUTHS

Azimuth is the clockwise angle measure from North or South, 0° to 360 degrees. (In forestry work it is measured from North). Azimuths are easily converted from or to bearings. NE bearings are azimuths of 0° to 90°; SE bearings are azimuths of 90° to 180°; SW bearings are azimuths of 180° to 270°; and NW bearings are azimuths of 270° to 360°.

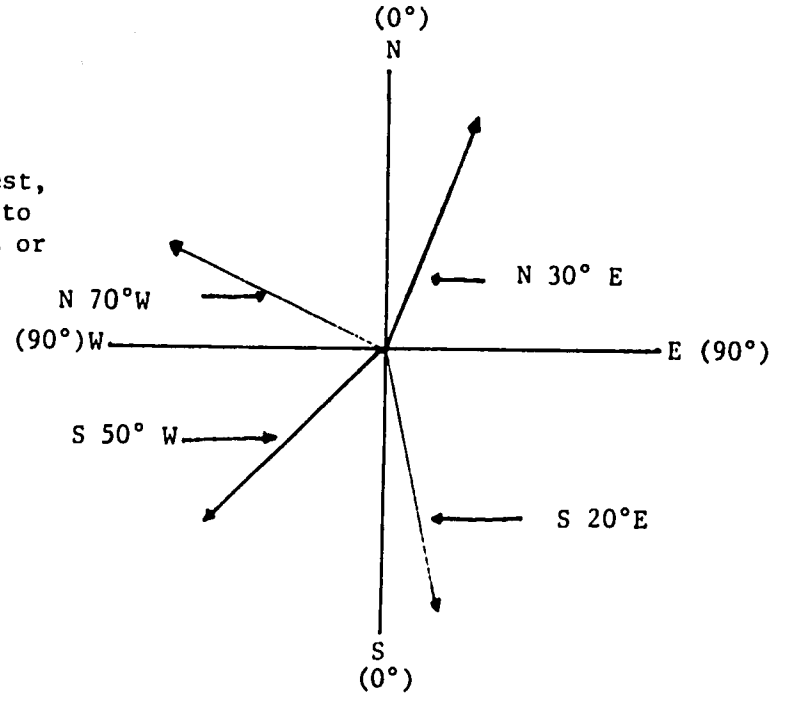
To solve azimuth-bearing relationships, it is often desirable to use back bearings and back azimuths. These are the reverse of the forward direction, a difference of 180°. Back bearings retain the same number, but the letters identifying the quadrant are opposite. For example: the back bearing of N 40°E is S 40°W. Back azimuth are found by adding or subtracting 180°, subtract if 180° to 360°). Thus the back azimuth of 270° is 270° - 180°= 90°, and the back azimuth of 45° is 45° + 180° = 230°.

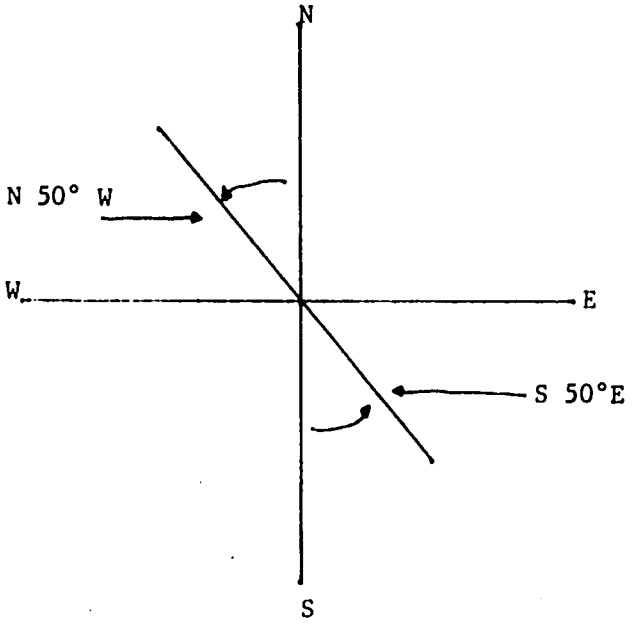
BEARING RELATIONSHIPS



(1) Circle contains 360°. Each quadrant has 90° measured 0° to 90° from N & S.

(2) Bearings always read from North or South to East or West, i.e., they increase from 0° to 90° from N or S toward the E or W.





(3) Back bearings have same number as forebearings but quadrant letters are opposite.

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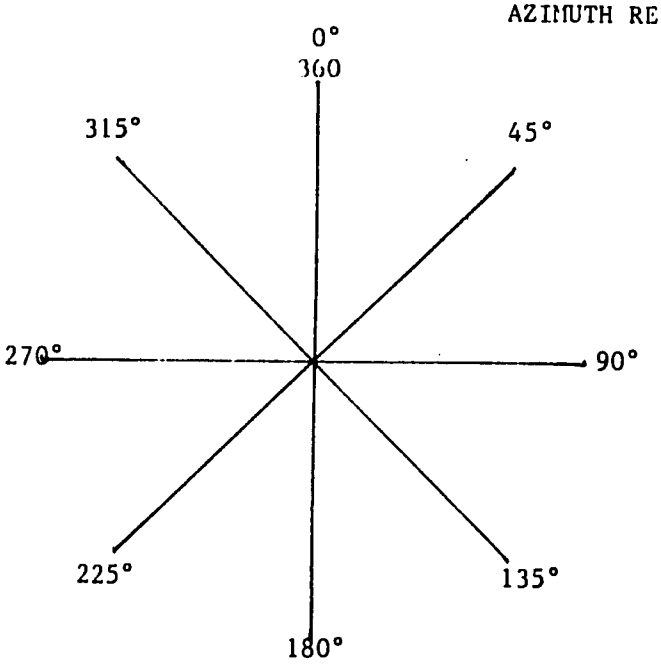
AZIMUTH RELATIONSHIPS

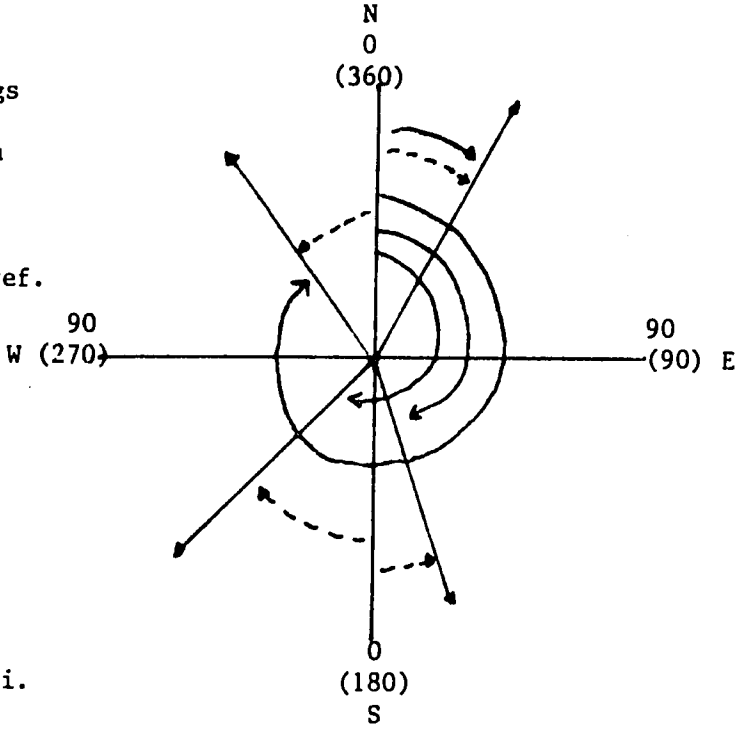


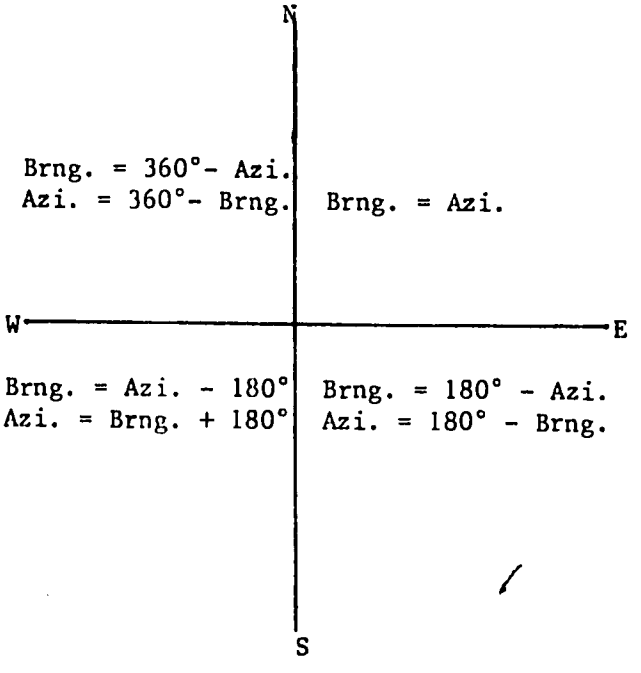
(1) Circle contains 360°. Quadrants not differentiated as "individuals." Compass marked off in degrees and half degrees.

(2) - - - - - - - - = Bearings

———————— = Azimuth

0, 90, 0, 90 = Bearing ref.
(90') (180) etc. = Azimuth ref.





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BEARING - AZIMUTH PROBLEMS

1. Convert the following azimuths to bearings:

   a. 17°30'
   b. 298°26'
   c. 359°29'
   d. 97°20'
   e. 210°03'

2. Compute the angle between the following bearings:

   a. N 21°35' E & S 89°13' E
   b. S 25°31' E & N 87°47' W
   c. S 47°28' E & N 01°22' W

3. Magnetic declination = 20°30' E. What is the magnetic bearing corresponding to a true bearing of S 7°00' E?

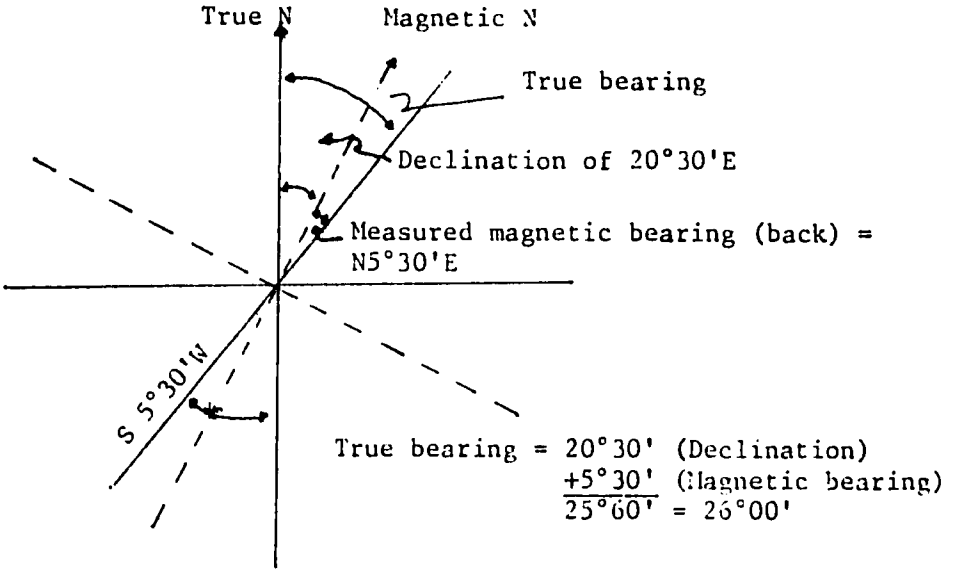
4. Bearing from A to B is S 45°E, from B to C is S 10° E. What is interior angle at point B?

5. Given:

MAGNETIC DECLINATION

The angle between a line of true direction and a line of magnetic direction is called the magnetic declination. It is the amount that the magnetic meridian varies from the true meridian. It varies from place to place from year to year. If the north end of the compass needle points to the east of the true meridian, the declination is east; if it points west, the declination is west.

Sometime you may need to convert magnetic to true direction or vice versa. Draw a sketch to portray the situation. Don't rely on rules. For example, the declination is 20°30'E. You have a magnetic bearing of 35°30'W and want to know the true bearing of that line.



USE OF LEVELS FOR SLOPE MEASUREMENT

A. Types

1. Abney levels
2. Sunto levels

B. Principles

1. Both types measure the angle between the horizontal plane and your line of site. Angle may be in terms of degrees, percent, or topographic units. Abney levels are available which measure in these 3 values. The Sunto level measures degrees, percent, or both.

C. Use

1. The percent level measures the number of feet rise per 100 feet of horizontal. Tables are usually used to find the horizontal distance. When the horizontal distance is known, the difference in elevation is equal to the horizontal distance times the level reading divided by 100.

2. The degree level gives the slope angle in degrees. The difference in elevation or vertical distance here is equal to the sine of the level reading times the slope distance. The horizontal distance is equal to the cosine of the level reading times the slope distance. The vertical distance also equals the horizontal distance times the tangent of the level reading.

3. Use of the degree or percent level is largely a matter of personal preference. Both types require field computations. If you have slope reduction tables (for degrees or percent), values of horizontal and vertical distance can be read directly instead of doing the computations yourself. This saves a great deal of time.

4. A common use of levels is to measure tree heights (also cliffs, gradients of ridges, streams, roads, etc.). The principle is shown as follows:

   Use percent reading:

   Since percent is the feet rise per 100' of horizontal distance, the level reading in percent equals height PROVIDING you are 100 horizontal feet from the tree. If you are more or less than 100' from the tree, (or object being measured for height), the horizontal distance must be multiplied by the level reading and divided by 100 to get vertical distance.

   Use of degree reading:

   Often it is more convenient to measure along the slope rather than on the horizontal. In this case height is slope distance times the sine of slope angle shown by the level.

If you know the horizontal distance, height is equal to the horizontal distance times the actual level reading (in degrees) divided by 100.

CAUTION: Height is the distance above and below eye level. Be sure to take two readings, one for eye level to top of object and one for eye level to bottom of object. The sum is total height. See the following diagram for procedure.

2. Slope tape:

Are two chains surveyors' tape, supplemented by correction graduations for use in slope chaining with the topographic Abney level. The correction graduation are placed on two "trailers." One trailer, for measuring distances of 1 chain, is found on the under side of the second chain, beyond the brass tab marking the end of the first chain. Care must be taken not to confuse its graduations with the standard graduations on the opposite side of the tape. The second trailer, for measuring distances of 2 chains, is an actual addition to the tape beyond the end of the second chain. Its graduation are likewise on the under side.

The error to be expected by using this tape is 1 ft in 500.

This assumes that where the slope changes sharply within 2 chains, only 1 chain - length will be measured at a time, and the Abney level will be read again for the second chain-length.

COMMON SOURCES OF ERROR IN TAPING

The principal mechanical error are bad alignment and sag of the tape. Adequate tension - generally a pull of 20-30 pounds on the tape will reduce sag sufficiently for ordinary work. Human errors in taping are unpredictable; they include adding or dropping a full tape-length; adding and dropping a foot (43.4 instead 42.4) when measuring fractional feet transposing or reading wrong numbers (37.81 for 37.18 or 89 for 68); careless calling of number to the notekeeper (53.0 for 50.3) taking the wrong point of the tape for 0 or 100 ft. Never fail to check the simplest measurements; for example a glance at the graduation 70 two feet from 68 would prevent anyone from inverting 68 to read 89.

The reference line is usually a true north-south line called a meridian. If the reference line is that indicated by a magnetic compass needle, it is referred to as a magnetic meridian.

BEARINGS AND AZIMUTHS

Bearings are measured from north and south to the east and west, dividing the circle into quadrants of 90° each.

Azimuth is the clockwise angle measured from north or south 0 to 360°. In forestry work the azimuth is usually measured from north.

CASTRO TRACT

BOUNDARY SURVEY

(Hand Compass, Hand Level & Tape)

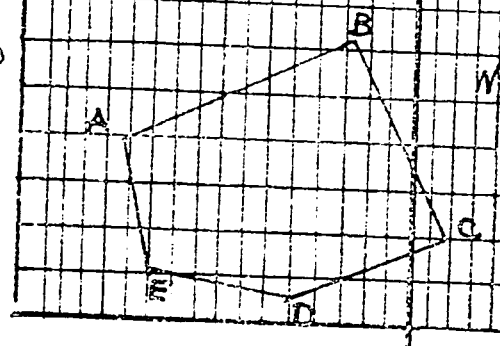
CASTRO EXPERIMENTAL FOREST

STA.	SLOPE DIST. DEG. LEVEL	HORIZ. DIST.	VERT. ELEV.	ELEV. (FT)	BRNG.
A				100.0	
	110.0 -9°39'	108.4	-18.4		N 10° W
E				118.4	
	300.0 -19.48'	282.3	-101.6		N 80° W
D				220.0	
	200.0 +44°02'	194.0	+48.5		S 50° W
C				171.5	
	300.0 +9°05'	296.2	+47.4		S 40° W
B				124.1	
	220.0 +6°17'	218.7	+24.1		N 60° E
A				100.0	

Headchain: Nasser
Rearchain: Ben Bella
~~Notes: Chua En Lai~~

5-30-65
Cloudy w/rain
~~Warm & windy~~

Note: Horizontal & Vertical distances must be computed if you do not have tables giving this information. Computations should be shown on this page.



Note: sketch not to scale.

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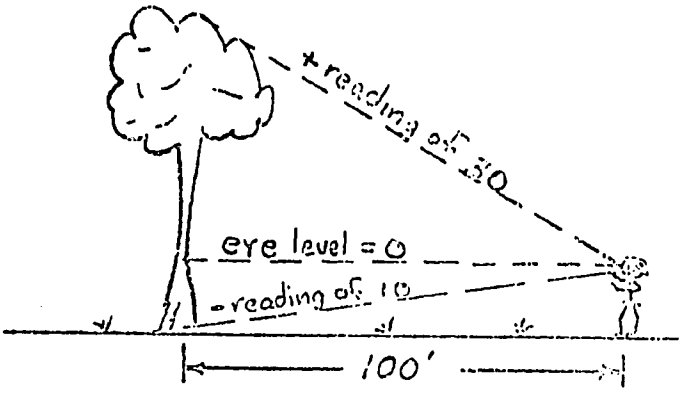
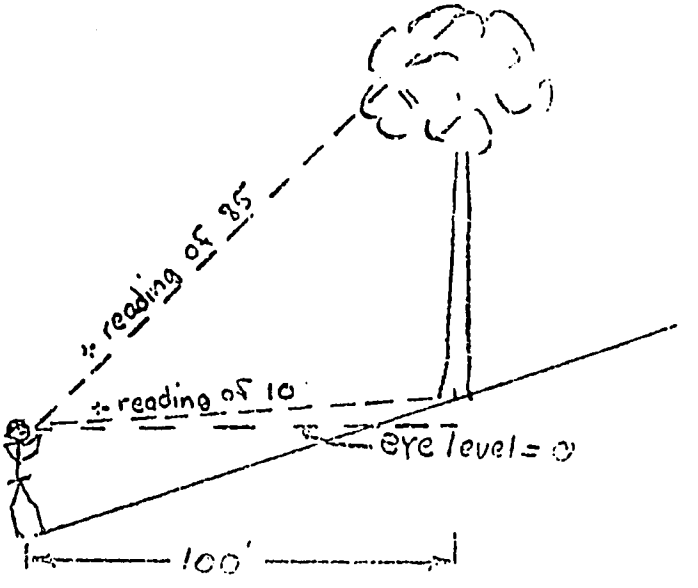
1. Height=Sum of 2 readings
30 + 10 = 40'

Height=40'



2. Height= Difference of 2 readings
85 - 10 = 75'

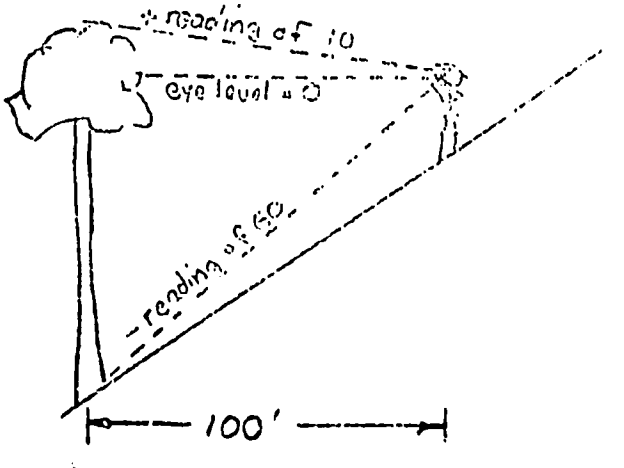
Height=75'



3. Height=Sum of 2 readings
60 + 10 = 70'

Height=70'

*With degree Sunto level, add individual readings in degrees to get "total degree height", then compute height: Hgt. = (Slope distance) X (sine of degree height)



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MEASUREMENT OF HORIZONTAL DISTANCE

Pacing

1. Least accurate of the means of measurement.

2. It can be used in timber cruising and in land surveying it may be very valuable supplement to the more accurate methods.

Rules to follow:

1. Be systematic. Because the method is crude, it should not be rendered valueless by careless recording of paces, ignoring changes of slope and cover, or by failing to check paced measurements against measured (chained or taped) distances at every opportunity.

2. Count double steps only. A pace means two steps.

3. Adopt normal pace that can be held all day. A convenient pace on open, level ground is 5.28 feet or 1,000 to the mile. Pace repeatedly over a measured course on such ground, until a variation of less than 3 paces in every 100 is attained.

4. In difficult terrain no attempt should be made to maintain a standard pace. Instead, allow for its inevitable shortening (downhill as well as uphill) by repeating the count at intervals. For example, on moderate slopes county every tenth pace twice: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 ... 19, 20, 20, 21, etc. On steeper slopes it may be found necessary to repeat every fifth count: 1, 2, 3, 4, 5, 5, 6, 7, 8, 9, 10, 10, 11 ... 12, etc. On the steepest slopes in very heavy brush, in swamps or among boulders every count may have be repeated 1, 1, 2, 2, 3, 3, etc. Consistent accuracy in pacing under such conditions is attained only by practice and is maintained only by constant checking. Errors of 2 to 4 chains per mile are to be expected of the average pacer of the experienced pacer, 2 chains or less.

5. It is suggested that pacing results be regularly recorded and checked against known distances under various conditions.

MEASUREMENT BY CHAIN OR TAPE

1. Gunter's chain:

This was the original tool used in the United States and Canada for measuring distances in the woods. It is 66 feet long and is composed of 100 links. Each link is 7.92 inches long or .66 feet. Because nearly all woodland areas are expressed in acres, and 10 square chains equals 1 acre chains and links are more convenient units than feet in areas surveys. In use it must be kept horizontal.

DENDROLOGY

FIRST DAY

Morning	:	Introduction
		Nomenclature
		Classification
		Botanical Terms
Afternoon	:	Botanical Terms (Lab)
		Preparation of Herbarium Specimens

SECOND DAY

Morning	:	Preparation of Botanical Key (Lab)
		Ecology
		Important Tropical Tree Families
Afternoon	:	Field excercise

Leaf Key to the Woody Plants in the Native Wood Plot at the Agricultural Experiment Station - Río Piedras 1965

Roy Woodbury

A. Palms with pinnately compound leaves, plant spiny and leaves with pararel venation — Acrocomia media-Corozo

A. Not palms and plants with net veined leaves.

B. Leaves compound.

C. Leaves palmately compound.

D. Leaves opposite.

E. Leaves of three membranous leaflets - Vitex divaricata Higuerillo

E. Leaves of 5 leatherly leaflets - Tabebuia heterophylla Roble

D. Leaves alternate, large - Didymopanax monototoni - Yagrumo macho

C. Leaves pinnately compound.

D. Leaves opposite of 3 leaflets - Vitex divaricata - Higuerillo

D. Leaves alternate.

E. Leaflets of 1-2 pairs, midrib very oblique, rachis without glands — Hymenaea courbaril - Algarrobo

E. Leaflets of more than 4. If 2 prs., glands are present on rachis

F. Leaflets of 2-3 pair, glands on rachis between paired leaflets — Inga laurina Guama

F. Leaflets opposite or alternate, more than six.

G. Leaflets toothed (serrate to crenate).

H. Plant with spines usually; leaves glandular; Leaflet blades less than 4 cm. wide Zanthoxylum martinicense Espino rubial

H. No spines or glands; leaflets over 4 cm. wide, prominently nerved below Cupania americana Guara

G. Leaflets entire, glabrous at maturity.

H. Leaves indeterminate (ending in a bud), lateral veins prominent below (Guarea trichilioides - Guaragua).

I. Leaflets even pinnate (Swietenia spp. - Caoba).

I. Leaflets odd pinnate.

J. Tree with 7-15 leaflets (Andira inermis - Moca).

J. Shrub or vine with 5-9 leaflets (Rourea glabra - Bejuco de garrote*)

B. Leaves simple.

C. Leaves opposite.

D. Leaves with stipules.

E. Stipules opposite the petiole, leaf large (to 1 ft) clustered at end of branch (Genipa americana - Jagua).

E. Stipules alternate with leaves or between the paired leaves, or a ring.

F. Stipule reduced to a ring.

G. Veins basal or palmate (Miconia prasina - Camasey*).

G. Veins pinnate, leaves clustered (Byrsonima spicata - Maricao).

F. Stipules well developed, single or two lobed.

G. Stipules two lobed.

H. Stipules lobed to the base; tufts of hairs at the base of main veins (Palicourea reparia* - Cachimbo).

H. Stipules lobed at the apew only (Psychotria brachiata - Cachimbo).

G. Stipules not lobed, simple.

H. Plant usually spiny; leaves less than 4 cm long and tufted on short branches; base cuneate (Randia aculeata - Tintillo*).

H. Plants not spiny, leaves longer than 4 cm.

I. leaf and young parts scarbous, reticulate below Guettarda scabra - Palo de cucubano).

I. Glabrous, leaves not prominently reticulate below.

J. Stipules abruptly long aristate, not soon deciduous, blades abruptly accuminate (Faramea occidentalis - Cafeillo).

J. Stipules accuminate, soon deciduous, blade acute to accuminate (Ixora ferrea - Cafeillo).

D. Leaves estipulate.

E. Leaves palmately veined.

F. Basal veins arising from above the base, leaves glabrous (Miconia prasina - Camasey*).

F. Basal veins arising from the base, leaves hairy.

G. Petioles 5 cm long or more (Miconia macrophylla* - Camasey).

G. Petioles short or sessile (Miconia impetiolaris - Camasey*).

E. Leaves pinnately veined.

F. Lateral veins numerous (over 100). A white latex exudes from injured young parts (Calophyllum brasiliense - Marie).

F. Lateral veins less than 100.

G. Young leaves and twigs prominently hairy. Numerous prominent lateral veins (50+) (Myrcia deflexa - Cieneguillo).

G. Young parts glabrous or only slightly hairy.

H. Leaves minutely glandular dotted.

I. Leaves mostly over 10 cm long (Eugenia jambos - Pomarrosa).

I. Leaves mostly under 10 cm. Main veins less than 5 mm, apart (Myrcia splendens - Hoja menuda).

H. Leaves without glandular dots.

I. Leaves commonly clustered on short branches, terminal bud rusty pubescent, stipular ring present (Byrsonima coriacea - Maricao).

I. Leaves not clustered; margin of some leaves with few teeth or entire (Aegiphila martinencis - Capaillo*).

C. Leaves alternate.

D. Plant with milky sap.

E. Leaves deep green above, golden brown below (Chrysophyllum caimito - (Caimito).

E. Leaves not golden brown below.

F. Fugaceous stipules producing a ring on young twigs; leaf ape abruptly acute (Artocarpus heterophyllus - Jaca).

F. Twigs without stipular rings; leaf apex acute to accuminate (Pouteria multiflora - Jacana).

D. Plant without milky sap.

E. Leaves palmately veined and producing a strong aroma when crushe (Riper amalago - Higuillo).

E. Leaves pinnately veined.

F. Leaf margins toothed.

G. Blade oblong to lanceolate or narrowly elliptic; young pa hairy.

H. Leaf margin serrate; stipules prominent; young parts greyish-pubescent (Caseria arborea - Rabo de ratón o Guía verde).

H. Leaf margin finely crenate; blade narrowly elliptic (Ardisia crenulata - Rasca garganta*).

G. Plant glabrous; teeth mostly rounded.

H. Leaves broadest at the middle or above.

I. Leaves thin, less than 6 cm long and finely tooth (Caseria decandra - Tostado).

I. Leaves leatherly to fleshy; teeth distant and rounded.

J. Main veins prominent below and strongly curve stipular scars present (Caseria guianensis - Palo blanco).

J. Main veins not prominent or curved, teeth inconspicuous (Symplocos martinencis - Aceitu blanca).

H. Leaves broadest below the middle.

I. Blade undulate (wavy); leaf-like branches; blade over 5 cm long (Caseria sylvestris - Cafeillo).

I. Blade not wavy and under 5 cm long; main veins strongly curved (Flacourtia inermis - Cerezo).

F. Leaf margins entire.

G. Branches leaf-like; small stipules prominent near base of branch; blade ovate, apex acute, pale below (Phyllanthus acidus - Grosella).

G. Branches not leaf like; stipules not present.

H. Leaves large (15-20 cm); branches commonly curved on young plants; blades producing galls (Ocotea leucoxylin - Laurel geo).

H. Blades seldom over 15 cm long.

I. Blades strongly ribbed (0-40); apex blumtly acute to acuminate. Strong aroma when crushed (Rollinia muscosa).

I. Blade not strongly nerved; main veins less than 30.

J. Apex rounded; blade elliptic-obovate, petiole short less than 5 mm.

J. Apex acute to anuminate; blade elliptic to lanceolate.

K. Main veins fewer than 20.

L. Leaves clustered; short and long petioled (1-10 cm); apex acute, blade elliptic (Dendropanax arboreus - Palo de pollo o Muñeco).

L. Leaves not clustered; petioles same length; apex of blade acuminate (Phoebe elongata - Laurel bobo).

K. Main veins more than 20; blade narrowly elliptic (Ardisia crenulata - Rasca* garganta).

* Shrubs.

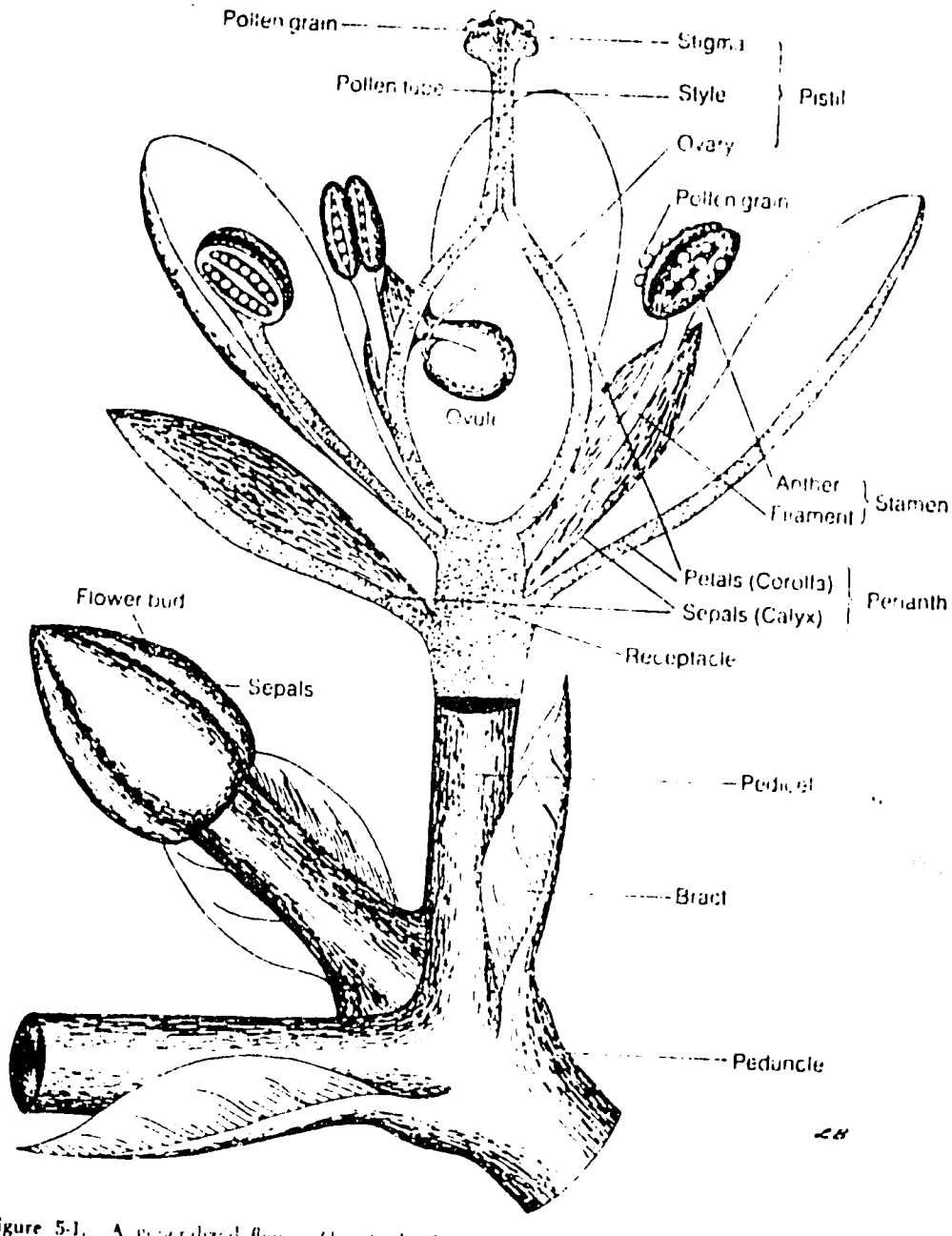

Figure 5-1. A generalized flower (longitudinal section of one in a cluster [umbel] of three), showing the parts. Semidiagrammatic.

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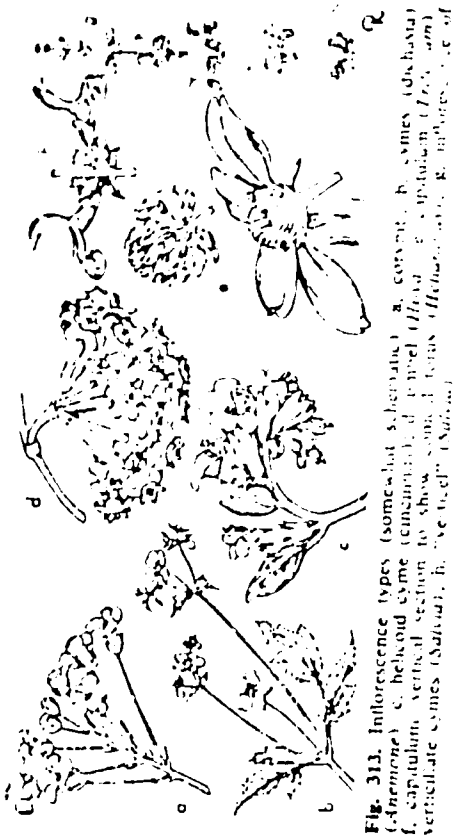

Fig. 313. Inflorescence types (somewhat schematic): a, corymb; b, cymes (dichasia) (*Anemone*); c, helicoid cyme (cincinnus); d, panicle (*Alyssum*); e, capitulum (*Tragopogon*); f, capitulum, vertical section to show scales; g, head (*Helianthus*); h, cymes vertiginate cymes (*Salvia*); i, "verticil" (*Salvia*).

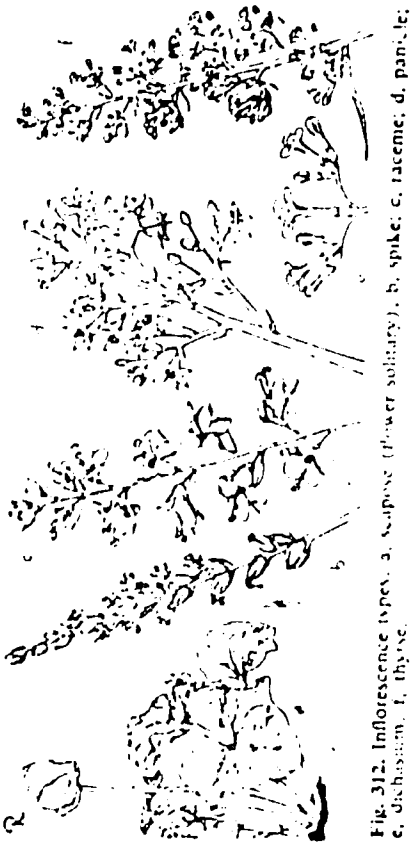

Fig. 312. Inflorescence types: a, scapose (flower solitary); b, spike; c, raceme; d, panicle; e, dichasium; f, thyrse.

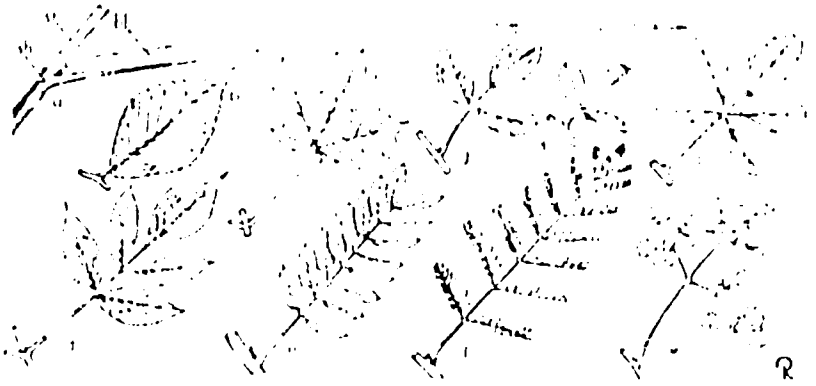

Fig. 304. Leaf parts and types: a, leaf sessile, parallel venation (bl, blade, sh, sheath, st, stem); b, leaf alternate and petioled, pinnate venation; c, leaf opposite and petioled, palmate venation; d, leaf compound, odd-pinnate; e, leaf compound, even-pinnate; f, leaf decompound (2-pinnate); g, leaf decompound, ternate; h, leaf compound, palmate; i, leaf trifoliolate and palmate; j, leaf trifoliolate and pinnate.

Fig. 303. Leaf arrangements: a, alternate; b, alternate, distichous; c, opposite; d, opposite, decussate; e, whorled; f, fasciculate; g, imbricated; h, cauline; i, rosulate (basal); j, equitant; k, cross section through equitant arrangement.

Fig. 320. Fruit types (dry): a, follicle (*Helleborus*); b, achene (*Paeonia*); c, achene (Compositae); d, pyxis (circumscissile); e, capsule (septicidal); f, capsule (loculicidal); g, capsule (poricidal); h, nut; i, loment; j, legume; k, schizocarp; l, samara (*Acer*); m, samara (*Pteleo*); n, samara (*Fraxinus*). (ca, carpophore; me, mericarp.)

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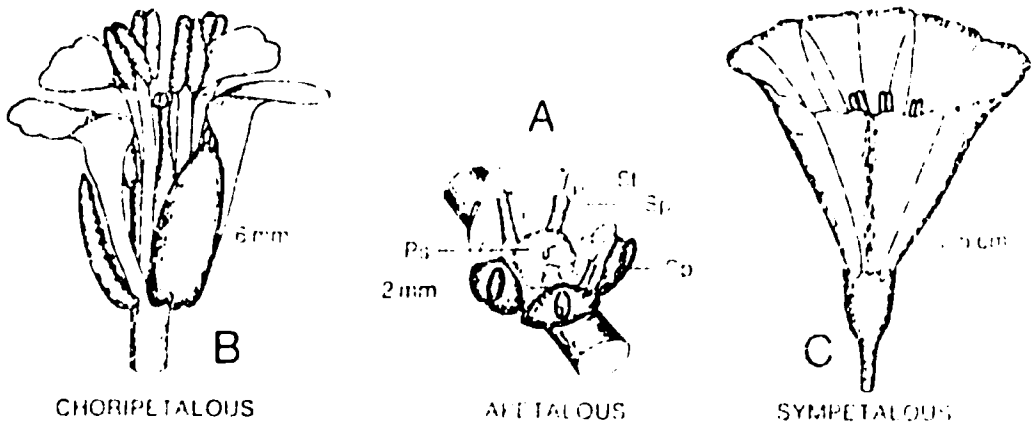

Figure 6-1 Apetalous, choripetalous, and sympetalous flowers. A, a view of the apetalous flower of a goosefoot (*Chenopodium murale*), showing the sepals and stamens and the top of the pistil (see also the flowers in Figure 6-1). B, side view of the choripetalous flower of a mustard (*Thlaspi* [*campestre*]), showing the sepals, separate petals, stamens, and pistil. C, sympetalous flower of a bindweed (in some places known as morning glory) (*Convolvulus arvensis*) (cf. also Figure 6-2 A).

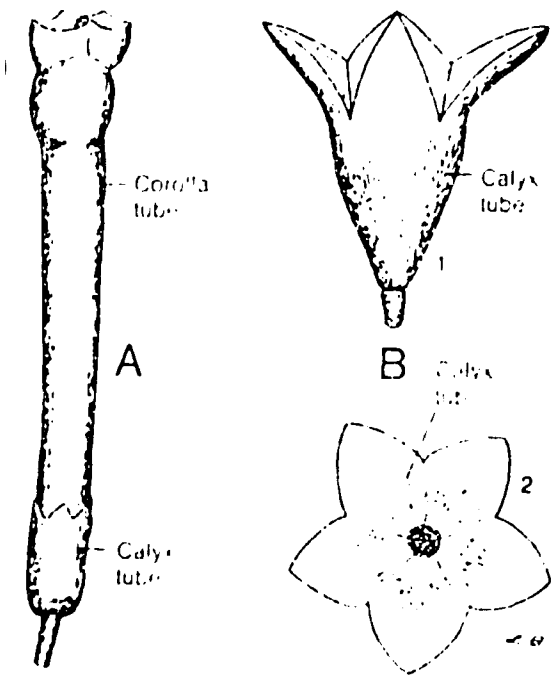

Figure 6-2 Coalescence of sepals and petals. A, coalescent sepals and petals of the tree tobacco (*Nicotiana glauca*). B, coalescent sepals of *Sterculia* (side view). 2, top view of the flower, which has no petals.

Fig. 316. Corolla types: a, ligulate or ray type (*Hieracium*); b, tubular or disc type (also bilabiate) (*Perezia*); c, bilabiate (lower petals of *Scutellaria*); d, bilabiate and personate (lip separated or calcarate) (*Linaria*); e, papilionaceous, habit, side view; f, papilionaceous, petals spread (*Lotus*). (k, keel petals; w, wing petals; st, standard or *vexillum*).

Fig. 315. Corolla types: a, urceolate (*Pieris*); b, campanulate (*Campanula*); c, funnelform (*Solanum*); d, salverform (*Quamoclit*); e, rotate (*Brunnera*).

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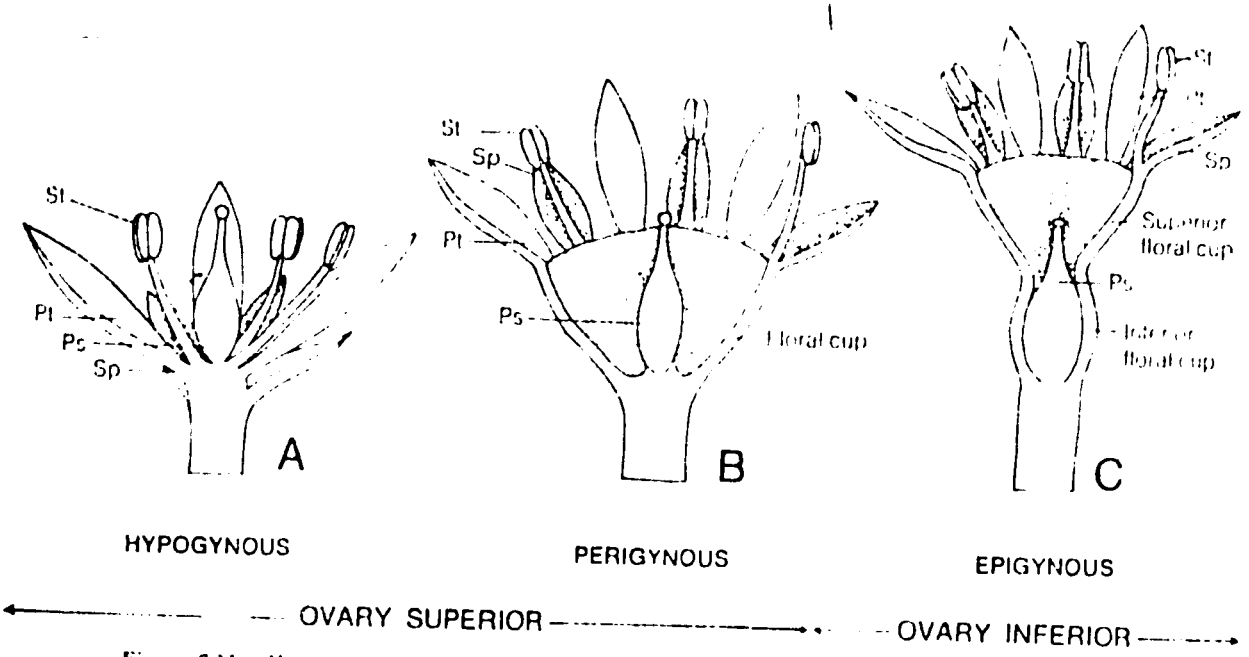

Figure 6.11. Hypogynous, perigynous, and epigynous flowers (diagrammatic). NOTE: B *differs from* A in presence of a floral cup, and C *differs from* B in adnation of the floral cup with the ovary.

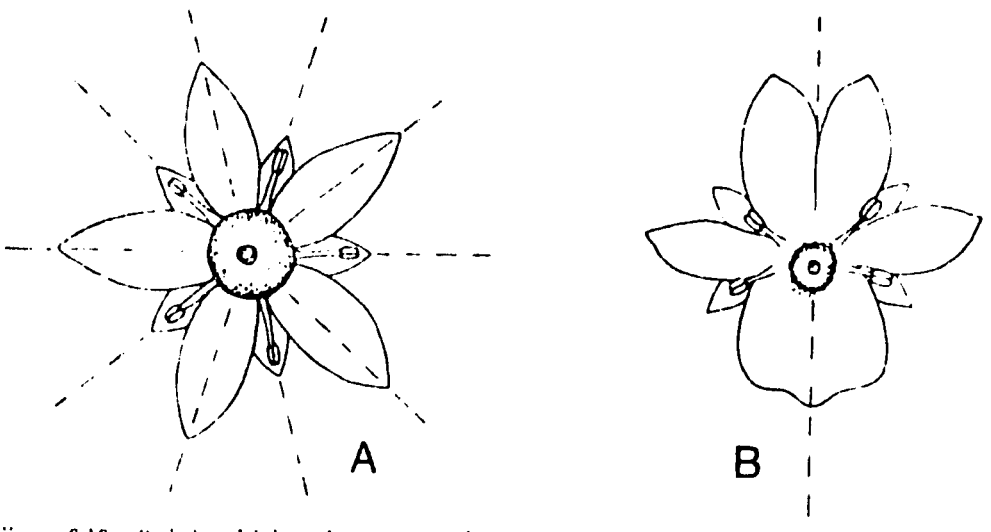

Figure 6.16. Radial and bilateral symmetry (diagrams): A radially symmetrical flower, divisible into mirror images on more than one axis, B bilaterally symmetrical flower, divisible into mirror images on only one axis.

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Fig. 306. Leaf or petal margins: a, entire; b, undulate, c, crenate, d, serrate, e, serrulate; f, double serrate; g, dentate, h, denticulate, i, incised, j, lacerate, k, laciniate; l, lobed; m, cleft, n, parted; o, pinnatifid, p, pectinate, q, palmate (palmatifid), r, pedate, s, revolute (cross-section in diagram), t, crispate, u, ciliate

Fig. 305. Leaf form or outline: a, subulate; b, acicular; c, filiform; d, filiform segments; e, linear, f, lorate, g, lanceolate, h, ovate, i, elliptic, j, oblong, k, oblanceolate, l, spatulate, m, truncate, n, pandurate, o, obovate, p, deltoid, q, rhombate (rhomboid); r, reniform, s, orbicular.

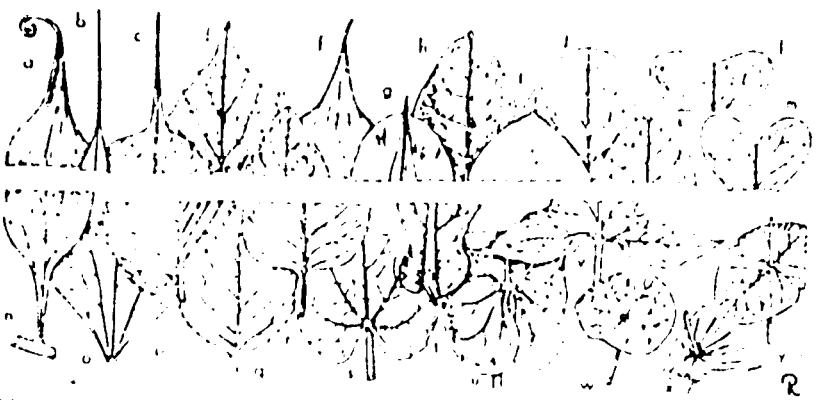

Fig. 307. Leaf or petal bases and apices: a, cirrhous, b, attenuate, c, caudate, d, acuminate; e, acute, f, cuspidate, g, mucronate, h, mucronulate, i, apiculate, j, obtuse; k, retuse; l, emarginate; m, obcordate, n, attenuate, o, cuneate, p, oblique, q, obtuse, r, truncate; s, cordate; t, auriculate, u, sagittate, v, hastate, w, peltate, x, perfoliate, y, connate-perfoliate.

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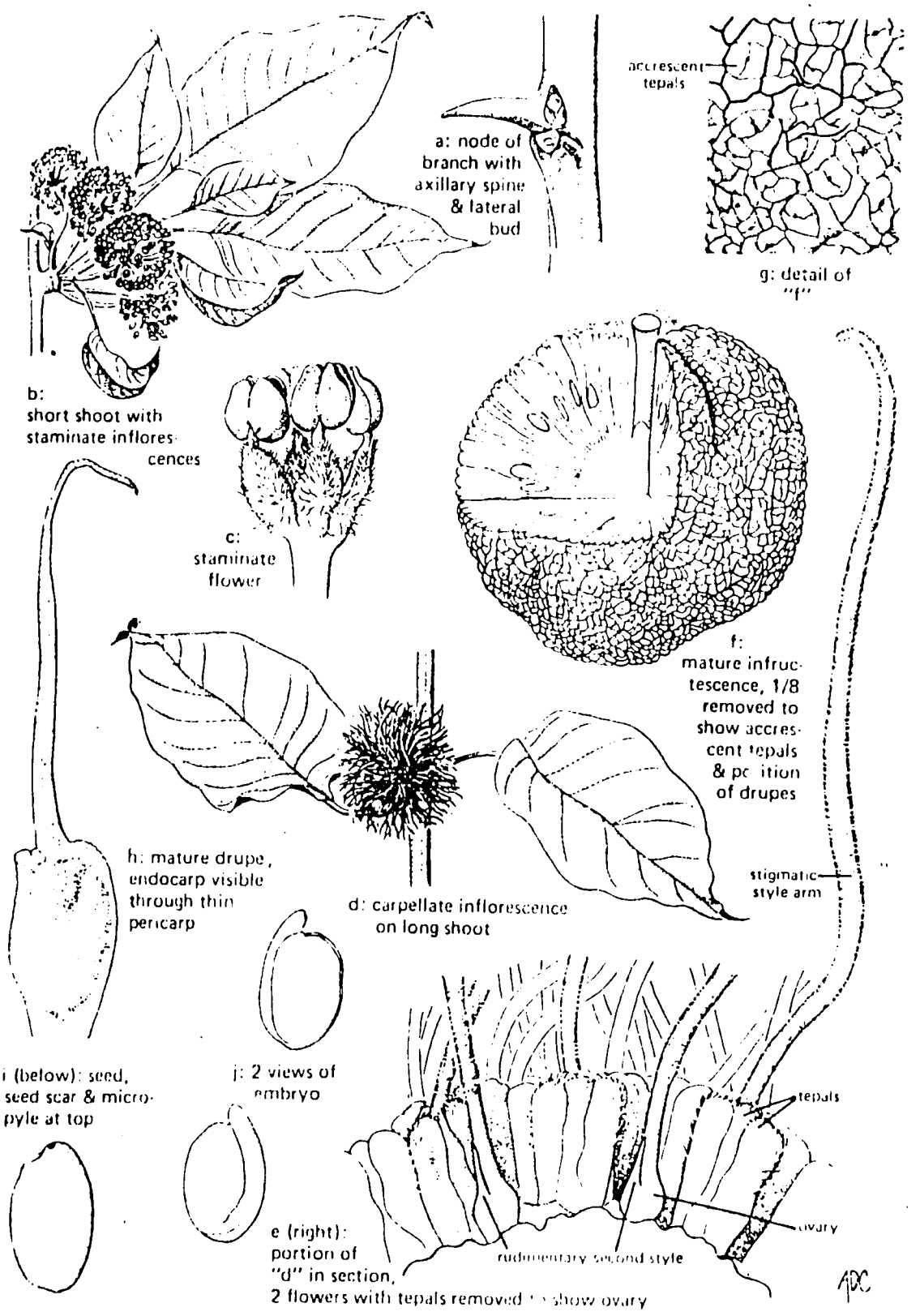
MORACEAE: Maclura. a-j, M. pomifera



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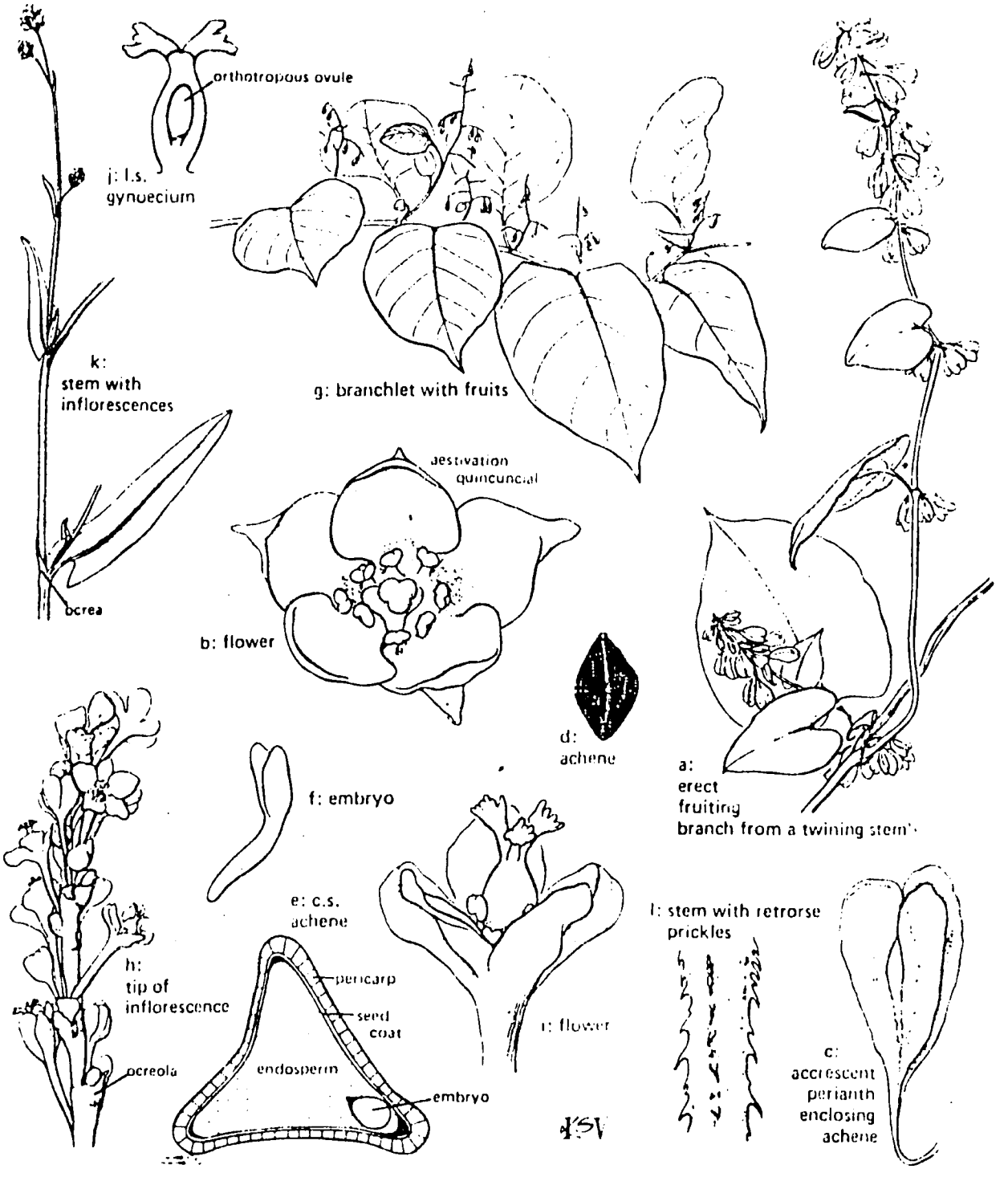
POLYGONACEAE: Polygonum sections Tiniaria (a-j) & Echinocaulon (k,l). a-f, P. scandens; g-j, P. cuspidatum; k,l, P. sagittatum



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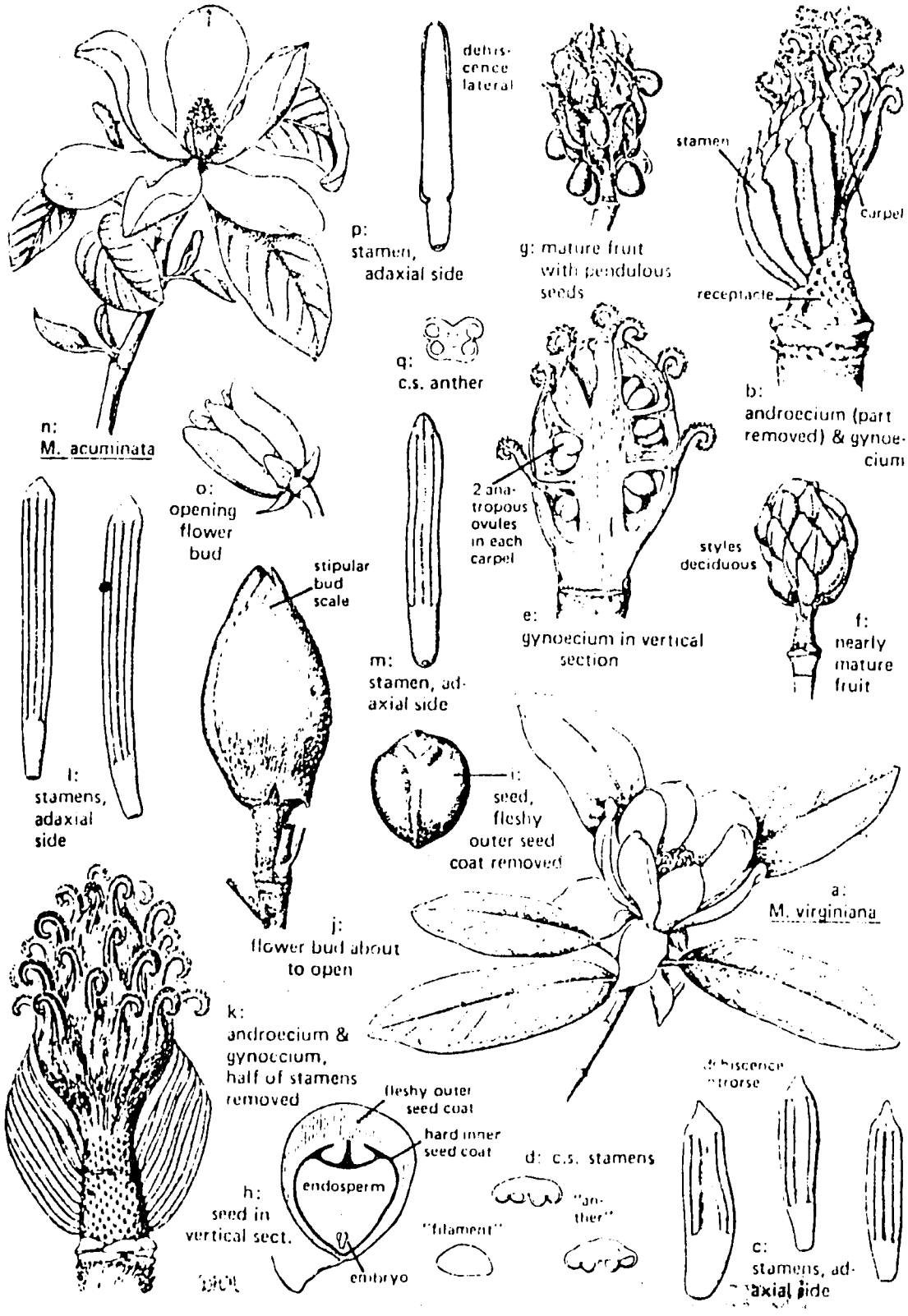
MAGNOLIACEAE: Magnolia. a-i, M. virginiana; j-l, M. grandiflora; m, M. tripetala; n-q, M. acuminata



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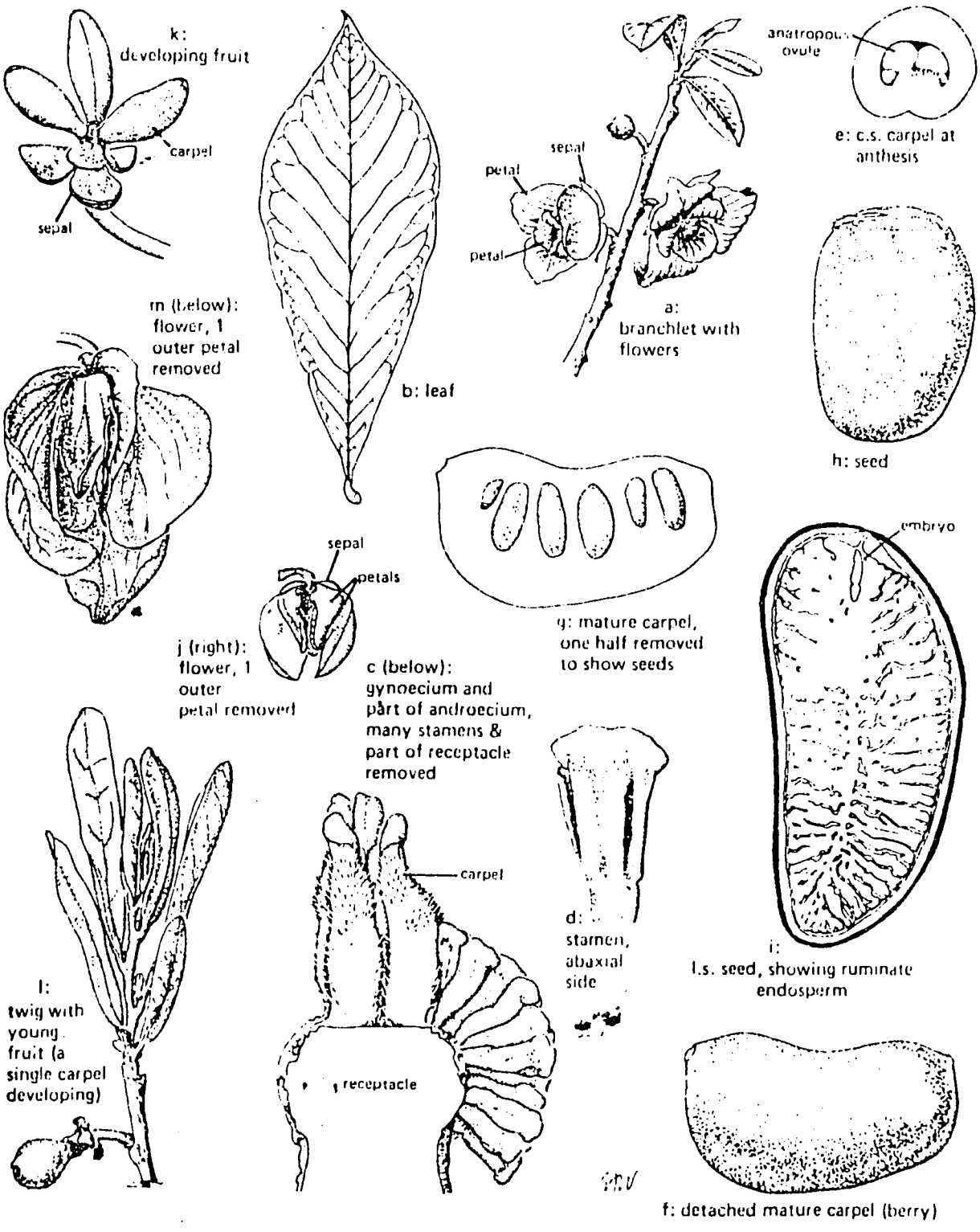
100

ANNONACEAE: Asimina. a-i, A. triloba; j-l, A. incana; m, A. obovata



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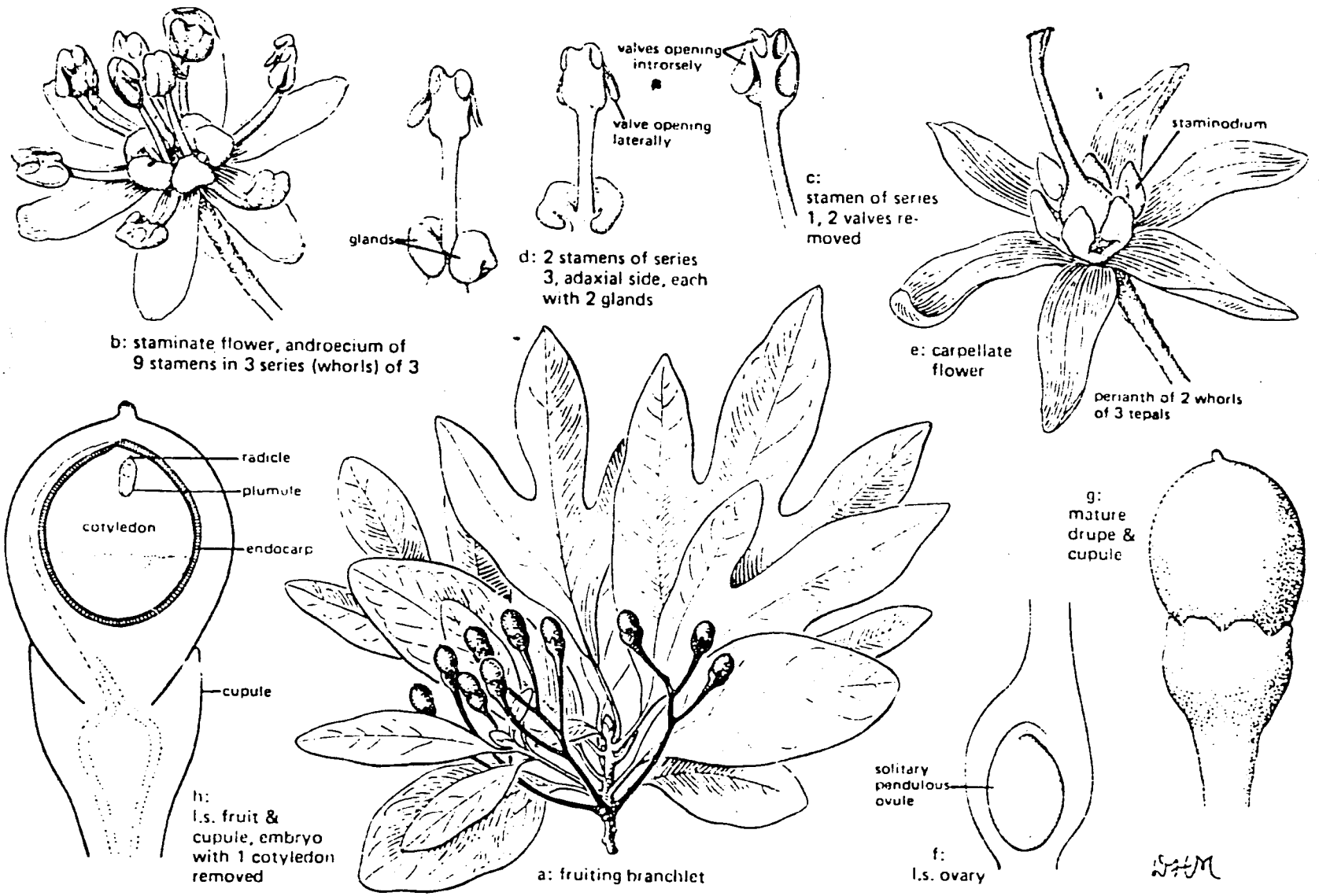
LAURACEAE: Sassafras. a-h, S. albidum var. molle



b: staminate flower, androecium of 9 stamens in 3 series (whorls) of 3

d: 2 stamens of series 3, adaxial side, each with 2 glands

c: stamen of series 1, 2 valves removed

e: carpellate flower

perianth of 2 whorls of 3 tepals

g: mature drupe & cupule

h: l.s. fruit & cupule, embryo with 1 cotyledon removed

a: fruiting branchlet

f: l.s. ovary

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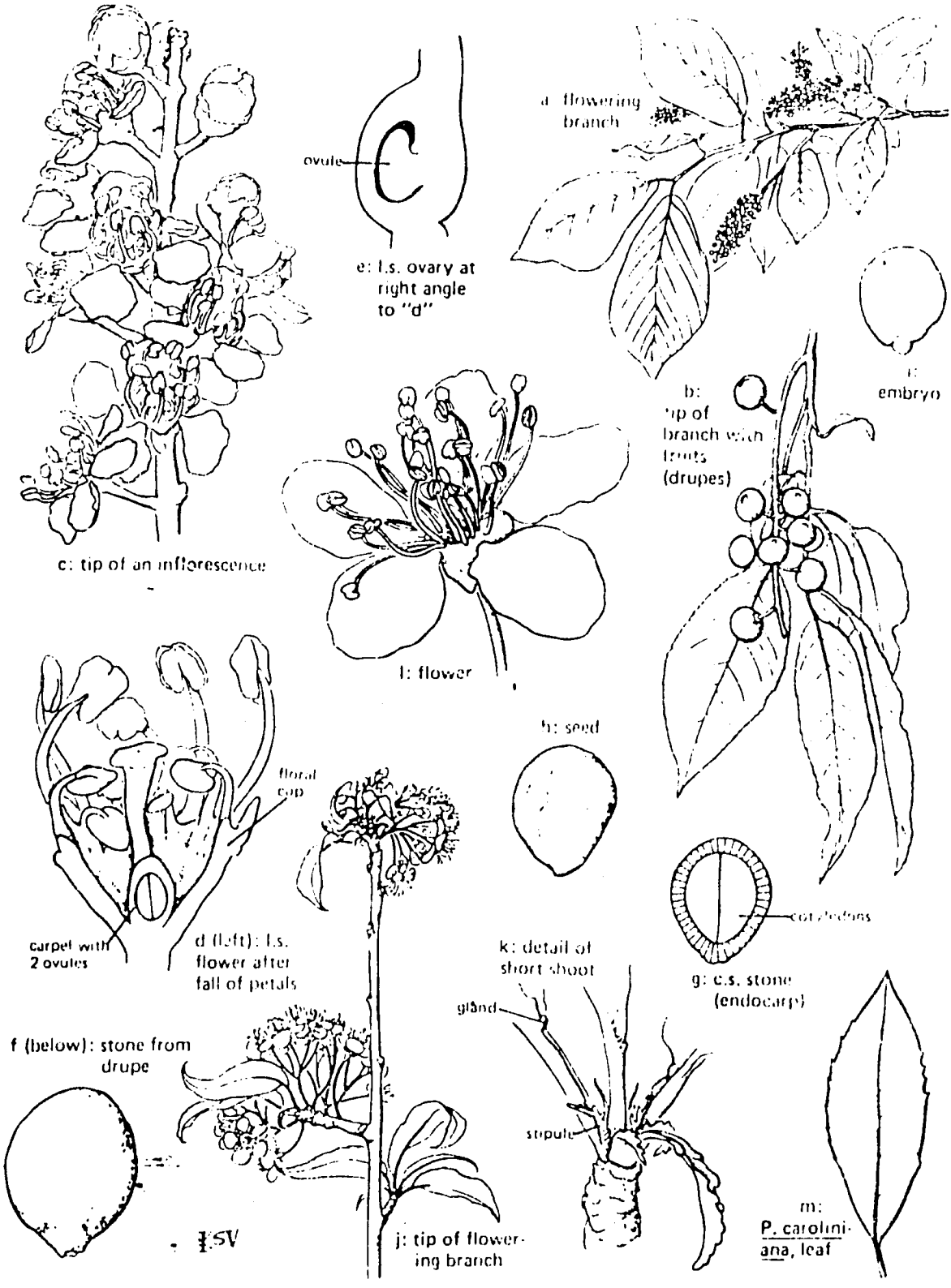
ROSACEAE subfamily AMYGDALOIDEAE: Prunus. a, P. virginiana; b-i, P. serotina; j-l, P. pensylvanica; m, P. caroliniana



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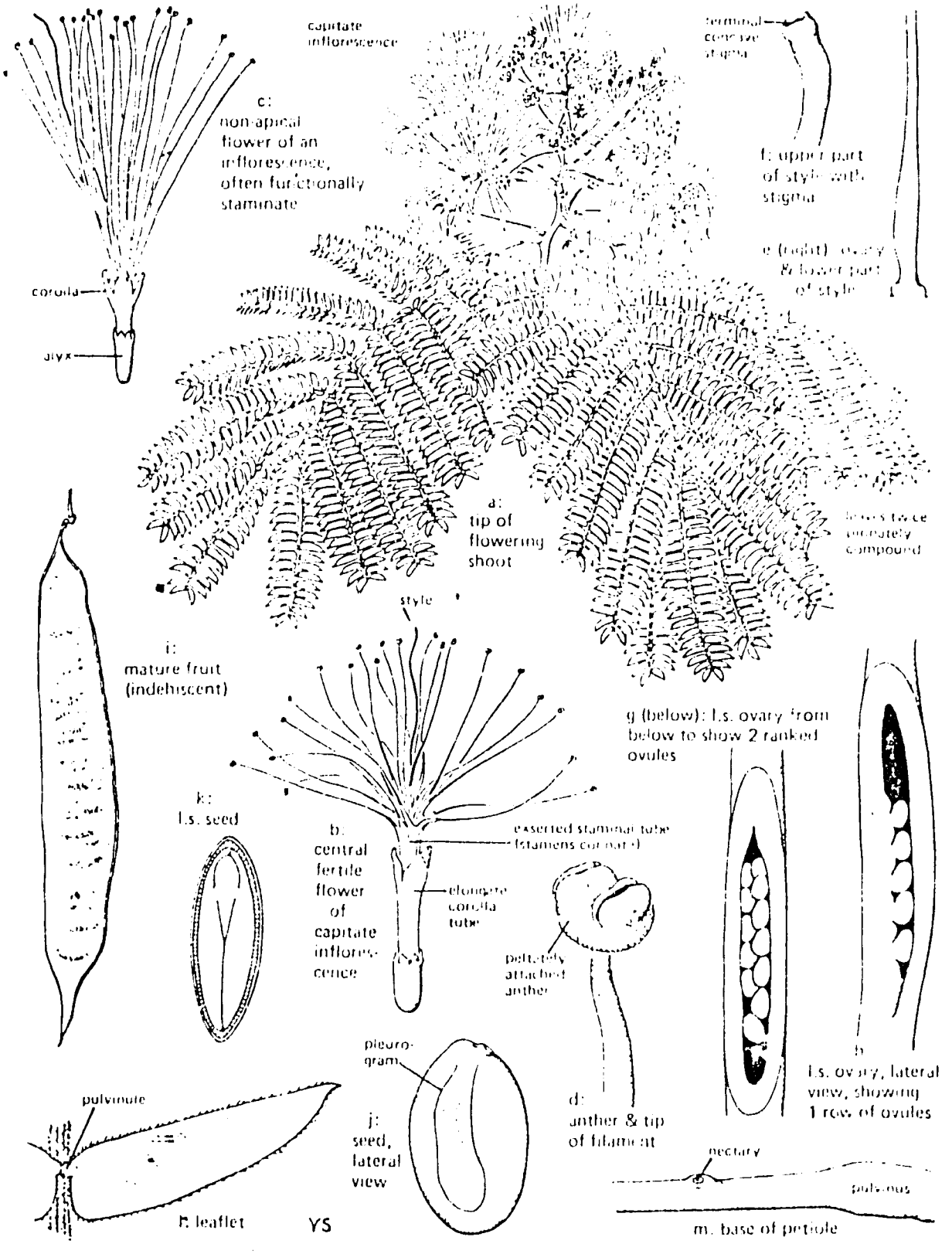
FABACEAE (LEGUMINOSAE) subfamily MIMOSOIDEAE. Albizia, a-m, A. julibrissin



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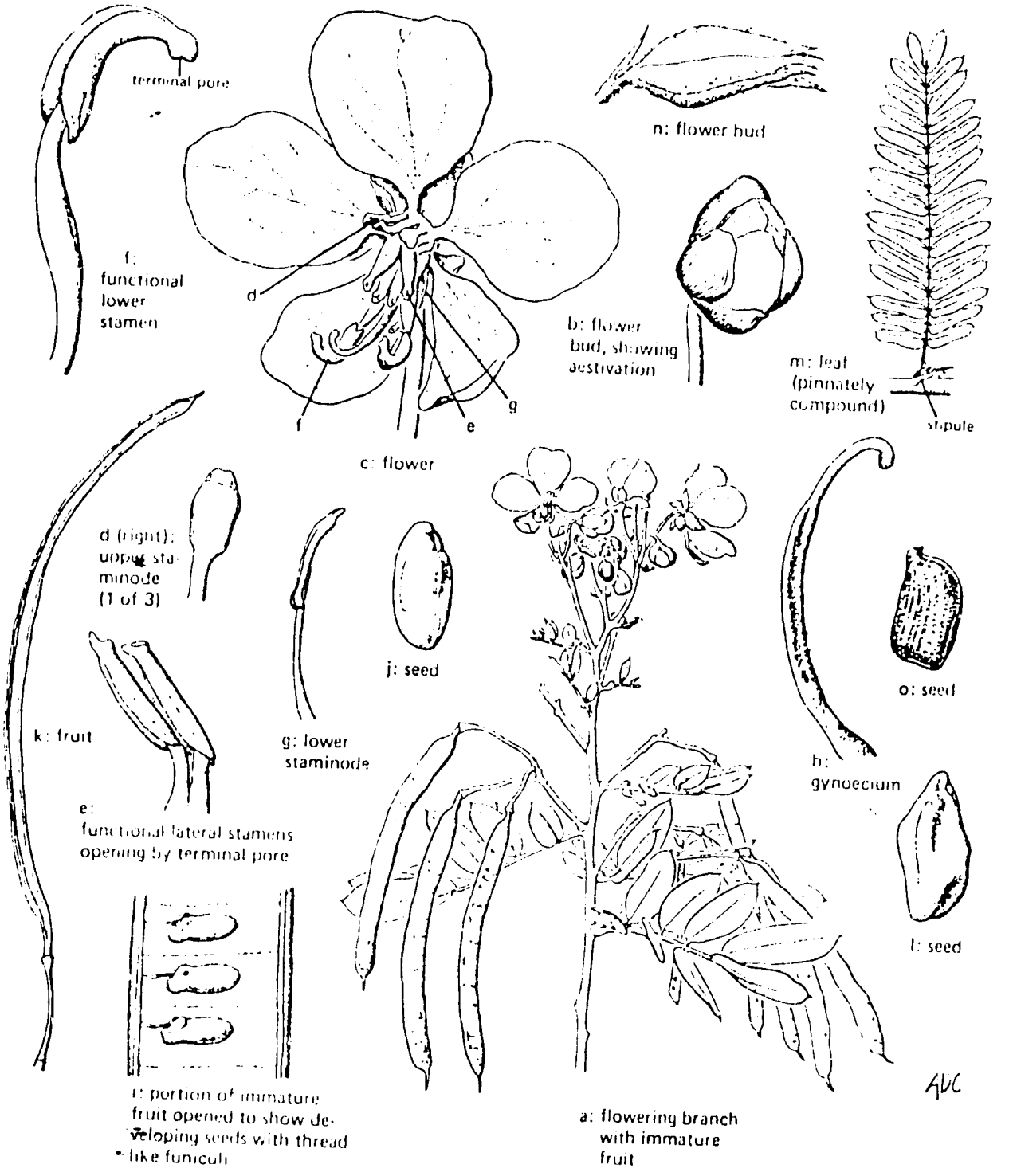
FABACEAE (LEGUMINOSAE) subfamily CAESALPINOIDEAE: Cassia. a j, C. bahamensis; k, l, C. tora; m-o, C. fasciculata



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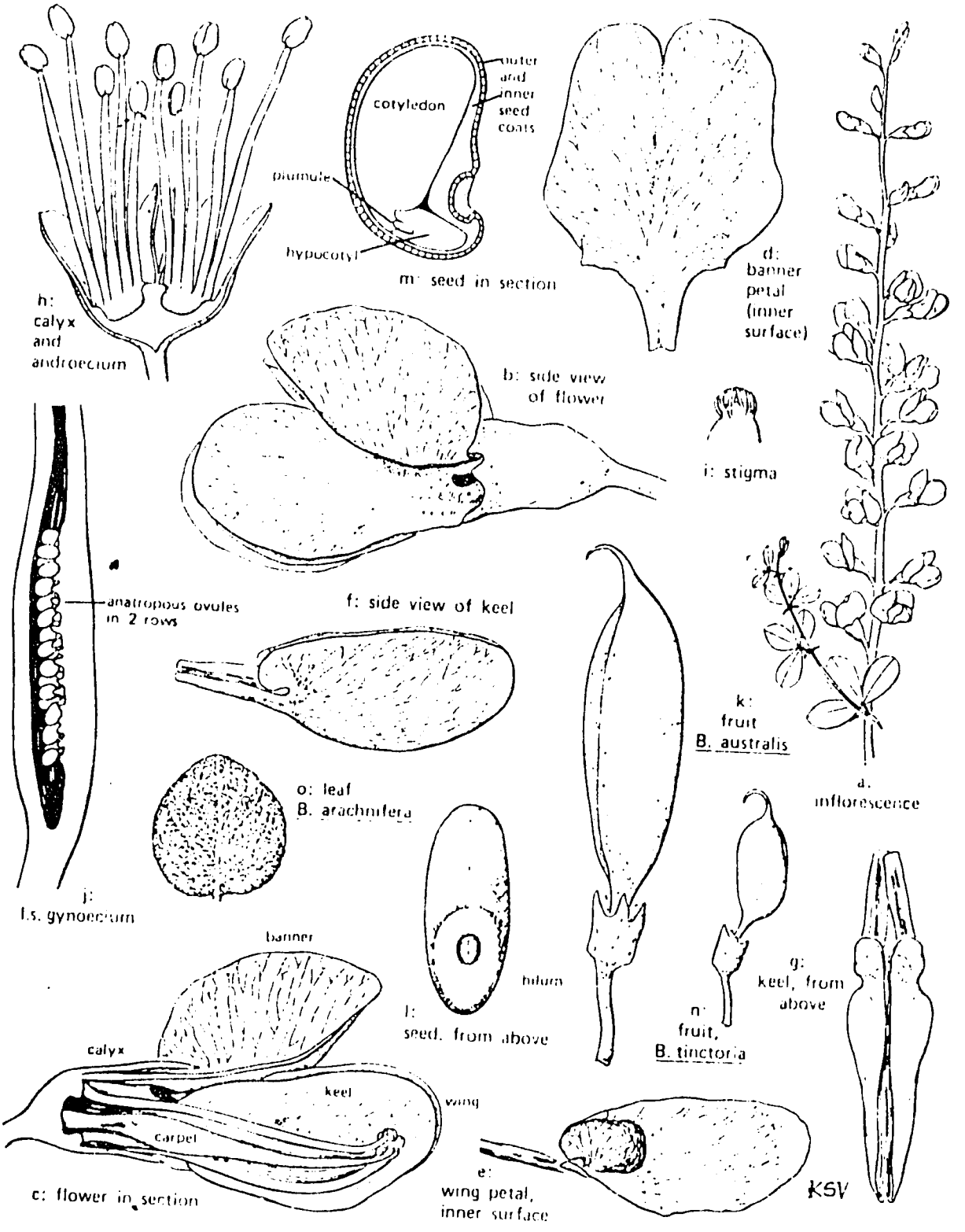
FABACEAE (LEGUMINOSAE) subfamily FABOIDEAE: Baptisia. a-m, B. australis; n, B. tinctoria; o, B. arachnifera



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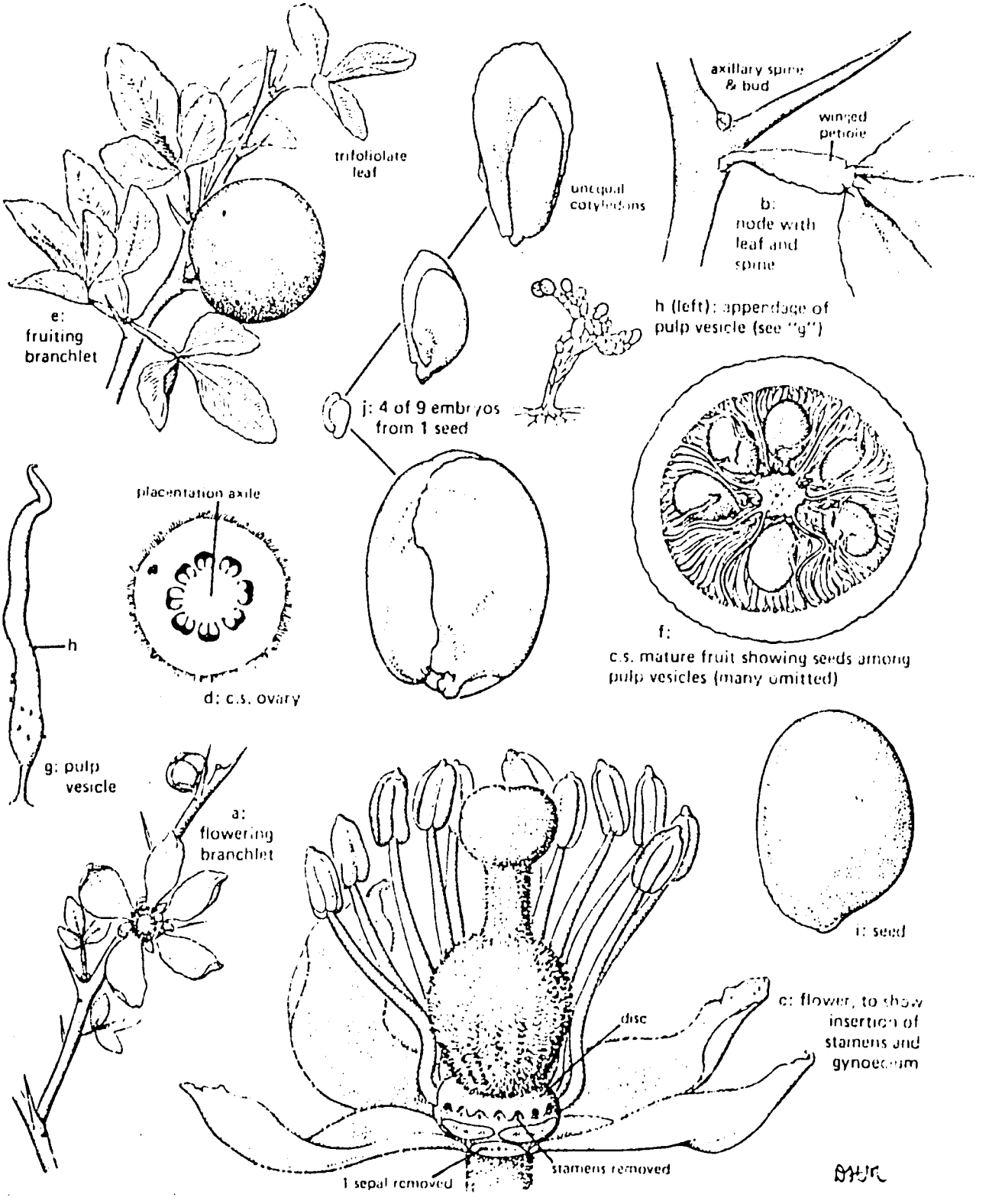
RUTACEAE: Poncirus. a-j, P. trifoliata



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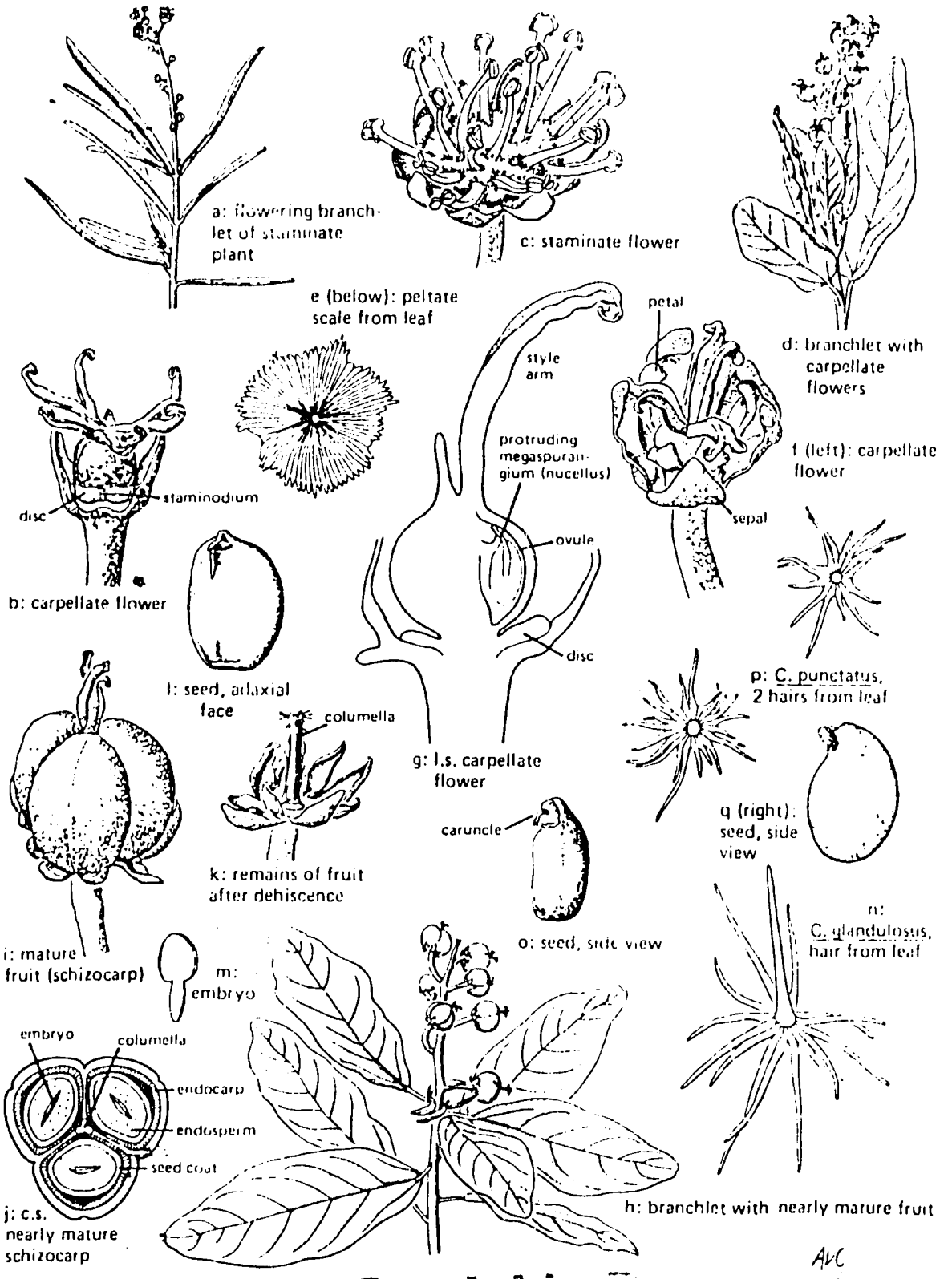
107

EUPHORBIACEAE: Croton. a-b, *C. linearis*; c-m, *C. alabamensis*; n, o, *C. glandulosus*; p, *C. punctatus*; q, *C. argyranthemus*



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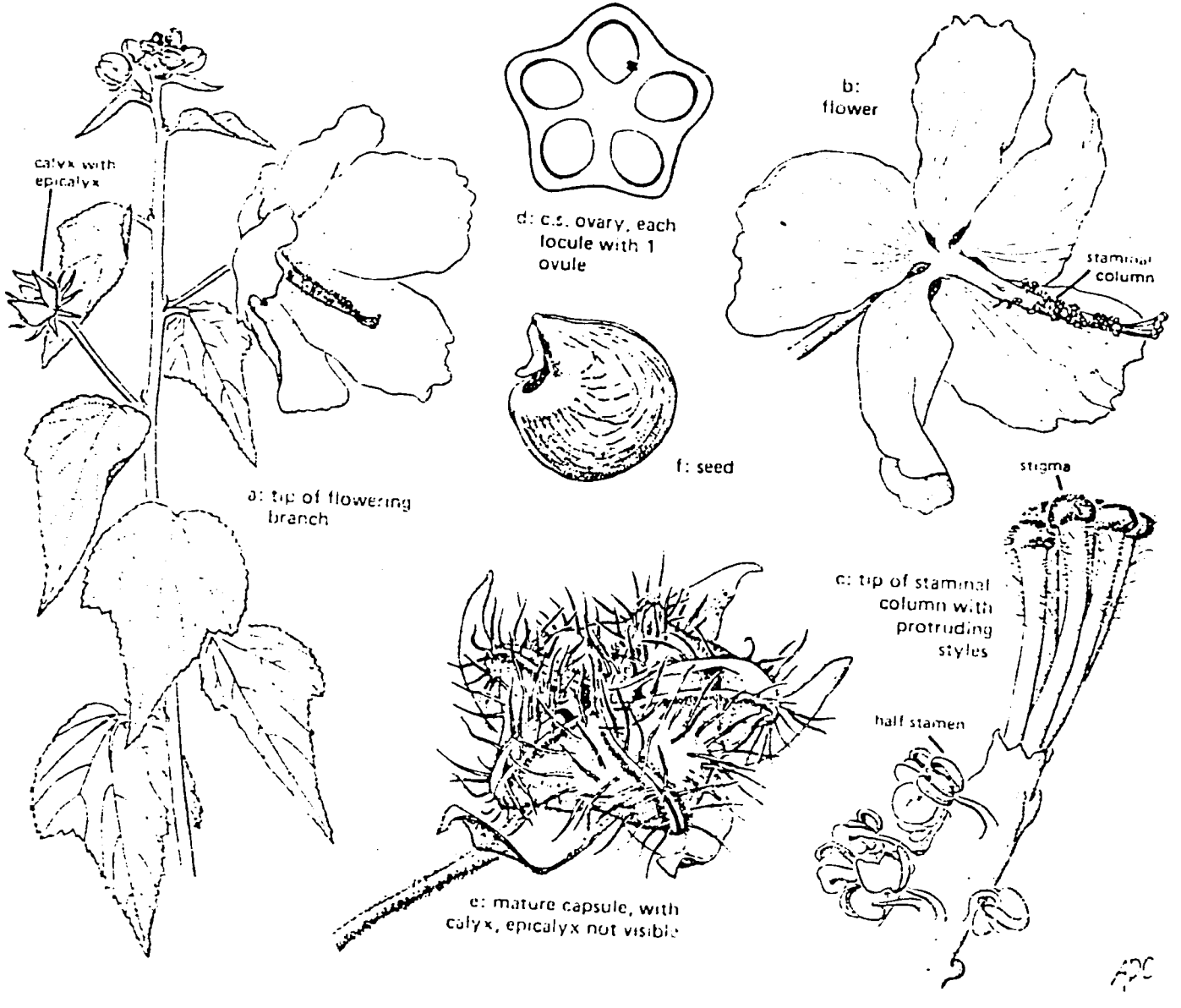
108

MALVACEAE: Kosteletzkya. a-f, K. virginica var. altheifolia



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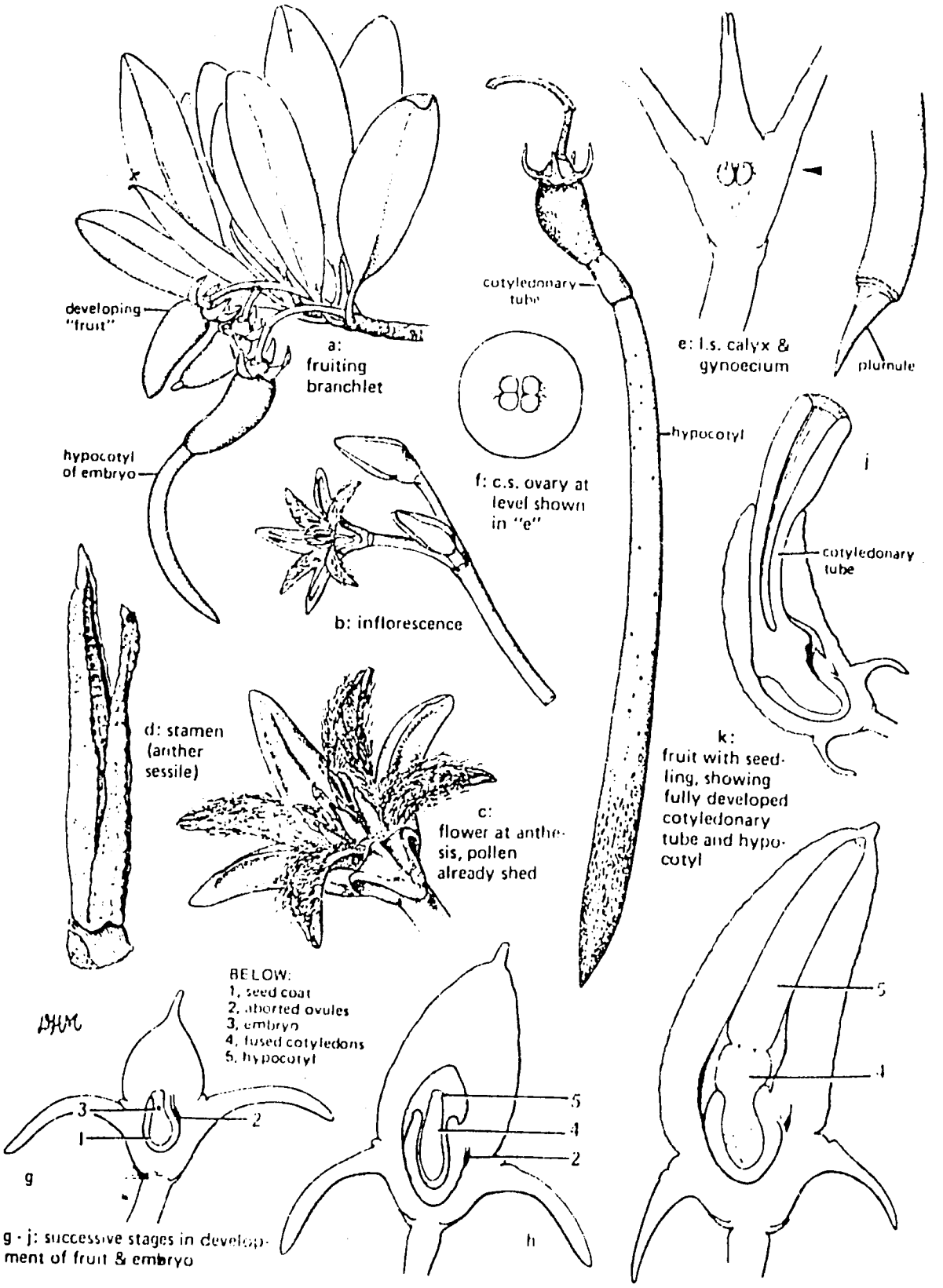
RHIZOPHORACEAE: Rhizophora. a-k, R. mangle



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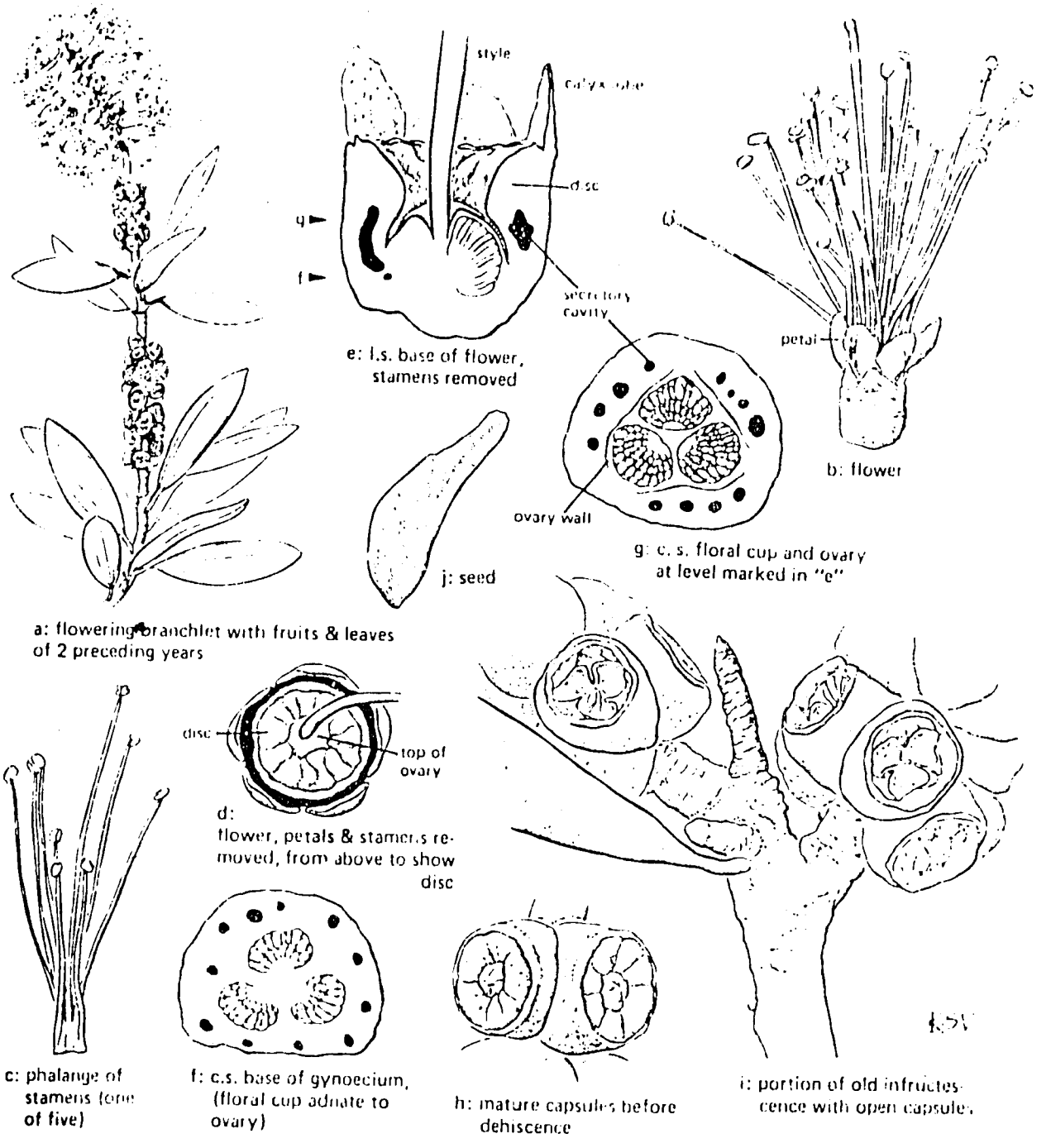
MYRTACEAE: Melaleuca, a-j, M. quinquenervia



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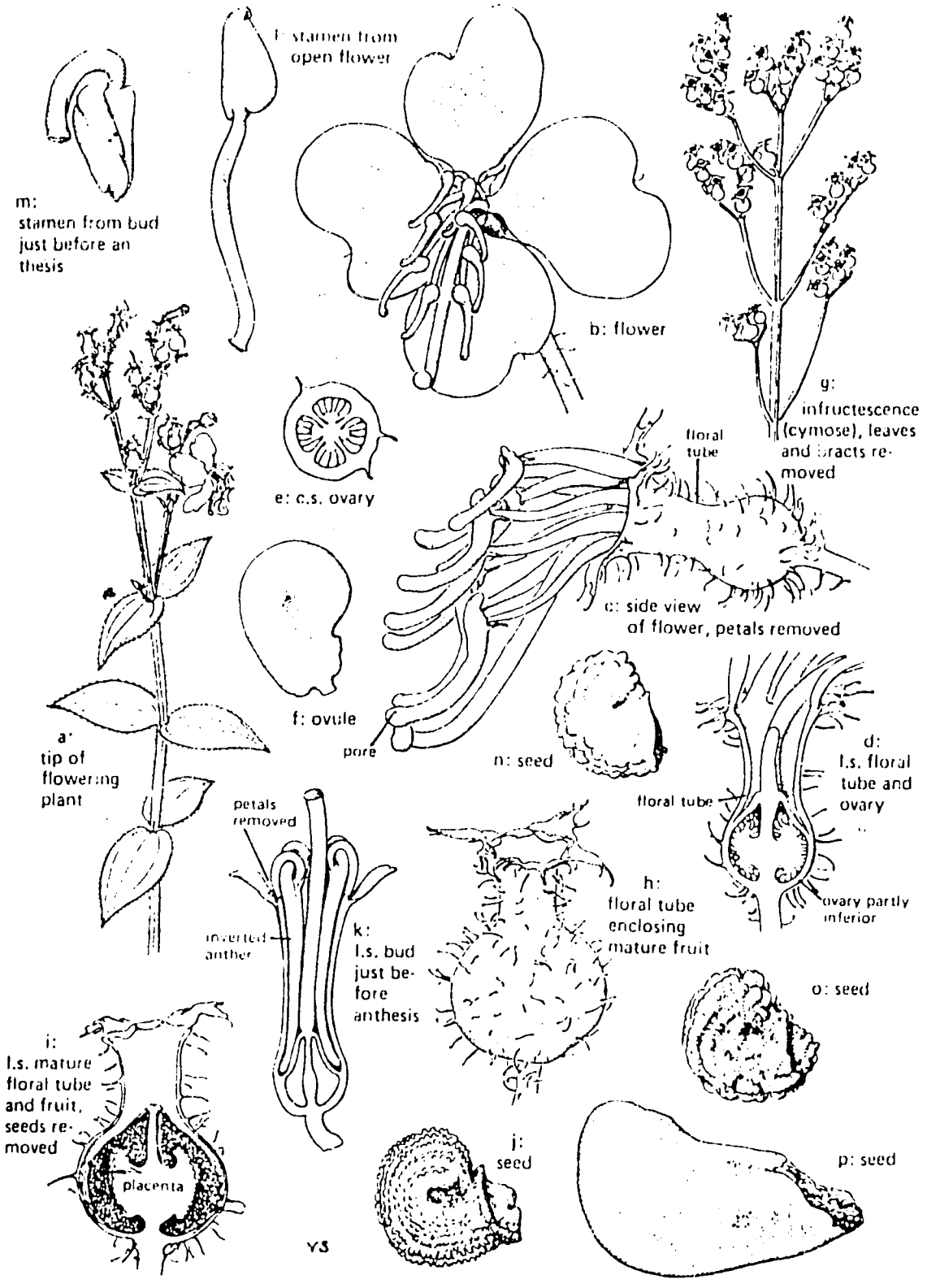
111

MELASTOMATACEAE: Rhexia. a-j, R. virginica; k, R. nashii; l, R. nuttallii; m, R. petiolata; n, R. nuttallii; o, R. cubensis; p, R. aliphanus



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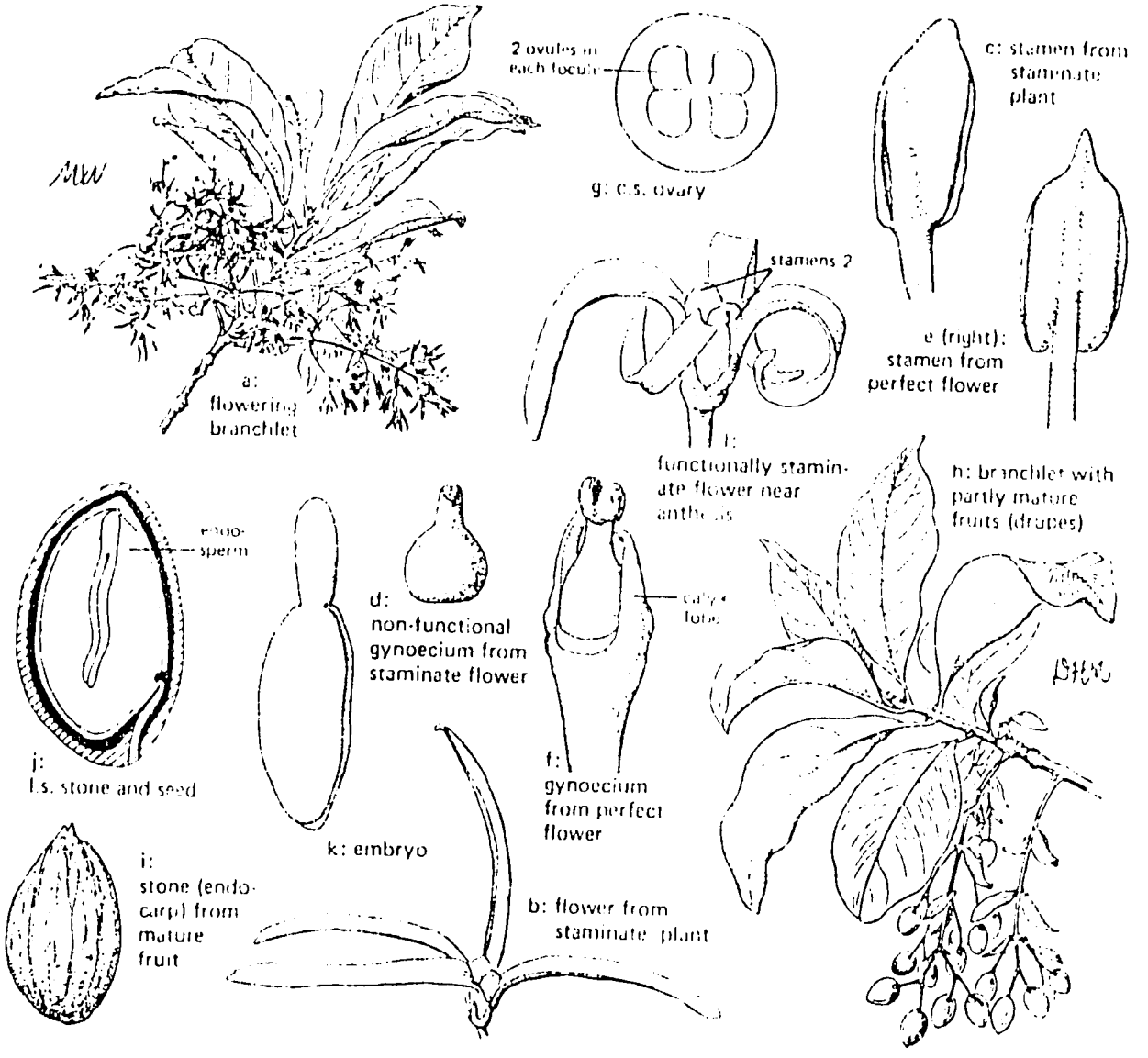
OLEACEAE: Chionanthus. a-k, C. virginicus; l, C. pygmaeus



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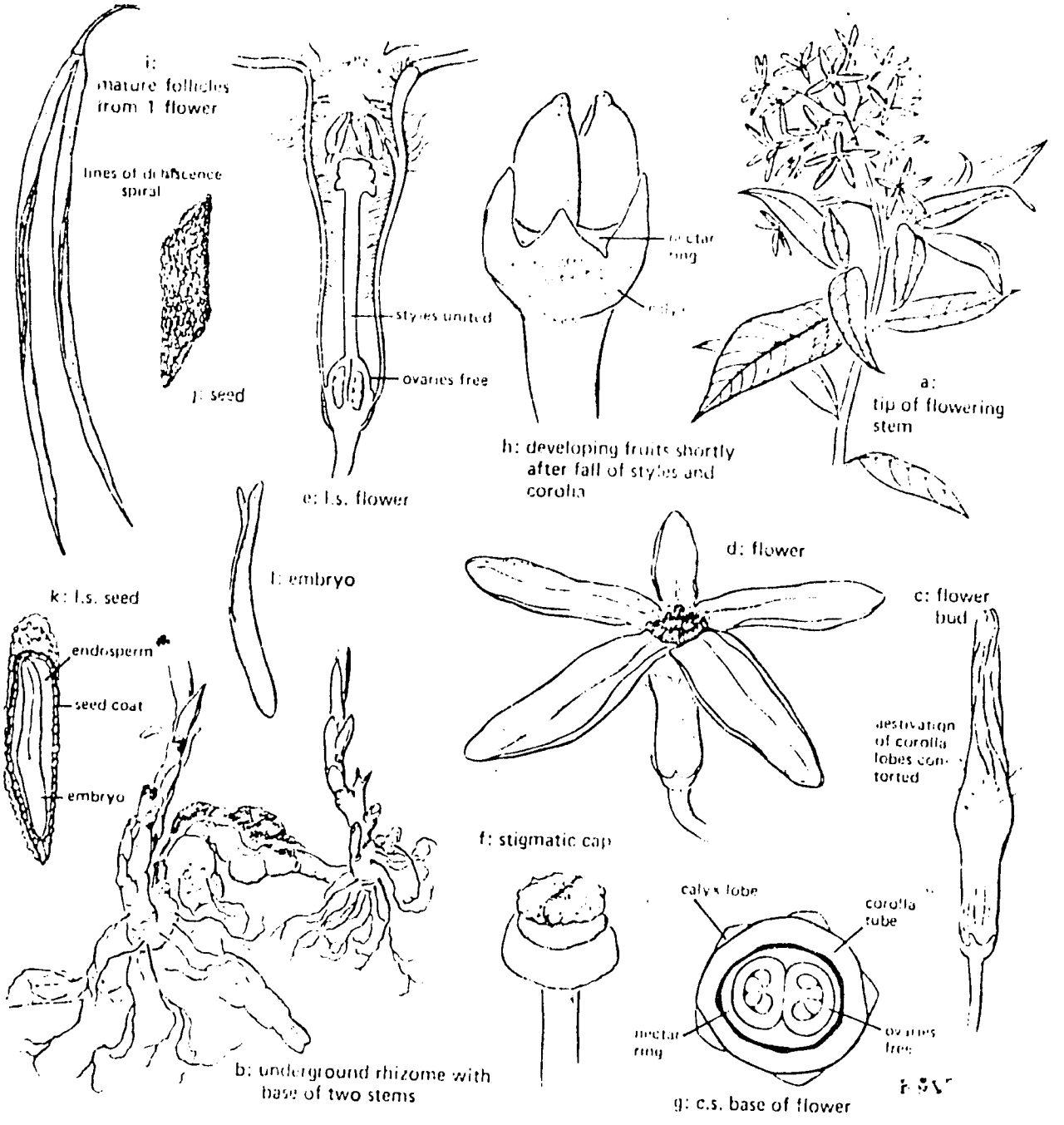
113

APOCYNACEAE: Amsonia. a l, A. tabernaemontana



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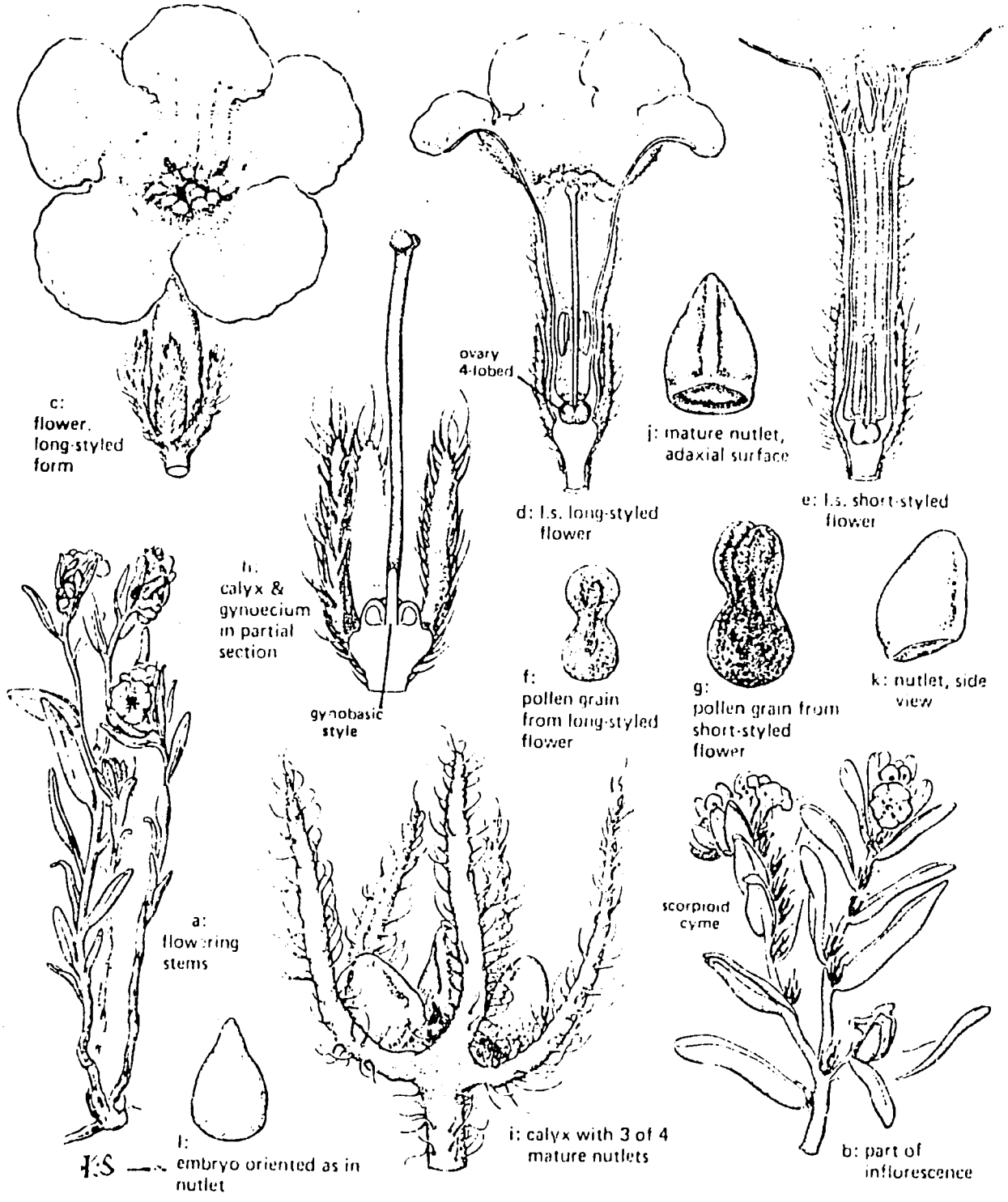
114

BORAGINACEAE: Lithospermum, a-l, L. canescens



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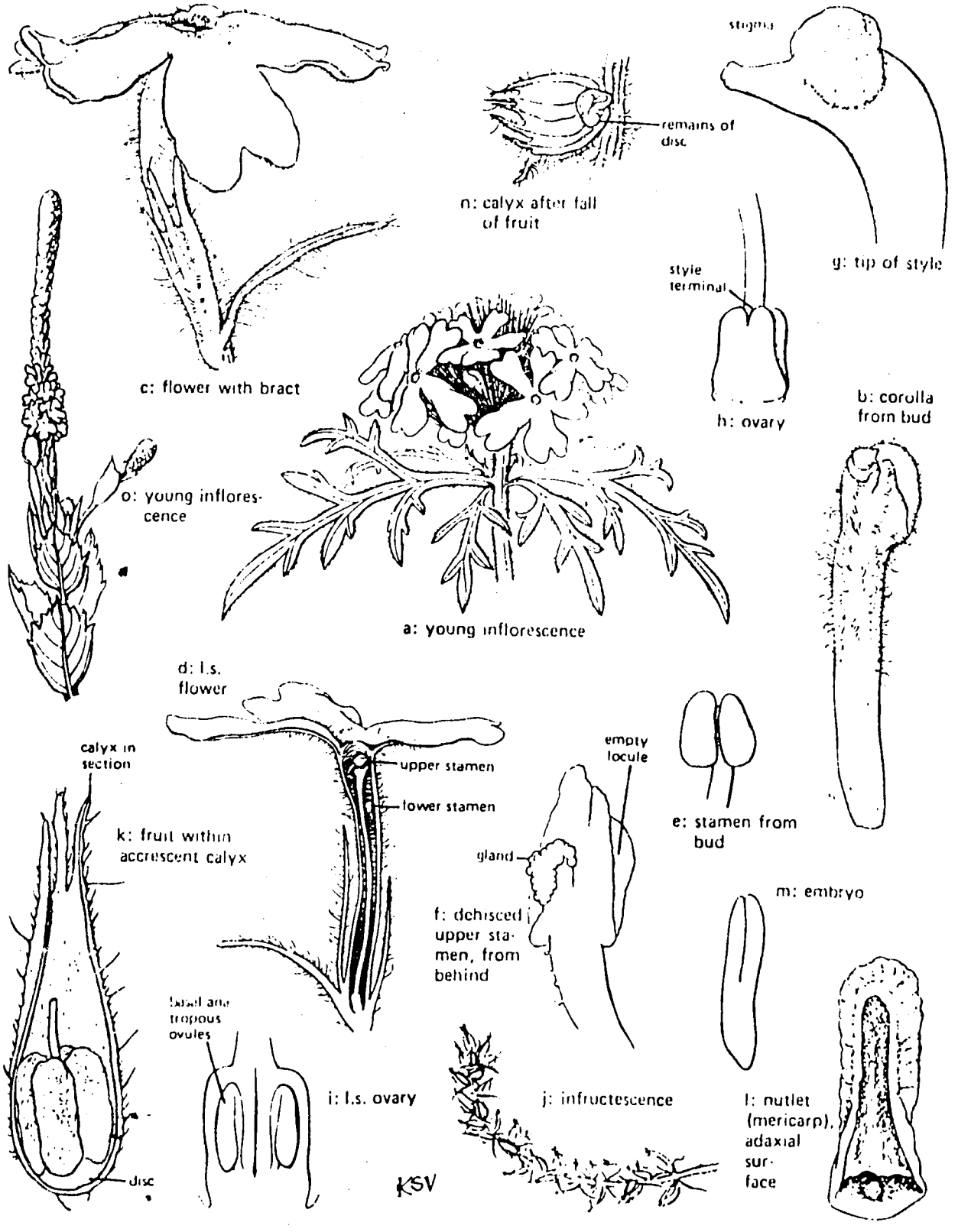
VERBENACEAE: Verbena: a-n, V. (Glandularia) bipinnatifida; o, V. stricta



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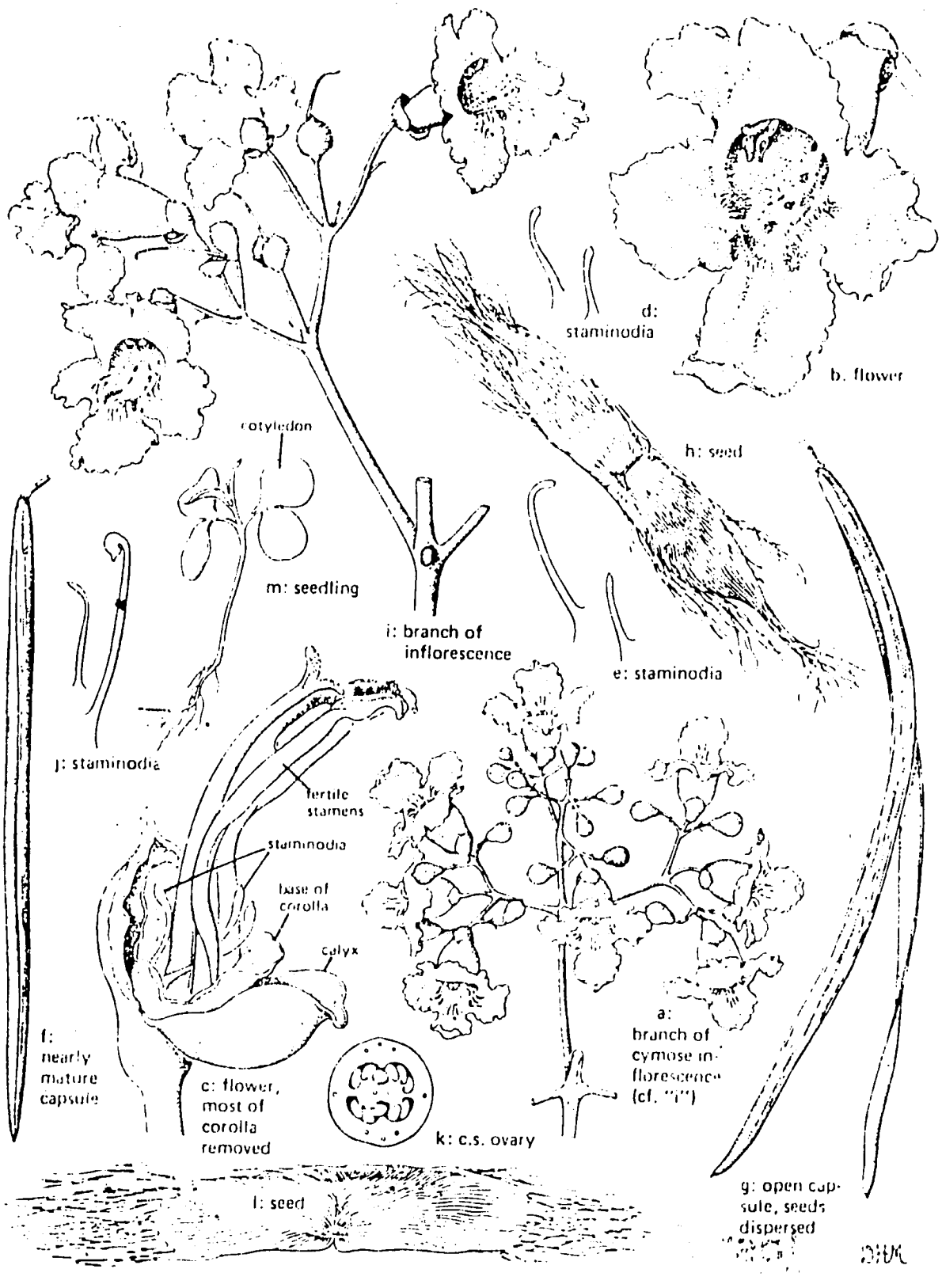
116

BIGNONIACEAE: Catalpa. a-h, C. bignonioides; i-m, C. speciosa



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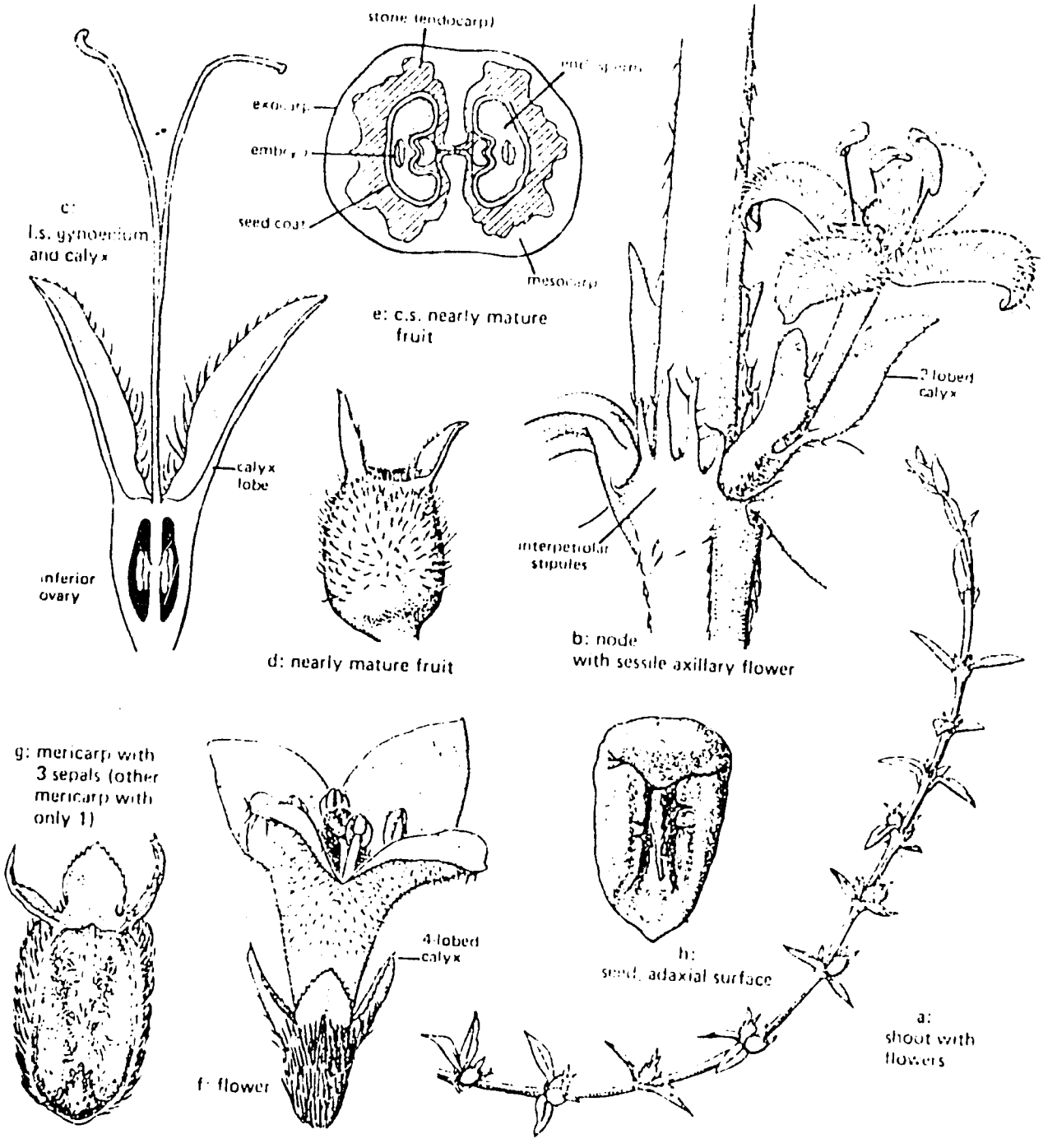
RUBIACEAE: Diodia. a-e, D. tetragona; f-h, D. teres



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FOREST MENSURATION

Introduction

Forest mensuration involves the measurement of forest products and the determination of timber volume and forest growth. Also included are:

- map work - locating forest areas on topographic maps
- aerial photos -determining the size, location and nature of forested areas on aerial photos
- surveying - running transect lines to permanent plots and establishing them accurately
- tree measurements - species, height, diameter, amount of defect, amount of merchantable volume, total volume, regeneration of valuable species, etc.
- statistics - analyzing the data mathematically based on inventory design.

Variety of tree and wood products - Trees and wood have many potential uses dependent upon species, size, and tree form, and community needs.

- furniture
- sawtimber
- novelties
- ties
- staves - barrel stock
- mine timbers
- poles/posts
- piling (for foundations)
- veneer
- chip-board products
- pulp and paper
- Christmas trees
- fuel

Justification for measurements - There are many related reasons for measurements of trees or forests.

- species compositions of forest stands
- diameter class distributions of trees

- quantity and quality of standing wood available for utilization
- tree growth rates - difference between inventories
- site evaluation - size of timber or rate of growth
- mortality or survival rates; ingrowth rates
- periodic inventories are needed for justification of management expenditures
- appraisal of lands
- tax records
- determine effects of recurrent climatic events such as hurricanes
- data needed for economic planning and development

Bias, accuracy and precision - A badly biased estimate may be precise, but it cannot be accurate.

- Bias - systematic distortion due to flaw in measurement or incorrect sampling.
- Accuracy - the success of estimating the true value of a quantity.
- Precision - a clustering of sample values around their own average.

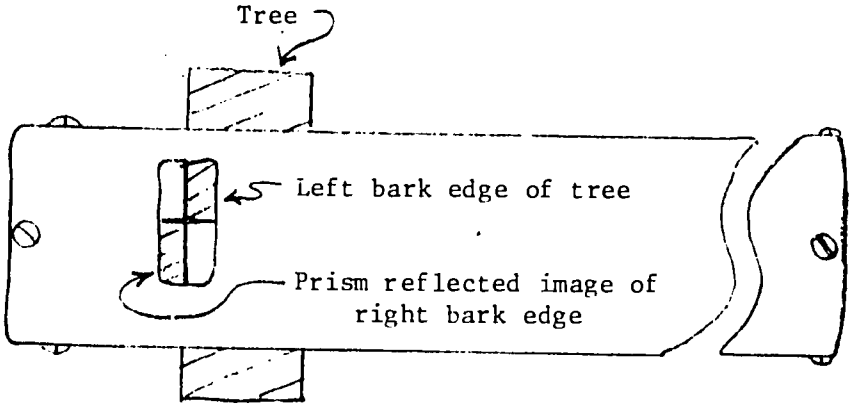
No matter how carefully one measures, if instrument errors or poor experimental design are built into the sampling technique, the data may not be accurate.

Measurement of Standing Trees

Diameter measurements (Instruments) -

1. Diameter tapes - tapes are in π units. DBH is measured at 4.5 feet from ground in the United States and 4.3 feet (1.3 m) from the ground in most other countries.
2. Calipers - usually two measurements are taken when the trunk is irregular. These are the largest and smallest (i.e., measured perpendicular to each other) which are averaged.

3. Pentaprism



How to use --

- Hold the instrument about 3-4 inches from eye
- Look into and through the viewing slot. Through the upper part of the slot, you will see the left edge of the tree. In the lower part of the slot, you will see the right edge of the tree reflected in the stationary prism.
- Slide the movable prism with right hand until the right edge reflection is brought into direct vertical allignment with the left edge, midway between the 2 vertical guidelines.
- Then, read the tree diameter as indicated on the scale by the pointer.

When to use --

- Measure tree diameters at any height above the ground, from any convenient point on the ground. There is no required baseline distance.
- Measure the diameter of any tree that may be inconveniently located across a gully from a convenient observation point.

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Height measurements (Instruments) - There are 2 aspects of tree height of interest to the forester. They are:

- Total tree height - from ground level to the top of the tree.
- Merchantable tree height - from ground level to a specified top stem diameter, usually 6 inches (15 cm) or 8 inches (20 cm), or to a point on the tree where major branching occurs.

1. Pole - graduated extension pole is read directly in feet, in this instance to a maximum of 35 feet.

2. Rangefinder - when focussed properly, the distance between the eye and the object cited is read directly on the scale.

   How to use --

   - Estimate the distance visually from the object to the eye adjust the dial to that distance.
   - Sight the object through the viewfinder. There will be 2 images of it.
   - Focus the dial until the 2 images merge into 1 image.
   - Read the distance to the object on the scale.

3. Abney level - the Abney level has 2 scales. One is in percent and the other in degrees. Both may be used to estimate height.

   How to use --

   - Look through the eyepiece at left side of tube, aligning the object sighted with the sighting vane.
   - Move the index arm until the bubble is centered on the sighting vane.
   - On the graduated circular arc, read the value which corresponds to the slope of the sighting.

   On the percent scale, the observer must move to a point 100 feet from the base of the tree. The abney is then read directly and gives the height of the tree in feet.

   On the degree scale, the observer may sight the tree from any convenient distance. To determine tree height, multiply the tangent of the angle measured by the distance from the tree (Figure 1).

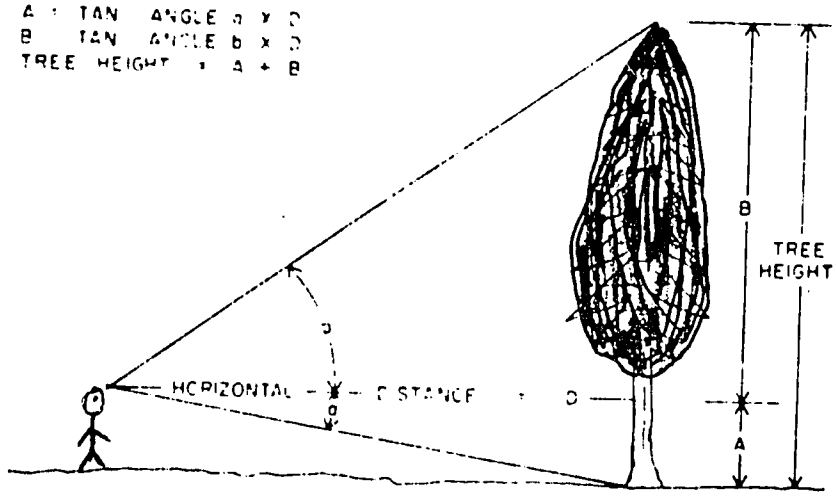

Figure 1. Determination of tree height with an Abney level.

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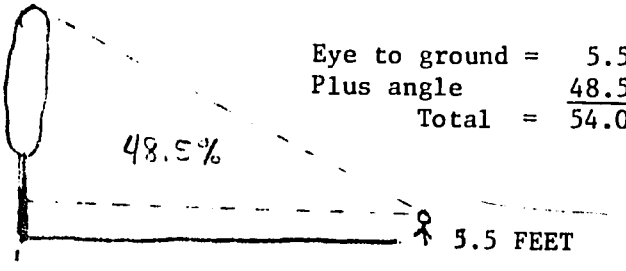
4. Suunto clinometer - the Suunto clinometer has 3 scales: (a) percent and degrees; (b) percent and topographic; and (c) degrees and topographic.

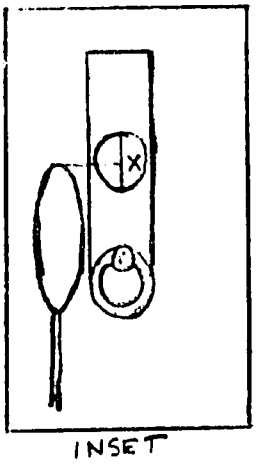
How to use --

- Keep both eyes open and hold the clinometer to eye.
- Simultaneously look through the lens and along the side of the clinometer housing. By optical illusion, the horizontal sighting line will appear to project to the side of the clinometer housing (see inset in Figure 2).
- Place the projected sighting line on the target (top of tree) and simultaneously read the scale.

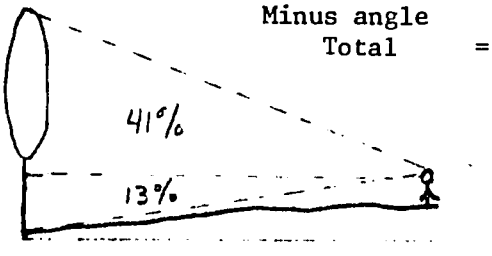
When base of tree is at same level as feet of observer, measure plus angles in percent. Add distance from eye to ground in feet to the plus angle.



Eye to ground	=	5.5 feet
Plus angle		48.5 "
Total	=	54.0 feet

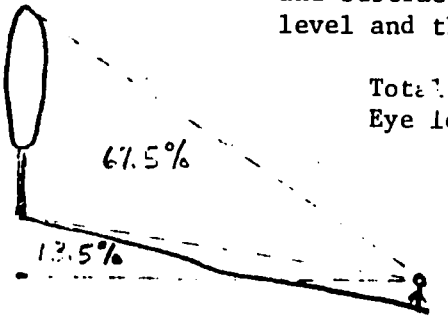


When base of tree is below the foot level of observer, measure the plus angle in percent and measure the minus angle in percent and add them.



Plus angle	=	41.0 feet
Minus angle		13.0 "
Total	=	54.0 feet

When the base of tree is above observer's eye level, measure total plus angle in percent, and subtract from it the angle between eye level and the base of the tree.



Total plus angle	=	67.5 feet
Eye level and base of tree		13.5 "
Total	=	54.0 feet

Figure 2. Use of the Suunto clinometer in three different positions with respect to a tree.

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5. Altimeter (Haga) - the Haga has 6 different scales. Its scale values indicate height directly for various known base length distances. The first four scales (15, 20, 25, and 30) may be used with base length distances in feet, meters or yards. The fifth scale (%) indicates height as a percentage of the base length distance. The sixth scale (topographic) indicates height directly in feet for a base distance of 66 feet (1 chain).

How to use --

- Select a scale whose base length distance is equal to or a multiple of the approximate tree height.
- Position yourself for measurement at the correct base length distance.
- Depress the pointer on the side of the Haga to release the pointer.
- Looking through the pinhole in the eyepiece, align the sighting prongs on the target (top of tree, etc.).
- Maintain a steady aim for a couple moments, gently depress the trigger to lock the pointer.
- Look through the window and read the scale value indicated by the pointer.

Then

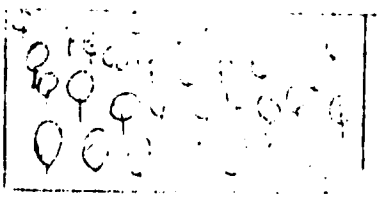
- If on level ground, add height up to eye level to the scale value for total height.
- If looking downhill to the target, take a second reading, this time at the base instead of the top of the target. Then add the 2 values together to get total height.
- If looking uphill at the target, take a second reading, again at the base of the target, but this time subtract the second value from the first value to get total height.

6. Hypsometer - any instrument that measures angles at specified distances (abney, altimeter, etc.) is classified as a hypsometer.

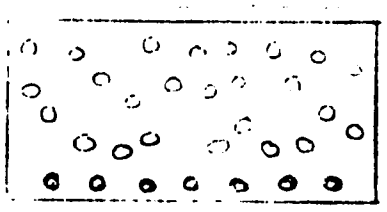
7. Experience - persons who have cruised timber for long periods of time often estimate the heights of trees visually. It requires a keen eye and sufficient practice, and must always be checked recurrently. Usually these persons make estimates visually and then check themselves when beginning in the morning. Throughout the day, they use instruments to assure that their visual estimates are reliable.

Basal area instruments - Basal area is the area of the cross section of a tree at breast height, usually expressed in square feet (or cm^2 or m^2), or of all trees in a stand, usually as ft^2/acre (or m^2/ha).

$$BA = \pi r^2 = \pi \left(\frac{D}{2}\right)^2 = 0.7854\ D^2$$



Side view - a stand of trees



Top view - all trees cut at breast height. We would see the basal area of the stand in square feet of tree trunks per square feet of land surface.

1. Diameter tape - Basal area may be determined by measuring the dbh of a tree and calculating basal area by the above formula, or by referring to a basal area table (Table 1).

2. Basal area prism - The prism is a useful instrument for rapidly determining basal area within a forest stand. It is a wedge-shaped piece of glass that bends light rays at a critical angle. The observer circles around the plot center and tallys all trees intercepted by the prism, and then multiplies this tally of trees by the appropriate basal area factor (BAF) to obtain the basal area/acre (basal area/ha).

   How to use --

   - Obtain a basal area prism and note its basal area factor.
   - Establish a plot center by placing a stick in the ground. Circle around the plot center when making prism counts. Don't stand at one point and swing the prism around you.
   - Hold the prism at a comfortable distance from the eye, in a vertical position, and at a right angle to the line of sight.
   - Close one eye and sigh along the upper edge of the prism so that it cuts the tree in question at breast height. The refraction of light passing through the prism will make the portion of the tree below breast height appear disjointed.

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Table 1 . Basal areas for diameters between 0.1 and 29.9 inches.

Basal area (Square feet)

Diam. (in.)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Diam. (in.)
0						.001	.002	.003	.0035	.004	0
1	.006	.007	.008	.009	.011	.012	.014	.016	.018	.020	1
2	.022	.024	.026	.029	.031	.034	.037	.040	.043	.046	2
3	.049	.052	.056	.059	.063	.067	.071	.075	.079	.083	3
4	.087	.092	.096	.101	.106	.110	.115	.120	.126	.131	4
5	.136	.142	.147	.153	.159	.165	.171	.177	.183	.190	5
6	.196	.203	.210	.216	.223	.230	.238	.245	.252	.260	6
7	.267	.275	.283	.291	.299	.307	.315	.323	.332	.340	7
8	.349	.358	.367	.376	.385	.394	.403	.413	.422	.432	8
9	.442	.452	.462	.472	.482	.492	.503	.513	.524	.535	9
10	.545	.556	.567	.579	.590	.601	.613	.624	.636	.648	10
11	.660	.672	.684	.696	.709	.721	.734	.747	.759	.772	11
12	.785	.799	.812	.825	.839	.852	.866	.880	.894	.908	12
13	.922	.936	.950	.965	.979	.994	1.009	1.024	1.039	1.054	13
14	1.069	1.084	1.100	1.115	1.131	1.147	1.163	1.179	1.195	1.211	14
15	1.227	1.244	1.260	1.277	1.294	1.310	1.327	1.344	1.362	1.379	15
16	1.396	1.414	1.431	1.449	1.467	1.485	1.503	1.521	1.539	1.558	16
17	1.576	1.595	1.614	1.632	1.651	1.670	1.689	1.709	1.728	1.748	17
18	1.767	1.787	1.807	1.827	1.847	1.867	1.887	1.907	1.928	1.948	18
19	1.969	1.990	2.011	2.032	2.053	2.074	2.095	2.117	2.138	2.160	19
20	2.182	2.204	2.226	2.248	2.270	2.292	2.315	2.337	2.360	2.382	20
21	2.405	2.428	2.451	2.474	2.498	2.521	2.545	2.568	2.592	2.616	21
22	2.640	2.664	2.688	2.712	2.737	2.761	2.786	2.810	2.835	2.860	22
23	2.885	2.910	2.936	2.961	2.986	3.012	3.038	3.064	3.089	3.115	23
24	3.142	3.168	3.194	3.221	3.247	3.275	3.301	3.328	3.355	3.382	24
25	3.409	3.436	3.464	3.491	3.519	3.547	3.574	3.602	3.631	3.659	25
26	3.687	3.715	3.744	3.773	3.801	3.830	3.859	3.888	3.917	3.947	26
27	3.976	4.006	4.035	4.065	4.095	4.125	4.155	4.185	4.215	4.246	27
28	4.276	4.307	4.337	4.368	4.399	4.430	4.461	4.493	4.524	4.555	28
29	4.587	4.619	4.650	4.682	4.714	4.746	4.779	4.811	4.844	4.876	29

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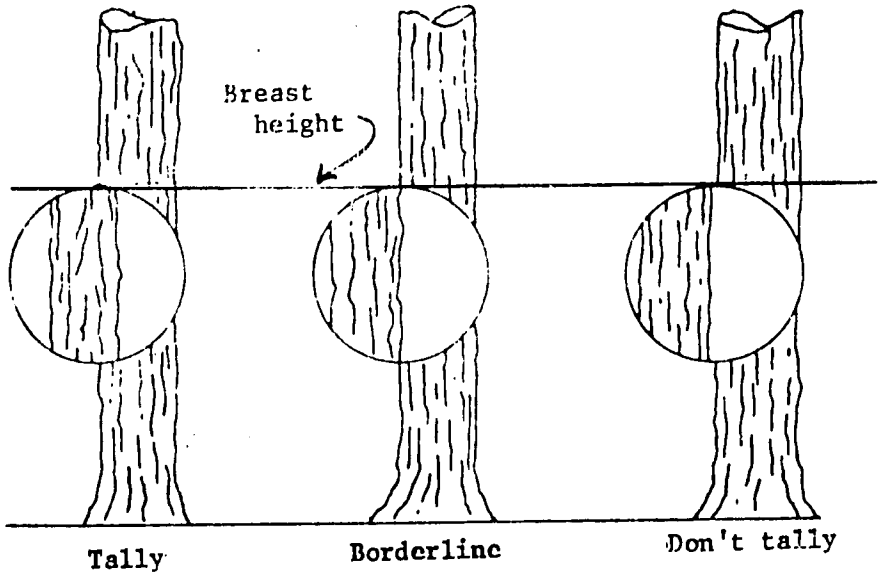

Figure 3. Refraction of light passing through the prism will make the portion of the tree below breast height appear disjointed.

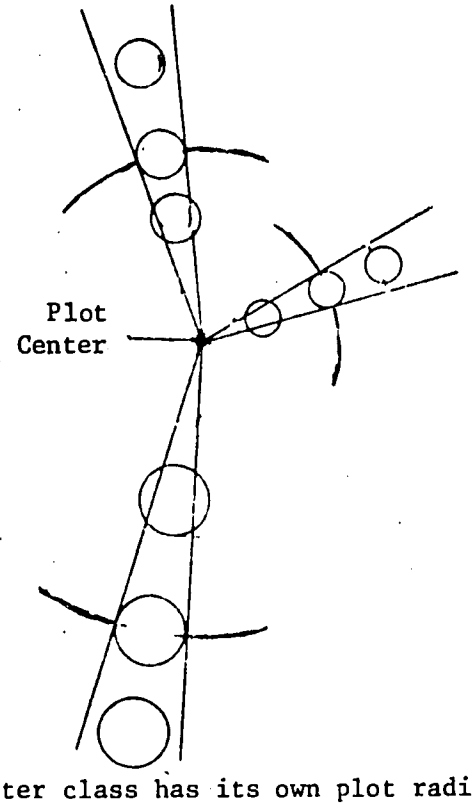

Figure 4. Each diameter class has its own plot radius which varies directly with tree diameter. Larger trees are counted are greater distances from the plot center than smaller trees.

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If it is completely disjointed, the tree is counted. If the edges overlap, the tree is counted. If borderline, every other tree is counted, or the tree is noted as a half of a unit (Figure 3).

- Turn through a complete circle around the plot center, gauging each tree. Be careful to observe large trees at considerable distance from the plot center. The larger the tree, the greater the distance it can be from the plot center and still be included in the tally.

- For partially hidden trees, move laterally maintaining the same distance between the prism and the tree, and make the observation.

- When the line of sight is at an angle from the horizontal, hold the vertical axis of the prism perpendicular to the line of sight.

- The number of trees counted multiplied by the appropriate basal area factor gives the stand basal area/acre (basal area/ha).

It is important to remember that each diameter class has its own plot radius, with the radius varying directly with tree diameter. Therefore, the larger, and more valuable trees, are usually measured more intensively than are the small stems (Figure 4).

Crown measurements - Crown classes provide useful information on the tree's capacity for growth and development. Research at the Institute has shown that trees with access to direct light grow about 3 times as fast as those that do not have direct light. Knowledge of crown class distributions is one of the first requirements for silvicultural planning.

- Crown classes - the crown class, or dominance class, is an evaluation of the tree's position in the canopy (Figure 5).
- Dominant - trees whose crowns are above the general level of the forest canopy, receiving light from above and partly from the side. They are larger than the average tree in the stand and have well developed crowns.
- Codominant - trees that form the general level of the canopy of the forest and receive light from above but comparatively little from the sides.
- Intermediate - trees whose crowns are lower, but still extending into the general level of the canopy. They receive a little direct light only at mid-day, and no light from the sides.
- Suppressed - trees whose crowns are entirely below the general level of the canopy. They receive no direct light from above or the sides.

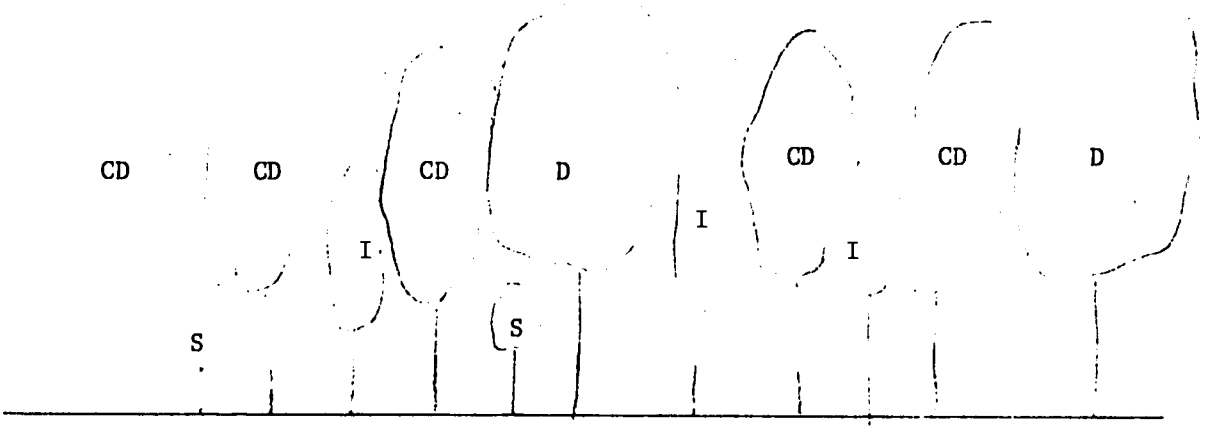

Figure 5 . Crown classes, or dominance classes, within a forest. D = dominant, CD = codominant, I = intermediate and S = suppressed.

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- Crown-to-bole diameter ratios - The ratios of crown-to-bole diameters (Figure 6) varies with the size class of the tree and with the type of forest. Usually, smaller trees have higher ratios than larger trees, and dry forests have higher ratios than wet forests. The ratios are useful for determining adequate stocking of forests.

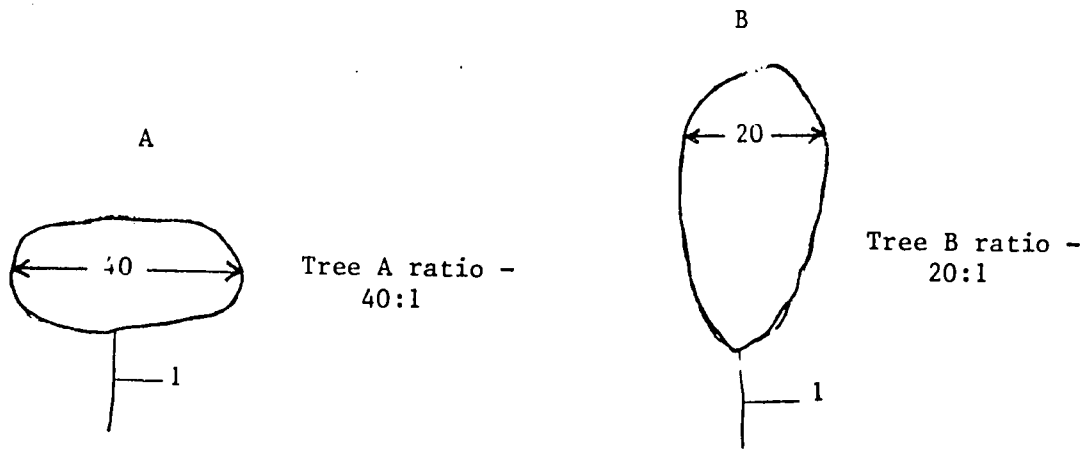

Figure 6 . Crown-to-bole ratios for trees. Both trees have diameters of 0.305 m (1 foot). Tree A has a crown diameter of 12.2 m (40 feet) and tree B a crown diameter of 6.1 m (20 feet).

- Leaf area index (LAI) - Leaf area index is the ratio of leaf area to land area, usually expressed in tenths For example, 4.5 m^2 of leaf surface per 1 m^2 of land surface equals a leaf area index of 4.5/1.0 = 4.5. Leaf area is measured by dropping a line through the canopy to the ground and counting the number of times the line touches a leaf.

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Taper - Because trees taper (gradually diminish in diameter) from the stump to top, this factor must be taken into consideration in the construction of volume tables. Taper is influenced by several factors including tree species, diameter, height and age (Figure 7)

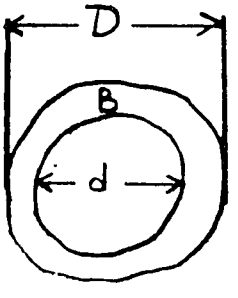
Girard Form Class -

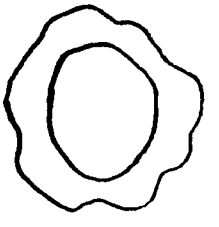
$$\text{G.F.C.} = \frac{\text{Diam. a 17' from ground (ib)}}{\text{DBH (ob)}}$$

Diameter inside bark = d = D - 2 B
(for standing trees mainly)

D = outside bark diameter of tree

B = bark thickness





Rough bark

Take two measurements:
one on ridge, one in gut.

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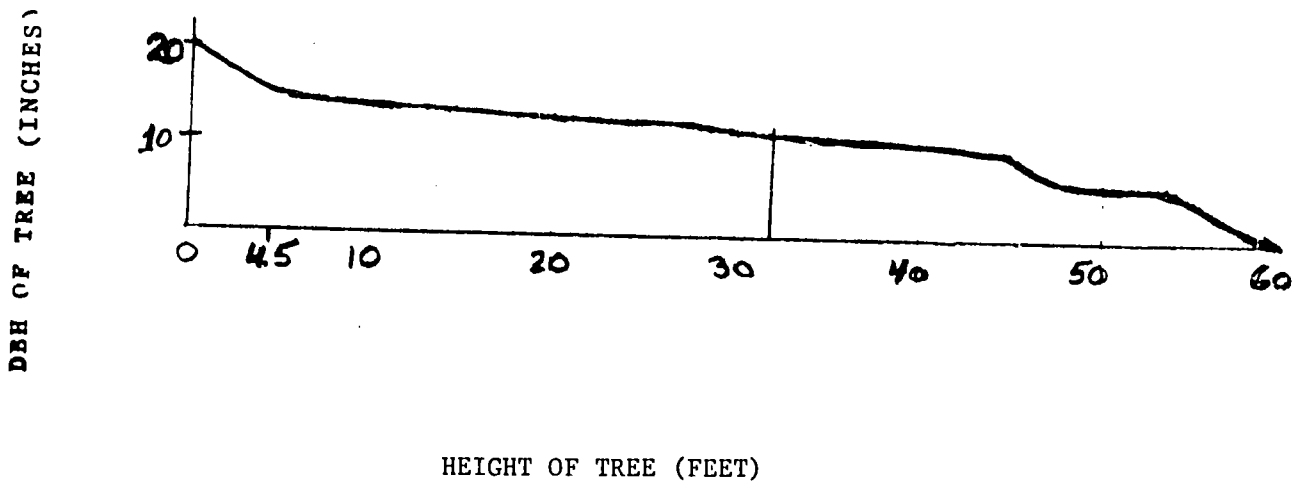

Figure 7 . The actual taper of a tree 60 feet tall. Note the swell at the base. Presented below are the actual diameter measurements, and basal determinations taken at the specified distances from the base Below that are summaries of volume calculations using the formulas. Errors in volume estimates tend to increase with longer sections of trunk. The actual volume determined by a precise method is 34.8 cubic feet.

Taper measurements of a 32-foot log

Distance of measurement from large end (ft)	Diameter outside bark (m)	Basal area (ft^2)
0	20.9	2.382
4	15.5	1.310
8	15.0	1.227
12	14.9	1.211
16	14.4	1.131
20	13.4	0.979
24	12.8	0.894
28	11.8	0.759
32	11.4	0.079

Volume calculations (ft^3) different formulas and different lengths of sections.

Sections Length (ft)	Newton	Huber	Smalian
32	40.6 (117%)	36.2 (104%)	49.5 (142%)
16	36.9 (106%)	33.9 (97%)	42.8 (123%)
8	35.5 (102%)	34.1 (98%)	38.3 (110%)

Volume obtained by planimeter method: 34.8 (100%)

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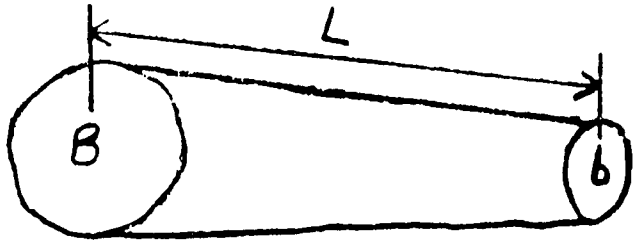
Cubic foot volume estimates - Several formulae are used to determine volumes. In general, the longer the sections of the log, the greater will be the deviations of taper, and the errors in volume estimate.

I. Smalian's formula

$$V = \frac{B + b}{2} (L)$$



V = volume in ft^3

B = basal area large end in ft^2

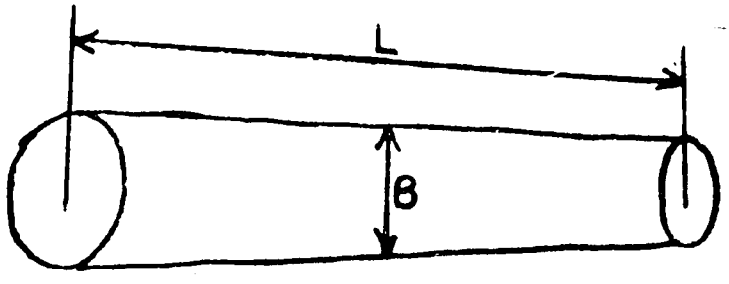
b = basal area small end in ft^2

L = length of log in ft

problems - yields too great a volume when the butt log is swollen.

II. Huber's formula

$$V = B_{1/2} L$$



V = volume in ft^3

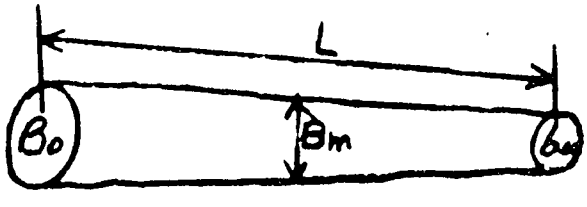
B = basal area in middle of log in ft^2

L = length of log in ft

problem - error increases with amount of taper; cannot be used to measure logs in a pile; otherwise, easily applied because it depends upon single measurement.

III. Newton's formula

$$V = \frac{Bo + 4\ Bm\ bu}{6} (L)$$



V = volume in ft^3
Bo = basal area at the butt in ft^2
Bm = basal area at the middle in ft^2
bu = basal area at the top in ft^2
L = length of log in ft.

problems - requires 3 measurements; cannot be used when the logs are in a pile; frequently used as check of

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Table 2. Cubic-Foot Volume of Logs by Smalian's Formula

Top diameter of log * (in.)	Log length in feet										
	8	10	12	14	16	18	20	22	24	26	28
6	2	2	3	4	4	5	6	7	8	9	10
7	2	3	4	5	6	7	8	9	10	11	12
8	3	4	5	6	7	8	10	11	12	14	15
9	4	5	6	8	9	10	12	13	15	16	18
10	5	6	8	9	11	12	14	16	18	20	22
11	6	7	9	11	13	15	17	19	21	23	25
12	7	9	11	13	15	17	19	22	24	27	29
13	8	10	12	15	17	20	22	25	28	31	34
14	9	12	14	17	20	23	26	29	32	35	38
15	10	13	16	19	22	26	29	32	36	40	43
16	12	15	18	22	25	29	33	36	40	44	49
17	13	17	21	24	28	32	37	41	45	50	54
18	15	19	23	27	32	36	41	45	50	55	60
19	17	21	26	30	35	40	45	50	55	61	66
20	18	23	28	33	39	44	49	55	61	67	73
21	20	26	31	37	42	48	54	60	67	73	80
22	22	28	34	40	46	53	59	66	73	80	87
23	24	30	37	44	50	57	64	72	79	86	94
24	26	33	40	47	55	62	70	77	85	93	102
25	28	36	43	51	59	67	75	84	92	101	110
26	31	39	47	55	64	72	81	90	99	109	118
27	33	42	50	59	69	78	87	97	107	117	127
28	35	45	54	64	73	83	93	104	114	125	136
29	38	48	58	68	79	89	100	111	122	133	145
30	41	51	62	73	84	95	107	118	130	142	154
31	43	55	66	78	89	101	114	126	139	151	164
32	46	58	70	83	95	108	121	134	147	161	174
33	49	62	75	88	100	114	128	142	156	170	185
34	52	65	79	93	107	121	136	150	165	180	196
35	55	69	84	98	113	128	144	159	175	191	207
36	58	73	88	104	120	135	152	168	184	201	218
37	61	77	93	110	126	143	160	177	194	212	230
38	65	81	98	115	133	150	168	186	205	223	242
39	68	86	103	121	140	158	177	196			
40	72	90	109	128	147						

* Taper allowance: 0.5 in. in 4-ft. of length. Volumes listed are subject to correction for other tapers.

Source: U. S. Forest Service, Northern Rocky Mountain Forest & Range Exp. Sta., The cubic foot as a national log scaling standard (mimeo.).

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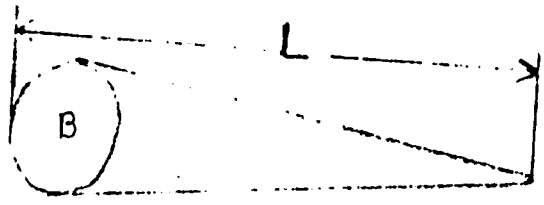
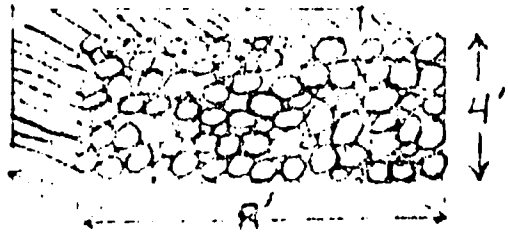
IV. Volume of a cone

V = 1/3 BL



Different species - different form or taper; consider taper in volume table construction.

V. Cord 8' x 4' x 4' = 128 cu. ft. standard cord; actual solid cubic foot volume is estimated at 70% and depends on lengthy diameter, and form (straight or crooked) of the sticks. Fuelwood or pulpwood are sold in cords.



VI. Volume by regression analysis

Volume (ft^3, o.b.) = 1.30 + 0.00378 BA (in^2) x ht (ft) r^2 = 0.986
SE = 0.017

In this case, 30 trees of 7 species at 4 different sites in the Caribbean area were measured for basal area and total height. Diameters ranged from 6-19.2 inches, height from 49.5-112.2 feet, volume from 31.8-116.5 ft^3 and the form factor from 0.55 to 0.68. The volume is total volume above ground including the trunks and branches.

VII. Biomass

Biomass is the oven dry weight of trunks, branches, and/or leaves. It is determined by wet weighing of the respective components in the field, and then taking representative samples to the laboratory for determining dry weight. The dry weight/wet weight relationships determined for the samples are then used to convert all wet weights to dry weights.

Biomass is useful for nutrient cycling studies.

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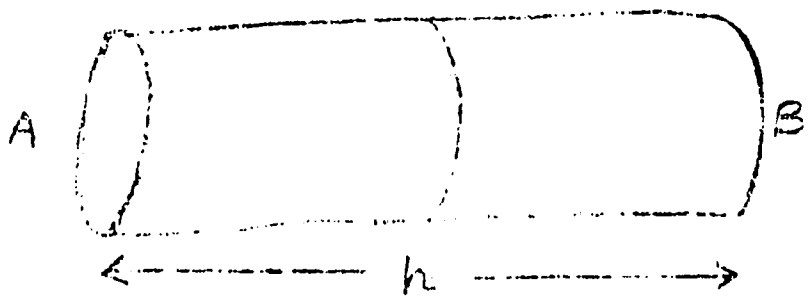
Volume outside bark - Volume measurements are often collected along with biomass. Sometimes, investigators use only base diameter and top diameter (where the crown begins) and the length of the trunk to make the calculations. This can lead to serious errors. It is preferable to make several measurements in conjunction with biomass determinations in the following way:



- measure the length, h
- measure the diameters of A and B
- determine the corresponding areas of A and B
- use the following formula to calculate volume (outside bark):

$$V = h \quad \frac{\text{area A} + \text{area A} \times \text{area B} + \text{area B}}{3}$$

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Biomass - Biomass is the dry weight of matter (leaves, branches, trunks). Methods to determine it include the following:

- Make the following observations on the standing tree
  - tree species
  - total height
  - diameter at the base of the tree
  - diameter at breast height
  - mean crown diameter (two perpendicular measurements)
  - assign the tree a number (i.e. 1)
- Cut the tree
  - assure that there is space on the ground to accommodate the tree
  - use all proper equipment and take all necessary precautions when felling the tree
- Measurements on felled tree
  - total length
  - length of main trunk
  - top diameter of trunk (at point when major branching begins)
  - diameter at every 4 feet from base of trunk; the base of the crown (top diameter of trunk)
- Weighing the leaves

  Field Procedures
  - spread tarp on ground
  - cut small branches with leaves
  - weigh burlap bag
  - place moist leaves in bag and weigh
  - subtract the weight of the bag

- subsample moist leaves in the field
- assign the subsample a number (i.e. L-1)

Office Procedures

- place subsample of leaves in drying oven in the laboratory
- weigh leaves after 3 days
- convert wet weight from the field to dry weight by:

$$\frac{\text{total leaf wet weight}}{\text{subsample leaf wet weight}} = \frac{x}{\text{subsample leaf dry weight}}$$

- Weighing the branches

Field Procedure - It is possible to divide the branch samples into any of several possible size classes. These classes would be determined by general tree size and particular interests of the investigator. For purposes of demonstration, only two size classes will be employed.

- separate branches $\leq$ 1 inch in diameter and weigh
- assign the subsample a number (i.e. B-1)
- separate branches $>$ 1 inch in diameter and weigh
- assign the subsamples a number (i.e. B-2)
- take subsamples of each and weigh
- collect all sawdust or machete clips and weigh

Office Procedure

- place branch subsamples in drying oven on the laboratory
- weigh subsamples periodically until no further decrease in weight is observed, usually 4-6 weeks
- convert wet weight from field to dry weight by:

$$\frac{\text{total branch wet weight}}{\text{subsample branch net weight}} = \frac{x}{\text{subsample branch dry weight}}$$

- Weighing the trunk

  Field Procedure

  - cut the trunk into several pieces conveninet for weighing in the field
  - assign numbers to each (i.e. T-1, T-2, etc.)
  - get wet weight of each in the field
  - cut 2-inch disc subsamples from each and assign corresponding numbers (i.e. T-1, T-2, etc.)
  - take wet weight of subsamples
  - weigh all sawdust and machete chips

  Office Procedure

  - place all subsamples in drying oven in the laboratory
  - weigh subsamples periodically until no further decrease in weight is observed, usually 4-6 weeks
  - convert net weight from field to dry weight by:

$$\frac{\text{total trunk wet weight}}{\text{subsample trunk wet weight}} = \frac{x}{\text{subsample trunk wet weight}}$$

Enter all data in Table 3.

Table 3 . Data summary sheet for biomass determinations. ALL data are entered in kg (units of 2.2 lbs).

Site: _____ Date: _____ Name: _____

STANDING TREE DATA: Species _____ Tree No. _____

Tree dbh: _____ (cm) Diameter at tree base: _____ (cm)

Mean crown diameter: long length _____ (m) perpendicular length _____ (m)

FELLED TREE DATA: Top diameter at point of branching _____ (cm)

Length of trunk: _____ (m) Total length of tree: _____ (m)

WET WEIGHTS								
LEAVES	SAMPLE	MAIN TRUNK		SAMPLE	BRANCHES ≤ 1"	SAMPLE	BRANCHES > 1"	SAMPLE

COMPARTMENT	SAMPLE NUMBER	SAMPLES DRY WEIGHTS (WEEKS) 1/2	2	4	6	8	CONVERSION FACTOR
LEAVES							
MAIN TRUNK							
BRANCHLETS							
BRANCHES							

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When wood is cut, some of it is lost in the form of sawdust, slabs and edgings. Log rules were developed years ago to take these factors into consideration. The following log rules are widely used:

- International rule - the international rule is the only log rule in common use that considers taper calculated at 1/2 inch per 4 foot logs. Slabs from an imaginary plank 2.12 inches thick with a width equal to the log diameter. Two rules are available:

  1. International 1/8 inch rule - this rule assumes a 4 foot log and allows 1/8 inch for sawkerf, 1/16 inch for shrinkage and 2.12 inches for slabs and edgings. The formula for computation is:

     $$\text{Volume in board feet} = 0.22\ d^2 - 0.71\ d$$

  2. International 1/4 inch rule - this rule assumes a 4 foot log and allows 1/4 inches for sawkerf, 1/16 inch for shrinkage and 2.12 inches for slabs and edgings. To convert from the International 1/8 inch rule, simply multiply by 0.905. Adjustments for taper are made for larger logs. The results have been compiled in a table at select diameters and lengths of logs (Table).

- Doyle rule - this rule is based upon the formula:

  $$\text{Volume in board feet} = (d - 4)^2 \frac{L}{16}$$

  where d is the diameter at the small end of the log in feet. For small logs, we get an overrun and in large logs and underrun, that is, when the logs are actually cut at the mill, smaller logs yield more board feet than the formula indicated, and larger logs yield fewer board feet. The point of transition is at about 28 inches in diameter.

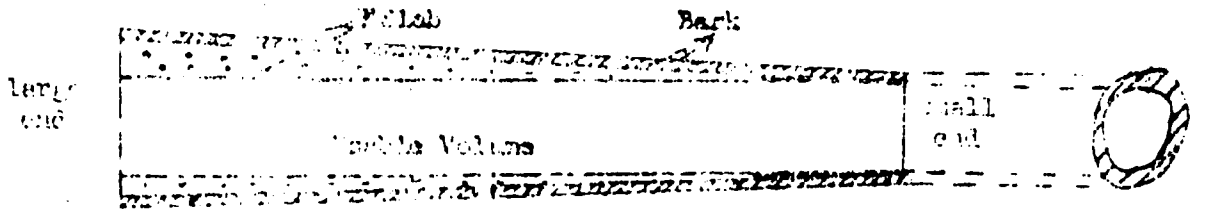
  The rule allows 4 inches for slabs, about twice as much as is needed. Moreover, sawkerf allowance is 25% instead of an actual 4.5%.

Log scaling - People who buy lumber want to know the number of boards of certain dimensions that can be cut from timber. Knowing the cubic foot volume of logs does not answer that question. Therefore, the board foot of volume was devised. A board foot is 1 foot long, 1 foot wide and 1 inch in thickness. The number of board feet is easily determined by knowing the length and width in feet or fractions of a foot, and the thickness in inches. For example a board 16 feet long, 6 inches wide and 2 inches thick measures 16 x 0.5 x 2 = 16 board feet.

Board foot determinations - The number of board feet that can be obtained from a log varies with the taper and with the thickness of the boards sawed. Thicker boards produce more board feet because they have less sawkerf.

° diameter measurement in logs

-- most people regard the log as a cylinder
-- most log rules consider average diameter inside bark at small end of log



° length measurement in logs

-- in the United States, the maximum length scaled is 16 feet. If longer, for example, 44 feet long, it is scaled 16 feet and 16 feet and 12 feet, but recorded as a single log 44 feet long.
-- the shortest log is 8 feet long and called a bolt.

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Table 4 International Log Rule, Board Feet

(Saw kerf ¼ in.) *

Top diameter, inside bark (in.)	Length of log in feet						
	8	10	12	14	16	18	20
4	...	5	5	5	5	5	10
5	5	5	10	10	10	15	15
6	10	10	15	15	20	25	25
7	10	15	20	25	30	35	40
8	15	20	25	35	40	45	50
9	20	30	35	45	50	60	70
10	30	35	45	55	65	75	85
11	35	45	55	70	80	95	105
12	45	55	70	85	95	110	125
13	55	70	85	100	115	135	150
14	65	80	100	115	135	155	175
15	75	95	115	135	160	180	205
16	85	110	130	155	180	205	235
17	95	125	150	180	205	235	265
18	110	140	170	200	230	265	300
19	125	155	190	225	260	300	335
20	135	175	210	250	290	330	370
21	155	195	235	280	320	365	410
22	170	215	260	305	355	405	455
23	185	235	285	335	390	445	495
24	205	255	310	370	425	485	545
25	220	280	340	400	470	525	590
26	240	305	370	435	500	570	640
27	260	330	400	470	540	615	690
28	280	355	430	510	585	665	745
29	305	385	465	545	630	715	800
30	327	410	495	585	675	765	860
31	350	440	530	625	720	820	915
32	375	470	570	670	770	875	980
33	400	500	605	715	820	930	1,045
34	425	535	645	760	875	991	1,110
35	450	565	685	805	925	1,050	1,175
36	475	600	725	855	980	1,115	1,245
37	505	635	770	905	1,040	1,175	1,315
38	535	670	810	955	1,095	1,245	1,390
39	565	710	855	1,005	1,155	1,310	1,465
40	595	750	900	1,060	1,220	1,380	1,540
41	625	785	950	1,115	1,280	1,450	1,620
42	655	825	995	1,170	1,345	1,525	1,705
43	690	870	1,045	1,230	1,410	1,600	1,785
44	725	910	1,095	1,290	1,480	1,675	1,870
45	765	955	1,150	1,350	1,550	1,755	1,960
46	795	995	1,200	1,410	1,620	1,835	2,050
47	830	1,040	1,255	1,475	1,695	1,915	2,140
48	865	1,090	1,310	1,540	1,770	2,000	2,235
49	905	1,135	1,370	1,605	1,845	2,085	2,330
50	940	1,185	1,425	1,675	1,920	2,175	2,425
51	980	1,235	1,485	1,745	2,000	2,265	2,525
52	1,020	1,285	1,545	1,815	2,080	2,355	2,625
53	1,060	1,335	1,605	1,885	2,165	2,445	2,730
54	1,100	1,385	1,670	1,960	2,245	2,540	2,835
55	1,145	1,440	1,735	2,035	2,330	2,640	2,945
56	1,190	1,495	1,800	2,110	2,420	2,745	3,050
57	1,230	1,550	1,865	2,185	2,510	2,845	3,165
58	1,275	1,605	1,930	2,265	2,605	2,945	3,275
59	1,320	1,660	2,000	2,345	2,690	3,040	3,390
60	1,370	1,720	2,070	2,425	2,785	3,145	3,510

* Scale for seasoned lumber with ½ in. shrinkage per 100 board, and saw cutting a ¼-in. kerf, or for green lumber, for saws cutting a ⅛-in. kerf, for saw cutting a ⅛-in. kerf add 0.5 percent. Formula: $(D \times 0.22) - 0.71D$ or 0.01762 for 4-ft sections. Taper allowance ... in per 4-ft lineal.

Source: U. S. Dept. Agr., Converting factors and tables of equivalents used in forestry, *Misc. Publ. No. 256*, 1949.

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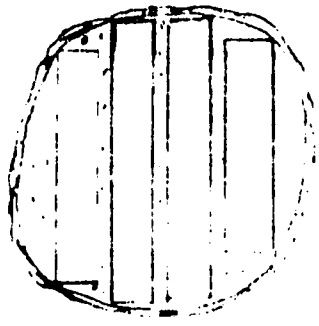
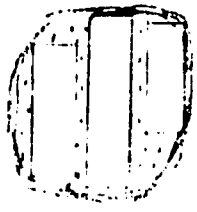
- Scribner log rule - this rule is based on diagrams in which a number of 1 inch boards have been drawn in a circle representing the small end of a log. Saw kerf of 1/4 inch is allowed between boards. The formula for computation is:

$$\text{Volume in board feet} = \frac{\text{sum of board widths in inches}}{12} \times \text{length of log}$$





No allowance is made for taper. Therefore, logs greater than 16 feet long tend to be underscaled. The rule is considered intermediate in accuracy.

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- Scribner Decimal C rule - this rule is derived from the Scribner rule by rounding off values to the nearest 10 board feet and listing in 10's of board feet (i.e., 128 board feet = 130 = 13. It is understood that the value is 13 x 10 = 130 board feet). The Decimal C rule does not take taper into consideration. Logs greater than 16 feet in length should be measured in sections, or the actual board foot volume will be underestimated. The rule was developed for a scaler who must record and total volumes for a large number of logs.
- Mill tally - the actual amount of board feet sawed from a log or timber. It is the most accurate method. However, it cannot replace the log scaling techniques because often logs are sawed many miles away from where they are scaled and sold.

<u>Differences between mill tally and log scale</u> - As mentioned, the most accurate method to determine board foot volume from a log is to measure what is actually produced after sawing at the mill. The difference between what is actually sawed at the mill and the estimates according to log scale is called overrun or underrun.

- overrun - the amount of lumber cut greater than the amount scaled
- underrun - the amount of lumber cut less than the amount scaled
- % overrun or underrun = $\frac{\text{mill tally - logs scaled}}{\text{logs scaled}} \times 100$
- Example of overrun: $\frac{110 - 100}{100} \times 100 = 10\%$

Log defects - The methods of deducting for defects in logs varys by region and the end use of the log. Local custom will prevail unless the timber sales contract specifies a particular technique. Common ways to deduct for defects are:

- reduce merchantable length - reduce the length of the log to the next lowest merchantable dimension.
- reduce merchantable diameter - reduce diameter by the amount of defect.
- log rule - scale out the defect using the log rule, then scale the entire log, and subtract the first from the second.

Types of defects - The effects of rot and other defects varys considerably among species and localities that no rule for making deductions applies universally. Log scalers are forced to use their best judgement. Estimation of defects and direct observation of cutting at the mill provide much valuable experience. The following are typical defects:

- interior defects - ground rot and stump rot are examples. *Cyrilla* in the montane forest often shows this defect. Fire may be a cause.
- side defects - damage by falling trees may cause this type of defect.
- deformed stem - curves or sweeps in the base log lead to this type of defect.
- crotches - the accumulation of water or organic matter in tree branches may result in this defect.
- dense branches - numerous branches, in particular from logs in the crowns of trees, may have an excessive number of knots, which are defects.
- worm holes - holes caused by boring insects often render logs unmerchantable.
- stain - certain fungi, although not wood destroying, often provide access to damaging organisms. Coloration may be undesirable and considered a defect.

Methods for deducting cull - A few general rules apply for the deduction of defect. They are:

- reduce the scale of interior defects by sawing out a rectangular cross-section of the defect (Figure 8 , panels B, E and G).

- always add 1 inch (2.5 cm) to both dimensions in the cross-section to include the unsound wood within sound wood.

- when the defect shows at both ends of the log, the end with the largest defect is usually used to calculate the amount of cull.

- when the defect is visible in only one end of the log, the length of the log is scanned for signs of rotten wood. If there are no visible signs of defect along the side of the log, the diameter of the interior rot may serve as an indication of its length. Here practical experience at the mill is helpful.

- standard rule - the Scribner Decimal C rule is used for deducting cull. Kerf deduction for any rectangle within the log (slabs removed) is set at 20%, and is deducted whether or not there is any cull. Therefore, it is not included in the allowance for defect. The formula is:

$$\text{Net allowance for defect in board feet} = 0.8 \frac{W \times H \times L}{12} = \frac{W \times H \times L}{15} \quad \text{where}$$

W = width of the cross section of the defect in inches,
H = the height of the cross section of the defect in inches, and
L = the length of the cross section in feet.
12 = the fraction for conversion to board feet in the first formula.

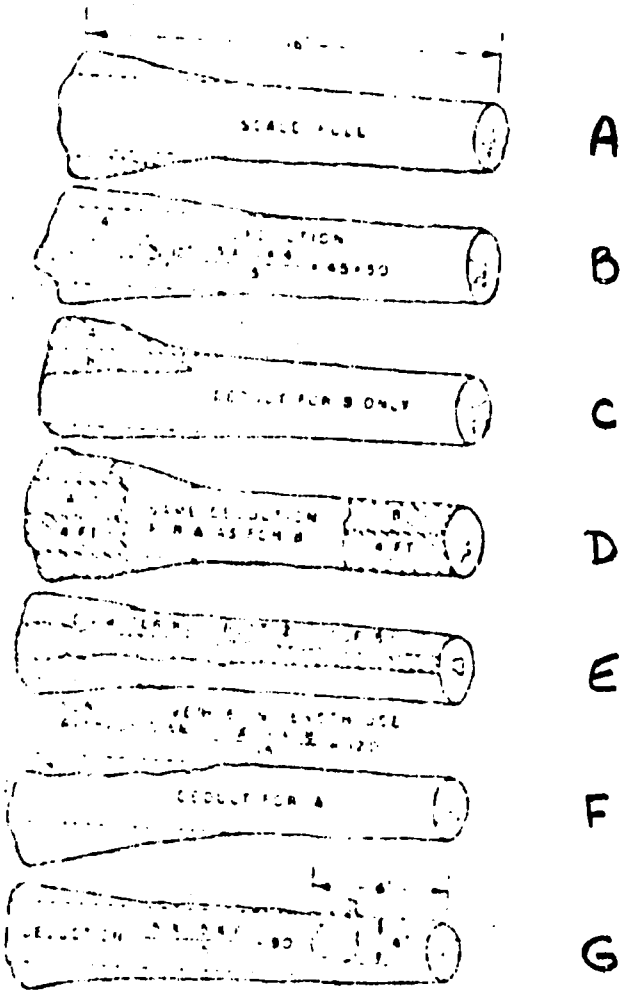

Figure 8 . Common defects in base logs and methods for deducting the portions of cull they contain.

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MANUAL OF INSTRUCTIONS

FOR THE USE OF

"SUPREME" - No. 802 ABNEY LEVEL

ABNEY LEVELS

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I - PRINCIPLES

The Abney Level is basically a device for measuring slope. It also can be used to determine the heights of trees, poles, overhead wire and the like....to measure ground elevations, to reduce measurements made on a slope to their horizontal equivalents....to run lines of levels and, as a clinometer to measure the slope of objects.

The observer, looking through the eyepiece at the left side of the tube, the sighting vane which he aligns with the object sighted. At the right side of the tube he sees the bubble vial reflected in a 45° mirror. By moving the index arm, the bubble can be centered on the sighting vane. The position of the index on the graduated circular arc then gives the value of the arc reading, which is the slope of the line of sight.

II - APPLICATION

TO MEASURE THE SLOPE OF THE GROUND

To measure the slope of the ground it is customary to measure the slope of a line parallel to the ground, either at eye height or at a fixed height above the ground, such as 5 feet. Three methods are suggested below.

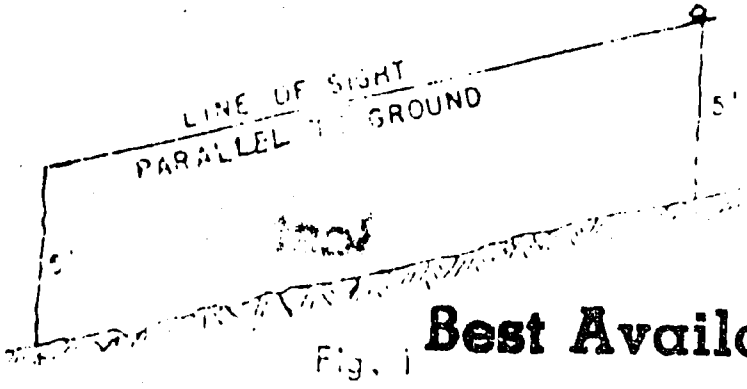

Fig. 1

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Instrument supported. For accurate measurement, notch two sticks or cut two forked sticks so that they will hold the instrument exactly 5 feet above the ground. Rest the instrument on one stick and sight to the top of the other, held by an assistant at a point on the slope. (Fig. 1) For maximum accuracy, the assistant should check by sighting back with a second instrument. The average of the two readings should be used.

E height method. Determine how high the observ eye comes on the assistant when standing close to him. When he is in position on the slope, sight that point on his body. (Fig. 2)

Estimation. Merely sight at a point estimated to be as far above the ground as the eye.

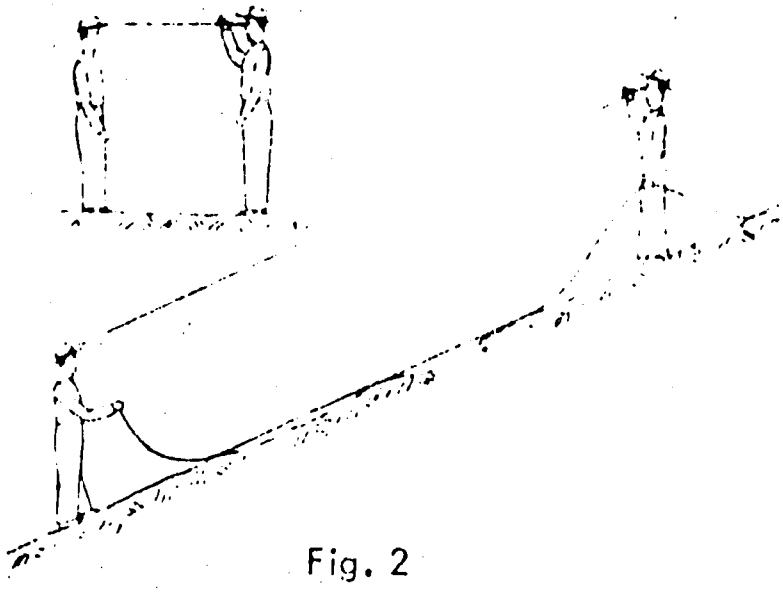

Fig. 2

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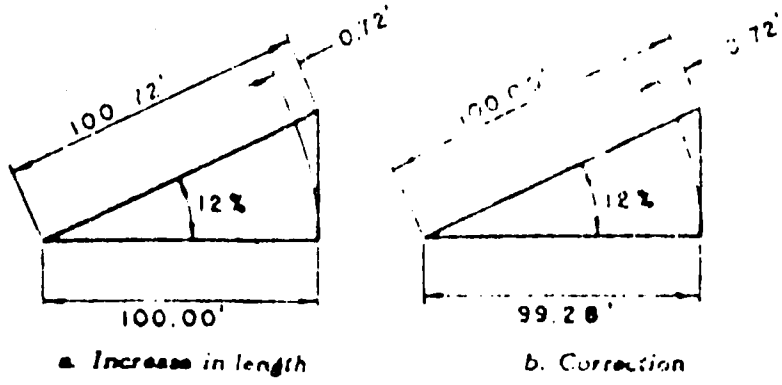
TO MEASURE HORIZONTAL DISTANCES

When a measurement is made on a slope, it is common practice either to measure slightly more than the distance desired (Fig. 3a), so that the horizontal equivalent will be correct,



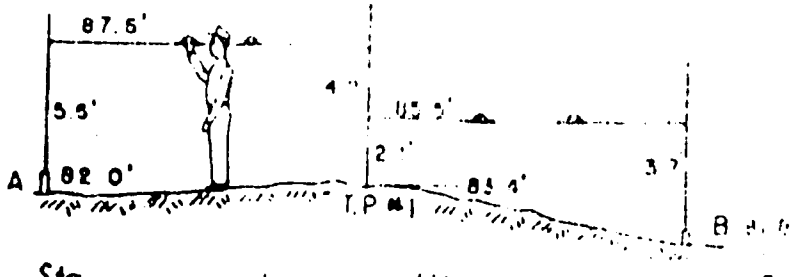
a. Increase in length b. Correction

Fig. 3

or to measure the slope distance exactly and then to subtract a correction (Fig. 3b). For all practical purposes the value of the increase in length for any slope is the same size as the correction to the length.

THE ABNEY AS A LEVEL

If it is desired to determine differences in elevation without making distance measurements, the Abney can be set at zero and used exactly like a level (Fig. 4).



Sta.	+	HI	—	Elev.
A	5.6	87.6		82.0
T. P. #1	2.1	85.5	4.2	83.4
B			[illegible]	81.8

Fig. 4

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Assume that A has an elevation of 82. It is desired to find the elevation of B. A graduated (leveling) rod is held on A. The level line of sight strikes at 5.6 feet. This is added to 82 to find the height of instrument, 87.6. A sight on a point called a turning point in the direction desired yields 4.2. This is subtracted from the height of instrument to obtain the elevation 83.4. This sequence can be repeated indefinitely. The usual form of notes is shown in the figure.

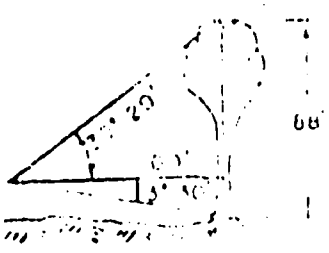
THE ABNEY AS A CLINOMETER

To measure the slopes of outcrops or other objects, place the instrument on the object and center the bubble by moving the index arm.

To use as a contact level, set the index arm at zero.

DETERMINATION OF HEIGHT OF TREES AND POLES

The Abney level is especially adapted to the determination of the heights of trees, poles, chimneys, overhead wires and the like.



100 tan 39° 20' = 82 ft.
100 tan 3° 30' = 6 ft
88 ft.

Fig. 5

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III - ADJUSTMENTS

STANDARD ABNEY LEVELS

Only the bubble adjustment is required for these instruments. One screw is used to regulate the bubble. This adjusting screw is at that end of the bubble which is nearest the eyepiece.

Adjustment 1, to Set the Bubble. To make the bubble center when the index is at zero and the line of sight is horizontal (Fig. 6). Select two trees about 30 to 50 feet apart. Pin a strip of paper for a target on one of them. Call this target A. Set the instrument at zero, steady it against the side of the second tree and, by trial, find a point apparently at the same elevation as A.

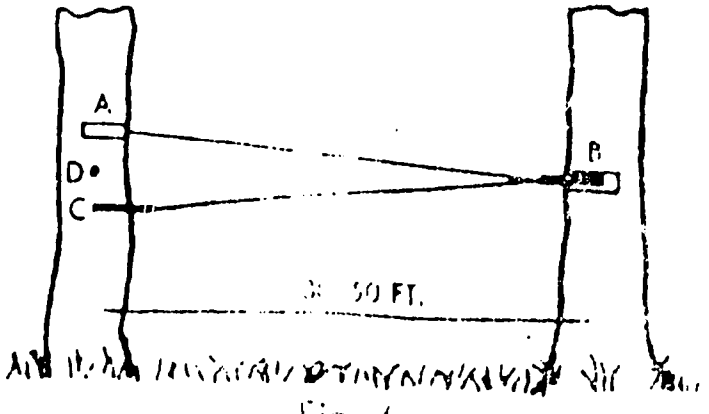

Fig. 6

Mark this point with target B. In the same manner find a point C on the first tree apparently at the elevation of B. Mark a point D on the first tree half-way between A and C. D will be at the same elevation as B, no matter how much the instrument may be out of adjustment.

Turn the adjusting screw until, when the instrument is held level at D, the line of sight will strike B.

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FOREST INVENTORY

Introduction

Timber inventories are usually conducted to know the volume of standing trees within a specific area. Time and money are the usual constraints. Accurate and reliable estimates of forest area, and measurement of an unbiased sample of trees within it, are the usual objectives. Before considering inventory techniques, it would be beneficial to review the types of information that may be available from inventories, and preliminary steps in conducting an inventory.

Types of information from inventories - The type of information available from a typical inventory includes specific data on forest area, species composition and timber volume. When the inventories are repeated in subsequent years, information on growth and species composition changes are available (Figure 1). When inventories are conducted in several forests, comparisons of stand density, species richness, avaerage height of the canopy, average diameter of the trees, and basal areas may be made (Figure 2).

Steps in making a forest inventory - Measuring trees is only part of a forest inventory. Several steps take place before and after actual measurements:

- objectives - determine the objectives of the forest inventory. Complementary information may be collected for other resource management groups in conjunction with the inventory and financial assistance may be available for these efforts. Possible objectives:

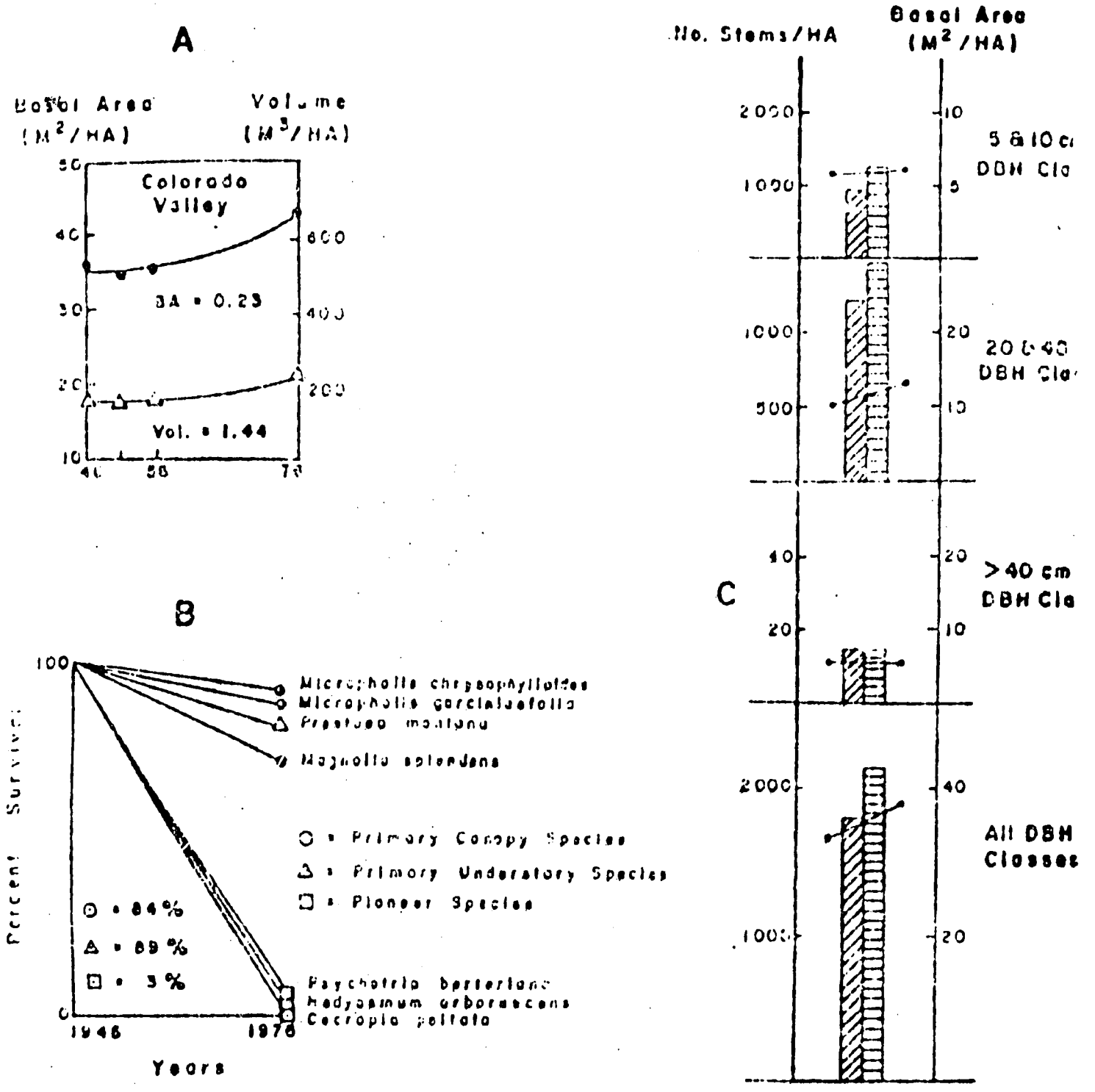

Figure 1 . Changes over 30 years on the Colorado Valley plot (Lower Montane Wet Forest).

(A) Basal area (m^2/ha.yr)
(B) Percent survival by species
(C) Number of stems (points) and basal area (bar graph) according to diameter class

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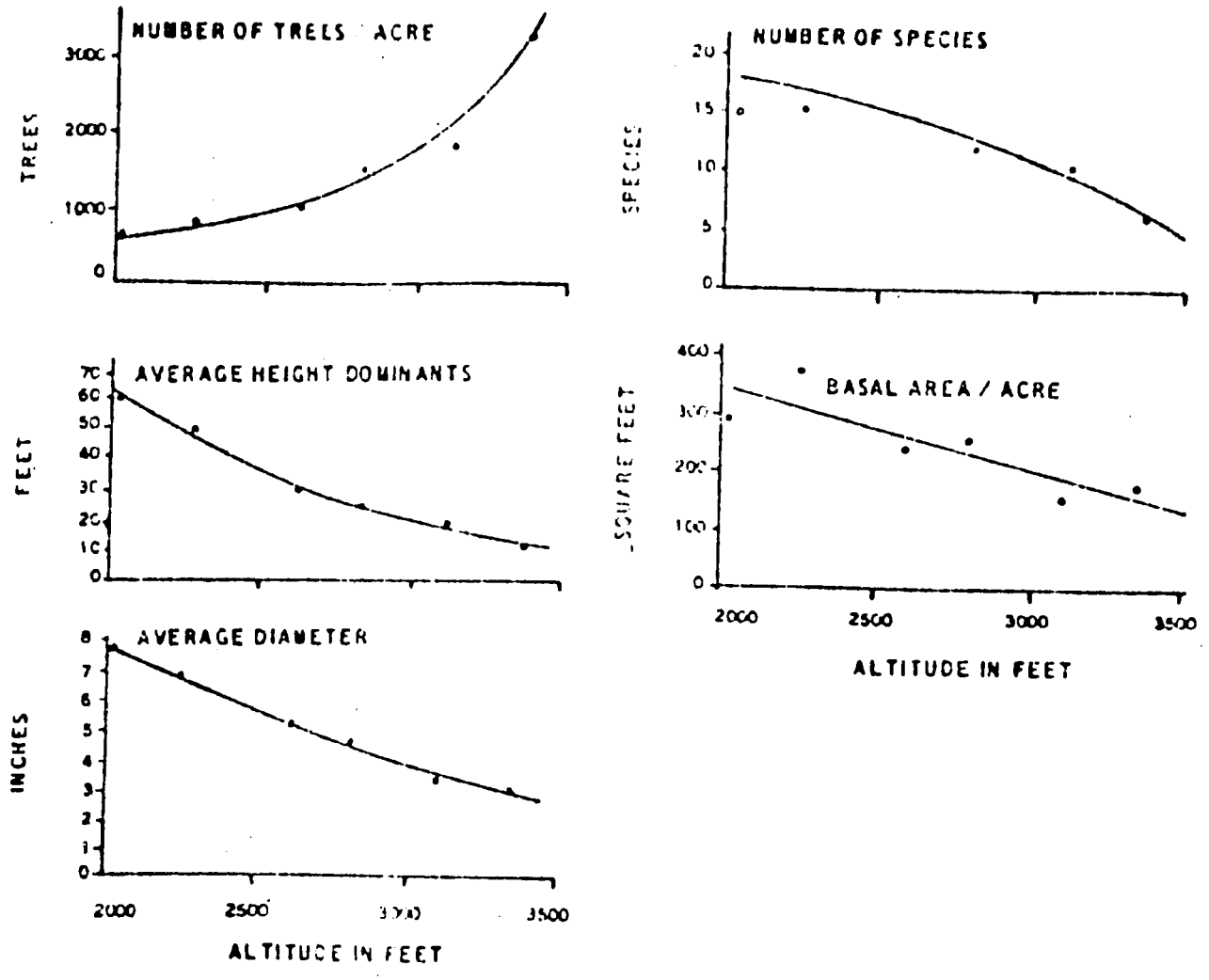

Figure 2a. Species area curves for several forests in Puerto Rico.

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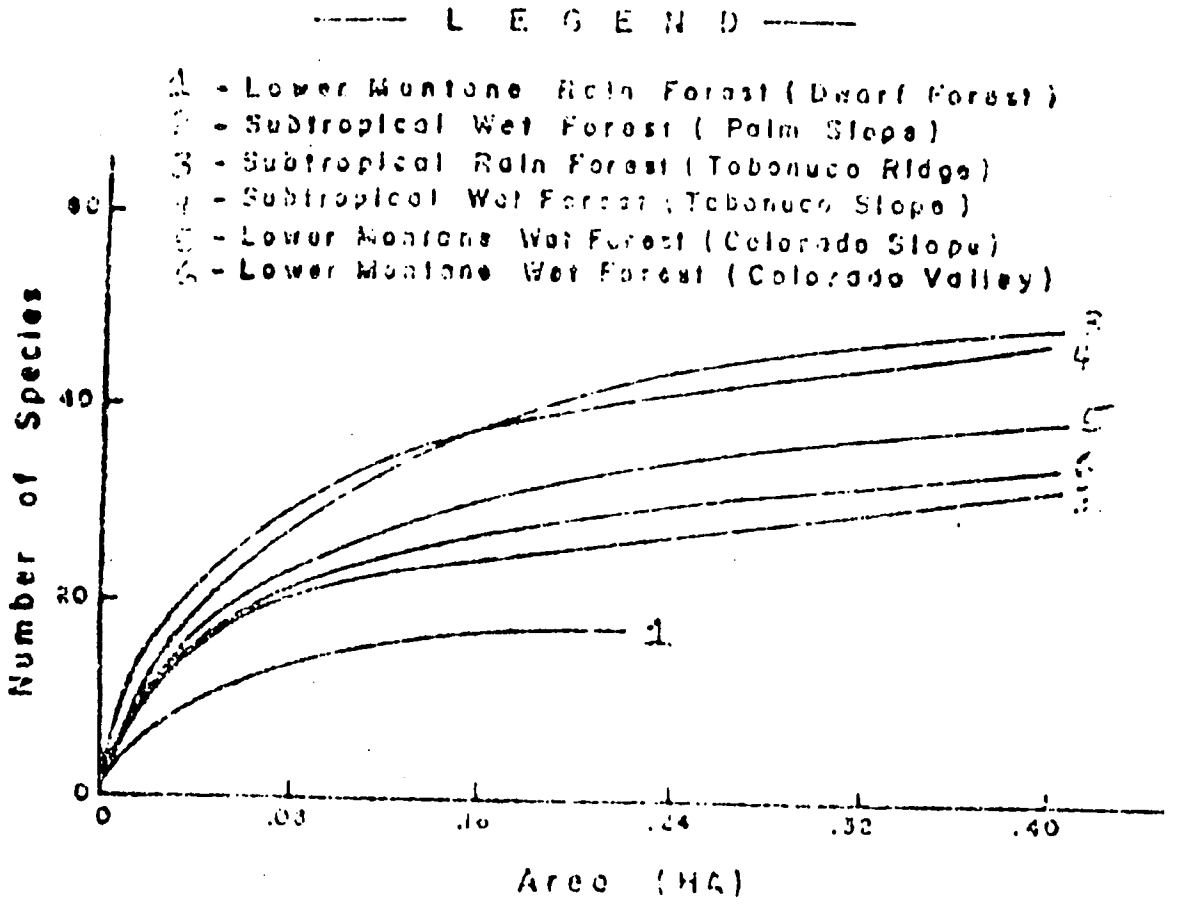

FIGURE 2b: SPECIES AREA CURVES FOR SILVICAL FORESTS IN PUERTO RICO

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reconnaissance, volume estimates, growth studies, species distribution studies.

- reference materials - collect relevant information from past surveys and the literature. Secure maps. Contact technical persons who lend assistance to the effort (for example: botanists, statisticians).
- focus scope - determine the areas to be surveyed on maps and on the ground. Areas considered to have limited commercial potential may be eliminated if the objectives are to assess commercial prospects.
- stratification - stratify the areas to be inventoried according to available environmental information and plot history to reduce variability in the results.
- related information - compile related information on valuable commercial species (size classes at maturity, wood characteristics, growth rates) and list of potential products (furniture woods, sawtimber, novelty woods, roundwood, and other timber uses).
- statistics - determine pertinent statistical information - allowable error, coefficient of variation, number of plots required for the cruise.
- sampling procedure - develop a systematic sampling grid or randomly distribute the plots over the survey area. Procedures will vary with the size of the area to be inventoried and survey objectives
- measurements - conduct measurements according to plan. In regions of seasonal climate, it is usually advisable to concentrate the work during the dry season when it may be done more efficiently.
- summarize data - calculate the averages and confidence limits for the data collected according to the stratification used in the design.

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- report results - wirte up the results in office reports and one or more publications for user groups who need the information

Types of plots - There are two basic types of plots that may be used to gather inventory data. They are:

- Temporary - on temporary plots, tree measurements and site information are recorded, but neither the plots nor the trees are permanently marked. Such plots are frequently used to determine volumes for timber sales, to characterize the area with regard to the information gathered, or possibly to observe differences in forest characteristics with regard to site (ordination and classification studies). The information might also be used to formulate forest policy.
- Permanent - on permanent plots, the plot center or corners are usually staked, and all the trees of interest (above a certain minimum diameter, or possibly, select species with commercial value) are permanently marked. Subsequent measurements will provide estimates of change over time within the stand. Continued forest inventories on the same plots provide information on growth, mortality and ingrowth rates, and are useful for management purposes.

Traditional Inventory Techniques

Complete tally of trees - Sometimes, either because of the value of the timber, or for experimental purposes, a complete tally of trees is made on a particular plot of land. These surveys are characterized by:

- size class limitation, below which trees are not measured
- most accurate estimate of volume possible
- most accurate deductions for defect because cull estimates apply to individual trees
- high costs because all trees are measured instead of a sample
- marking of all trees after measurement to preclude omissions or duplications. In a timber survey, this may involve spraying the tree with paint at its diameter. On an experimental research plot, it will involve labelling each tree with a numbered tag.

In the case of experimental plots, much information regarding the structure and dynamics of the forest may become available with continued measurements:

- structure - mean diameter and mean height of trees, diameter class distributions, crown class distributions, species diversities, typical stand densities, typical basal areas, volumes and standing biomass.
- dynamics - growth by species and forest type, ingrowth and mortality rates, recovery mechanisms in response to disturbance including hurricanes. Response may be characterized by species composition changes, changes in basal area, a shift in height classes, a pulse in the number of stems, etc.

The sample plot technique used in Puerto Rico over the past 40 years is described below. It is inexpensive, efficient and accurate, and well within the budgets of most research stations in the Caribbean area. The steps involved are:

- after preliminary inspection of the forest, an area representative of the forest type (for example, Dacryodes-Sloanea forest) is selected. The representative area is selected on the basis of rainfall, topography, and lack of human intervention.

- plot size is usually 1 acre in size. Species-area curves indicate that for most of Puerto Rico, this is adequate to include a representative number of species.

- all trees greater than or equal to 1.6 inches (4.1 cm) in diameter are measured with a cloth tape at breast height, 4.5 feet above the ground (about 1.4 m), and permanently labelled with sequentially numbered tags at 6 inches (15 cm) below breast height. Placing the tag below the point of measurement precludes future errors in measurement that may be caused by swelling around the nail.

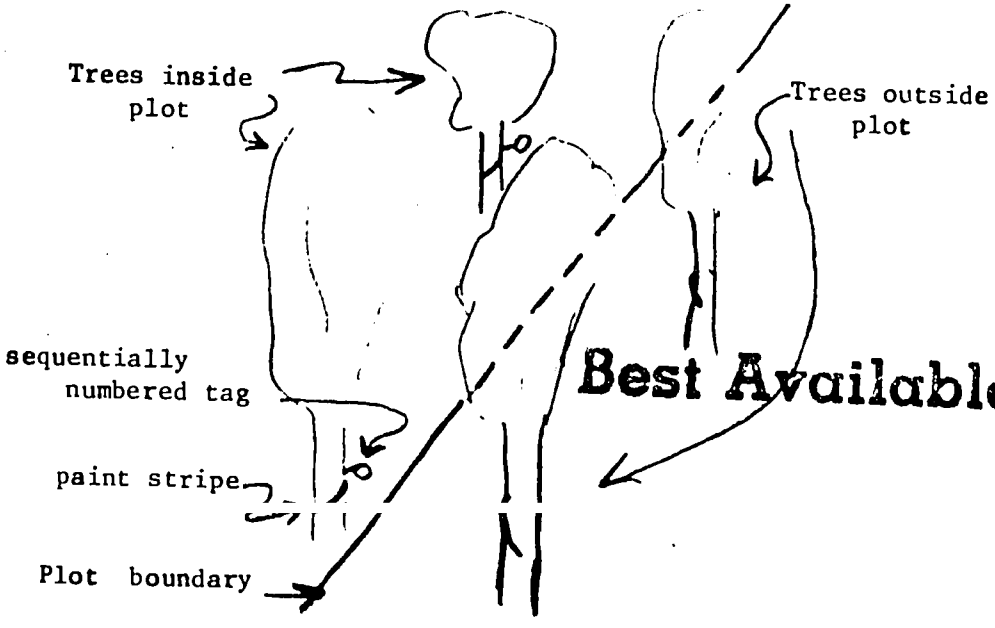
- tree height and crown class are also noted for each tree.

- in subsequent measurements of the same plot, usually at 5 to 7 year intervals, all live trees are measured again, and the tags are replaced if loose or lost. In addition, all new trees that have entered the minimum diameter class, 1.6 inches, are tagged as ingrowth. These are labelled by the year of the survey, a dash, and the number of the tree. For example, if ingrowth is tallied in 1983, the tree would be labelled 83-1, 83-2, etc., until all ingrowth is recorded. Mortality is also observed and recorded. For example, tree number 72 tallied on the original survey is marked as dead in the notes if it has fallen, or is stillstanding but dead.

- aluminum nails are driven about an inch into the tree, and about 1 inch is left exposed to accommodate future diameter growth of the tree. The tag is pushed against the nail head to prevent growth of the bark over the tag.

- a stripe is painted on the tree at breast height using forestry paint.

- all boundary trees are marked to facilitate work in the field. Trees inside the plot, but near the boundary, are marked on the side facing the boundary indicating that they are to be included in the tally. Trees outside the plot, but near the boundary, are also marked on the side facing the boundary indicating that they are to be excluded from the tally.



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Line plot cruising - In line plot cruising, only a percentage of the total forest is measured. Sample areas are a series of plots arranged in a grid pattern. The number of plots, their diameters, and the distance between the grid lines determines the percentage of the area sampled. The samples are characterized by:

- a series of circular plots (occasionally square or rectangular) that are arranged in a grid that encompasses the forest area. The plots are fixed in size according to the size of the vegetation being sampled. Distance between the plots in a line, and distance between lines are adjusted according to the percentage of sample desired.
- plot size is usually 1/4 to 1/5 acre for sawtimber, and smaller for poletimber and saplings.
- a single person may plot cruise efficiently.
- brush and fallen trees are not a problem because the cruiser is not required to tally trees while running a compass line.
- the data tallied are separated by plot allowing rapid summaries of information by timber types and other factors.

Basic statistics - Several basis statistics are extremely useful in planning inventories and interpreting their results, among them the following:

- range - the difference between the highest and lowest observation within a data set.
- mean - the arithmetic average of all the observations of a data set
- variance - the variance is a measure of dispersion,

$$S^2 = \frac{x^2 - (\frac{\quad}{n} x)^2}{n - 1}$$

DATA LISTING FOR 80 COL. PUNCHED CARD

SOUTHERN FOREST EXPERIMENT STATION T-10210 USPSB 701 LOYOLA AVENUE NEW ORLEANS, LOUISIANA 70113	STUDY	ENTERED BY	DATE	SOFRS
	RESEARCHER	CHECKED BY	DATE	APPN

LINE NUMBER	FIELD DESIGNATIONS: Tree number	Species code	1946 Measurements: DBH (cm)	1946 Measurements: HT (m)	1976 Measurements: DBH (cm)	1976 Measurements: HT (m)	Crown class: 1946	Crown class: 1976
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								

Table 1. Sample data collected on long-term plots in the montane forest (subtropical lower montane wet forest) of the Luquillo Mountains. Plot size is 0.025 acres (0.01 ha).

167

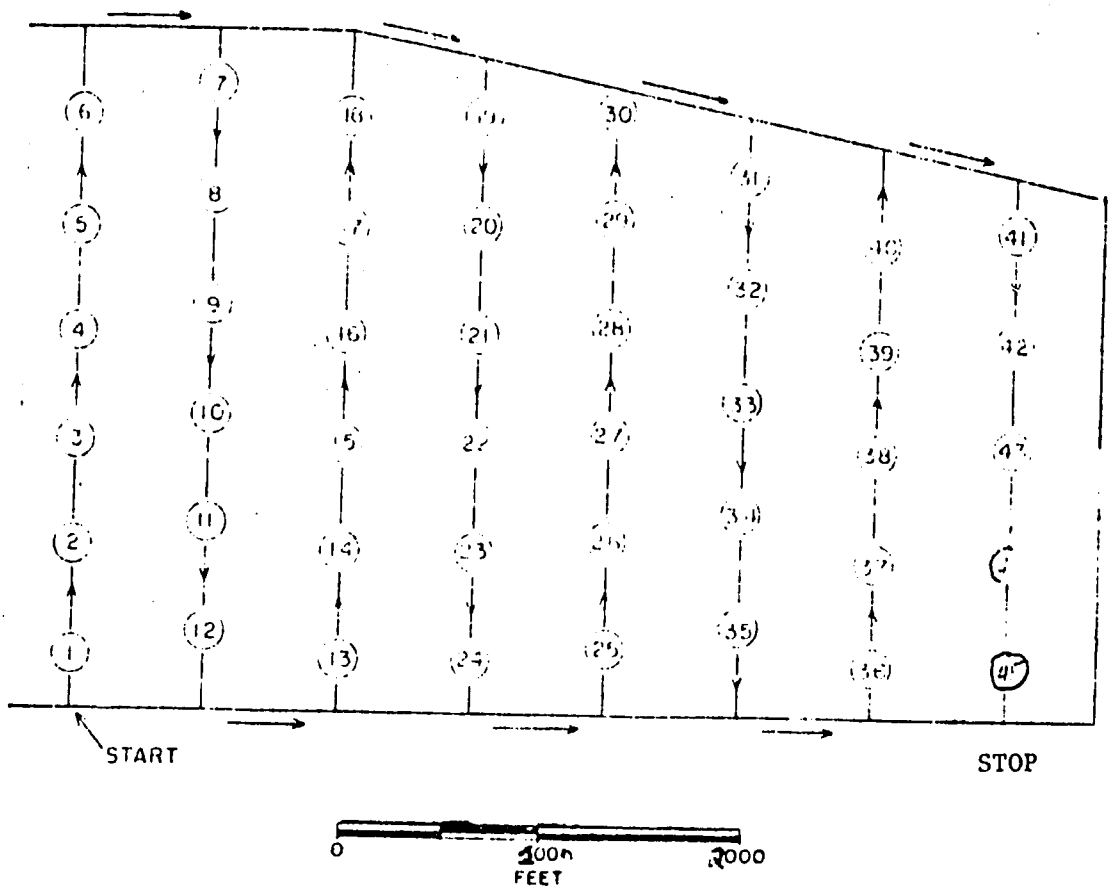

Figure 3 . Sample layout of plot cruising of forest, in this case, a 5% sample using 1/5 acre circular plots. The distance between plots is 264 feet and the distance between lines is 600 feet.

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- standard deviation - is the square root of the variance, a measure of the dispersion of individual observations about their arithmetic mean. In a normally distributed population, about

  - 68% of the observations are ± 1 standard deviation

  - 95% of the observations are ± 1.96 standard deviations

  - 99% of the observations are ± 2.58 standard deviations

$$S = \frac{x^2 - (\quad x)^2/n}{n - 1}$$

s = standard deviation
x = an individual observation
n = the number of observations

- standard error of the mean - is a measure of the variation among sample means. It is analygous to the standard deviation, but for sample means instead of individual observations,

$$S_{\bar{x}} = \frac{s^2}{n} \quad \text{where} \quad S^2 = \frac{x^2 - \underline{\quad x}^{\,2}}{n - 1}$$

s^2 = the variance
$s_{\bar{x}}$ = the standard error of the mean

and the remaining symbols are the same as above.

- confidence limits - are certain values greater than and less than the mean, and equidistant from the mean. The standard error of the mean and the table of t values are used for establishing confidence limits. The confidence limits provide a way of estimati the probability that a sample mean may be greater than a certain distance from the population (true) mean.

Mean ± (t x standard error)

- sample size - when planning a timber inventory that will be informative and useful as well as efficient (maximum information for minimum effort and cost), enough sample units should be measured to yield a desired level of precision. The formula

$$n = \frac{t^2 s^2}{E^2}$$

provides this, where

n = sample size needed, the unknown,
t^2 = t x t, a value derived from the appendix table; the value used

Strip Cruising- In strip cruising, only a percentage of the total forest is actually measured. Sample areas are continuous strips that run the entire distance of the forest. The number of strips, their width, and the distance between them determines the percentage of the area sampled. These samples are characterized by:

- continuous strips of uniform width, located at fixed distances, dependent upon the percentage of sample desired. The width of the strip is dependent upon the size of trees, with wider strips for larger trees.
- sampling is continuous and no time is lost walking between sampling stations.
- in comparison to plots, strips generally have fewer border trees, a possible source of error.
- estimation of strip width at times causes errors in that the personnel conducting the survey sometimes do not carefully measure the distance to each tree.
- brush and fallen trees sometimes delay strip crusing
- because the strip centerline is rarely laid out on the ground, it is difficult to return for checks of data entries. Laying out a permanent centerline is expensive and time consuming.

s^2 = the variance (square of the standard deviation), and
E^2 = the desired width of the confidence level, or the allowable error.

How to use the statistics - Let us suppose that we desire a 95% confidence limit on a field sample. First, we conduct a preliminary survey to derive an estimate of the variation about the sample mean. Our ultimate objective is to determine the sample size or the number of plots we must measure to get a mean estimate of volume per hectare (or acre) with a 95% probability of being within 10 m^3 of the true population mean. Our preliminary sample data are:

250 m^3	260
280	240
240	250
210	260
260	290

For purposes of this exercise, let's determine each of the statistics mentioned.

- range = the difference between 290-210, or 80
- mean = 254
- variance = $\dfrac{649{,}600 - \dfrac{6{,}451{,}600}{10}}{9} = 493.33$
- standard deviation = $\dfrac{649{,}600 - \dfrac{6{,}451{,}600}{10}}{9} = 22.21$
- stadard error = $\dfrac{493.33}{10} = 7.02$
- sample size = $\dfrac{(2.262)^2 \ (493.33)}{10^2} = 25.24$, or about 25 plots

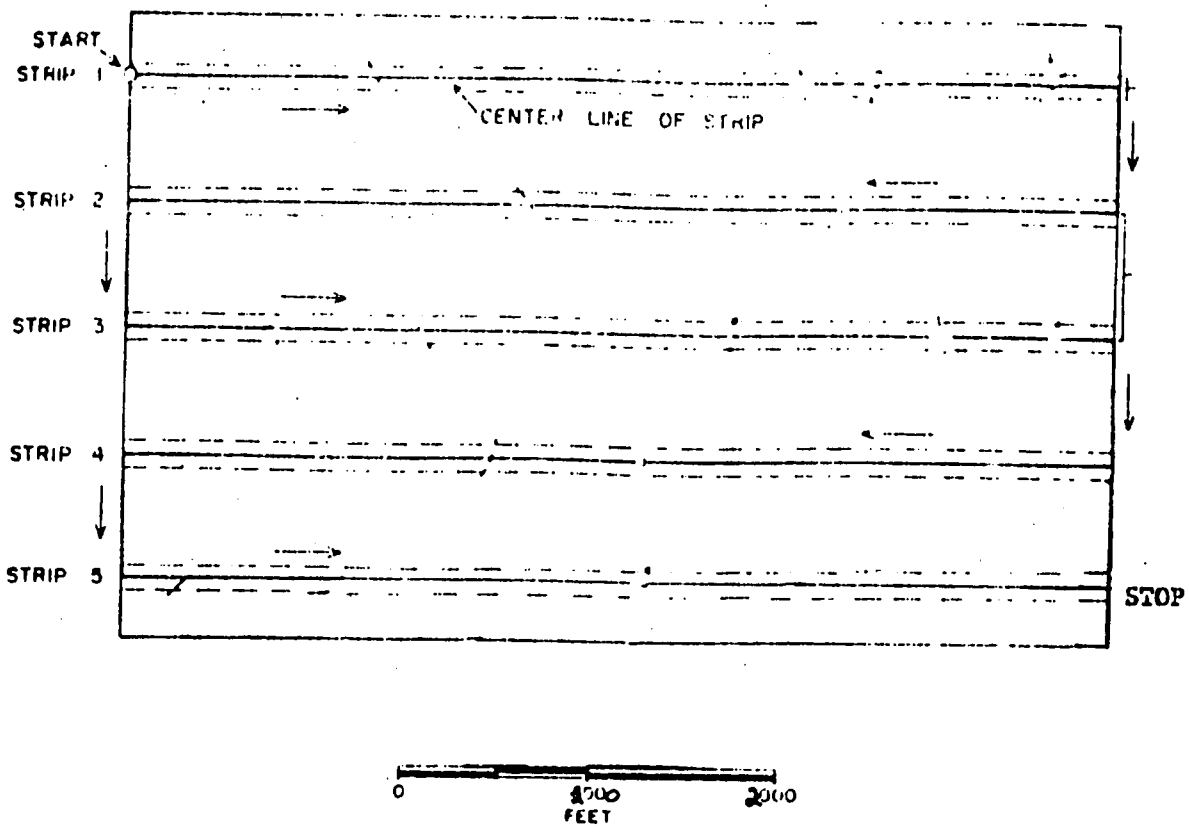

FIGURE 4 : SAMPLE LAYOUT OF STRIP CRUISING OF FOREST, IN THIS CASE, A 10 PERCENT SAMPLE USING STRIPS 66 FEET WIDE SPACED AT DISTANCES OF 660 FEET.

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Regional Forest Inventories - Puerto Rico as an Example

The approach - Sometimes the area covered in an inventory encompasses an entire region -- for example, the recent forest resource survey of Puerto Rico. Reviewing the steps taken to conduct such an inventory should be informative.

- formulation of survey objectives - assess the secondary forest resources with commercial potential in Puerto Rico. These include active coffee shade, abandoned coffee shade, and secondary woodlands.

- focus scope to reduce costs - partition the island into commercial and non-commercial regions. Non-commercial regions include those in the Subtropical Dry Life Zone (less than 40 inches/yr. of rainfall), critical watersheds (those with slopes greater than 60%, or with rainfalls in excess of 100 inches/yr), unproductive soils, agricultural areas and metropolitan zones, and mangroves and swamps (Table 2).

- stratification of forest lands with commercial potential - use of two ecological factors, life zones and soil types, to stratify the forest information for analysis (Table 3).

- compilation of tree species information - development of a complete tree species list for Puerto Rico including the most appropriate uses of timber trees. The categories used for classification of the species included furniture woods, sawtimber, novelty woods, roundwood and other species (Table 4).

- development of sampling grid - superimposing a sampling grid of 3 km by 3 km on the island for selection of potential sampling sites. These were then checked with aerial photos to separate all grid intersections into forest and non-forest classifications. All sites classified as forest in the commercial forest region of the island were inventoried.

Table 2 . Land area by survey region, Puerto Rico, 1980.

Survey region	Area
	Hectares
Commercial	
Subtropical Moist Forest Life Zone[1]	
Deep volcanic soils[2]	69,000
Shallow volcanic soils	116,700
Granite soils	33,100
Limestone soils	81,100
Total Subtropical Moist Forest Life Zone	299,900
Subtropical Wet Forest Life Zone	
Deep volcanic soils	99,600
Shallow volcanic soils	20,600
Granite soils	12,000
Limestone soils	4,500
Total Subtropical Wet Forest Life Zone	136,700
Total commercial	436,600
Non-commercial[3]	
Subtropical Dry Forest Life Zone	121,500
Critical watersheds	109,300
Unproductive soils	92,200
Alluvial and metropolitan	76,000
Mangrove and swamp	7,500
Noncontiguous Puerto Rico	47,200
Total non-commercial	453,700
Total land area	890,300

[1]Life Zones according to Holdridge (1967), determined by Ewel and Whitmore (1973).

[2]Soil groups defined and mapped by Zambrana (1978).

[3]Areas were defined sequentially in the order presented.

Table 3. Summary of standard tables resulting from the inventory of Puerto Rico's secondary forests. Stratification of the inventory by life zone and soils type, and the collection of site and stand data along with tree measurements provided the basis for the analyses.

FOREST AREA

1. Area by land classes .....
2. Forest area by Life Zone and forest class .....
3. Area of timberland by Life Zone, soil group, and forest class .....
4. Area of timberland by stand-volume class and forest class .....
5. Area of timberland by stand-volume class and soil group .....
6. Area of timberland by stand-size class and forest class .....
7. Area of timberland by stand-size class and soil group .....
8. Area of timberlnad by stand age class and forest class .....
9. Area of timberland by stand age class and soil group .....
10. Area of timberland by basal area class and forest class .....
11. Area of timberland by basal area class and stand-size class .....
12. Area of timberland by Life Zone, soil group, and slope class .....

SPECIES COMPOSITION

13. Number of live trees by species and diameter class, ranked by basal area plurality .....
14. Number of growing stock trees by species and diameter class, ranked by basal area plurality .....
15. Number of live trees on stocked timberland by diameter class and forest class .....

16a. Basal area and number of live trees per hectare of stocked timberland for selected species, secondary forests .....

16b. Basal area and number of live trees per hectare of stocked timberland for selected species, abandoned coffee shade .....

16c. Basal area and number of live trees per hectare of stocked timberland for selected species, active coffee shade .....

17. Basal area of poletimber and sawtimber trees by tree class and forest class .....
18. Basal area of poletimber and sawtimber trees by tree class, Life Zone, and soil group .....

TIMBER VOLUME

19. Volume of timber on timberland by class of timber and forest class .....
20. Volume of timber on timberland by Life Zone, soil group, and tree class.
21. Volume of timber on timberland by species and diameter class .....
22. Volume of growing stock on timberland by species and diameter class ....
23. Volume of sawtimber on timberland by species and diameter class .....
24. Volume of sawtimber on timberland by species and butt log grade .....
25. Volume of timber, growing stock, and sawtimber on timberland by stand-size class .....
26. Volume of timber on timberland by Life Zone, soil group, and slope class .....

Table 4 . Information about natural forest tree species that is useful for inventories and management of the forest.

Species name - Latin name if known; common name (assure that each species has but a single common name. Sometimes closely related species are grouped under the same name by forest laborers).

Size at maturity - get an estimate of the height in m and diameter in cm that each species commonly attains at maturity.

Most appropriate use[1]

A. furniture wood - quality timbers that attain a diameter of at least 60 cm at maturity.

B. sawtimber - good timbers that attain a diameter of at least 60 cm at maturity.

C. novelty woods - quality timbers that rarely exceed 40 cm in diameter and that have value as turnery stock, or for other species uses.

D. roundwood - large or small dimension timber that is best adapted to use as poles or posts, usually after appropriate treatment.

E. other species - tree species whose greatest potential use is for pulpwood or fuelwood.

worthless species - tree species which, because of size or wood characteristics have limited utility.

Wood characteristics - specific gravity, particular wood features, resistance to termites, and related characteristics.

Silvicultural characteristics:

tolerance - shade tolerant, that is, capable of regeneration below canopy; shade intolerant, that is, requiring direct sunlight for germination.

growth rates - specify diameter increment in cm/yr.

crown characteristics - spreading crown, narrow columnar crown

life history information - germination good, germination surfaces (on logs, cleared ground, ground covered with leaves); abundant seedlings.

common sites - areas where the species is most frequently encountered -- river banks, areas flooded annually, wetlands, bommomlands, slopes, ridgetops, elevational ranges in mountains, unknown.

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[1] The dimensions given here apply in Puerto Rico, and will vary with locale elsewhere in the American tropics.

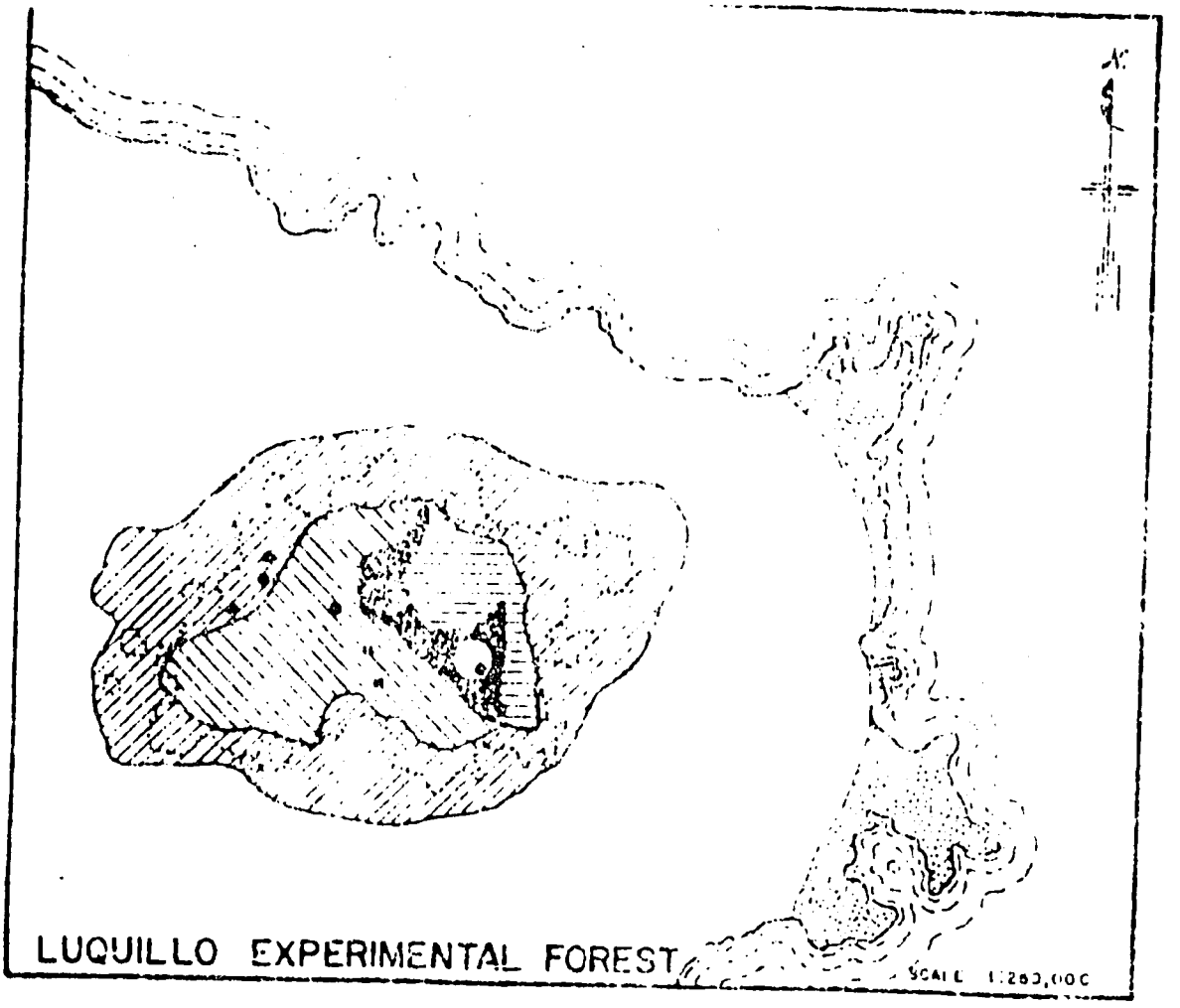
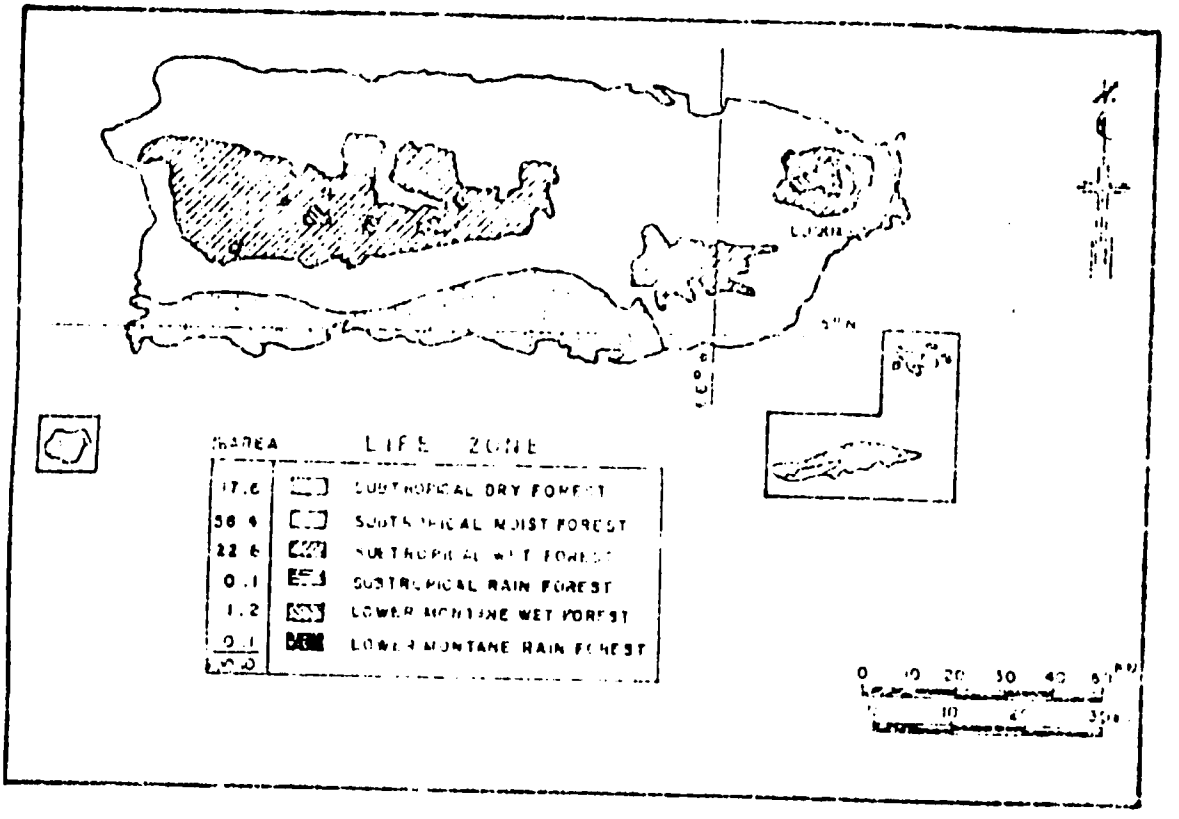


Figure 1. The life zones of Puerto Rico (below) and the Luquillo Mountains (above). Colorado forest = lower montane wet forest.



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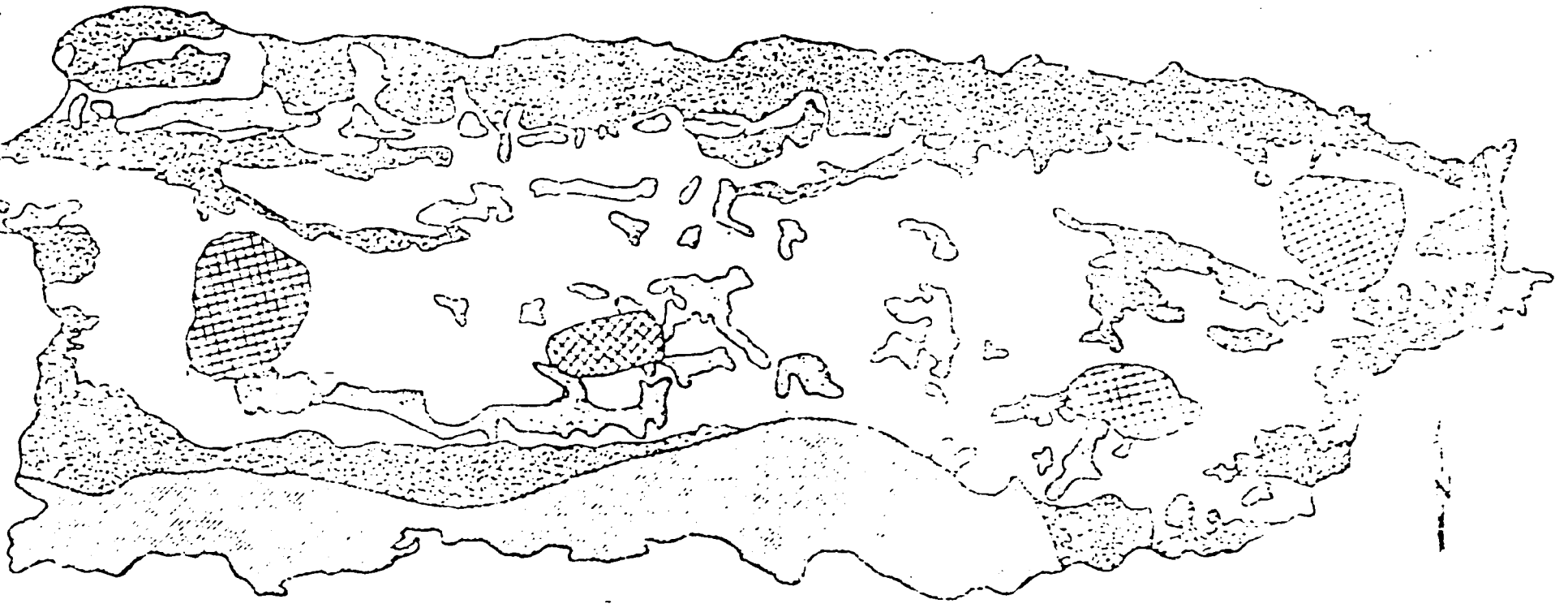

SUBTROPICAL DRY LIFE ZONE (≤ 1,000 MM/YR RAINFALL)

EXCESSIVE RAINFALL (≥ 2,500 MM/YR)

EXCESSIVE SLOPE (≥ 60 %)

UNPRODUCTIVE SOILS & HIGHER PRIORITY USES

COMMERCIAL SURVEY REGION

0 10 20 30 40 50

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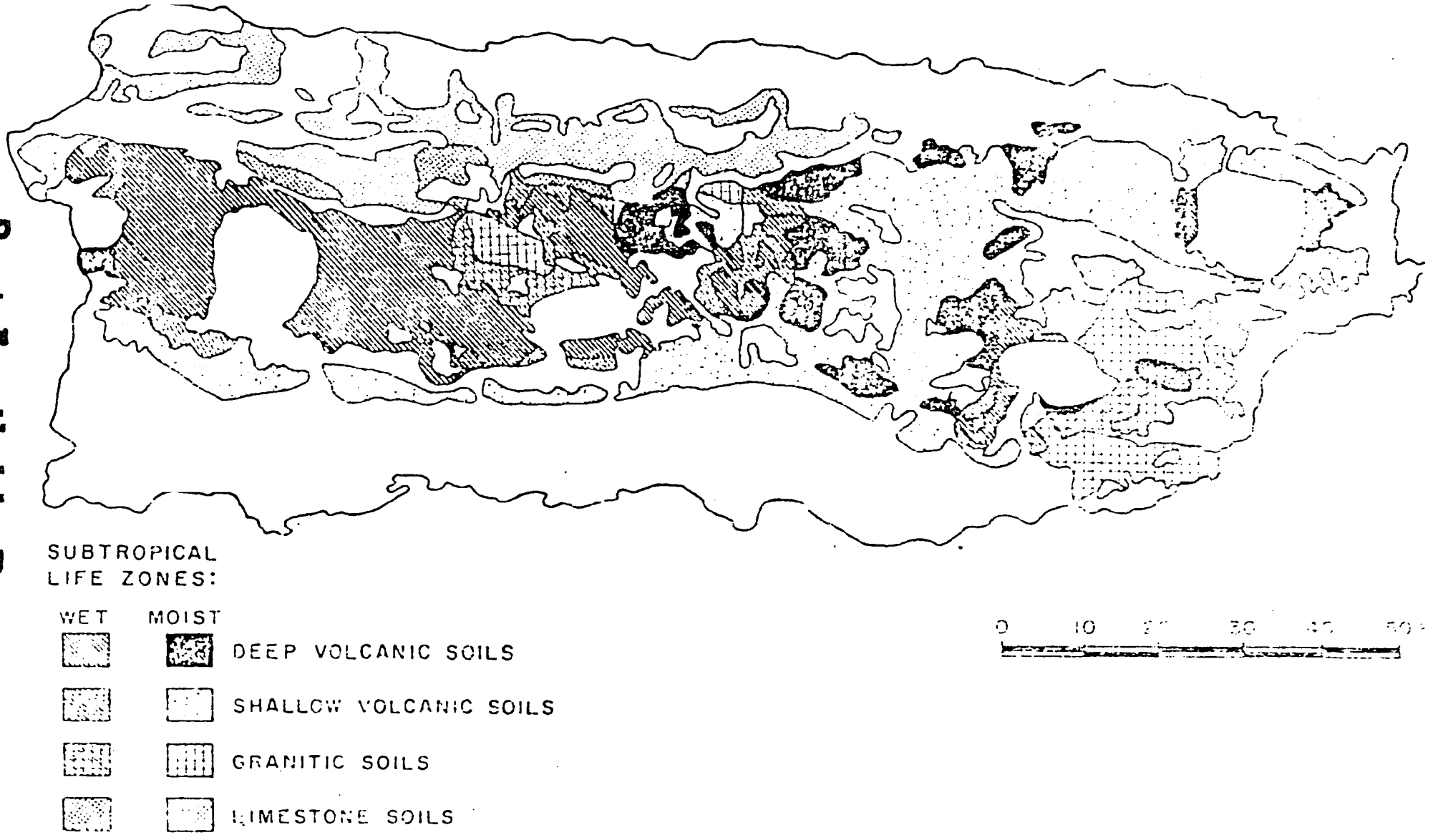

Figure 3. Life Zones and soil groups in the potential commercial forest region, 1980.

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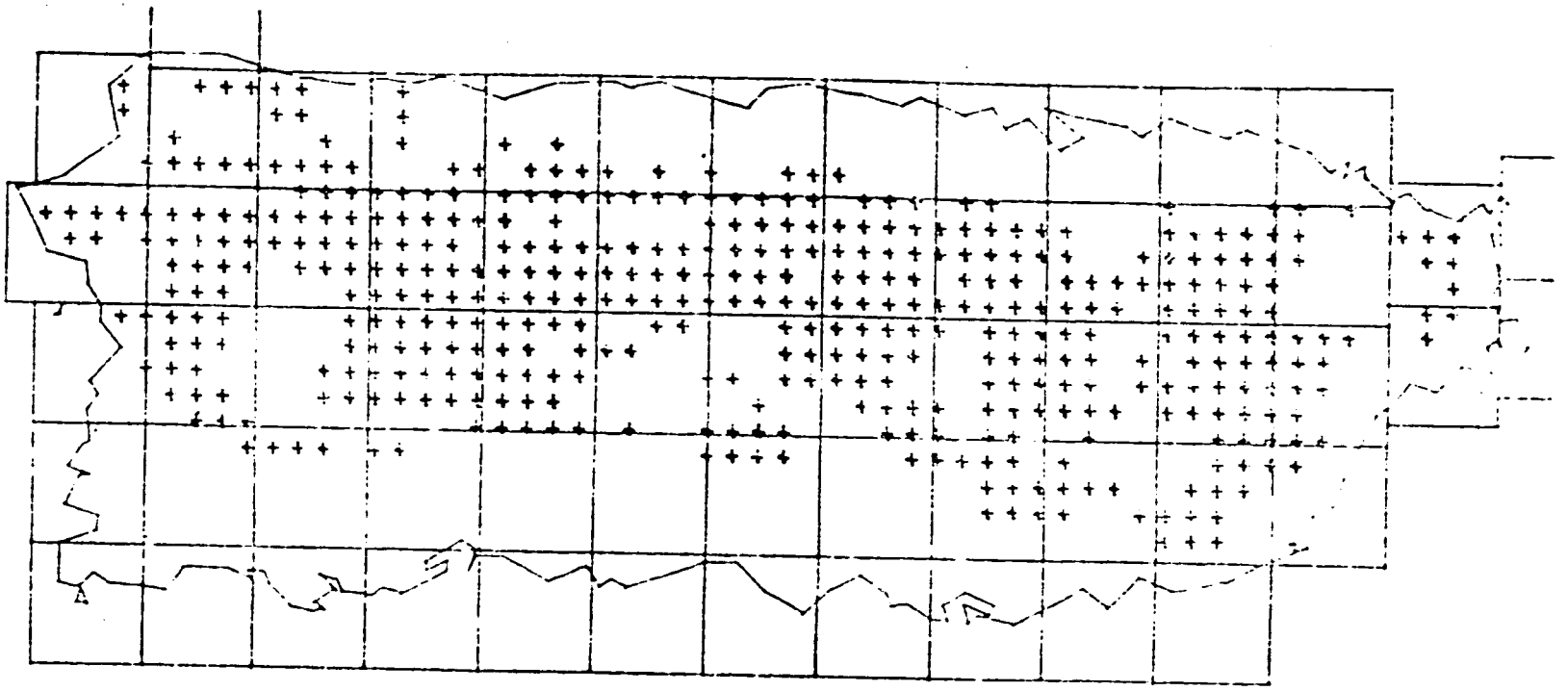

Figure 4: Locations on 3 km. grid included in 1980 survey. Red = forest. Blue = nonforest.

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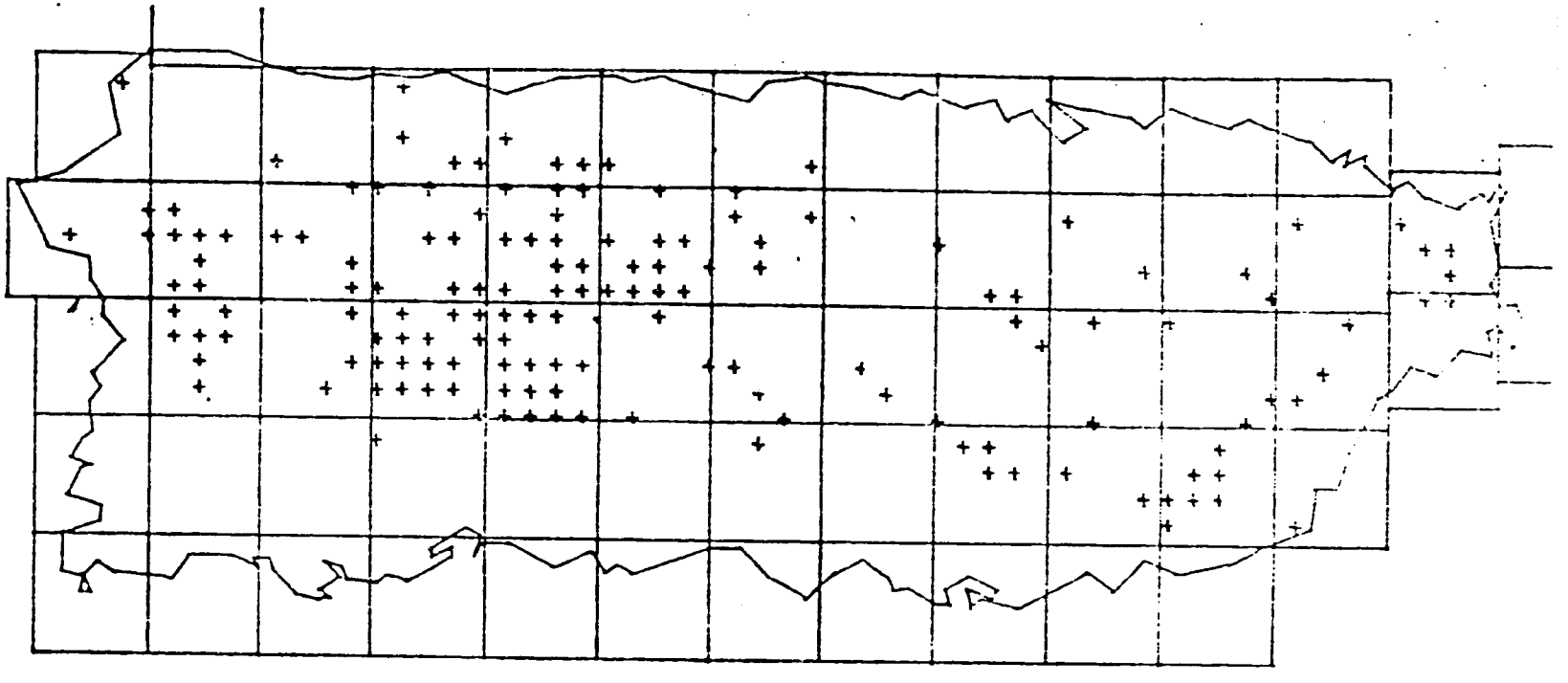

Fig 5 COMMERCIAL FOREST LOCATIONS - FOREST 1980

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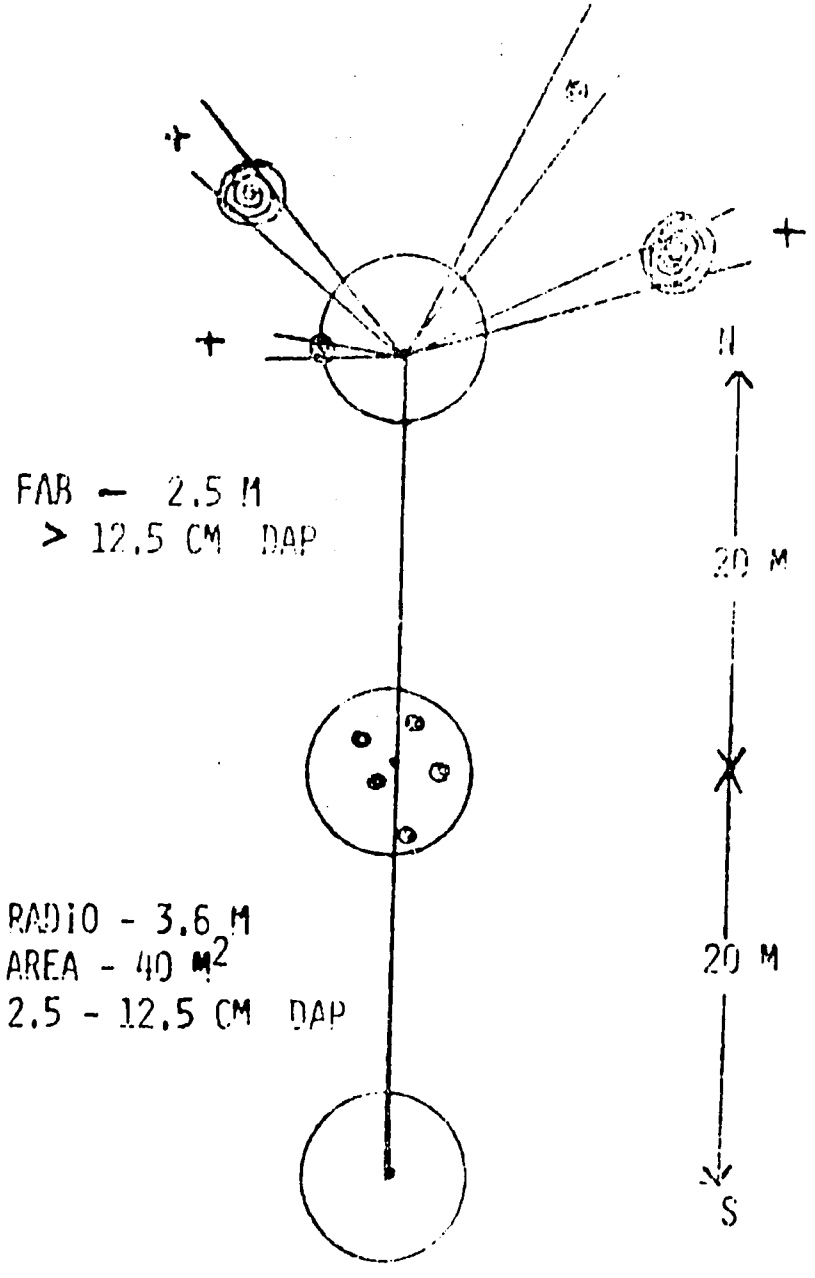

DISEÑO DE LOS RODALES

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[illegible]CATION XXX	8 GROUND USE X	15 [illegible] X	22 FOREST TY[illegible]
X COORDINATE XX	9 OWNER X	16 ROUGHNESS X	23 CRUISER
Y COORDINATE XX	10 LIFE ZONE X	17 DRAINAGE X	24 DNR USE XX
MUNICIPALITY XX	11 MS SOIL TYPE X	18 DISTANCE XX	
SAMPLE KIND X	12 GROUND SOIL X	19 SIZE X	
DATE XXXX	13 LANDFORM X	20 ELEVATION XX	
MS LAND USE X	14 SLOPE PERCENT X	21 STAND AGE XX	

[illegible]	DISTANCE (dm)	POINT NUMBER	TREE NUMBER	TREE HISTORY	SPECIES	D.B.H. (mm)	BOLE LENGTH (dm)	SOUND CUBIC CULL (dm³)	UNSOUND CUBIC CULL (dm³)	LOG LENGTH (dm)	POLE TOP D.O.B. (mm)	SAW TOP D.O.B. (mm)	LOG CULL (10dm³)	LOG GRADE	STEM CLASS	DAMAGE	TREE CLASS	DOUBLE BARK (.01")	STUMP DIAMETER (mm)	TOTAL HEIGHT	TOTAL HEIGHT (m)	H.L.C.	R.S.T. DOS
[illegible]	27	28	29	30	31	32	33	34	35	36	37A	37B	38	39	40	41	42	43	44	45	46	47	48
[illegible]	XXX	X	XX	XX	XXX	XXXX	XXX	XXXX	XXXX	XXX	XXXX	XXXX	XXX	X	X	XX	XX	XXX	XXXX	XX	XXX	XXX	XXXX

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Each step of this process served to better define the nature of the inventory. Statement of precise objectives eliminated areas without commercial potential, or about half of the island. Stratification of the forest lands into two life zones, the Subtropical Moist and the Subtropical Wet forests, and by four soil types, deep clays, shallow clays, areas of granitic intrusions, and limestone, allowed the use of the best ecological information available for partitioning forests. Tree species information is important for determining the value of the timber resource. Elimination of those points on the sampling grid that do not contain forest precludes the need to visit the sites.

- sample plots - each sample plot consisted of 3 subplots separated by 66 feet (20 m). A basal area prism with a basal area factor of 2.5 m^2 (10.89 ft^2) was used to tally trees with diameters greater than 5 inches (12.5 cm) in diameter. A cricle with a 3.6 m (11.8 ft) radius was used to sample all trees between 2.5 to 12.5 cm (1 to 5 inches). The tree and site information outlined in table 4 was also recorded.

- analysis - because the site and stand information were collected along with tree data, and the entire sample was stratified by life zone and soils type, many analyses of the data were possible (Table 3).

REGENERATION SAMPLING
SAPLING 5 METER QUADRATS
OFFICE SHEET

Compartment nº

Total area ..... ha Area sampled .....ha Intensity ..... %

Species	Chosen tree	Size class			Dominance class				Secondary tree	Size class			Dominance class			
		2	3	4	D	CD	I	S		2	3	4	D	CD	I	S
Total stocking Stocking %																
Total unstocked Unstocked %																

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REGENERATION SAMPLING
SEEDLING 2 METER QUADRATS

FIELD SHEET

Compartment nº ..... Line nº .....N/S Date .....

Plot nº	Chosen tree		Species Secondary Seedling	Palms	Notes
	Species	Abundance*			

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* Abundance symbols:

0 plot unstocked
1 A solitary seedling of chosen species in plot
\+ 2 to aproximately 20 seedlings of chosen species in plot
++ Over approximately 20 seedlings of the chosen species in plot

FOREST MENSURATION AND INVENTORY

Regeneration Sampling

Sampling of regeneration in secondary forest is done to see if the forest is adequately stocked with valuable species. Lands that are adequately stocked may be managed to improve species composition over time and to enhance the growth rates of potential crop trees. The assessment techniques should be inexpensive, easy to implement, and should yield reliable information on the species composition, distribution, stage of development, and status of competition within the area sampled.

Information on sampling is condensed in Table 5. Included are plot sizes for different size classes of vegetation, the intervals between the sampling lines, and the percent of the area that is sampled. As is evident, the size of the plot is variable and dependent upon the size of the vegetation being sampled.

Steps in regeneration sampling - Natural regeneration is not uniform in size, density or distribution. Through the use of areal photographs and field inspection, areas with similar tree size classes should be demarcated on topographic maps, and the appropriate plot sizes selected in order to sample each area. The following steps are followed:

- Species list - A list of valuable timber species is compiled by a knowledgeable authority. Table 6 is an example form the Rio Piedras woodlot.
- Areas are demarcated on topographic maps according to the predominant size class of the natural regeneration.
- Sampling theory - One economic seedling in each 2 x 2 m plot (2500 seedlings per hectare) constitutes sufficient regeneration to allow for all normal mortality and still provide for complete stocking at maturity. Similarly, one sapling or small pole in each 5 x 5 m plot (400 saplings per hectare) constitutes sufficient regeneration to allow for all normal

Table 5 . Samples, sampling lines and size classes of the vegetation to be recorded in each sampling class

Sampling Class	Size[1/] (m x m)	Intensive sampling[2/] Interval (m)	Intensive sampling[2/] Percent	Regeneration included	Size class of vegetation	Size class number
2 m plot	2 x 2	50	2	seedlings only	under 1.5 m tall	1
5 m plot	5 x 5	50	5	saplings and small poles	1.5 - 3 m tall	2
					3.0 m tall - 5 cm d.b.h.	3
					5.1 cm - 10 cm d.b.h.	4
10 m plot	10 x 10	50	10	small poles and large trees	5.1 cm - 10 cm d.b.h.	4
					10.1 cm - 20 cm d.b.h.	5
					20.1 cm - 30 cm d.b.h.	6
					30.1 cm - 40 cm d.b.h.	7
					40.1 cm - 50 cm d.b.h.	8
					greater than 50.1 cm d.b.h.	9

1/ Shape of all plots is square.

2/ If more extensive sampling is desired, double the interval between the respective plots. For example, on the 2 m plot, increase the interval to 100 m to get a 1 percent sample, and so on.

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Table 6 : Species list for Río Piedras woodlot. Potential uses of the wood are indicated.

Species name	Dimensions		Wood use			
	Ht (m)	dbh (cm)	Cabinet and Sawtimber	Novelty	Poles/post	Other
Acrocomia media	12.1	25.4				x
Aegiphila martinicensis	6.1	7.6				x
Andira inermis	15.1	30.5		x		
Ardisia crenulata	5.4	7.6				x
Artocarpus heterophyllus	12.1	30.5			x	
Byrsonima coriacea	18.1	45.7		x		
Calophyllum calaba	19.7	45.7		x		
Casearia arborea	9.0	15.2				x
Casearia decandra	4.5	7.6				
Casearia guianensis	9.0	5.1				x
Casearia sylvestris	19.7	10.2			x	
Cupania americana	15.1	25.4			x	
Dendropanax arboreus	12.1	30.5				x
Didymopanax morototoni	18.1	45.7		x		
Eugenia jambos	9.0	20.3			x	
Faramea occidentalis	9.0	7.6				x
Flacourtia inermis	9.0	--				x
Genipa americana	18.1	45.7		x		
Guarea guidonia	22.7	91.4	x			
Guettarda scabra	4.5	10.2				x
Hymenaea courbaril	19.7	121.9	x			
Inga laurina	21.2	45.7		x		
Ixora ferrea	6.1	10.2				x
Miconia impetiolaris	6.1	7.6				x
Miconia prasinia	7.5	10.2				x
Myrcia deflexa	9.0	15.2			x	
Myrcia splendens	9.0	10.2				x
Ocotea leucoxylon	15.1	25.4		x		
Palicourea riparia	4.5	7.6				x
Phoebe elongata	30.3	40.6		x		
Phyllanthus acidus	9.0	15.2				x
Piper aduncum	6.1	10.2				x
Psychotria berteriana	6.1	10.2				x
Pouteria multiflora	24.2	45.7		x		
Randia aculeata	6.1	7.6				x
Rollinia mucosa	13.6	15.2			x	
Symplocos martinicensis	9.0	15.2				x
Swietenia spp.	18.1	88.9				
Tabebuia heterophylla	18.1	45.7		x		
Vitex divaricata	19.7	76.2	x			
Zanthoxylum martinicense	19.7	45.7		x		

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mortality and give complete stocking at maturity. One tree in each 10 x 10 m (100 trees per hectare) is complete stocking at maturity.

- Selection of chosen tree - On the 2 x 2 m plot, the chosen tree is the seedling of any acceptable timber producing tree on the species list that is established and most probably will survive. On the 5 x 5 m and 10 x 10 m plots, the chosen tree is one that is on the species list and also has good form(i.e., likely to develop a utilizable trunk). It is also considered to have the best chance of any species in the sampling unit of surviving through to maturity.
- Secondary tree - The secondary tree on the 5 x 5 m and 10 x 10 m plots is a tree on the sampling unit because of the value of its timber. It is not the chosen tree because, in the view of the person conducting the survey, it most likely will not survive to maturity.
- Crown class - The crown class, or dominance class, of each chosen tree and secondary tree is indicated.
- Field procedure - The starting point for the first sampling line is selected at random. After that, they are spaced equidistant through the entire block of forest to be sampled according to the intervals selected (Fig.--6--). Sampling lines are cut through the forest following a compass bearing until the end of the forest block is reached. As the lines are being cut, the vegetation is sampled. For the 2 x 2 m plots, the samples are taken on one side of the line. Two straight sticks are cut and every 2 m along the measuring tape, they are placed perpendicular to the tape forming 3 sides of a square, using the tape as one side. The outer side of the square is estimated visually, and demarcated only when in doubt. When the data for for the plot have been recorded (Table --7--), the rear stick is moved

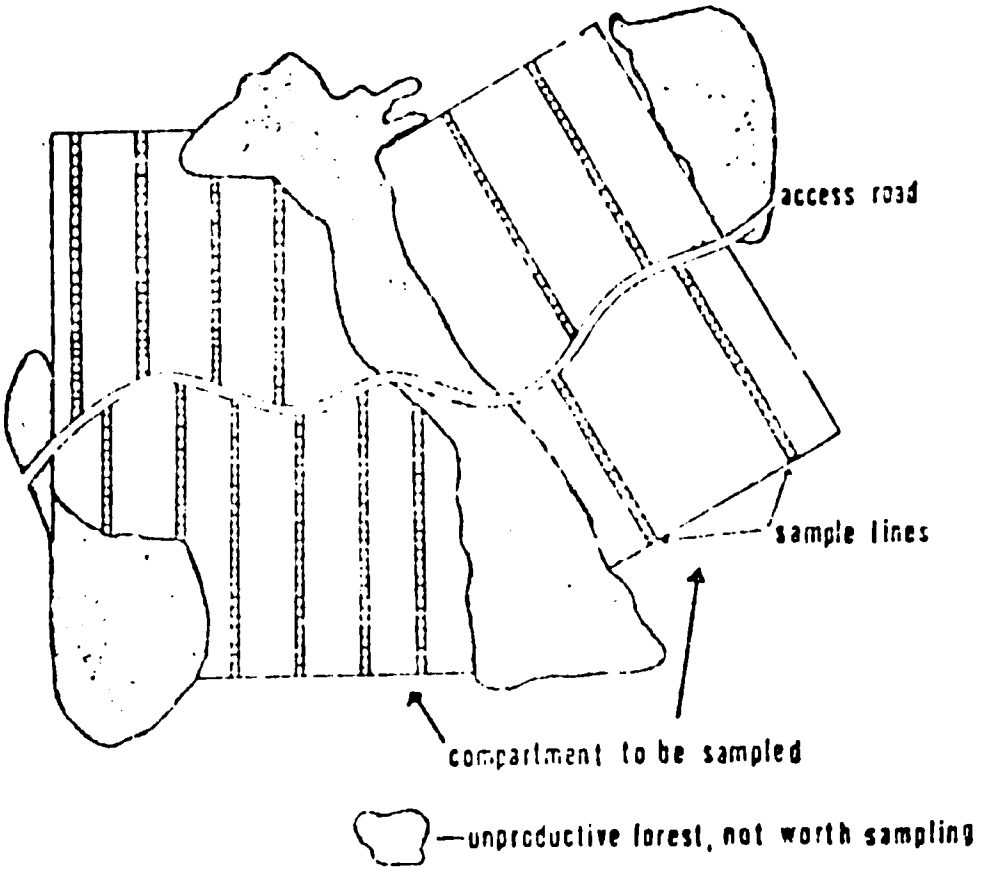

FIGURE 6 . SAMPLING OF REGENERATION IN SECONDARY FOREST. THE SAMPLE LINES ARE 2 M, 5 M or 10 M WIDE DEPENDING UPON THE SIZE OF THE VEGETATION ENCOUNTERED. THE INTERVALS BETWEEN THE SAMPLING LINES MAY ALSO BE VARIABLE DEPENDING UPON THE INTENSITY OF THE SAMPLE DESIRED.

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Table 7. Sample of field data collected for regeneration survey of seedlings under 1.5 m tall.

REGENERATION SAMPLING-
SEEDLING 2 METER QUADRATS

(FIELD SHEET)

Compartment no. 5-8 Line no. 1 Date 6/83
Sampled by Joe Smith

Plot no.	Chosen tree		Species of Secondary Seedling	Notes
	Species	Abundance 1/		
1	MB	1	0	Climbers
2	MB	1	TR	Weeds
3	DE	1	0	Trail 4 m W
4	DE	+	0	----
5	SB	+	NC	----
6	MB	++	NC	Stream 10 m E
7	0	0	0	----
8	CP	1	0	----
9	MB	1	NC	Climbers
10	MB	1	0	Climbers

1/ Abundance symbols:

0 plot unstocked
1 A solitary seedling of chosen species in plot
+ 2 to approximately 20 seedlings of chosen species in plot
++ Over approximately 20 seedlings of the chosen species in plot

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forward in "leap frog" fashion to form the forward boundary of the next plot. The corners of the 5 x 5 and 10 x 10 m plots may be temporarily staked when the data are being recorded (Table --8--). For these plots, the transect line runs through the center of the plot.

- Office procedures - Once the data have been collected according to specifications, it is necessary to summarize them in a way that will be useful to the forest manager. At the bottom of tables ---9--- and ---10---, the data found in the respective tables have been summarized. Recommendations based on the summaries are then made. In both instances, regeneration of chosen trees has been found satisfactory, and management of the forests is suggested.

Stocking standard - Regeneration of chosen trees on 40% of the plots of any size (i.e., 2 x 2 m, 5 x 5 m or 10 x 10 m) is considered adequate for secondary forest management. If the areas deficient in stocking are contiguous and cover large areas, enrichment planting may be used to improve stocking.

Interpretation of Tables XX through XY. - Table X shows the field data for seedlings, and Table XI presents a summary of the same data worked up in the office after the survey.

Ninety percent of the plots are stocked with chosen seedlings, 20% of them from class A timber species and 70% from class B timber species. Refer to Table A for species classifications. Thirty percent of these plots have more than a single chosen seedling. Forty percent of the plots also contain secondary seedlings. Seedling stocking is good and well distributed throughout the forest block. Because more than 40% of the plots are adequately stocked, secondary forest management for the area is recommended.

Table 8. Sample of field data collected for regeneration survey of saplings between 1.5 m tall and 10 cm in d.b.h.

REGENERATION SAMPLING -
SAPLING 5 METER QUADRATS

(FIELD SHEET)

Compartment no. 5-9 Line no. 6 Date 7/83

Sampled by Joe Smith

Plot no.	Chosen tree			Secondary tree			Notes 1/
	Species	Size Class	Dominance	Species	Size Class	Dominance	
1	MB	4	D	0	0	0	Road #19
2	MB	3	CD	DE	2	S	C
3	0	0	0	0	0	0	---
4	DE	4	D	0	0	0	Small stream
5	SB	4	D	NC	3	I	C
6	SB	3	CD	NC	2	I	---
7	DE	2	I	0	0	0	---
8	MB	2	S	0	0	0	---
9	0	0	0	0	0	0	---
10	0	0	0	0	0	0	Tract 6

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1/ The symbol + is entered if the sample area is dominated by a useless relic of the original crop whether its stem is inside or outside the plot.

The symbol C is entered if a climber is on the stem or in the crown of the chosen or secondary tree.

Table 9. Sample of office summary of field data collected for regeneration survey of seedlings under 1.4 m tall.

REGENERATION SAMPLING-
SEEDLING 2 METER QUADRATS

(OFFICE SHEET)

Compartment no. 5-8 Compiled by Fred Jones

Total area 100 ha Area Sampled 2 ha Intensity 2 %

Species		Plots Stocked with chosen seedling	Abundance			Plots stocked with secondary seedling
CLASS	SYMBOL		1	2 - 20	Over 20	
A	DE	2	1	1	0	0
	NC	0	0	0	0	3
	TR	0	0	0	0	1
Total		2	1	1	0	4
%		(20)	(10)	(10)	(0)	(40)
B	MB	5	4	0	1	0
	SB	1	0	1	0	0
	CP	1	1	0	0	0
Total		7	5	1	1	0
%		(70)	(50)	(10)	(10)	(0)
C	---	---	--	--	---	---
D	---	---	---	---	---	---
Total stocking		9	6	2	1	4
Stocking %		90	60	20	10	40

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REGENERATION SAMPLING- SAPLING 5 METER QUADRATS
(OFFICE SHEET)

Compartment no. 5-9 Compiled by Fred Jones
Total area 100 ha Area sampled 1 ha Intensity 1 %

Species CLASS	Species SYMBOL	Chosen tree	Size class 1/ 2	3	4	Dominance class 2/ D	CD	I	S	Secondary tree	Size class 1/ 2	3	4	Dominance class 2/ D	CD	I	S
A	DE	2	1	0	1	1	0	1	0	1	1	0	0	0	0	1	0
	NC	0	0	0	0	0	0	0	0	2	1	1	0	2	0	0	0
Total		2	1	0	(1)	1	0	1	0	3	2	1	0	2	0	1	0
%		(20)	(10)	0	(10)	(10)	0	(10)	0	(30)	(20)	(10)	0	(20)	0	(10)	0
B	MB	3	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
	SB	2	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Total		5	1	2	2	2	2	0	1	0	0	0	0	0	0	0	0
%		(50)	(10)	(20)	(20)	(20)	(20)	(0)	(10)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Total stocking		7	2	2	3	3	2	1	1	3	2	1	0	2	0	1	0
Stocking %		(70)	(20)	(20)	(30)	(30)	(20)	(10)	(10)	(30)	(20)	(10)	(0)	(20)	0	(10)	(0)

1/ Size class described in Table

2/ Dominance classes are crown classes: D = dominant, CD = codominant, I = intermediate and S = suppressed.

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Table x shows the field data for saplings and small trees, and table xl presents a summary of the same data worked up in the office after the survey. Seventy percent of the plots sampled are stocked with chosen saplings and small poles, 20% of class A species and 50% of class B species. Thirty percent of these plots also contain secondary trees. Fifty percent of the plots have chosen trees in the dominant and codominant classes. Fifty percent of the plots also have chosen trees in size classes 3 and 4, that is, from 3 m tall to 10 cm in diameter. Stocking of plots at 70% is adequate, and development with 50% of the plots with chosen trees in size classes 3 and 4 is good. Competition, with 50% of the plots with chosen trees in the dominant and codominant classes, does not appear intense. Thinnings to release chosen trees in intermediate and suppressed conditions on 20% of the plots is required, and should be done soon.

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INTRODUCTION TO SILVICULTURE

I. Anatomy and Physiology

A. Anatomy

1. All living cells of same basic components
2. Root tips modified to permit passage of H_2O and minerals
3. Leaves modified to permit passage of gases and Ps

B. Physiology

1. Respiration, food synthesis, absorption, excretion, division, and maturation carried on in living cells throughout tree, plus photosynthesis in chlorophyll-bearing tissues
2. All these activities can be explained by some mechanistic theory
3. Some theories are vague or dubious and a tree is a far more complex organism than simply many million individual cells plastered together.

II. Physical Factors

A. Climate

1. Temperature

a. Most trees develop at 35-110°F

b. Physiological processes generally retarded at low temperatures and speeded up at high temperatures

c. A temperature of 120°F is lethal for individual cell

d. Lethal cold temperature varies at least from 40° to -50°F, depending on species and state of cell. More tightly bound the water, the more resistant to cold is the cell.

2. Moisture

a. Moisture available depends on rainfall, interception, evaporation, runoff, and percolation

b. Lack of moisture limits tree growth and/or survival at some time of the year almost everywhere in the world almost every year

c. There is no evidence that a tree can have too much water; however, abundant water may -indirectly- cause a dearth of some other factor, esp. O_2

d. Rain may hamper pollen and seed dispersal

3. Wind

a. Increases transpiration and evaporation, thus increases total moisture needed to support vegetation

b. Strong winds may cause breakage or windfall

c. Necessary for pollination and seed dispersal of many species

d. Virtually absent, normally, within a forest in leaf

B. Topography and Soil

1. Topography

a. Steepness influences depth of soil, water runoff and drainage, air drainage, seed distribution, wind exposure, solar insolation, fire hazard, and animal activity

b. Altitude, especially in relation to surrounding areas, influences temperature, rainfall, and light quality

c. Aspect greatly influences effective solar insolation

2. Soil

a. Soil is the least-understood environmental factor, chiefly because it is the most difficult to study

b. Of the 15 elements definitely necessary for plant life, 14 come from the soil

c. Although for practically all species, the optimum soil is a well-drained, well-aerated soil with a near-neutral pH, trees vary greatly in the texture, depth, pH, composition, etc. of soil which they will tolerate.

d. Trees influence very makedly the soil beneath them. Generally mixed stands improve the soil more than pure stands, which may even cause its deterioration. Pines and scrub caks improve soils the least.

C. Light

1. Incident light is adequate for forest growth, in quantity and quality, everywhere on earth.

2. Light actually reaching leaf surfaces strongly influences growth and development, survival, and species composition.

D. Fire

1. As noted above, a temperature of 120°F is fatal to the individual cell; therefore, hot fires may kill any individual tree.

2. Certain species are adapted through insulation, fruit maturation, growth habits, or other processes to thrive under certain conditions of fire incidence.

3. Many species (practically all hardwoods) suffer mortality or value loss in the presence of even occasional light fires.

III. Biotic Factors

A. Microbes

1. Generalizations are difficult because relationships vary from those of pines which cannot survive without the presence of mycorrhizal fungi to chestnuts which can survive only in the absence of the blight fungus.

2. In most cases, maintaining mixed stands of vigorous trees appears

to be adequate to obtain satisfactory tree-microbe relationships.

B. Insects and "Macrobes" earthworms, millipades, etc.

1. Again, the relationship with trees varies from essential to fetal.

2. Mixed stands of vigorous trees seldom are severely damaged by forest insects. In some cases a stand less than fully stocked benefits soil fauna. More lite and warmth.

C. Birds and Mammals

1. Birds vary from mildly beneficial to mildly harmful. Probably local seed depradation is the main important action of birds.

2. Hooved mammals vary from midly beneficial to severely harmful. In many cases exclusion may be necessary to permit reproduction, but light grazing in mature stands is seldom very deleterious.

3. Rodents may occasionally benefit trees by distributing seed. In poor seed years, rodents may eat all seeds of the larger-seeded species.

4. Man almost invariably interferes with normal successional trends. At his best he greatly increases both quality and quantity of yield per unit area; at worst he eliminates existing forests and degrades the site so it will not permit tree growth in his own lifetime.

D. Plants

1. The successional position of a species is determined largely or entirely by its tolerance of phytoganic competition.

2. The survival and growth of an individual tree depends largely upon the facility with which it utilizes its environment, as compared to its neighbors.

3. Biological success is not the primary criterion for selecting commercial species or marketable individuals.

IV. Genetics

A. Heredity: progeny resembly parents.

1. Trees are produced from tree parents.

2. Oak trees are produced from oak parents.

3. Good oak trees are produced from good oak tree parents.

4. Removing the best individuals and reproducing the worst is genetic suicide.

5. After one high-grading reproduction cut in a forest, ten tree generations of selected parents will be required to regain the original quality.

B. Variability: progeny are not identical to parents.

1. Vegetative progeny are normally identical genetically, but are subjected to different environment so differ in their expressed characters. Therefore, vegetative propagation is a genetic dead-end. Progeny will all be genetically as good as the parent but none will be better.

2. Sexually produced progeny differ somewhat from their parents

a. Progeny tend to approach the population mean.

(1) Progeny of poor parents tend to average slightly better than parents.

(2) Progeny of good parents tend to average slightly worse than parents.

b. Crossing poor parents tends to produce a few very poor progeny

c. Crossing good parents tends to produce a few superior progeny

C. Evolution: av. progeny today differ from the av. progeny a few

thousand years ago.

1. Variations which increase survival of the individual and/or its progeny tend to be perpetuated.
2. Variations which decrease survival either of the individual or to progeny tend to disappear (if dominant when present) or reach a stable low level (if recessive).
3. Mutations (changes in gene character through physical, mechanical, chemical, or physiological accident) are of predictable frequency, often repetitive, but seldom beneficial. They are the only genetic change possible in vegetative reproduction. They are the source of most horticultural varieties, so may occasionally be useful and very valuable.

V. Forest Types of Luquillo Mountains

A. Climatic types

1. Moist, wet, rain forest

B. Atmospheric type

1. Dwarf forest

C. Edaphie type

1. Palm
2. Pterocorpus

D. Elevation effects

1. Canopy height
2. Crown height
3. Proportion of branches
4. Taper
5. Time to maturity
6. Increment

E	Tabonuco	Colorado	Palm	Dwarf
Elevation	600 m	600 m	450 m	750 m
Rainfall	180.350 cm	250.450 cm	220 cm	375 cm
Tree Species	170	50	---	12
% of area	70	17	11	2
Height	30 m	15 m	15 m	7 m
Stories	2 1/2	2	2	1
Canopy	irregular	regular	regular	regular

Silviculture of Natural Forests

Silviculture: Theory and practice of controlling the establishment, structure, composition, and growth of forests. Objective usually maximum sustainable economic yield, both in quality and quantity.

Principles:

1. Existing forests should be tended if feasible rather than replaced.
2. Significant modifications of natural forests should be tested before application.
3. Biological and economic consequences of interventions should be monitored continously.

Extent of natural tropical forests:

Nearly 50% of world's forests: 7,500,000 mi^2

Accessible and capable of crop production: 3,000,000 mi^2

Need for silviculture:

1. A few timbers are superior to all others.
2. Economic tendency to cut best, leave worst.
3. Market for additional timbers growing
4. Without culture land taken for other purposes.
5. Timber is becoming scarce, demand increasing.
6. Accessible forest lands non productive.
7. Water needs dictate caution in forest treatment.
8. Yields are known to respond to silviculture, by growth increase of 3 times.

Condition of natural forests:

1. Old growth poorly balanced, few large trees.
2. Old growth with few good species.
3. Cutover forests relatively inaccessible

4. Cutover has poor trees of good species, more of poor.

5. Cutover usually deficient in density

6. Cutover yields very low increment.

History of tropical silviculture

1. Began on East (India, Burma, Indonesia, Malaysia. 1860±

2. About 30 years ago in America (Brazil, Trinidad)

Selection of areas to culture:

1. Concentrate where extensive area available, tributary to outlet for processing and marketing.

2. Consider original stand quality, if known. Canopy height, presence of good species.

3. Present or potential accessibility.

4. Freedom from hazard of encroachment by other land uses. (agriculture)

5. Freedom from constraints such as high watershed or scenic values.

6. Quality of existing forest.

Selection of products

1. Needs, present and perspective, of the local community (Construction, plywood, cabinet woods, fence posts, pulpwood.

2. Types of uses for which existing trees suitable.

3. Select high quality uses as primary and others as by products.

Selection of species:

1. Utility for the products desired (size, form, wood)

2. Widely adapted to available sites (degraded), natives if satisfactory.

3. Rapid rate of growth to maturity.

4. Easy to regenerate

5. Utilize more than one species for each site.

Culture vs Replacement:

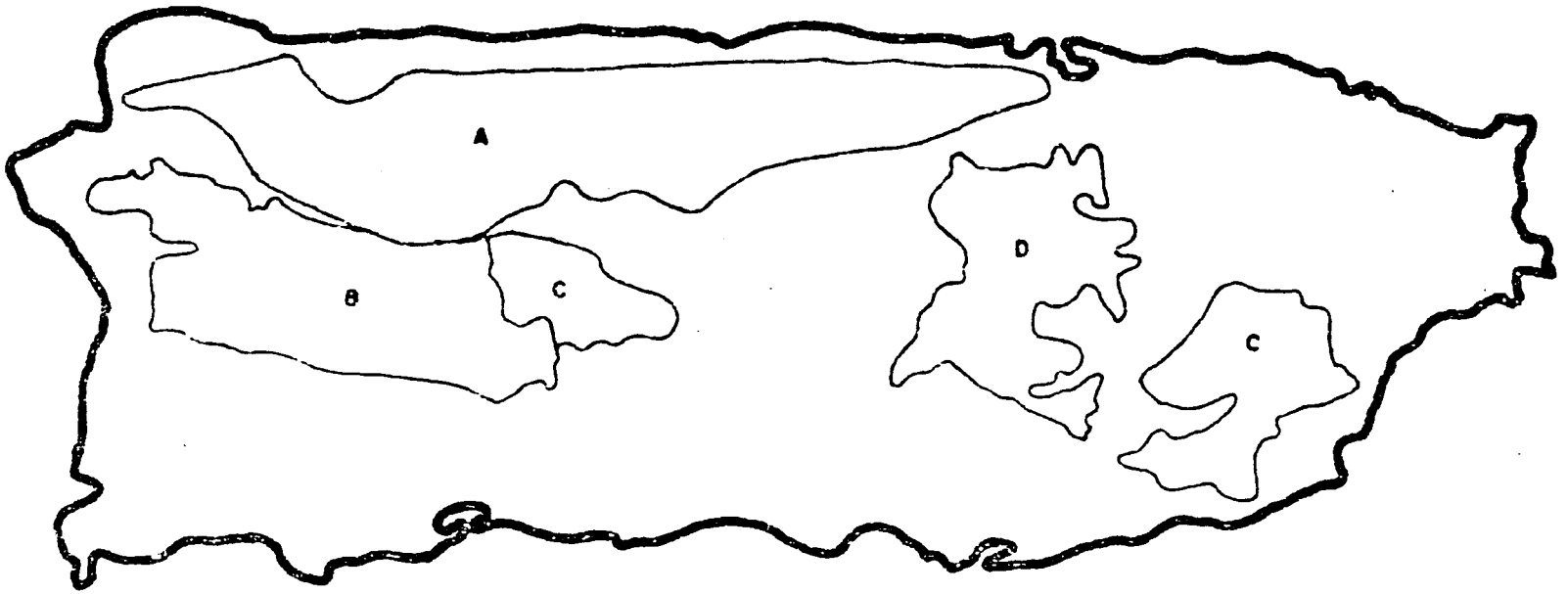
1. Culture good young stands
2. Replace poor young stands.
3. Doubt between these extremes.
4. Culture utilizes (avoids loss of) immature growing stock.
5. Culture exposes site less.
6. Culture deals with trees unmistakably adapted.
7. Culture less expensive than replacement.
8. Replacement provides complete control of composition, including genetically improved trees.
9. Replacement promises higher yields from rapid growing species - more competitive land utilization.
10. Replaced stands (plantations) are simpler to manage and harvest.
11. Replacement may be gradual (underplanting) and thus reduce initial investment and precipitate risks.

The case of Puerto Rico

Selection of sites:	Acres
Limestone soils	60,000 (1/3)
Deep clays	165,000
Shallow clay loams	150,000
Sandy loams	125,000
	500,000

Allocation of products

Broadleaf species (deep clays and limestone)	
Cabinet woods, plywood and veneer	90,000 acres
Fiber products (eucalyptus ?)	135,000 acres
Softwood species (sandy loams, shallow clays)	
Construction lumber, plywood, poles	160,000 acres
Fiber products	115,000 acres
	500,000 acres



The Location of Puerto Rico's Potentially Productive Forest Lands.

A. Northern Limestone Region

B. Western Deep Clays

C. East and Central Sandy Soils

D. East-central Shallow Loams

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Map of forest lands.

Relative Returns from Different Practices:

No treatment, refining, natural regeneration, underplanting, field planting

Selection of Practices:

1. Chart
2. Definition of adequate stocking

   Species list

   Full stocking table (crown diameter/DBH ratio)

   40 trees/acre at 24" dbh

   100 trees/acre at 5-10" dbh poles

   200 trees/acre at 1-5" dbh saplings

   Adequate stocking

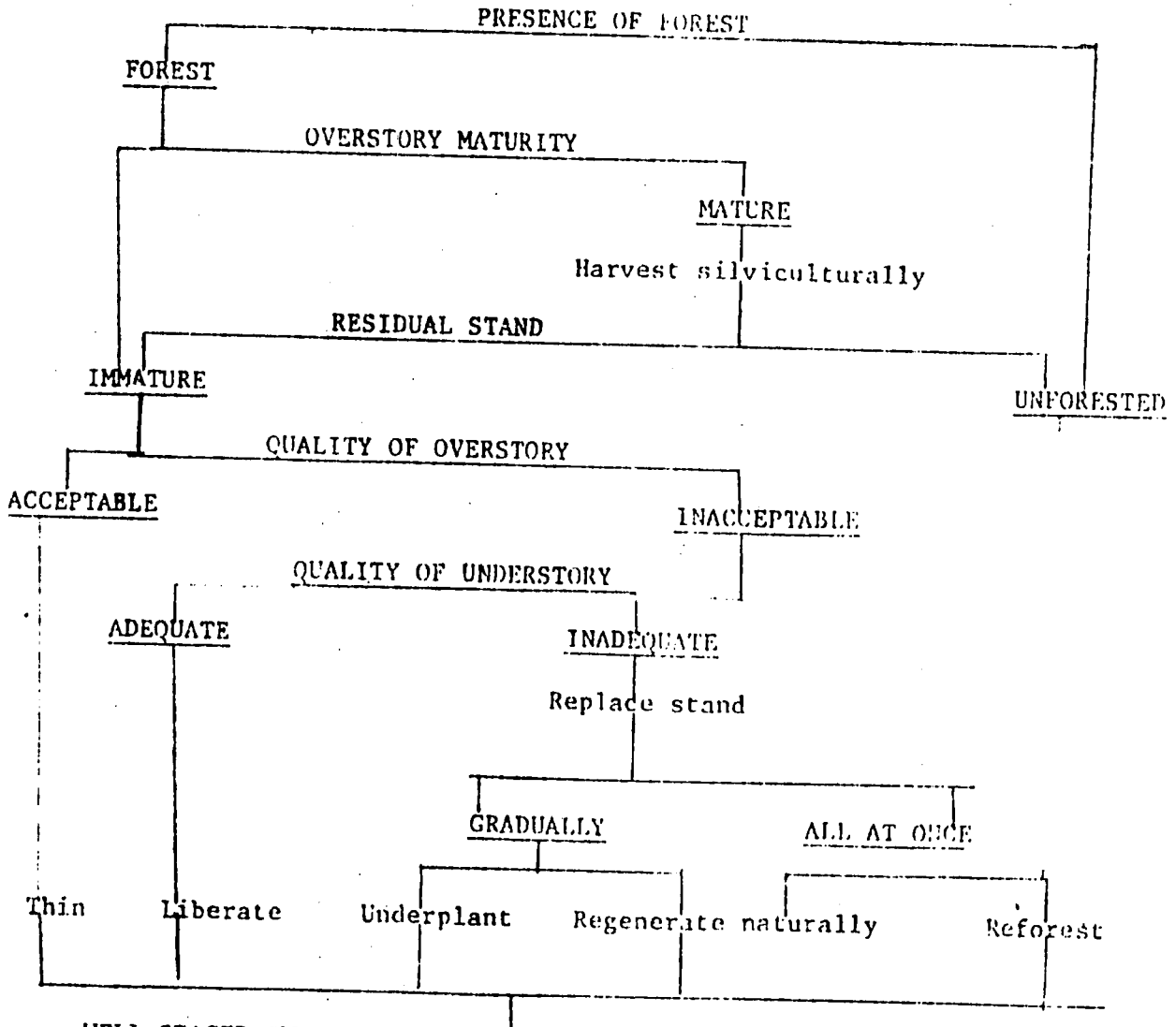
   40 trees/acre in pole stands

   100 trees/acre in sapling stands.

Stocking of Puerto Rican Forests:

1. 58,000 acres of secondary forest with adequate pole stands (71 trees/acre averaging 7.2" dbh)
2. 69,000 acres of secondary forest with adequate sapligs (294 trees/acre averaging 2.0" dbh)
3. Location (map).

SEQUENTIAL SELECTION OF SILVICULTURAL PRACTICES FOR TIMBER PRODUCTION



WELL SPACED IMMATURE TREES OF POTENTIALLY HIGH TIMBER QUALITY

Thin, liberate, and regenerate

as needed

to sustain high yields

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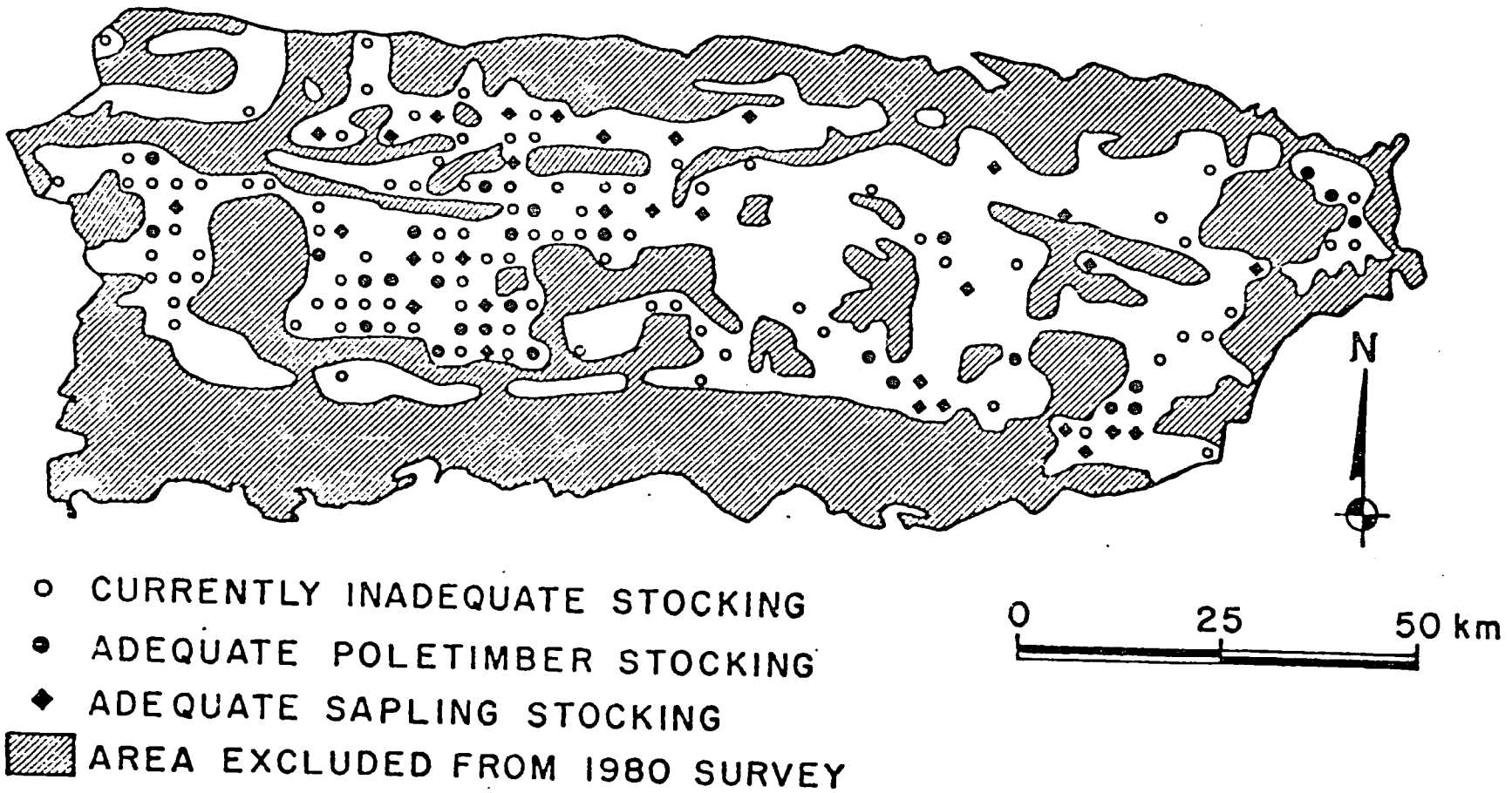
Common timber species in natural timberland forests.

Scientific name	Common name	Highest use 1/
Andira inermis (W. Wright) H.B.K.	Moca	Turnery
Buchenavia capitata (Vahl) Eichl.	Granadillo	Turnery
Bucida buceras L .	Ucar	Turnery
Byrsonima coriacea (SW.) DC	Maricao	Cabinetwork
Calophyllum calaba L.	Maria	Cabinetwork
Cedrela odorata L.	Cedro	Cabinetwork
Cordia alliodora (Ruiz & Pav.) Oken	Capa prieto	Cabinetwork
Dacryodes excelsa Vahl.	Tabonuco	Cabinetwork
Didymopanax morototoni (Aubl.) D.+ P.	Yagrumo macho	Plywood, matches
Guarea guidonia (L.) Sleumer	Guaraguao	Cabinetwork
Hymenaea courbaril L.	Algarrobo	Turnery
Inga fagifolia (L.) Willd.	Guama	Cabinetwork
Meliosma herbertii Rolfe	Aguacatillo	Millwork
Micropholis chrysophylloides Pierre	Caimitillo	Cabinetwork
M. garciniaefolia Pierre	Caimitillo verde	Turnery
Nectandra spp.	Laurel	Millwork, novelties
Ormosia krugii Urban	Palo de matos	Millwork
Petitia domingensis Jacq.	Capa blanco	Turnery
Pouteria multiflora (A.DC) Eyma	Jacana	Turnery
Spondias mombin L.	Jobo	Plywood, matches
Tabebuia heterophylla (DC.) Britton	Roble blanco	Cabinetwork

1/ From Longwood (1961).

Full Stocking

DBH Class inches	Crown/DBH Ratio	Spacing (Δ) ft.	No./acr
2-6	26	8	782
6-10	24	15	222
10-14	22	20	125
14-18	20	26	74
18-22	19	30	56
22-26	18	34	43



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Luquillo Forest Refinement:

1. Prospective growth response (Table)
2. Stand changes due to first treatment (Table)
3. Treatment rules (Table)
4. Results from application in El Verde

   87 crop trees/acre, 97 competitors eliminated.

   Number of trees by species: ausubo, 27; motillo, 27; tabonuco, 12; guaraguao, 9; granadillo, 3; others, 9.

   Analysis of 0.34 acre plot treated 3 times since 1948.

   84 crop trees/acre, averaging 13.1" dbh. Mean annual dbh growth of crop trees, 0.31". End of rotation for 16" trees=9years; for 20" trees, 22 years; for 24" trees 35 years. Composition is 70% ausubo, 26% tabonuco, and 4% other species.

PROSPECTIVE TREE GROWTH RESPONSE TO LIBERATION

Crown Position Before Release	D.B.H. Growth Rate Increase after Release to:		
	Dominant	Codominant	Intermediate
	%	%	%
Codominant	32		
Intermediate	95	48	
Suppressed	350	241	131

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Sample Indication of Effects of Improvement Cutting

	Old Growth		Secondary Forest	
	Before	After	Before	After
Trees/acre				
Desirable species				
4 - 9"	98	68	166	122
10" +	32	20	8	4
Other species	190	30	149	37
Total	320	118	323	163
% Desirables	41	75	54	77
Basal area/acre, sq. ft.				
Desirable species				
4 - 9"	22	13	32	23
10" +	45	23	9	3
Other species	103	12	24	5
Total	170	48	65	31
% Desirables	39	75	63	84
Volume/acre, cu. ft.				
Desirable species				
4 - 9"	254	187	271	223
10" +	866	437	52	36
Other species	480	83	99	46
Total	1600	707	422	305
% Desirables	70	88	77	85
Volume/Basal Area				
Desirables	16.7	17.3	7.9	10.0

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Inventory, Selection, and Liberation of Desirable Trees
Luquillo Experimental Forest

Plan of Inventory

Lay out strip of plots 50 x 80 links (1/25 acre)
Count up to 4 desirable trees per plot
Record species, DBH, and march. Ht. of desirables

Definition of Desirable Trees

1. Must be of following species

   a. Furniture

(1) Teak	(4) Granadillo	(7) Caimitillo Verde
(2) Bigleaf Mahogany	(5) Tabonuco	(8) Masa
(3) Guaraguao	(6) Laurel Sabino	

   b. Novelties

(9) Ausubo	(14) Guama	(19) Caracolillo
(10) Nuez Moscada	(15) Jagua	(20) Guayabota
(11) Motillo	(16) Maricao	(21) Higuerillo
(12) Moca	(17) Caimitillo	(22) María
(13) Roble	(18) Jecana	

2. Must, if furniture species be 3.0 to 20.0 inches DBH and if novelty species be 3.0 to 12.0 inches DBH

3. Must have at least 16 feet of usable straight bole.

Selection of Best Desirables

1. First preference to species highest on list, regardless of other factors. No more than 2 of the 4 selected trees to be of the same species, unless there no alternatives.

2. If an excess within a selected species remains, a selection among them will be made solely upon merchantable height, regardless of other considerations.

3. If an excess still exists the tree of largest DBH will be given preference, regardless of spacing.

4. Any excess trees remaining will be eliminated on a basis of uniform spacing of those remaining.

Liberation of Desirables

1. Eliminate all trees 3.0" DBH and within 8 feet (except other desirables)

2. Eliminate all trees overtopping desirables (except desirables)

3. Eliminate other competitors (trees of larger dbh) closer to desirables than spacing specified below (unless crop tree).

D + d	Minimum Spacing	D + d	Minimum Spacing
	Feet		Feet
6-8	8	23	20
9	9	24-25	21
10	10	26-27	22
11	11	28-29	23
12-13	12	30-31	24
14	13	32-33	25
15	14	34-35	26
16	15	36-38	27
17-18	16	39-41	28
19	17	42-43	29
20	18	44-46	30
21-22	19	47-48	31

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NURSERY MANAGEMENT

INTRODUCTION

Reasons for Establishing a Tree Nursery

It is necessary to define and set the reforestation goals before a final decision is made in establishing a tree nursery. The group or agency in charge must decide if the nursery investment can be justified on a long term basis. The areas to be planted may determine the need of a nursery. To assure that the investment will be used effectively some factors have to be considered, these are:

a. Distance of the proposed nursery site to plantation areas.

b. Maximum number of seedlings which will be required annually in foreseable future.

c. In large countries it is necessary to consider the possibility of having two or more small nurseries strategically situated in the plantation areas or have a large centralized nursery. To calculate the size of the nursery and safely satisfy the seedlings demand, it is necessary to consider the following aspects:

   1. total net plantable areas
   2. annual planting program
   3. planting spacing
   4. quantity of seedlings needed annually
   5. 20% loss for diseases, culls or natural catastrophe losses.
   6. If nurseries are to be used to satisfy only reforestation demand by means of establishment of plantations, or it can

also supply planting stock for private landowners interested in the enrichment of their lands.

Example:

Total net plantable area	=	4,000 acres
Annual planting program	=	1,00
Planting spacing	=	8' x 35' = 156 t/a
Quantity of seedling needed annually	=	15,560 seedlings
20% cull, affected by diseases or natural catastrophe losses	=	3,000
Total seedlings needed	=	18,560 to 19,000 to plant 1,00 AC

This total does not include seedlings to be provided to private citizens or to be distributed between interested landowners. In these cases the amount of seedlings may increase according to needs.

In addition to the factors already mentioned, it is necessary that those involved consider the possibility of a permanent and constant supply of seedlings. This source or sources must be able to provide, when needed and as needed, enough high quality planting material to accomplish the planting targets. The use of these sources, if available, may depend on:

1. Cost of handling materials.
2. Distance from seedlings source to plantation areas.
3. Quality of the seedlings required.

Once these factors are evaluated the decision is made to go ahead on establishing a tree nursery or if available, purchasing of the planting stock.

BENEFITS OF ESTABLISHING A NURSERY

1. Control of seedling quality - Once the nursery is established, selection of seedlings to be out-planted should be effectively monitored and controlled to assure that the best healthly seedlings are out-planted. This requires proper and effective supervision of the nursery crew(s). Trees of poor form and vigor and, those that show signs of nutrition deficiencies, (like chlorosis), grow slow in relation to other seedlings planted at the same time, will be eliminated and not out-planted.

2. Seedlings must be available and provided in appropriate quantities once the reforestation targets are set and the approximate amount of seedlings needed per year are established. The nursery supervisor will be responsible to have available the material on time for the planting period. This requires a knowledge of the species that are going to be planted to coordinate seed sowing in such way that seedlings have the necessary time to develop at the nursery before being lifted and out-planted. The nursery supervisor must coordinate seed sowing with the planting seasons (in our case during the rainy season) to have the seedlings available on time, and the quantity necessary.

NEGATIVE ASPECTS OF THE ESTABLISHMENT OF A TREE NURSERY

The nursery establishment brings administrative problems that can raise the cost of planting. Once the nursery is established, care needs to be provided to the seedlings, especially during the first weeks before and after germination. It must be necessary to have personnel assigned permanently

to nursery duties. These costs must be added to the planting costs. Costs for materials, tools, and other necessary supplies also increase the cost of planting.

SITE SELECTION

Once the tree nursery is decided to be established, comes one of the most important factors that will determine the success of the tree nursery. Site location and selection must be done with considerable care. The site has to meet present needs as well as future needs. Space for future expansion needs to be considered. Following are some basic requirements for the successful operation of a tree nursery:

a. Climate - The site needs to be located in an area with the most favorable climatic conditions. The site must be neither too wet nor too dry. It may be necessary to consult long term rainfall data to assure that rainfall is evenly distributed during germination and growing seasons. Areas exposed to the wind should be avoided to prevent the possibility of desiccation of seedlings during hot and windy days. If these areas are considered, windbreaks should be provided to minimize the effects of the winds. During periods of long drought, seedlings must be watered daily to prevent desiccation, especially after the first leaves are opened. Establishment of the nursery will also be influenced by the species to be planted. Requirements such as humidity and sunlight need to be considered when deciding on a nursery site.

b. Transportation facilities - Nurseries should be located as close as possible to reforestation areas or to existing road systems. The

closer the nursery to planting sites, the less stress will be imposed on the seedlings. Also, this will accelerate the planting process, avoiding long waits for planting material.

c. Water supply - The key factor for the success of the nursery is water. To have enough seedlings to outplant, seeds might have to be sowed during drough or dry periods. This imposess a need for an ample and constant supply of water for the nursery. Water needs to be free of pollutants, and contain low amount of salts. Water needs to be monitored to prevent a rise in soil pH as a consequence of heavy amounts of salts and calcium. This may produce root rotting of the seedlings.

d. Soils and topography - The area to be used for beds should be as flat as possible. To avoid expensive and time consuming drainage construction the beds should be constructed following the countour and slope. Those areas known to be subject to flooding should be avoided. Also, areas with steep slopes and rocks outcroppings must be avoided. To ensure an appropriate nursery site location, a soil scientist and soil engineer should be consulted.

Selection of a good nursery site must be based on soil survey data and accurate field analysis. Since nurseries are long term commitments, it is better to sacrifice closeness to existing roads and facilities in order to obtain good soil physical and/or chemical properties.

Soils that range between sandy loam and silt loams will have the fewest problems in relation to soil texture. It's recommended to avoid heavy clay soils to raise bare-root seedlings, since large and small roots

are damaged during lifting. Soil acidity is the most important chemical factor to consider in nursery soils. This property will affect other chemical reactions in the soils and the behavior of seedling roots.

EQUIPMENT AND TOOLS

Use of heavy motorized equipment will depend on nursery size, topography and funds available for maintenance and repairs. In addition, the use of this type of equipment requires the skills of an operator that also may raise the cost of the seedlings production.

a. Handtools - All tools need to be kept in an inventory system to prevent losses and to keep records of available tools. Basic tools for small scale nursery will include hoes, shovels, (long-handle) rakes, wheelbarrows, mattocks, water hoses or an irrigation system and pruning shears. Also, a small roto-tiller must be available to facilitate bed preparation. Other equipment that can be included should be sprayers, backpack pumps, rubber gloves, goggles and rubber boots.

SOIL MANAGEMENT

A sound soil management program at the nursery will directly affect the yield, size, and quality of the seedlings produced.

a. Maintenance of soil texture and soil structure - Soil texture is considered fixed and is not ordinarily changed, but some small changes can be made by mixing sand with clay soils. The best soil to grow trees are sandy loam and loam soils; these present a better balance between soil moisture retention and aeration. Soil

structure can be improved by means of tillage. It is important to time the tillage with the optimum moisture for structure formation. This happens when the capillary pores are filled with water and soil particles can stick together.

b. Maintenance of soil organic matter - The presence of organic matter in soils influences the chemical and physical properties of that soil. In a tree nursery, depletion of organic matter is higher than in crop lands because the whole plant is removed. The amount of organic matter to be maintained in the soils depends upon soil texture, drainage and climatic factors. If organic matter content is low, soil structure and nutrient availability may be poor. On the other hand, if it's too high, nitrogen-carbon ratios will be high and this promotes micro-organism activities which may result in a decrease in available phosphorus and nitrogen for the growing seedlings. To maintain soil organic matter, it is better to add organic matter that decays rapidly. Peat moss, sawdust, animal manure, and compost can be used to maintain soil organic matter.

c. Maintenance of pH - Soil pH regulates the solubility and availability of many important nutrient elements. Aluminum, iron, manganese, and zinc ions become increasingly soluble as the soils become more acid. This causes toxicity to the seedlings. Potasium, phosphorus, calcium, and magnesium availability is reduced with a reduction of pH. If a soil is neutralized 7.0, this provides a more favorable environment for the growth of bacterias and other soil micro-organism. These convert nitrogen, sulfur, and phosphorus from organic compounds, that are otherwise not used by the plants, to usable inorganic compounds.

To effectively use or lower the soil pH, one must know the soil structure and texture.

d. Use of fertilizers - All the necessary nutrients needed by the seedlings to grow can be provided either as organic or inorganic fertilizers. One disadvantage of organic fertilizer is cost. The simplest and cheapest way to provide the necessary nutrients is by means of inorganic fertilizers. It is important to properly select the appropriate fertilizer and to apply it at the right time in the optimum amount.

Some disadvantages of heavy applications of fertilizer:

1. succulent tissues
2. unbalanced top-root ratios

Fertilizers can be purchased in different forms and combinations. Some factors to consider in applying a given fertilizer are:

1. how much of a given element is needed
2. is pH to be raised or lowered
3. if the element is to be applied and turned under, use as top dressing or as side dressing
4. equipment available at nursery

e. Specific nutrient requirements - Plants require 16 essential elements but the most commonly applied and most needed in quantity are the macro-nutrients, nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Small amount of other elements are also required.

1. Nitrogen - this promotes growth of stem, foliage, and gives the leaves a dark green color. Symptoms of an oversupply of

nitrogen are:

1. very dark green leaves
2. soft leaves

Seedlings with these conditions are subject to diseases, and insect attacks. Symptoms of insufficient use of this element are:

a. stunted growth

b. yellow to yellowish green leaves that tend to drop off

These symptoms, if they are recognized in time, can be corrected by applying nitrogen.

2. Phosphorus - is necessary for cell division, developing of roots, especially lateral and fibrous ones. Its abailability increases with the addition of organic matter. During periods of high microbial growth its availability may decrease because it becomes bound in organic compounds.

3. Potassium - this element influences the vigor of the plant's growth. If an adequate amount is available, resistance to diseases is increased and root development will be favorable. It helps to counteract the damaging effects of excessive nitrogen. In a general way it produces a balancing effect on both nitrogen and phosphorous. Potassium, in delaying maturity, works against the ripening influences of phosphorous. Its important in the development of chlorophyll. Leaves from plants suffering potassium deficiency, appear dry and scorched at the edges and the surfaces are irregularly chlorotic.

4. Magnesium - a common symptom is the loss of green color between the veins following by chlorosis. Necrotic areas may also develop.

5. Calcium - moderate and acute stage of deficiency are more apparent in root growth. Root rotting frequently occurs. Leaves are small, distorted and frequently show necrotic area.

6. Sulfur - plants suffering deficiency are characteristically small and spindly. Younger leaves are light green to yellowish.

7. Micro-nutrients - These elements need to be added to the soil carefully. The difference between the amount needed for normal growth and the amount of toxic is very small, so great care should be taken when adding these to the nursery beds. The best way to apply them is by means of foliar sprays.

8. Importance of soil micro-organisms - the presence of soil micro-organism influences the soils as a medium for plant growth. Some examples of these micro-organism are:

    a. bacterias

    b. fungi

    c. actinomycetes

It is very important to use pesticides and fertilizers that would not affect the natural balance of these organisms in the soil.

SEEDS

1. Collection

Seed collection is a significant expense in nursery management. It is very important that good viable seeds be collected.

2. Sources

Seeds should be collected from areas that contain several trees of the species of interest. In addition, trees of a superior phenotype should be used as seed source. Areas of collection should be marked on a large scale map, and records keep, of the area showing number of trees, amount of seeds collected, and type of crop (good, poor, fair, etc.)

3. Seed collection period

It's very important to know the seed collecting period for the species of interest.

4. Collection equipment and techniques

The equipment used for seed collection varies according to the species and site of collection, but may commonly include bamboo or fiberglass poles, safety belts, extension ladders, hook cutters and different type of containers.

5. Seed bed preparation, sowing and care

a. Seed bed formation - seed beds are raised above general land level to improve soil aeration and drainage. If cement beds are going to be used they can be prepared according to the following pattern:

1. A mixture of crushed rock at the bottom.

2. Charcoal

3. River sand

4. Fertile soil as a sowing media

Seed beds are raised at least 6 inches above the ground level. Good drainage is essential to provide a good sowing area.

6. Seed bed fumigation

The use of fumigation can control soil borne insects, nematodes, fungi disease and weeds in one operation. The benefits of fumigation decrease with ime because fumigated areas become contaminated from outside sources.

7. Seed sowing

a. Methods - seeds are aaplied by hand or small broadcast spreader or planted in with drills. The use of mechanical sowing equipment is not presently available for all species. Hand sowing distributes the seed uniformly over the entire seed bed.

PESTICIDE USE

The first step to consider in solving any problems caused by pests is to understand what is causing it. To effectively start a control program the pests must be recognized or identified.

Pests can be divided in five main groups:

a. insects

b. snails and slugs

c. vertebrates

d. weeds

e. plant disease agents

Insects - they can survive in almost every environment. They can live on the earth, but within the soil and in the water. Some damage caused by insects are:

1. feeding on leaves
2. tunnel or bore in steam stalks and branches
3. feed and tunnel the roots
4. feed on seeds and nuts
5. suck sap from leaves, stems, roots, fruits and flowers
6. they may carry plant disease agents

Seedlings attacked by insects are weakened, damaged or killed. This reduces yield, lowers quality, and increases cost of producing seedlings. One important aspect to consider when dealing with the control of insects is that not all insects are pests. Pollination is one of the biggest contributions of insects to mankind; also, some insects feed on other insects that are considered pests.

How to recognize insects:

a. adults have six jointed legs and three body regions.

b. mouth parts and wings

Mouth parts :

1. chewing mouth parts - insects have toothed jaws that bite and tear the food.

2. piercing, sucking mouth parts have a long beak which they force into plant or animal to suck out fluids or blood.

Wings:

Vary in shpae, size, thickness and structure. All insects change in shape, form, and size during their lives. This change is called metamorphosis.

Some insects that may affect nursery seedlings are:

a. Thrips: they may cause misshapen or poorly developed fruits and leaves.

b. Aphids, leaf-hoppers, etc.: suck the juices from plants.

c. Beetles: both adults and larval stages may damage leaves and or roots.

Snails and slugs - they belong to the group of animals called mollusks. Snails have a hard shell, slugs have no shell. They feed on plant foliage.

Vertebrates - in this category can be included birds, mammals and reptiles. Their presence in the nursery may adversely affect the process of seed sowing, germination and growth. Birds may feed on seeds; they also look for food in the soils that are removed and expose seeds already sowed. Mammals such as rats and mice damage not only seeds and seedlings, but also equipment and materials. Reptiles like lizards live underground, making tunnels that affect survival and development of seedlings.

In order for a parasitic disease to develop, three situations need to be present:

1. a susceptible host plant
2. a parasitic agent
3. an environment favorable for parasitic development

Fungi - are organisms that lack green color (chlorophyll). Not all are harmful. Their variation in size is from microscopic to large as mushrooms. Reproduction in most cases is by spores. They attack plants above or below the soil surface.

Bacteria - are microscopic unicellular organisms. The reproduce by simple division. In ideal conditions they can reproduce in enormous quantities in a short time.

Viruses - they are so small that they need special instruments to be recognized (electronic microscope). They are usually recognized by the effects that their presence has on the affected plants. Some of them arrive at the host plant by means of insects, men, or infected equipment.

Nematodes - these are usually small round worms. Most feed on the roots of the plants. Their effects are to weaken plants, making them more susceptible to other diseases. They feed on the root area, either inside or outside the root system.

Development of plant diseases -

The life cycle of the parasite influences the development of the disease. Environment plays an important rate in the cycle of the parasite. The most important environmental factor involves temperature and moisture. These two factor effects are:

Weeds - weeds are plants that are growing out of place. In the nursery they are considered a pest because:

1. Reduce yield of the amount of seedlings produced.

2. Increase cost of seedlings production because maintenance is needed to remove them.

Weeds can be recognized by the way and how they grow. Knowledge of their life cycle also help to control and/or eradicate them.

1. Annuals - these have a one-year life cycle. They grow from a seed, mature, and produce seeds foı the new generation in one year or less.

2. Biennials - these have a two-year life cycle. They develop from seeds , develop a heavy root the first year, mature the second year, and finally produce seeds and die.

3. Perennials -- these live more than two years and may live indefinitely.

Plant diseases - these are any harmful condition that makes a plant different from a normal plant in tis appearance and/or function. Plant diseases are divided into two groups:

1. Non-parasitic - caused by non-living orgamism or agents. Some of the causes include:

   a. nutrient deficiency

   b. extreme temperatures

   c. mechanical injury

   d. lack of or too much water

2. Parasitic plant diseases - these are caused by living agents with live and feed on or in plants. They can move from plant to plant. Some of the most common causes are:

   a. fungi

   b. bacterias

   c. viruses

   d. nematodes

a. parasite activity

b. susceptibility of the plant to attack

c. development of the disease

Plants react to parasite infection by means of:

a. Overgrowth of tissue at the infected areas, such as galls, and swellings.

b. Underdevelopment of tissue or incomple organ development.

c. Death of tissue as in cankers, blights, wilting, and leaf spots.

Identifying a plant disease:

They cannot always be recognized by looking at the plant. Many disease agents cause the same or similar infury; the visual recognition is not enough. It is better to try first to identify the casual agent rather than the disease itself.

Pest control

In order to solve a pest problem at a nursery, the following should be followed:

1. Identify the pests.

2. Knowledge of available control methods.

3. Weigh risks and benefits of each method or combination of them.

4. Choose the most effective method that may eradicate or control the pest with the least harm to the environment.

5. Know laws and regulations that affect pesticide use.

Modern pest control is the use of all available methods to keep pests below economically harmful levels, producing last damage to the environment.

Pest control methods

Several methods exist that are known and used for years. Some of these methods are now being applied and others are not. Following are some of the most common and important pest control methods:

1. Resistant varieties - genetically some species have evolved and can resist pest attacks better than others. Using them, the environment is less attractive and favorable for the pests.

2. Biological - this is commonly used for insects. This method deals with the natural enemies that the pests may have.

Cultural control

The method of planting, tillage and growing techniques may help to control pests or create an unfavorable habitat for pests.

Mechanical control

This method includes traps, sound, and heat radiation to sterilize or kill.

There are other methods thay may not be applied to the nursery situation. It is important to know that the most important principle of control is: to use a method only when the pest will be prevented from causing more damage than is reasonable to accept. In some situations, the cost to eradicate a pest can cost more than the loss caused by the pest damage.

Pesticides

These are chemicals used to destroy or control pests. Some type of pesticides commonly used at the nursery are:

Insecticide - control insects and other related pests

Fungicide - control fungi

Nematicide - controls nematodes

Herbicides - controls weeds

Pesticides can be divided in four groups according to their chemical composition and/or origin. These are inorganic which are made from minerals. The most commonly used are arsenic, cooper, lead, boron, zinc, sulfur, tin, boron and mercury. Examples are: lead arsenate and Paris green. The second group are the organic pesticides that are man-made pesticides. They contain carbon, hydrogen, and other elements as chorine, phosphorous and nitrogen. Examples are 2, 4, D, captan, parathion and malathion. Third group is divided from living organism as bacterias, viruses, and fungi. Examples: Bacillus thuringiensis and polyhedrosis virus. The fourth group is composed by plant derived organic-pesticides. These are made from plants or plant parts. Examples are: Rotenone, red squill, strychnine and nicotine.

How pesticide works

Pesticide can be grouped according to their effect on the pests. Organic pesticides may have more than one way to affect the of the major types used in the nursery are:

Contacts - kills pests simply by contact

Systemics - taken into the sap of the plant

Fumigants - gases that kill when absorbed by the pests

Stomach - kill when swallowed

Use of pesticides

Labels describe when and how to use pesticide to obtain the maximum benefits of the application. Pesticide can be used as follows:

Preemergence - before seed germinates or weeds emerge

Prepont - bofore seeds are sowed

Post-emergence - after germination of seeds or weeds

Application of pesticide can be done using the following methods:

a. band - application along a row

b. basal - application to stems or trunks or just above ground line

c. broadcast - uniform application to the whole area

d. foliar - application to the leaves

e. sidedress - along the sides

f. over the top - over the top of the seedlings

g. in furrow - application in the furrow in which seedlings are planted

h. soil injection - application beneath the soil surface

i. spot treatment application to a small area in the nursery

Rate and time of application is critical during pesticide use. Commonly pesticide works at very low rates. Excess pesticides may kill plants that are to be protected. It is important to use them only on the intended target. Areas in which drift by the wind may be present should be avoided.

The degree of pesticide toxicidy to pests is affected by: soil organic matter and texture. Soils with a high content of organic matter may need greater amounts of pesticides to obtain a good pest control. Soils with fine particles (silts and clays) provide more surface area, thus requiring more pesticide. In coarse soils, a lower rate is needed because of less surface area. In any case, always follow label instructions carefully to determine the appropriate rates.

Climate affects how effective a pesticide is. Soil moisture and rain determines how long pesticide will stay on the ground. Rain causes soluble pesticides to leach away. Soil moisture also prevents the pesticide from adhering to soil particles. High temperature causes some soil particles to evaporate quickly. Low temperature may slow down pesticide activities. High temperature can break down chemical compounds if they are left on the soil surface for a long time.

Formulation

Chemicals that actually do the work of killing the pests are named "active" ingredients. They need other ingredients to mix with these other ingredients: inert ingredients, that are safe to handle and held direct the pesticide towards the target.

Types of formulation:

1. Emulsifiable concentrates (EC or E)

   These can be mixed with water to form an emulsion. Usually they are diluted at the rate of 2 to 8 pounds of active ingredients per gallon of water.

2. Solution

   These are divided on high concentration and low concentration. High concentrates usually contain 8 or more pounds of active ingredient per gallon. Some of them are designed to be used as they are or are diluted with oil or any petroleum solvents. Low concentrates contain less than 2 pounds of active ingredients per gallon. Most are solutions with refined oils.

3. Flowables (F a L)

These are finely ground solid put into a liquid to make a suspension. They can be mixed with water.

4. Aereosols (A)

These contains the active ingredient in solution in a solvent. They are made for use only in fog or mist generating machines.

5. Liquified gases

The formulation is stored under pressure. They are applied to the soils by injection into the soils or are released under tarps.

Dust (D)

This formulation comes ready to use; the active ingredient is mixed with a fine or powdered, dry, inert substance like talc, clay, or volcanic ash. Active ingredients range from 1% to 10%. They offer certain disadvantages: they must be used in dry from and present a drift problem to non-target areas or pests.

Wettable powders: (WP or W)

These are dry, finely ground pesticide. They look like dusts. They are made to mix with water. They contain 15 to 95 percent active ingredients. When added to water they form a suspension rather than a solution. They are safer to use on plants than emulsifiable concentrates.

Types of pesticides

General calssification - those pesticides not harming the environment or the applicator when used as directed.

Restricted use

Those pesticides which could cause some human injury or environmental damage even when used as directed on the label.

Directions for use

The instructions on how to use the pesticides are provided on the label. These will tell:

1. What kind of pests to control
2. The product that can be used on crops and animals
3. Form of application
4. Dosage to be used
5. When and where to apply

Pesticide safety

The two major reasons for using pesticides safely are:

1. Keep yourself and others from being poisoned.
2. Avoid harming the environment.

Pesticides are toxic. Most of them can cause severe illness or even death, if misused. They can enter the body through the skin. Accidents with pesticides can be prevented if:

a. They are stored away from children and other untrained persons.
b. Taking care to follow directions when using them.

Symptoms of pesticide poisoning:

It is important that pesticide users know to recognize what effects are caused by the pesticides they are using. There are two kinds of clues to pesticide poisoning. These are symptoms and signs.

Symptoms are feelings that are noticeable by the person who has been poisoned. Examples are: nausea or headache. Signs can be noticed by others, like vomiting, change in respiration rates, or loss of coordination.

Safety equipment:

1. gloves
2. boots
3. goggles
4. respirator

Pesticide storage

Labels will tell you how to store the product. They should be stored in their original containers. Never store them near food, seeds, fertilizers, or animals. Storage should have appropriate ventilation.

Application equipment

The use of the proper equipment guarantees the success of the pest control. There are different types of sprayers, and the use of them is influenced by the pesticide to be used and the size of the area of application. The most commonly used in necessary operations is the hand sprayer. It is easy to carry, economical, and can be used in areas where motorized equipment will not work.

7.0 NURSERY MANAGEMENT

Nurseries produce planting stock when natural regeneration and direct seeding at reforestation sites are not practical or not possible for silvicultural reasons. Two major questions to answer before starting any nursery are:

Will the nursery be temporary or permanent?

Will the nursery produce seedlings by container or bare-root (open-rooted) systems?

Answers to both determine funding levels needed to construct and maintain nursery facilities and indicate labor intensive or more mechanized operations. Nursery site selection must be done with care and caution, always considering environmental and human resources of the surrounding community. Major considerations in answering these questions are presented in this chapter, along with descriptions of operations essential to that system eventually chosed by the project manager.

7.1 Site Selection and Layout

7.1.a. Climate and Environment

Nurseries are best located at sites neither too wet nor too dry, and well away from coastal areas having salt-laden winds. Consult long-term rainfall and temperature data when available. Ideally, there should be uniform rainfall distribution throughout the planting and growing seasons. Avoid windy areas to reduce windburn and dessication to seedlings.

7.1.b. Location and Facilities

Locate nurseries close to the reforestation or afforestation sites to allow timely transportation of seedlings to the field; fewer trucks are needed if short trips are used. For larger operations, housing on the grounds for personnel deters vandalism, creates strong identify related jobs, and allows watering and maintenance on long weekends or holidays. Basic structures for potting, tool storage, or seed storage and cleaning, and shipping are best located at the main nursery entrance. Catalog and inventory all tools and machines (Table 7.1).

after they are purchased; reorder after planting season operations are finished. Secure all tools and equipment in designated storage sheds and develop regular maintenance and/or preventive maintenance schedules for major items.

Adequate electrical power sources are essential to run equipment like irrigation pumps, potting machines, and refrigerators; some equipment usually needs high voltage (3-phase) lines. Diesel or gas powered generators are needed for areas with frequent power outages.

Good communication, via telephone, radio-phone, mail service, and roads are needed for handling seedling requests, informing landowners of seedling availability, or coordinating field planting and delivery schedules. An all-weather access road should lead in and out of the nursery area (Fig.7.1).

7.1.c. Soils and Topography

Areas designated for nursery beds should be as flat as possible. For drainage control, construct beds with proper contour and slope rather than give a slight slope to the entire nursery area. Avoid areas subject to flooding or having steep slopes and large stone or rock outcrops. Also avoid former forested sites containing numerous subsurface roots, formerly cultivated sites that have known root pathogens or weed problems, and areas with wolf trees.

For container production, native soil type is not so important since potting media are brought in from outside. But for the traditional field nursery, using seed beds subject to drainage, trafficability, and nutritional problems, soil and topographic considerations are crucial (Fig. 7.2).

Soils between sandy loam and silt loam have good drainage and do not compact easily; they also till easily and do not crust over following rains or irrigation. Heavy clay soils are undesirable since they cause root breakage in lifting bare-root stock; they also require greater monitoring to detect poor drainage and associated poor root system development. Optimum pH values vary according to the species grown: for pines, the range is usually pH 5.5 to 6.0; for hardwoods, slightly higher pH values around 7.0 are suitable. When acidity drops below

pH 5.1 or much higher than 7.0, corrective actions must be taken (see Nutrition and Fertilizers section). Include fallow areas if nursery expansion is planned.

7.1.d. Water and Air

Preferred water sources are large lakes or pollution free rivers and streams. Water can be pumped to elevated tanks and then distributed under pressure through a sprinkling system. Wells can be used if underground acquifers have sufficient amounts for expected pumping frequencies and if the underground sources are not subjected to salt-water intrusion near coastal areas. Before tapping public water systems, check first if supply is adequate and free from excess minerals.

Monitoring all water sources once a week for excess salts, especially calcium, is important. Higher salt levels can raise soil pH, causing roots to rot, or may be toxic to plant roots or affect nutrient availability. Soil pH above 7.0 is less favorable for mycorrhizae growth and tends to favor the pathogenic fungi that cause damping-off.

Air pollution may be a problem in developed or even in rural areas, depending on local wind and related factors. Phototoxic pollutants, including sulfur dioxide (SO_2), hydrogen fluoride (HF), and ozone (O_3), can be carried downwind onto a nursery and settle out directly on seedling foliage; they may also enter the nursery area indirectly through incoming rainwater. In extreme cases, acid rainwater has burned seedlings foliage and caused death of seedlings.

7.1.e. Labor

Locating nurseries near towns or villages allows unskilled workers and laborers to commute short distances to the nursery work site. Since much nursery work is seasonal, people can supplement their income from other jobs found in their communities or their own small farms. If labor must be brought in from far-away cities, housed, and fed in work camps, expenses will be very high.

7.2 Production Scheduling

Developing and following production schedules assure that seedlings delivered to planting sites are strong and well-developed for transplanting. Schedules are based on a thorough knowledge of the nursery physical plant limitations; available equipment, supplies, and human resources; biological growth requirements of seedlings; and species quantities needed by government agencies or individuals.

7.2.a. Flow Chart of Scheduling Procedures

It is helpful to divide major production steps into separate stages, listing them sequentially in a flow chart. This permits the nursery manager to focus on each step, allowing detection of potential bottlenecks(Fig.7-3). Using it may show that two pieces of equipment (like soil mixers) are more efficient than one, because of work volume anticipated.

Nursery managers are also responsible for introducing new technological and scientific advancements, including training foremen in use of newer, cheaper, and more efficient equipment. If they are content to let local traditions and labor habits dictate seedling production methods, an entire reforestation project may be adversely affected. Yet, managers must be cognizant of particular community needs and realities. For example, although a semi-mechanized container operation may produce more seedlings in a shorter time, utilizing a less automated operation, drawing on a large unemployed local labor force, may be more effective in promoting community self-help, while fostering grass roots acceptance of nursery/reforestation long-term objectives through acitve community involvement.

7.2.b. Time Schedule Considerations

Overall time schedules are calculated from knowing a) how long each species must be grown in the nursery and b) how much time is actually available for seedling growth before optimal outpoanting time begins; in many countries, this usually coincides with the rainy seasons.

For example, if 24 weeks remain before rains begin and the major species to be planted needs at least 16 weeks in the nursery to develop fully, then 8 weeks are left for seeding in beds or in containers:

24 weeks before rains start
- 16 weeks in nursery for growth development

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8 weeks left for seeding in beds or containers

Two other considerations are very important. First, not all species have the same nursery requirements. In the above example, if a species needed 20 to 22 weeks in the nursery, then that species must be seeded first to allow sufficient development time before the rains come. Contrarily, a species needing only 12 to 14 weeks in the nursery could be seeded later since it needs less development time in the nursery.

Second, nursery managers must provide for even flows of seedlings for planting. If all seeding is done at one time, all seedlings will be ready for outplanting at the same time. However, field crews can only plant a limited number of seedlings in any one week; their planting schedules may be interrupted also by bad weather or equipment break downs. Thus, the manager must stagger seeding operations so that seedlings are available for planting throughout the entire expected planting season. Development and following realistic and flexible production schedule is a very necessary concern, not merely an idealized one.

7.3 Seed Procurement and Treatment

7.3.a. Seed Sources

Forest trees are generally propagated by seeds, fruit trees less frequently. Seed is collected locally or obtained from seed companies. Importing seed from other countries usually requires a phytosanitary certificate for admittance; it is sent with the package and certifie that the seeds are free of insects and any diseases.

Collecting seeds requires some knowledge of assessing maturity, an important factor in obtaining maximum germination. Many fruits change color as they mature: going from green to blue, red, brown, or black and sometimes orange. Others remain green. For most pines, cones turn from green to dark brown or reddish brown. Examining the fruit for firmness but not springiness is another way of assessing maturity as is looking at seeds inside fruits to see if they are dark brown or black and fairly firm. When seeds disperse, they are mature; but harvesting is then almost impossible. So harvest at the point of maturity just before dispersal.

When collecting seed, select from healthy, well-formed parent trees (Fig. 7.4). In buying seed, order from reputable sources that specify and guarantee seed germination percent; some addresses are given in the Appendix. Transport seeds or recently collected fruits in air-breathing canvas or paper sacks or open boxes; avoid using impermeable plastic bags that trap moisture and foster mold development.

7.3.b. Inspection and Cleaning

Seed processing includes drying and initial extraction from cones (pines), pods (mahogany), or flesh (kadam); separation from dirt and foreign matter; culling of empty or damaged seed; reducing and maintaining proper moisture content; and, if needed, applying protective treatments like fungicides. The ultimate goal for each fruit type is the same: maximum production of clean seed having high viability.

After collection, dry seeds and non-fleshy fruits on raised screens that allow free air movement and reduce rodent damage. For large operations, kilns or solar dryers are used. Before drying, discard anything with visible signs of disease, insects, mold, and dampness; excess moisture and mold cause the most damage to newly collected or stored seed.

Cut open fleshy fruits, placing them and seeds in a bucket of water. Flesh is loosened by rubbing seeds between the palm of the hand or by machines; kind,

quantity, and value of the fruit determine whcih method is used. In either insance, if fleshy fruits are not processed quickly, fermentation and spoilage will occur because of the high moisture and sugar content of the flesh. Dry seeds by methods used for processing cones or pods.

7.3.c. Moisture Content and Storage

Low seed moisture content and low ambient temperature are both essential for maintaining high seed viability over long periods. When moisture content is too high, seeds can begin to germinate prematurely within storage containers, sustain mold growth, or sustain attacks from insects. Reducing seed moisture content to between 10 and 12% eliminates most of these problems.

After drying, some seeds like mahogany do not store for periods longer than 2 or 3 months. For short-term storage, a) leave seeds in low humidity ambient temperatures of 13 to 20°C, in well aerated containers, or b) store in sealed bags or containers in a refrigerator. In both cases, internal seed moisture will usually equilibrate to between 12 and 18%.

For long-term storage, some seeds like pines can be frozen at 0°C or colder. Before freezing, internal seed moisture must be 5 to 10%. Throughout storage, periodic checks at 6 month intervals must be made to determine seed moisture changes

For determining seed moisture content, the air-oven method is used. Weigh a representative sample to at least one decimal place, dry at 103 $\pm$ 2°C for 17 $\pm$ 1 hour, and reweigh after cooling down in a dessicator for 30 to 45 minutes. Percentage moisture (i.e. seed moisture content) is obtained by dividing the weight of water lost in drying by the wet weight or weight before drying. Duplicate determinations are run on the same seed lot. If results for the lots differ by 0.5% or more, another duplicate determination must be made, following the same procedures.

For example, assume that wet weights of a duplicate set of samples, A and B, are 20.2 and 20.1 g. After 17 hours, dry weights for A and B are 18.0 and 18.1 g. Seed moisture contents are:

A: $\frac{20.2 - 18.0}{20.2} \times 100 = 10.9\%$

B: $\frac{20.1 \quad 18.1}{20} \times 100 = 10.0\%$

Since the difference between the two determinations is greater than 0.5%, another set of determinations should be run. If differences still surpass 0.5%, check whether weighing techniques are correct or whether the balance is working properly

If seed moisture contents are known to exceed 17%, seed subsamples are weighed, predried just at 130°C for 5 to 10 minutes, reweighed after cooling, and then run through the normal air-oven technique. Percentage moisture is found by dividing the weight of water lost from the two dryings by initial

Long-term storage containers must be rigid-walled and screw-tight to restrict air and moisture entry. For short-term storage, plastic bags are economical and effective if tied propertly. In both circumstances, complete labeling information is essential (Fig. 7.5), particularly from imported lots from different climatic or elevational zones than those in the reforested zone.

7.3.d. Pre-sowing Treatment

Presowing seed treatments or pretreatments are sometimes needed for tree species whose seed has internal dormancy that delays germination from months to years after seed fall. A classic example is teak seed which may not germinate for two or three years, even when left in unrefrigerated storage. Delayed or irregular dormancy may be beneficial for natural survival of a species, postponing germination until more favorable growing conditions exist for seedling survival. But irregular or delayed germination is disastrous for nurseries

where all seedlings must reach uniform outplanting size by specific dates. The purpose of pretreating is to break sedd dormancy uniformly for all seed that is germinated.

Seed coat dormancy is done by chemically or mechanically braking the impermeable coat that surrounds seeds (e.g. most legumes and teak). Acid scarification is done with commercial grade sulfuric acid (H_2SO_4). Determine correct immersion time by soaking small seed lots for different periods in acid followed by soaking in water at room temperature for 1 to 5 days. The acid-water soaking treatment with the highest percentage of swollen seeds (caused by water uptake), without splitting seeds or exposing the endosperm, is the best treatment. Another alternative is placing seed in a conical pile on a flat, hard surface; applying acid at a rate of 1 liter per 36 kg of seed; mixing thoroughly with a shovel; and rinsing and drying.

Advantages of acid scarification are:

- little or no special equipment
- low cost
- recovery of acid for future pretreatment unless the pile method is used

Disadvantages are:

- length of treatment time must be carefully determined
- temperature must be controlled, particularly when large lots are pretreated
- workers face potential hazard of burning from incorrectuse of acid

If acid is used, NEVER ADD OR SPLASH WATER ON ACID because a violent reaction or explosion can occur.

Water soaking in hot or cold cater is the other major chemical method for pretreating seeds. Large seed species like teak and legumes have best success in hot water. The method involves preheating water from 77 to 100°C, placing the seeds in 4 to 5 times their volume of this water, and allowing seeds to soak in the gradually cooling water for 12 to 24 hours. Problems are:

- difficulties in standardizing the technique
- maintaining precise control of times and temperatures
- treating large seed lots

Cold soaking in water at or near freezing temperature for a few days to 2 weeks has successfully speeded up germination for coniferous seeds; it is not successful for hard-seeded ones on which acid scarification is used. Alternate day soaking in water and night drying for 7 days before sowing has increased germination percent of Terminalia ivorensis from 30 to 50 to 70% in Ghana. And germination period for P. caribaea has been reduced by water soaking for 48 hours at room temperature before germinating.

Mechanical seed scarification is done by using files, razor blades, and hand- or motor-driven drums lined with sand paper. Tests of small lots are needed, as for acid scarification, to determine optimum treating times as verified by swelling after water uptake or visual examination with a hand lens. Over-treatment will damage seeds such that germination is greatly reduced or the seeds succumb quicker to fungal or mold attack.

Advantages of mechanical scarification are:

- less risk of injury to workers
- no need to control temperature
- seeds remain dry throughout pretreating, allowing immediate sowing afterward

Disadvantages are:

- seeds easily damage by overtreatment
- large lots require special equipment
- scarified seeds are perhaps more easily damaged by pathogens than are nonscarified seeds
- seeds with resins or soft pulp cannot be used in sandpaper-lined tumblers

Besides seedcoat or "external dormancy" there is "internal dormancy" for some tree seeds, especially for species from colder, temperate latitudes, or for species growing at high elevations within tropical areas. Before such seeds germinate, they must undergo changes that are either biochemical in nature or physiological in which the seed embryo must grow and develop further.

In cold stratification, seeds are stored in well-aerated media like sphagnum moss and kept at low temperatures from 1 to 4°C for 2 to 4 months. Several pre-

cautions must be taken. Store seeds losely, never pack them in plastic or canvas bags which are routinely used for storage. Inspect seeds and media every few days to assure that moisture is adequate. If stratification is 30 days or longer, take bags out and inspect for mold or drying every 2 weeks. Poor aeration is detected by smelling alcohol, indicating aerobic respiration is taking place. At the end of stratification, remove and clean seeds by washing in water, then dry. Immediate sowing is then recommended; extreme drying before sowing may reinduce a second dormancy.

7.3.e. Germination Percent

Before actual sowing and upon arrival of seeds from seed suppliers, checking germination percent is helpful in determining how many seeds are needed for seeding. The procedure involves taking a known number of seeds; moistening them on tissue paper in petri or other dishes, or in rags; and periodic recording of actual number germinated. Fully germinated seeds are usually discarded to prevent mold or mildew; water is added as needed to keep sees and germination media moist.

For example, consider a lot of 100 seeds that are inspected after 7, 14, and 21 days. Cummulative counts of seeds germinated were 40, 75, and 85. Corresponding cumulative germination percents are:

7 days	14 days	21 days
$\frac{\text{40 seeds germinated}}{\text{100 seeds originally sown}} \times 100 = 40\%$	$\frac{75}{100} \times 100 = 75\%$	$\frac{85}{100} \times 100 = 85\%$

This procedure is usually done 2 or 3 times, with results being averaged to even out variability differences in similar seed lots. Always take samples at random and from several areas of storage containers, drums, or boxes. For very small lots, total seeds sampled may be only 25 or 50 instead of 100. At least 2 replications should be run for small or large test amounts.

Remember, seed viability, or living, is different than germination, or growing. Thus, there can be positive viability with no germination. "Quick tests" for viability include cutting with a knife to reveal healthy, firm, undamaged embryos; biochemcial (embryo) staining; and soft x-rays.

7.4 Container Systems

Container or pot nursery systems are used when site reforestation conditions are too harsh (usually too dry and exposed) for survival of bare-root stock. Even on non-critical sites, potted seedlings have higher survival than bare-root stock. Other advantages and disadvantages over bare-root systems are:

<u>Advantages</u>
- good soil is not necessarily needed at the nursery site
- time in the nursery is shorter
- roots are not exposed to air or heat during transport to field

<u>Disadvantages</u>
- more expensive to produce
- individual pots pose storage problems in transport to field
- fewer seedlings are transported to field per trip
- extraction from pots is difficult unless media moisture is controlled before removal from the nursery
- more potential damage to root systems if seedlings are repacked for transport to field to conserve multi-cavity containers for future seedling production

7.4.a. Pot Shape/Volume Considerations

Pot types commonly used are: clay balls (hand-made), split bamboo pots (hand made), polyethylene bags, clay pots, tar paperpots, tin cans, milk cartons, etc. Whatever the material, or system, two important considerations are pot shape and volume. Longer pots have longer and better-developed root systems, being better for dry sites; smaller pots produce smaller root systems but are adequate for more moist sites.

Larger pot size also means a greater volume of growing media is needed to fill it; if synthetic media is used to fill pots, cost becomes the most limiting factor. Volume also affects seedling development and holding time in the nursery. Once available root volume is used, seedlings must be outplanted quickly or root

strangulation occurs and/or deterioration of seedling vigor. Reusable pots are more expensive than disposable containers but may reduce long-term production costs. The ideal is to choose that one pot which provides an adequate root volume and root systems for the sites being planted, after remaining a reasonable time period in the nursery. For pines, this means growing a seedling to 25 or 35 cm in 6 to 8 months, or 4 to 5 months if they are "forced" to grow quickly by frequent use of fertilizers and water.

Overall, labor intensive or mechanized pot systems have the same basic steps (Fig. 7.6).

7.4.b. Selecting and Preparing Pot Growth Media

Potting media selection is determined primarily by materials that are cheap and readily available in the community or those than can be economically brought in form areas outside. Alternaives are: soil alone; soil/sand mixtures; organic bases mixtures with various proportions of peat moss, compost, sugar cane waste, rice hulls, sawdust and bark; and synthetic mixtures.

Soil alone is usually undesirable because of excess weight; however, if nothing else is available, select sandy to sandy loam materials, not heavy clays, for reasons given earlier. Synthetic and pre-packaged mixtures are usually too expensive, except for large and specialized projects with considerable research emphasis. Organic based mixtures are desirable because they reduce media weight considerably and greatly improve texture and water holding capacity of the media.

Precise ratios of sand, soil, and manures or organic materials will vary according to local materials used. Fertility, pH, and physical composition are all different among sand, silt, and clay soils. Use replicated nursery trials to determine the best mixture proportions for local media. As a starting point, managers can try a 1/3 mixture of soil/river sand/decayed manure or organic materials.

7.4.c. Filling Pots

Screen or sieve all soil of clods and stones before using it alone or with other materials (Fig. 7.7A). Metal or bamboo funnels are used to guide potting media into containers (Fig. 7.7B). Potting tables with both media and pots handy for filling are very practical (Fig. 7.7C), particularly when located under a protective shed (Fig. 7.8C). Rigid-walled containers can be filled directly by shovel after being lined out in beds, rather than being filled individually. Avoid letting excess soil drop down between pots because weeds are easily established in these interspace areas.

While some workers fill pots, others can set them out in neat lines and rows (Fig. 7.9). Methods of shading pots are simple or complex, using specially constructed metal frames (Fig. 7.8A, 7.8B) or wooden T-frames and shade trees for very temporary operations (Fig. 7.9).

7.4.d. Seeding and Early Tending Care

Germination percent test results determine how many seeds are actually needed to fill specified seedling amounts; always allow for 10 to 15% natural mortality in the nursry. For example, if 15,000 seedling are needed, germination percent is 85%, and allowing for 15% mortality, then the actual number of seeds needed is:

15,000 seedlings needed = 100% but
+ 15% to allow for germination test results
+ 15% maximum expected natural mortality
130% of actual seedlings required or

15,000 X 130% = 19,500 seeds or rounded up to 20,000 seeds

Two procedures exist for seeding or sowing:

a - directly onto potting media for medium to large seeds: pines, Gmelina (Fig. 7.10).

b - onto media in wooden or metal seed flats for very small seeds: eucalypts and kadam; and transplanting to pots a few days after germination (Fig. 7.11).

Seeding Media

Possible media for seed flats are vermiculite; washed and sterilized river sand or sand/soil moistures; rice hulls; or tissue paper for very small seeds. One can always sterilize sand and sand/soil mixtures first by chemical treatments like methyl bromide, streaming, or dry heat in an over ($\leq$ 102° C for 2 hours) to prevent pre- or post-emergence damping-off. If chemicals are used, read instructions carefully and follow all safety precautions. Vermicultie involves extra cost but is ideal for germination flats because it is initially sterile, has a neutral pH, and has optimum particle size, allowing moisture passage between seeds and media but not restricting new root development. For medium to large seeds like pine, seed at a rate of 100 seeds per 30 x 30 cm area.

Cover seeds with 6 to 10 mm of vermiculite, rice hulls, or fine sand (sterilized) which allow better seedling emergence than soil alone. Pushing large seeds deeper than 6 to 8 mm below the surface will prevent emergence, particularly if sand or soil/sand mixtures are used. For mahogany, dewing first and lay seed flat on germination media; never push seed into media with wing protruding since this will cause formation of J-roots. Place seed trays and pots under 20 to 50% shade (Fig. 7.9). As seedlings get older, gradually reduce shade to full sunlight before outplanting.

Watering

Check germinating media moisture at least 2 to 3 times a day; if media feels moist to fingers but water cannot be extracted by squeezing, moisture is adequate. If overwatering occurs, remove shade temporarily to speed up evaporation. A fine spray from overhead irrigation nozzles or on back pumps is needed for fine seeds to prevent washing out of seeds from flats.

Transplanting

Time for transplanting, or pricking-out (Fig. 7.12), from seed trays to pots

varies with species. For pines, optimum transplanting is between 3 and 6 days following emergence and before the seed coat has been thrown. Smaller seeded species like eucalypts should be at least 2 cm tall. Seedlings that have not germinated according to past experience or too slowly should be culled; these later germinates are physiologically inferior and will not perform well in the field. Once exception is teak as was mentioned earlier.

Avoiding J-root systems is very important in pricking-out (Fig. 7.12). If planted in the field, seedlings with sick or deformed root systems are more susceptible to windthrow since root anchorage and development is abnormal. If damaged by wind, older seedlings or saplings probably face greater potential damage from insects and disease.

5.4.e. Later Tending Care

Pots with transplanted seedlings can be lined out on the ground or other surfaces (Figs. 7.9, 7.13A) as well as placed in permanent raised or sunken beds (Fig. 7.8A, 7.8B).

Also, after transplanting, conifer seedlings should be inoculated with mycorrhizal fungi. For areas lacking native or planted conifers, mycorrhizae must be imported from elsewhere. Otherwise, pick up litter and duff in a plantation or forest, grind, and broadcast on top of containers.

Check pot media moisture every day by the feel method discussed earlier. Watering frequency will depend on components in the media, season of the year, and nursery exposure. Water losses are less in the early morning or late afternoon hours, when the sun's rays are less direct.

As seedlings develop, some will lag behind or surpass others in height and foliage growth, the faster growers being ready earlier for outplanting than slow growers. When labor is plentiful, different sized seedlings can be grouped in separate areas of the nursery, several times during their development. Never let overtopping by a few seedlings stunt growth of other surround seedlings.

Remove weeds from pots when they are young, small, and succulent; this causes minimal damage to tree seedling root systems; it also prevents weeds from seeding. Hand labor is all that is needed, except for bed boundary edges where small tools may be n-eded to eliminate larger growing grasses and weeds.

Since containers need some sort of drainage, there are small holes at the bottom. Roots tend to grow out of these when pots are placed directly on the ground. If this happens, pot removal is difficult for transport and root systems may actually be damaged. Natural (air) pruning is possible by placing pots on raised wire screens or flat on sloping cement floors and plastic sheets, from which excess water still drains off adequstely (Fig. 7.13A). Otherwise, use a shears or machette for pruning (Fig. 7.13B).

7.4.f. Lifting and Transporting

Watering should be reduced gradually before lifting. About 4 to 6 weeks prior to lifting, reduce watering to once a day for one week; the second week, reduce to every other day. Progressive water reduction can be continued unless trees begin to wilt seriously. If this happens, apply more water immediately to prevent permanent damage. A day or two before actual lifting, styrofoam or tube containers should be drenched so that seedlings and media can be pulled out together, without breakage or stems or roots.

During moving and transporting, keep trees in the shade as much as possible. Pack containers tightly to prevent jumping in transport vehicles which would cause damage to root systems. Depending on length of trip and type of transport used, one or more stops might be needed to water seedlings.

If planting must be delayed, keep pots in the shade and provide for watering and perhaps "heel in" pots in shallow trenches to conserve moisture in the potting media (Fig. 7.14). Never let lifted containers remain unattended over weekends before planting. Carefully planned and executed nursery production and distribution schedules should avoid most delays.

7.5 Bare-Root Systems

Bare-root nursery stock can be produced by hand or mechanized systems. Both are discussed here. Like container systems, bare-root systems have certain advantages and disadvantages over container systems:

Advantages
- using ground-level or raised beds avoids transplanting after germination
- tending care is usually easier for mechanized operations
- less weight to transport from nursery to field, allowing more seedlings per trip
- bundling, handling and packing is fairly simple for transport

Disadvantages
- nursery sites must have very good physical and certain chemical properties if permanent use is desired
- seedlings need 2 to 3 months more time for development
- more physical space is needed for beds in the nursery
- damage to roots is potentially greater if they are exposed to air for a long time after lifting

Species successfully grown by bare-root systems are pines, teak, Gmelina, Casuarina, and kadam.

7.5.a. Bed Orientation and Preparation

Orientation of bare-root seed beds in the tropics should be east/west; in temperate areas, orientation is north/south. Tropical areas are close to the equator. The sun's rays are more direct than in more northerly or southerly latitudes. The east/west orientation provides shade during the hottest part of the day and helps minimize shading material needed while effectively providing shade protection for seedlings.

Fallows

Beds that have been in fallow should be plowed 4 to 6 months before sowing seeds, allowing grass and weeds to decompose first. Seedling/fallow cycles vary as do crop/fallow cycles. Local soil scientists or agronomists can help make

recommendations. Two possible cycles are 2/1 and 2/2. In some instances, a cash crop could be used for a cover crop or fallow.

Cultivation

Beds are cultivated by horses, oxen, mules or tractors, using plows or other implements. Mechanized operations may have beds from 60 to 100 m long; hand operations may use beds as short as 5 m (Fig. 7.15). Standard beds are 1.2 m wide, with 5 seedling rows. Each group of 1000 seedlings needs about 10 square meters (10 m^2) of land. Walkways are at least 45 cm wide to allow good access.

Over time, heavy tractors and equipment tend to compact soil or form a plow pan under the beds. Correct this by deep plowing to $\geq$ 46 cm or pull a subsoiler/ripper across (90°orientation) to the beds.

The soil within beds should be raised or mounded (Fig. 7.16 A). This is done with special plows or by hand tool. Benefits of mounding are:

- lose mounds increase soil aeration which is vital for good root growth
- raised mounds increase drainage and reduce water logging potential
- mounded portions of beds are above tractor paths and unaffected by compaction

Soil Sterilization

Large commercial nurseries routinely fumigate beds after mounding. Soil sterilization helps control weeds, nematodes, and pathogenic fungi, and other soil pests, all of which can destroy an entire seedling crop worth thousands of dollars per hectare.

Sterilization is usually done with gaseous fumigants like methyl bromide. It is used effectively for small soil volumes by releasing gas under tarps or by chiseling gas below ($\pm$ 40 cm) the soil surface via plows with injection valves. Beds are then covered with 1.5 mm or greater thickness plastic sheets, tied down along the edges. Fumigants are not effective in heavy clay or very wet soil.

Other weed control alternatives are spraying with pre-emergence herbicides or saturation beds with a solution containing 4 liters of formalin and 160 liters of water. Sow beds about 21 days after drenching. Steam sterilization is effective for small soil amounts if steaming machines are available from horticultural or agronomic operations.

In almost all instances, sterilization will also kill soil mycorrhizae. If conifers are seeded, reinoculation must be done. Use ground up litter from beneath nearby plantations or import mycorrhizae when not available locally; the latter will require following phytosanitary requirements. Pelletized forms are now available for commercial, mechanized operations; it is seeded in along with seeds.

7.5.b. Seeding and Early Tending Care

Mechanical planters can drill both seed and fertilizers to specified depths at the same time, and cover both all in one operation. For smaller operations, dig furrows along a string and stake guides (Fig. 7.15). Cover seeds with soil to a depth 2 or 3 times their width. Fertilized along side or under seeds, never directly on top; doing this will burn new roots or might cause flushes of damping off fungi.

Immediately after planting, spread a thin, non-toxic, biodegradable mulch over the beds. Mulches provide:

- protective cover from birds and prevention of washing out by rain and irrigation water
- reduction of erosion in beds themselves
- soil moisture conservation which aids in germination.

Mulches should not be so heavy that they prohibit egress of germinating seeds or rot/ferment on top of the seed beds. Some mulch alternatives are: sawdust; grit or sand (sterilized); vermiculite; chopped, dead pine needles, straw, or similar agricultural by-products; and chopped bark or newspapers.

Pre-emergence Herbicides

Hand weeding is no problem when seed beds are small and labor is plentiful and cheap. Using herbicides for chemical weed control is a must for large nurseries The major concern is to select herbicides that are non-toxic for the species being sprayed. Random control plots not receiving herbicides are used to check effectiveness of the chemicals applied. Always follow precautions indicated on herbicide storage containers and use any recommended safety equipment like gloves and masks.

Watering

Seedlings in beds are more exposed to air and light then container stock unless movable screens are used, as for container stock. Thus, water needs of bare-root stock may be greater than that for container-stock. Check soil frequently for moisture by the feel method as well as for signs of wilting. If soils are clayey and hold moisture, avoid overwatering to prevent root rot.

Wrenching

Root wrenching effectively stimulates lateral root growth. It is done by a tractor-mounted blade which moves back and forth across the bed. The wrenching is really a cutting, uplifting, and falling back of the root system. This causes numerous cracks in the soil, increases aeration, and promotes bushy root development. First wrenching is done at about 10 cm below the soil surface with subsequent cuts at about 15 to 18 cm, every 21 to 30 days. Blades must be smooth and sharp for clean cuts.

Undercutting

This operation can be done by tractors or by hand with sharp machettes; it makes a clean cut of seedling taproots with a rigid blade. This action stimulates lateral root branching but stops shoot growth. It is effective in slowing down

top growth of seedlings. Disadvantages are:

- undercutting at slow tractor speed on wet soil will cause seedlings to be pulled over
- repeated undercutting at the same depth can create plow pans which restrict root growth as well as decrease soil drainage

Top Pruning

Most conifers can be top pruned after the fifth month. The operation slows height growth of fast growers that threaten to suppress others. It also allows development of a more uniform shoot/root ratio among seedlings and promotes uniform seedling height for outplanting.

Clipping is done with tractors and movers or by had with shears. Potential problems are:

- cutting back seedlings too much whn tractors hit low spots in tractor paths
- wounded stem and needles serve as entry points for disease

Lateral Root Pruning

This operation is done immediately before lifting. The purpose is to slice through root systems growing between seedling rows. Lateral pruning also reduces time required for separating seedlings during grading and packing. Tractors and rollers or lifters are used or hand tools in smaller nurseries.

7.5.d. Lifting and Transporting

Young stock can be lifted by hand with shovels or undercut and lifted with tractors. In hand operations, soil is shaken off the roots after lifting, roots are then washed immediately; trimmed (Fig.7.13C; and packed in water, water slurries, or wet moss. Planting within a few hours of lifting is best, particularly when soils at planting sites are also moist. Therefore, schedule outplanting for rainy or wet periods.

Because of warm temperatures and the directness of the sun's rays in the tropics, seedling roots must be kept protected and moist at all times. This applies to operations in the nursery, in transporting, or at the field before planting is actually done. If delays in transporting, or planting, cannot be avoided, do not lift the seedlings. If unexpected delays occur after lifting, leave seedlings in well shaded areas, standing in buckets with plenty of water; or use a walk-in cooler if available. Shading reduces transpiration loss of water from seedlings. For some trees like neem and kahya, side leaves may be stripped to avoid water loss from tissues (Fig. 7.17A). Avoid ripping or tearing of seedling parts, especially the terminal bud.

When labor permits, seedlings should be graded and bundled (100 seedlings is a convenient number) into size classes, based on similar root collar diameters; inferior seedlings are culled. Only the larger, well-devellped seedlings are planted since there is plenty of evidence showing that larger seedlings outgrow smaller ones. Workers could cull inferior seedlings in the field, but this takes time and may not be done at all if laborers are paid by the number planted, and not per day of work done.

Keep transport vehicles well shaded and avoid long trips that preclude planting the same day as lifting. When roads are very bad, special packing and handling care is needed since water is easily spilt from buckets or tubs.

Stump Planting

Some species like Cassia, Gmelina, and teak can withstand cutting back of the entire top portion of the seedling and most of its root system. The result after trimming is a stump, about 15 to 30 cm long (Fig. 7.17B). Stumps are easily bundled, packed, and shipped. Weight is minimal and many more seedlings are moved per day as compared to container or even bare-root operations. Follow shade and watering instructions as for transport of bare-root stock.

7.6. Vegetative Propagation

Using certain vegetative parts of a plant rather than seeds to promote new growth of stems, leaves, or roots is called asexual or vegetative reproduction. For fruit trees, vegetative reproduction is the most important means of propagation. For forest trees, the method is less common, especially for large reforestation efforts. It is important though for establishing ornamentals and seed orchards which produce seeds from genetically superior stock.

7.6.a. Cuttings

This method includes using stem or root cuttings. Root cuttings are made from species like some eucalypts that produce suckers in good numbers. Do not take root cuttings from grafted plants because the mature plant will have characteristics of the root stock only. The most frequently used method is stem cuttings from stem parts of mature healthy trees.

Cuttings are 10 to 14 cm long, and $\geq$ 1.2 cm thick (Fig. 7.18). For best results, take cuttings from terminal shoots or flushes of new growth. Leaves are stripped from the larger, basal half, which is also treated with a growth hormone if available. The cuttings are then stuck into raised or ground level beds, or even seed flasts, on 6 to 30 cm centers. Use shade to protect against excess water loss. Water regularly but check bed moisture frequently to avoid overwatering which will cause rotting.

Cuttings should root in 2 to 3 months. This is checked periodically by taking out one or two to see if rooting has initiated. Vigorous stock has rigid stems and well-developed lateral roots. Optimum outplanting size varies by species: 25 to 35 cm for pines and 30 to 60 cm for most broadleaved species. Always plant in the wet season.

7.6.b. Layering

This method usually refers to layers or branches of a tree covered with soil. The branch part to be covered with soil is slightly broken, forming an "elbow" and this is where probable root growth develops; growth substances accumulate at the broken point and promote rooting. After sufficient rooting occurs, both branch and root systems are dug up and planted as a separate unit. There are three common types of layering used: tip, mound, and simple (Fig. 7.18).

7.6.c. Grafting

This is a more complex method by which one stem part (scion) of a seedling is united (grafted) to the rootstock of another seedling. The major caution is obtaining good union between cambium of each scion and rootstock so that the cambium of each continues to grow and form a permanent and compatible bond between them. Ability to do this successfully and repetitively takes considerable practice and is easier for some species than for others.

Best time for grafting is just before active shoot growth starts in the wet season for species that stop growth in the dry season. For pines and other species that grow all year in the humid tropics, there is no restriction. Extreme care is needed in binding cuts closely together with grafting tape. Adding wax or polyethylene film keeps out disease spores and conserves moisture. After grafts have "taken," remove tape and wax carefully or the graft may be strangled.

A serious drawback in grafting is tht not all scions and rootstocks are compatible; incompatibility may not show up until 5 to 10 years after grafting work was originally done. However, grafting is still the most common kind of propagation for orchard trees because of greater flexibility in uniting different scions to several kinds of rootstocks. Different rootstocks are used because they may have a dwarfing influence, may be tolerant to high salt levels in the soil, or may be more resistant to low soil pH. Whip and cleft grafts are favored (Fig. 7.19).

7.7 Nursery Nutrition and Fertilizers

Growth and performance of nursery stock is related to the genetic component and vigor of planted seeds. Just as important is nutritional status of the soil or container media in which seedlings spend their time in the nursery. Predicting fertility of nursery soils can be done chemically or biologically. If nutrient deficiencies occur, they can be corrected by inorganic fertilizers that are either short- or long-term acting.

7.7.a. Nutrient Deficiency Symptoms

Visual symptoms are usually the first signs that seedlings are growing abnormally. Common observable symptoms are: severe stunting, delayed or abnormal growth like twisted or missing needles, leaf discoloration (bright yellow or red instead of green), and abnormal root growth.

Lack of one element can be caused by deficiencies of different elements that even experienced observers cannot differentiate easily. Some symptoms are not related to nutrient deficiencies at all. For example, when seedlings turn yellow, check root systems first to see if overwatering and waterlogging have reduced aeration, thus killing roots and reducing nutrient and water uptake.

Many visible symptoms are caused by multiple nutrient deficiencies that are impossible to diagnose by observation along. Before deficiencies become observable, chances are great that irrepairable damage to growth has already occurred to seedling shoots or roots. Recognizing these limitation on trouble shooting visual symptoms, a very generalized "key" to visual symptoms is shown in Table 7.2.

7.7.b. Soil Tests

Soil tests directly determine if nutrient amounts in the soil are adequate for seedling growth. Results require a basic knowledge of chemistry and laboratory instrumentation, both of which are usually available to staff from a country's agricultrual research program. Chemical soil tests are more rapid then foliage tests; They also indicate a soil's nutritional status well before seedlings are germinated

In air layering moist sphagnum moss dipped in rooting powder is "layered" over a completely girdled branch in the crown. The moss is then covered with plastic sheeting or aluminum foil to retain moisture. Roots will form in 6 to 8 weeks but the branch is left until they are firm and have developed side branches. The branch is clipped 10 to 12 cm below the girdle and then planted in a suitable potting medium; plants are outplanted after the root system is well developed.

in or transplanted to nursery beds. Other objectives of soil testing are:

- to maintain long-term fertility status of nursery beds
- to predict probabilities of obtaining responses to lime or fertilizers

The nutrients of greatest interest are amounts of cations (Ca, Mg, and K), phosphorus, and organic matter; pH and salt problems are also important.

The most important aspect of soil testing is obtaining a representative sample. All areas that vary in appearance, slope, draingage, soil type, or past treatment should be sampled separately. For each area, take a single 0.5 to 1.0 kg sample consisting of a composite of 10 to 20 tube cores or soil scraped from a shovel or trowl. Samples are ordinarity taken to normal rooting depth of nursery seedlings, usually between 15 and 20 cm, maximum normal plow furrow depth. All sampling should be done well ahead of seedling outplanting so that fertilizers can be applied if needed.

7.7.c. Special Problems: pH and Salts

Soils with pH values of less than 7.0 are acid while those with pH greater than 7.0 are alkaline. The pH scale is a logarithmic one; thus an increase or decrease in pH by one unit means a 10-fold change in pH. For example, a soil with pH 5.0 is 10 times more acid than a soil with pH 6.0. but a soil with pH 4.0 is 100 times more acid than a soil with pH 6.0.

Soil pH strongly influences nutrient availability in nursery soils or container mixes. Macronutrients are readily available within a pH range of 6.0 to 8.0 but availability decreases rapidly as pH decreases. Contrarily, iron and zinc are unavailable if pH is over 7.5. Pine seedlings grow best in acid soils, ranging in pH 4.5 to 6.0. If they are grown in soils with high pH ($\geq$ 7.0), pine seedlings will develop a deep yellow color, caused by lack of iron.

Where soil reaction is too acidic for optimum plant growth, it can be raised by applying various grades of limestone. Amounts of limestone needed will vary according to the degree of pH change desired, existing soil texture, organic matter content, anf form of limestone used. When pH is too high, acid-forming fertilizers can be applied. Soil scientists and agronomists can help in choosing alternatives to upgrade nursery fertility.

Soluble salts should be monitored regularly for nursery beds and containers. Many species will not tolerate saline conditions and may be injured by high levels of sodium, boron, and chlorides found in irrigation water, particularly in drier climatic areas. Fertilizer components can alos break down into soluble salts that accumulate in soil or potting media.

7.7.d. Fertilizers

Fertilizers are classified as inorganic or organic and natural or synthetic. They can be single- or multielement in composition and are available in dry or liquid forms.

Complete fertilizers have the three primary elements, expressed as % elemental N, P_2O_5, and K_2O (potash). Thus a label with 5-10-5 on it means 5% N, 10% P_2O_5, and 5% K_2O; in 1 kilo (1000 grams) this means 50 g N, 100 g P_2O_5, and 50 g K_2O. Natural organic fertilizers or composts vary greatly in amounts of N, P, and K they contain (Table 7.3).

There are three options possible in applying fertilizers:

- mix fertilizer directly with the growing medium
- use soluble fertilizer mixes available commercially
- formulate fertiizer mixes or solutions on site.

Each option has distince advantages or disadvantages, depending on whether field- or container-grown seedlings are produced.

Mix Fertilizer With Growing Medium

This alternative is commonly used for dry fertilizers applied to nursery beds. They dan be broadcast by hand, applied by small, hand-pushed or tractor pulled drills, or applied in bands between seedling rows. Disadvantages are impracticality and high cost of mixing different fertilizers and media mixes for different stages of seedling growth and tendency of most slow-release fertilizers suitable for mixing in containers to raise media pH.

Soluble Fertilizer Mixes

This alternative is ideal for smaller nurseries needing minimal fertilizer inputs or very large nurseries with good irrigation equipment. Commercial fertilizer powders or granules are dissolved in water and are applied to seedlings with hand pump sprayers or injected into irrigation water systems. However, what works well in one location might not work well in another because of differences in local well or stream water quality, inherent chemical properties of nursery soils or pot media, and other climatic factors. Commercially formulated soluble chemical fertilizers are easy to purchase and to prepare with minimal instruction or precautions.

Formulate Nutrient Solutions on Site

This alternatige consists of making "home-made" fertilizers that are applied by hand or injected into irrigation systems. Home-made solutions or mixes are not practical for small field or container nurseries but they are very cost effective for larger nurseries that need to tailor their fertilizers to particular crops, pot mixes, and water composition. The major disadvantage is that the user must be highly trained in chemistry and be able to handle hazardous materials carefully and safely.

In genreal, use fertilizers when necessary, but only in amount really needed to correct known problems. Over-fertilization is costly and may increase diseases.

7.8 Protection and Pests

Raising seedlings in nurseries involves considerable investment of time, human, and monetary resources. Without protecting this investment adequately, large or complete seedling losses may occur. When seedlings are needed by communities to produce firewood or protect critical, water-producing watersheds, such losses will be catastrophic. Both large and small nurseries need protection from several living and non-living elements as well as against insects and diseases.

7.8.a. Property and Seedling Security

Providing 24-hour guards to protect seedlings and nursery property against animals or unwanted visitors is costly. It may be the only alternative though in areas where animal and human populations are very high. Outline guard responsiblilties well, particularly for small tools and seedlings that are actually stolen or destroyed while guards are on duty. For very poor communities, payment in food rather than direct cash may be best.

For high and low risk areas, adequate fencing may deter animals and/or people. Fences are also costly, but if built of treated wood and with proper materials, they will last long. During a long reforestation project, replacement posts can be harvested from field plantings. Hot-cold treating with diesel oil and pentachlorephenol in barrels or welded drums is easy if both materials are available. In some instances, living fences with trees, thorny plants, or local shrubs may be sufficient. If local people do not know how to construct self-closing gates and other fencing structures, consult diagrams in the Peace Corps manual on Reforestation in Arid Lands by Webber, cited in the Bibliography.

Windbreaks are very important in areas with constant, dry winds that can evaporate moisture from seed beds or containers. Use local species when possible but do not use the same species as those planted in the nursery, particularly those like Leucaena which are prolific seeders. Seeds can fly into the nursery area; they disrupt lined seed bed rows or germinate on top of pots or seed trays.

Removing the germinating invaders could distrub root systems or promote stem breakage for desirable species already germinating or growing in the beds and trays.

In native grasslands or areas where natural or man-made fires are frequent, leave a wide 2 to 3 m fire strip around the entire nursery perimeter. Weed it regularly to maintain its effectiveness. Locate water outlets at several places near the perimeter so that water is readily available should a fire jump the fire strip.

7.8.b. Pests and Disease

Symptoms

When seeds or vegetative materials are collected or imported from outside, check them for symptoms of disease or insect attacks immediately when they arrive in the nursery. Unfortunatley, even phytosanitary certificates are not always a guarantee that undesirable critters have not obtained a free ride.

Some insects are noticed by holes that are chewed in leaves; some are seen by examining the bottom side of leaves. Webs and eggs are other signs. Some common pests are those shown in Fig. 7.20.

Diseases can include sooty appearing materials, a form of fungus, rusty spots, irregularly shaped blotches of different color, sticky discharges, and troublesome to pinpoint mosaics and chlorosis color symptoms. These last two can be caused by disease organisms as well as by mineral deficiencies.

Control

If insect or disease outbreaks occur, control measures are needed quickly. These take the form of applying appropriate chemicals. Use them only as directed by labeling instructions, with respirator and adequate clothing to reduce risk of toxicity to the person applying the chemicals. Kind of control used depends on wha is locally available and kind of insect.

Insects are divided into two major groups: those which chew leaves and those which suck the juices out of the plant. The broad controls for each are quite

different. For the insects with piercing-sucking mouth parts, a direct contact poison is required, i.e. one that covers them and kills them. For the chewing mouth parts insects, depositing toxic substances on the leaves allows insects to ingest the material and eventually die.

Common sucking pests in nurseries are the aphids. They are usually found in groups along the stems and under the leaves of the young plant. Aphids secrete honeydew which can lead to the formation of sooty molds which gives the plant a dark, sooty appearance. Mealybugs are another major pest, related to the aphids. They are not too visible until they begin reproducing and their numbers increase substantially. A third common suching pest are scales. Their bodies are covered with wax, and they range in color from green to brown. Mites can occur; their damage appears as small spots, usually on the lower leaf surfaces. They have 8 legs rather than the 6 of true insects.

Chewing insects include such familiar pests as grasshoppers, caterpillars, snalis, and sometimes slugs. All are easier to spot than sucking pests because they are larger and their damage more visible. Stomach poisons are best to handle an outbreak of these destroyers.

Pesticides are applied as dusts or sprays. For limited damage, small cloth dusting bags are adequate and available. Sprays are better for larger attacks because there is less likelihood of material drifting out of the area in which it is applied. Back pumps and tractor sprayers are possible. Properly handled, either will meet the needs of the nursery manager.

Other cosmopolitan nursery diseases are damping-off and fusarium. The former hits germinating young seedlings, causing them to fall over at ground level. Captan is a good control, as a soil drench every 2 or 3 weeks. Fusarium shows up when plants are about 10 cm high, and causes them to have bluish color. Use a fungus spray like Dithane or Benlate. Other specific pesticides are listed in the Appendix.

7.9. Documentation/Record Keeping

Record keeping is more than just documenting number of seeds germinated, number of seedlings produced, and number of seedlings actually shipped out of the nursery to field sites. Managers should keep complete records of all nursery activities, from exact proportions of pot media, where and when media were obtained, whether special mixtures were substituted for usual media, amounts and/or frequencies of watering, kinds and composition of fertilizers applied, and special lifting or handling techniques used.

Detailed documentation will help refine future production schedules and may provide insights later on about seedling performance after outplanting, i.e. why they grew very well or very poorly. If other nurseries are established on similar sites in other communities in the same country, recods are useful in avoiding costly mistakes in land preparation and nursery tending practices.

A good way to keep detailed records is by maintaining a daily diary. The manager records what he did; who else worked and what they did; how many hours were spent by each person on which activity. When many species are grown, it may be more helpful to have a diary for each species.

For overall reforestation project planning, monthly nursery reports are also useful. Each manager can develop a suitable and comfortable format. Essential information should include:

- a summary of all activities from the previous month, based on the more detailed entries from the diary
- a basic plan of activities for the coming month
- a brief explanation whenever planned activities differed from those actually done

Such comparisons and explanations enable both the project manager and the sponsoring agencies to better understand and support the project and promote good lines of communication about problems as well as successful activities.

Table 1: A partial list of tools and equipment necessary to operate a nursery.

Adding machine

Adze

Anemometer

Apron, cloth
Apron, rubber

Auger, soil type

Autoclave (pressure cooker type)

Balance, analytical
Balance, Bar
Balance, spring type

Baskets, metal
Baskets, woven

Bench, sitting

Binocculars

Blackboard

Boots, rubber

Boxes, wire mesh bottom
Boxes, wooden bottom

Buckets, galvanized
Buckets, plastic

Burlap bags and rolls

Cans, gasoline
Cans, oil
Cans, watering

Carpenter supplies and tools

Chain saw

Cloth babs

Containers, Large capacity measuring, Containers, polyethylene
Containers, Tin

Crow bar

Cutters, wire

Desk lamps

Drafting supplies

Drill, electric (plus bits)

Drums, 55 gallons (several)

Electronic calculator
Electric Bag sealer
Electric Fan
Electric grinder
Files

Filter paper (seed germination)

Table 1 (con.)

Fire extinguisher

First aid cabinet

Flats (galvanized)

Fork, garden type
Forklift

Freezer (seed storage)

Funnels, metal and, plastic

Germinator

Gloves, cloth
Gloves, rubber

Goggles, industrial type

Graduated Cylinders
Gratting tape

Hacksaw and blades

Hammers
Hammer Mill (large capacity)

Hand cart

Hand lens (10x)

Hoes, Garden

Hormone for vegetative propagation

Hygrothermograph (recording)

Knives, grafting
Knives, pruning

Labels,Dagger type
Labels, plastic slip-on

Laboratory chemicals and glassware

Machetes
Mallets, wooden and rubber
Masks, repiratory
Metal working equipment

Microscope

Mirror

Mixer, soil
Nails (galvanized)
Nozzles, Fogg-it type

Nylon Line

Office supplies and equipment

Petri-dishes
pH meter electronic and portable type
Pick-axe

Pitch forks
Plastic trans (seed germination)
Pliers

Polyethylene bags
Polyethylene sheeting Black

Polyethylene sheeting clear

Rakes, garden

Rain guage station

Rasps, wood

Refrigerators

Rulers metric

Saran shade
20, 30 an 50%

Saw, electric

Screw drivers

Seed blower
Seed divider
Seed moisture testor
Seed separator
Seed sieve
Shovel
Shredder (for compost)
Side cutters

Table 1 (con.)

Soil moisture tester

Soil sieves (large capacity)

Soil Sterilizer

Soil thermometer

Soldering equipment

Spade

Spreay tanks
3 gallons (Fertilizer and pesticides)

Stakes (wooden, treated)

Storage bins

Tables

Tape measures

Test tubes

Thermometers, (recording)

Tractors

Vise

Wagons

Welding equipment

Wheel barrows

Wire (galvanized)

Wire mesh 1/4", 1/2" sizes

Wrenches (plumbing type)

Table 7.2 Key to the classical symptoms of various nutrient deficiencies.

Symptoms	This symptoms may be related to:
a. The dominant symptom is chlorotic foliage (discoloration).	
b. Entire leaf blades are chlorotic.	
c. Only the lower leaves are chlorotic followed by necrosis (tissue death) and leaf drop.	Nitrogen
cc. Leaves on all parts of plant are affected and often have a beige cast.	Sulfur
bb. Yellowing of leaves takes the form of interveinal chlorosis.	
c. Only older leaves exhibit interveinal chlorosis.	Magnesium
cc. Only younger leaves exhibit interveinal chlorosis.	Iron and/or Manganese
d. This is the only symptom.	
dd. While younger leaves have interveinal chlorosis the tips and lobes of leaves remain green followed by veinal chlorosis and rapid, extensive necrosis of leaf blade.	Copper
ddd. Young leaves are very small, sometimes missing leaf blades altogether and internodes are short giving a rosette appearance.	Zinc
aa. Leaf chlorosis is not the dominant symptom.	
b. Symptoms appear at base of plant.	
c. At first, leaves are dark green and smaller than normal. Later, purple pigment develops in older leaves.	Phosphorus
cc. Margins of older leaves burn or small necrotic spots appear on older leaf blades.	Potassium
bb. Symptoms appear at top of plant.	
c. Terminal buds die giving rise to a witches broom.	Boron
cc. Margins or young leaves fail to form sometimes yielding trap-leaves. Growing point ceases to develop leaving a blunt end.	Calcium

Table 7.3 Average nutrient content of several animal manures prior to composting.

Nutrient or element	Cattle	Chicken	Horse (%)	Sheep	Swine
Nitrogen (N)	0.53	0.89	0.55	0.89	0.63
Phosphorous (P_2O_5)	0.29	0.48	0.27	0.48	0.46
Potassium (K_2O)	0.48	0.83	0.57	0.83	0.41
Calcium (Ca)	0.29	0.38	0.27	0.21	0.19
Magnesium (Mg)	0.11	0.13	0.11	0.13	0.03
Copper (Cu)	0.00079	0.0006	0.00079	0.00079	0.00016
Manganese (Mn)	0.003	0.003	0.003	0.003	0.0008
Zinc (Zn)	0.0016	0.0021	0.002	0.002	0.0006
Chorine (Cl)	0.03	0.08	0.08	0.08	0.03
Sulfur (S)	0.036	0.06	0.036	0.06	0.03
Boron (B)	0.016	0.016	0.016	0.016	0.0005
Organic matter	16.74	30.70	27.06	30.70	15.50
Moisture	81.33	64.82	68.85	64.82	77.56
Ash	2.06	4.72	6.70	4.72	6.02

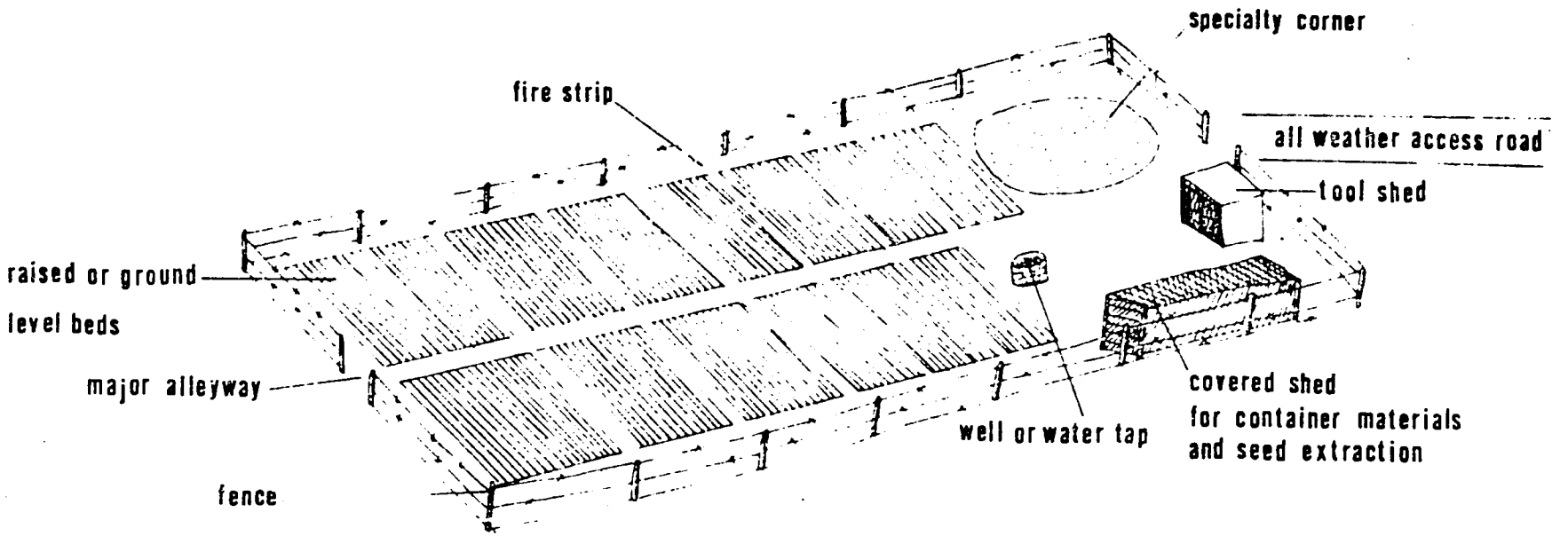

Figure 7.1 Generalized nursery layout. Adapted from ACTION/ Peace Corps, 1977.

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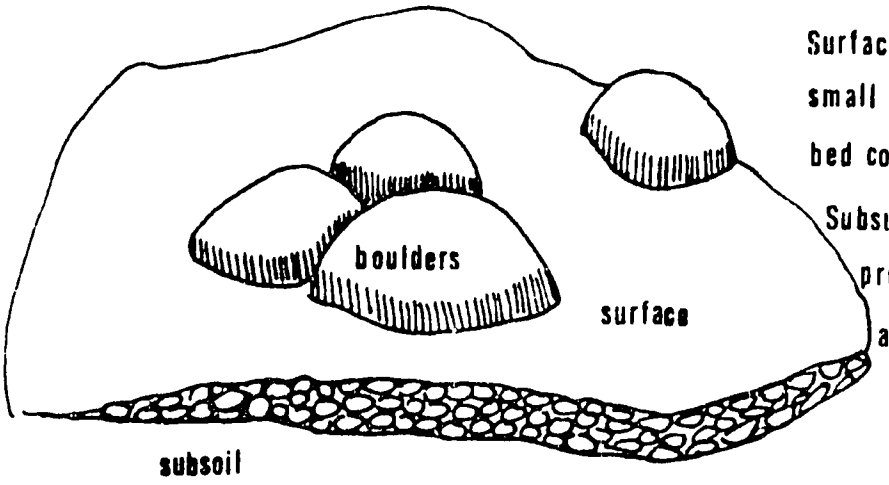
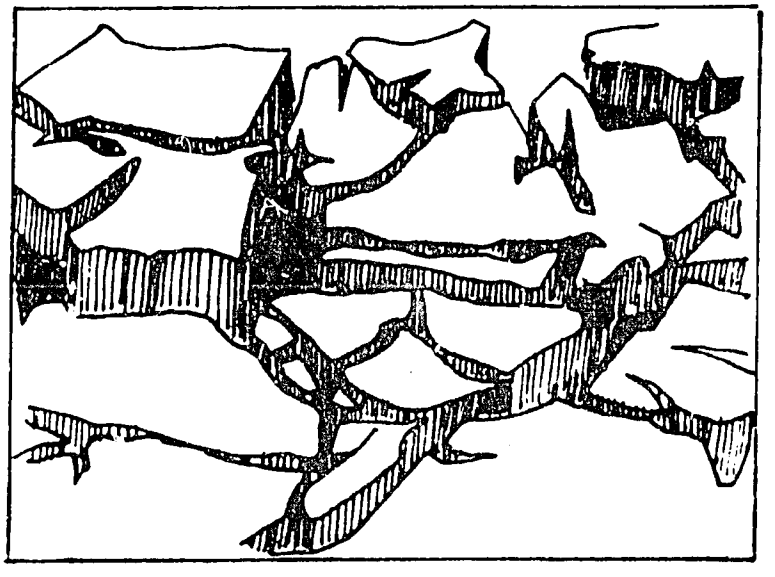
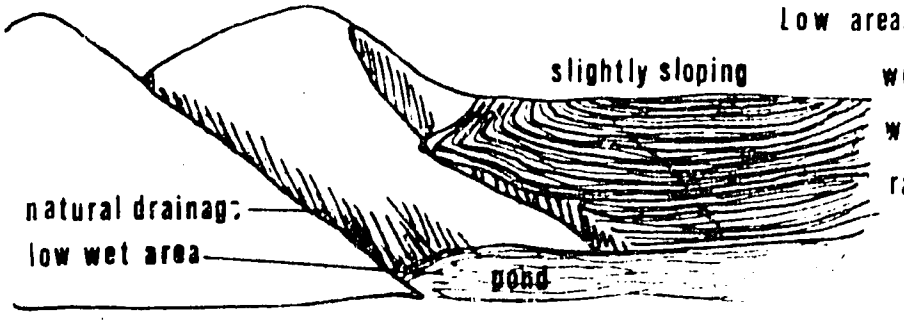


Surface rocks prevent use of small machines and restrict bed construction.

Subsurface rocks or "pans" prohibit good root penetration and may indicate drainage problems.



Cracked soil indicates high clay content and water shortage in dry periods or poor drainage in wet periods.



Low areas and drainages are too wet in rainy periods. Choose areas with slight slopes so that excess rain drains off site adequately.

Figure 7.2 Soil considerations when selecting nursery sites. Adapted from ACTION/Peace Corps, 1977.

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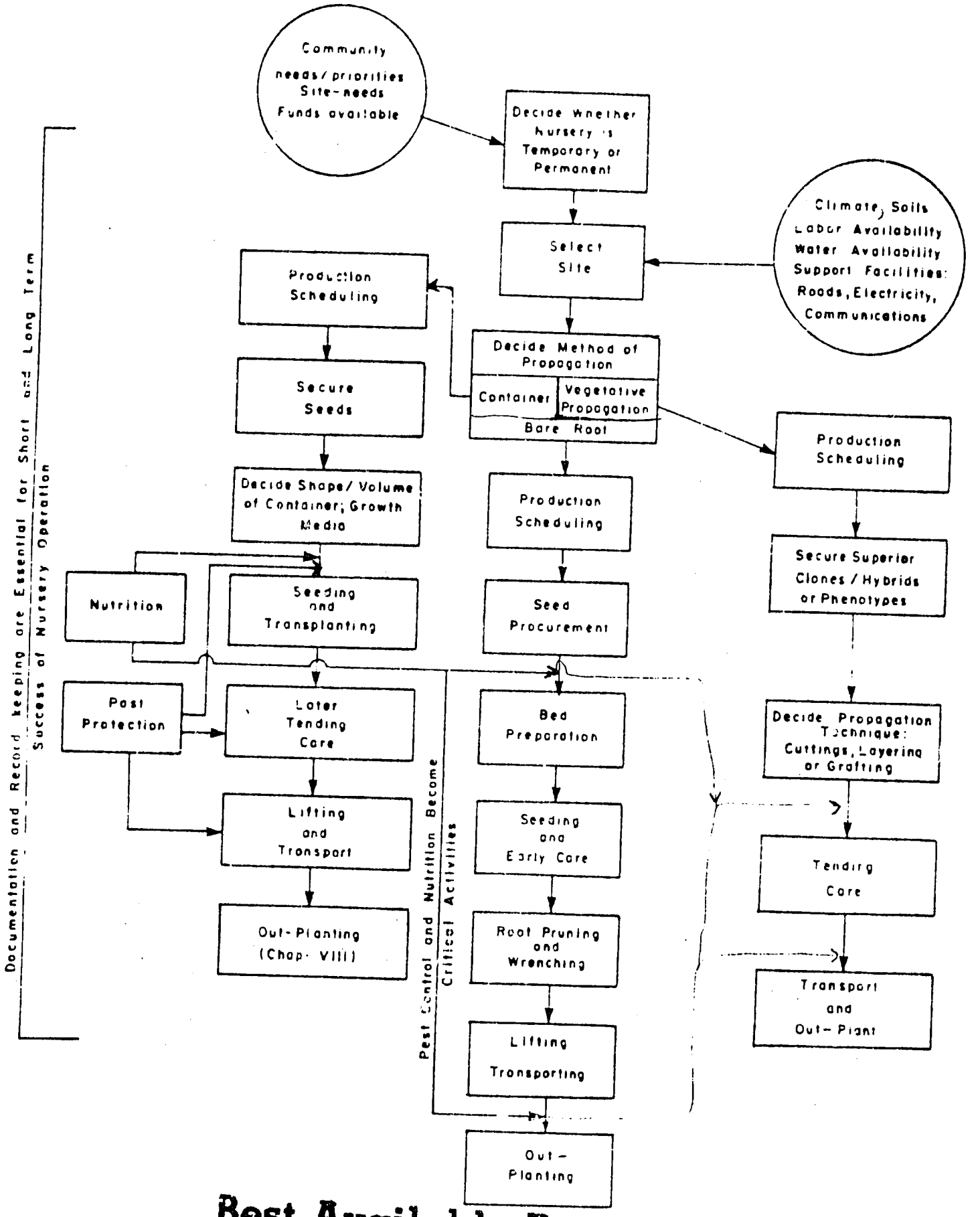

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Figure 7.3 Flow-chart of procedures for successful nursery establishment.

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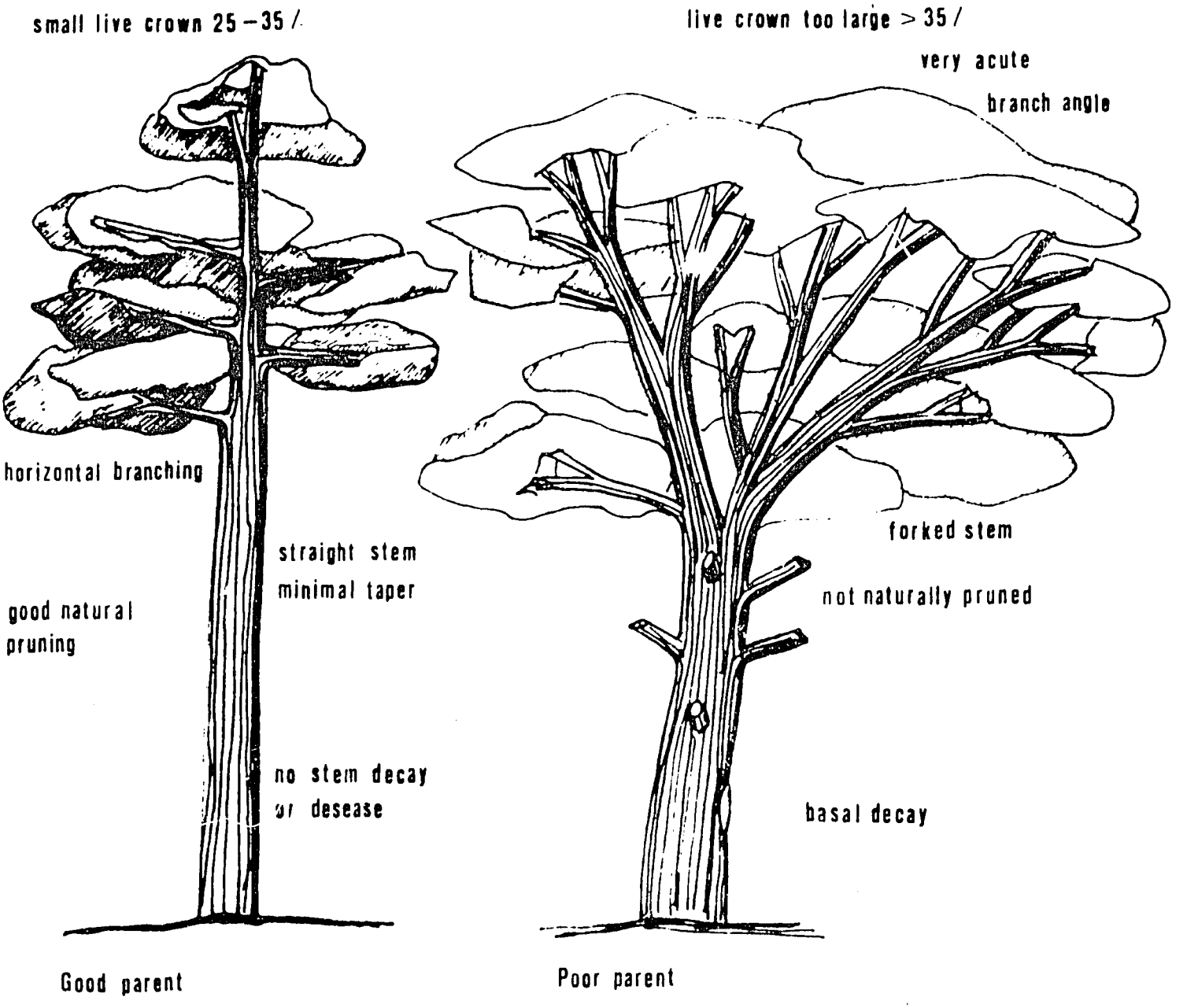

Figure 7.4 Guides for seed selection from parent trees.

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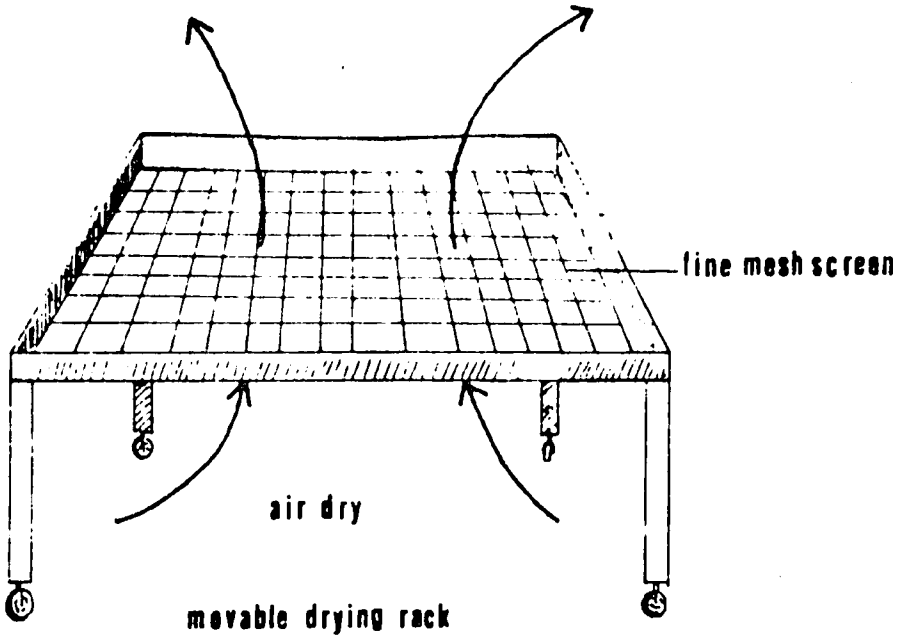

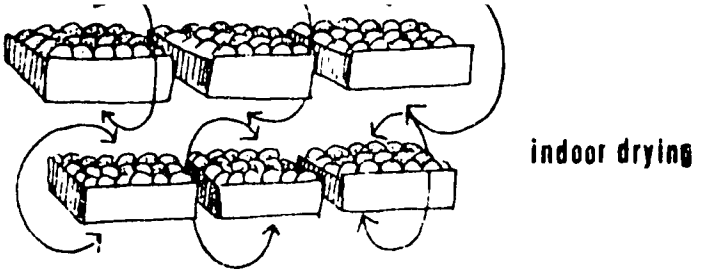

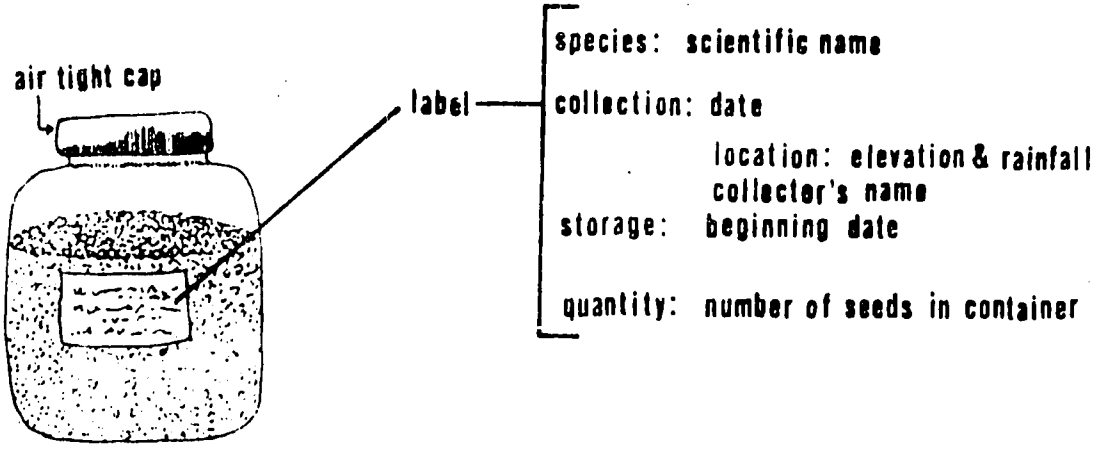

storage and labeling

Figure 7.5 Seed extracting, drying and storage. Adapted from ACTION/Peace Corps, 1977.

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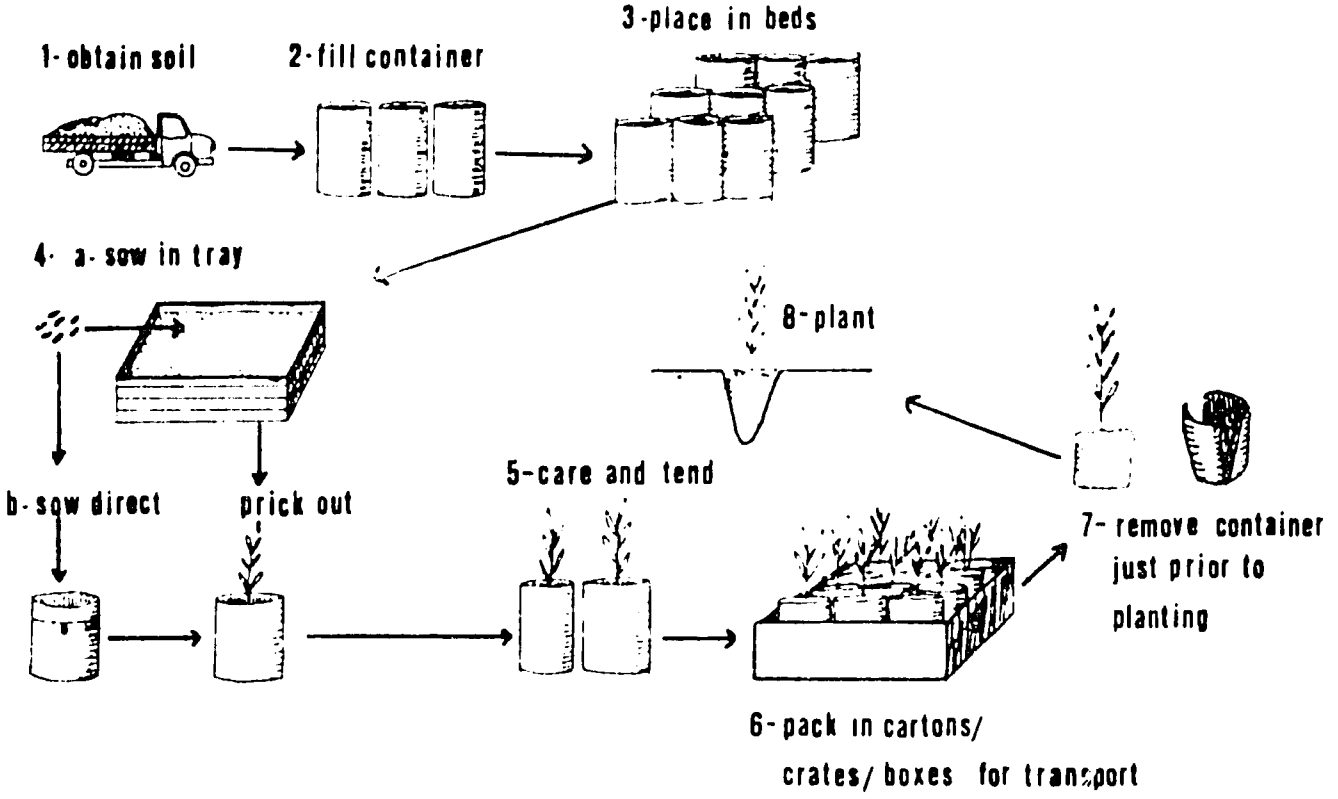

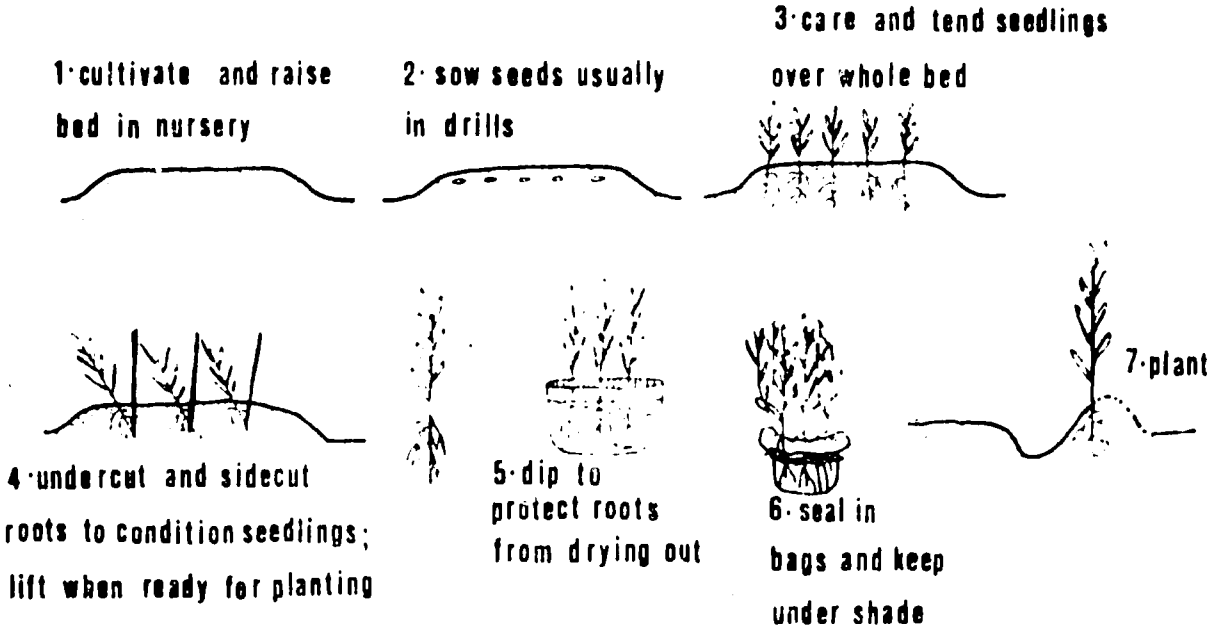

Figure 7.6 Container and bare-root nursery procedures. Adapted from J. Evans, 1982.

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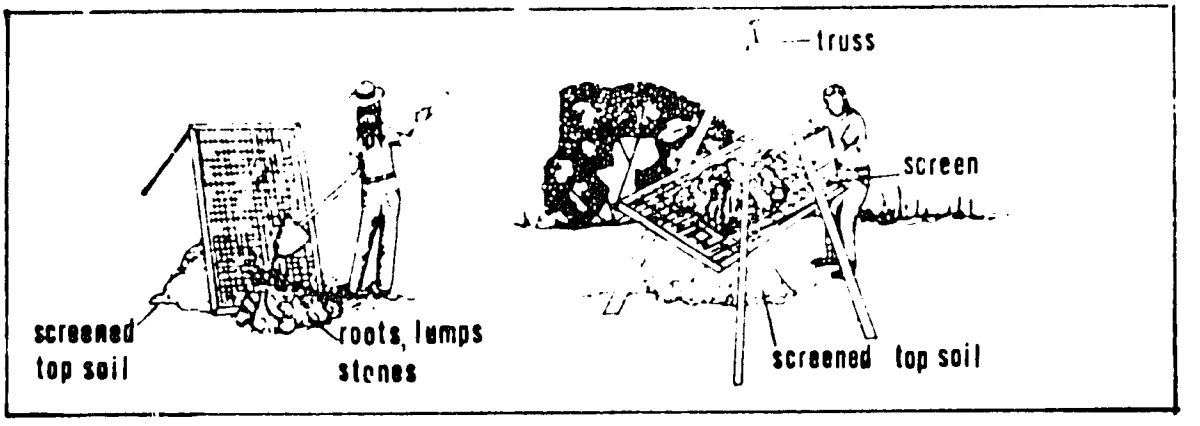
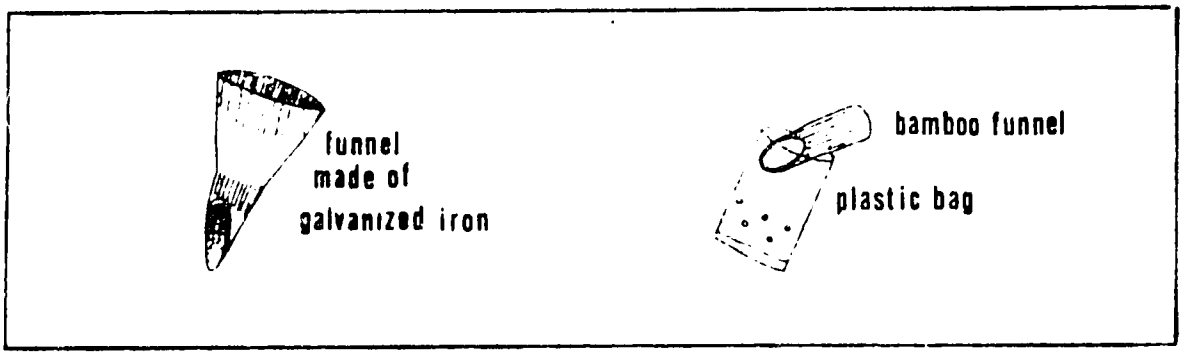
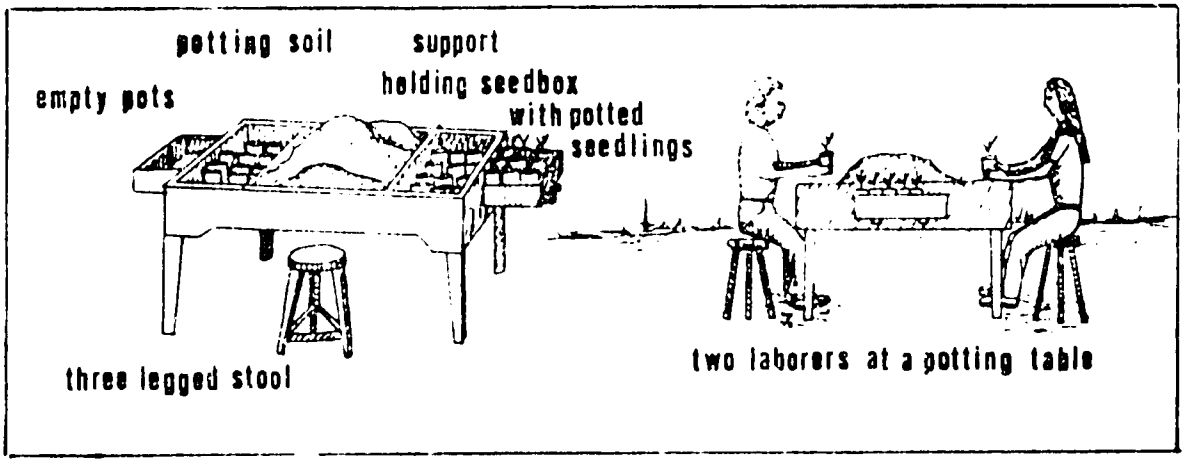


A Soil/mixture screening



B Funnel for filling bags, tubes, or other containers



C Potting table

Figure 7.7 Containerized techniques. Adapted from German Technical Agency (GTZ), 1975.

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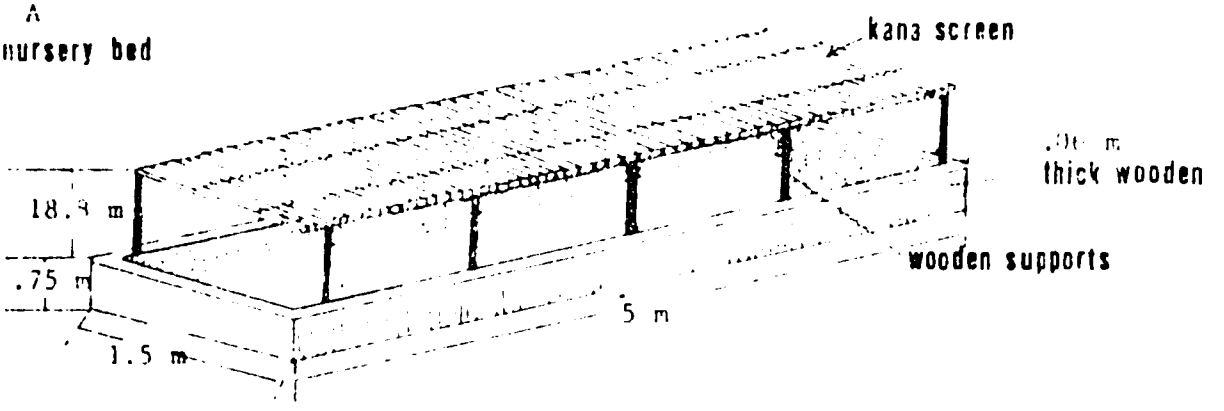
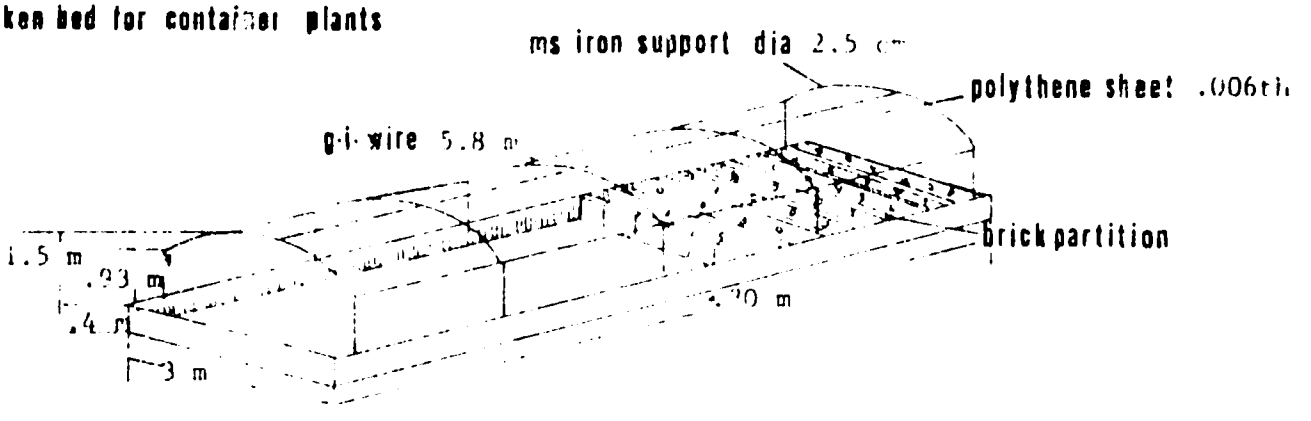
A

Raised nursery bed



B

Sunken bed for container plants



C

Covered shed

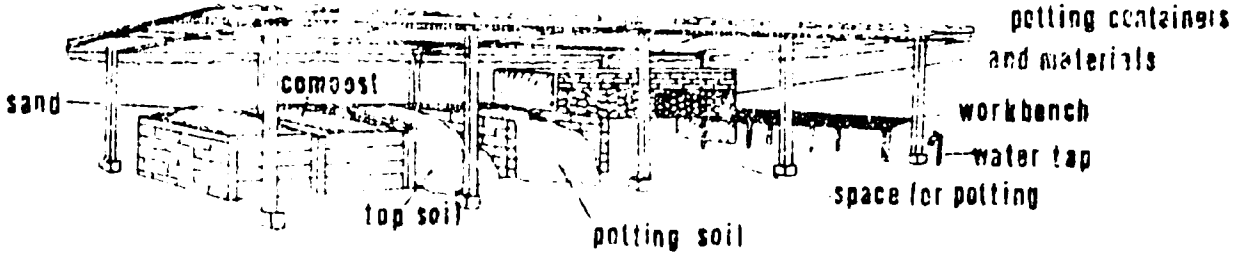


Figure 7.8 Nursery structures. Diagrams A and B by A. Krochmal, diagram C adapted from German Technical Agency (GTZ), 1975.

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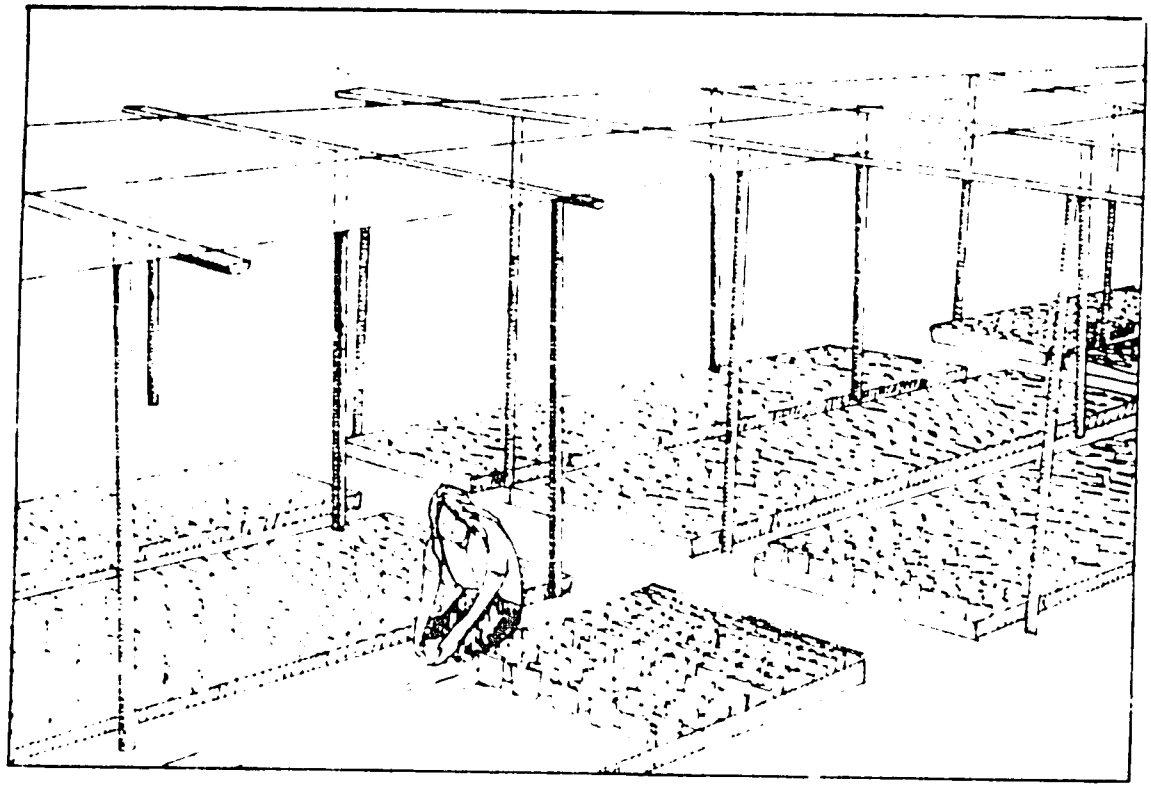
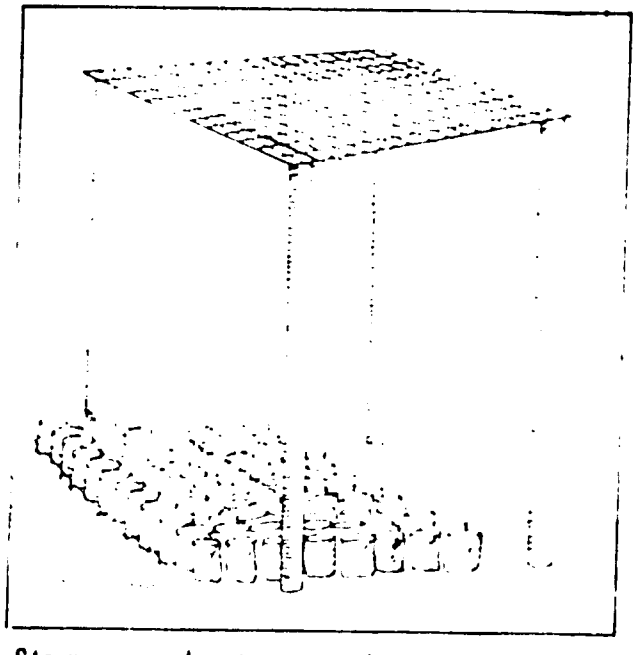
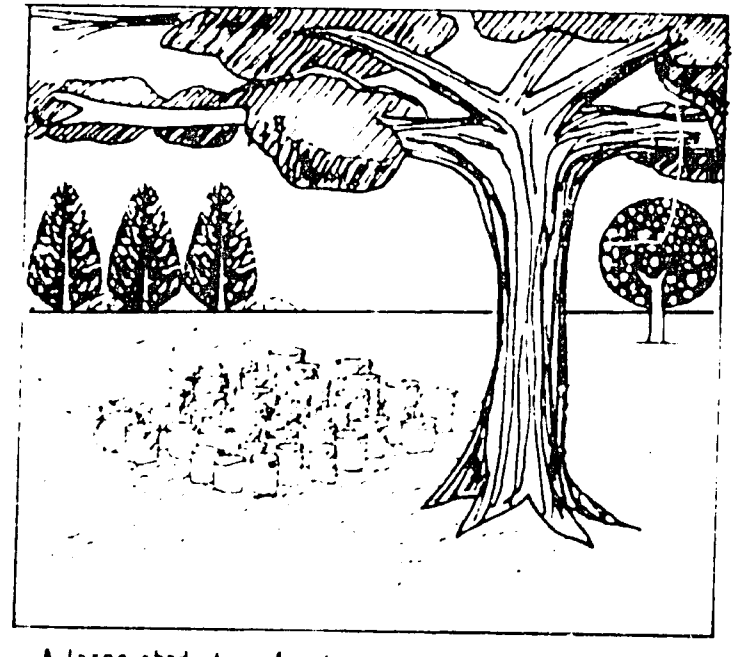


T-bar shading screens, using plastic maya material; palm fronds or bamboo kana screening could be used



Straw or reed mats over poles



A large shade tree for temporary "flying" nurseries

Figure 7.9 Nursery shading alternative. Adapted from D.G. Paul, 1972 and ACTION/Peace Corps, 1977.

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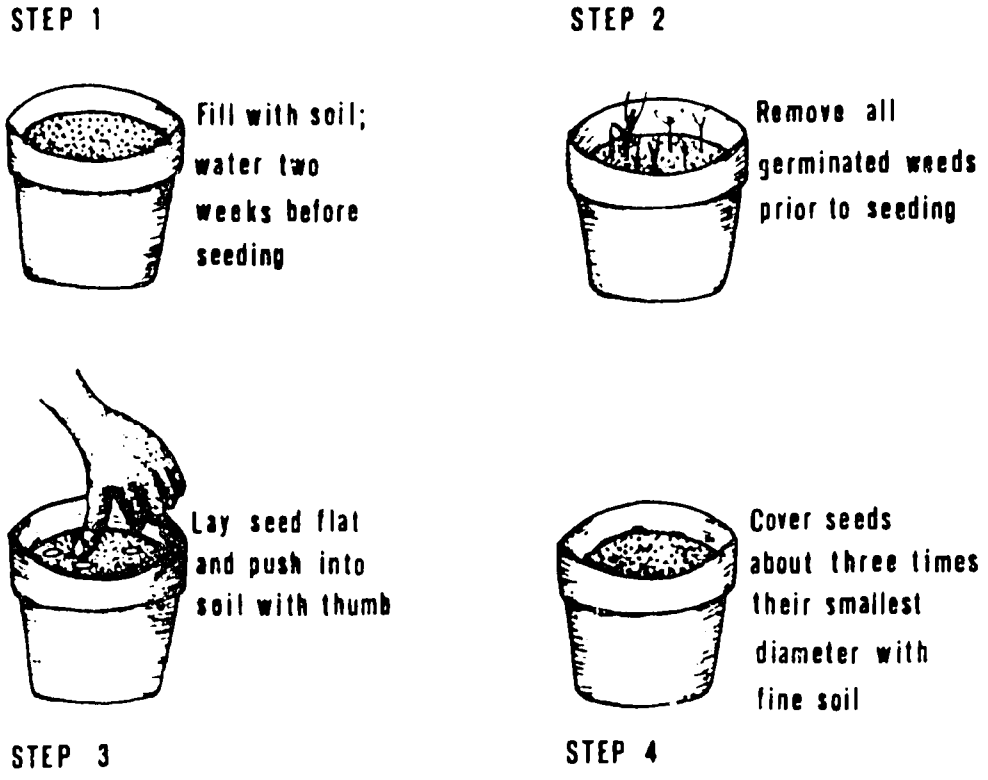

Figure [illegible] Seeding procedures for medium and large seeds. The same technique can be followed when seeding onto raised seed beds. Adapted from ACTION/Peace Corps, 1977.

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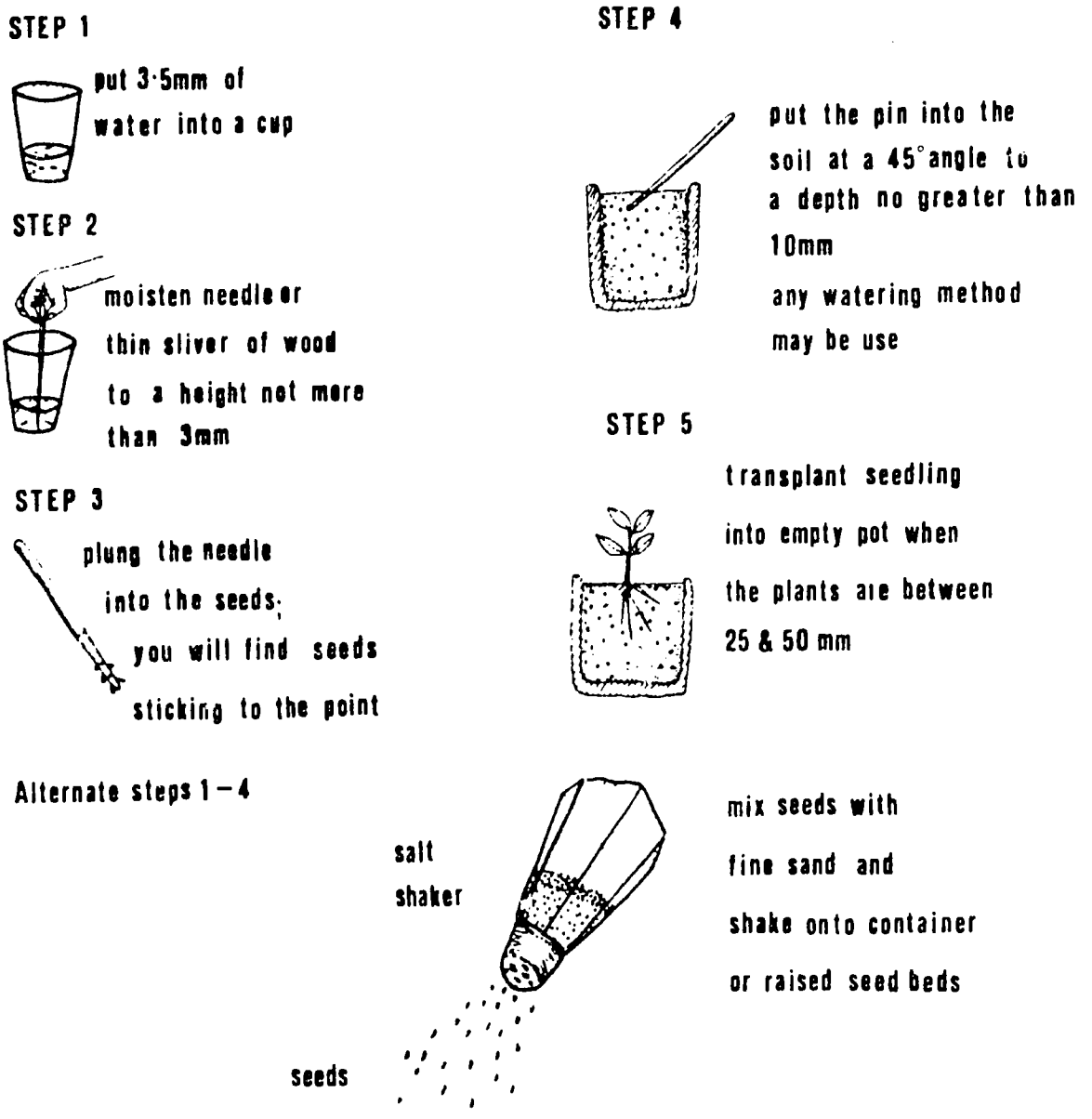

Figure 7.11 Seeding very tiny seeds like eucalypts or kadam. Adapted from ACTION/Peace Corps, 1977.

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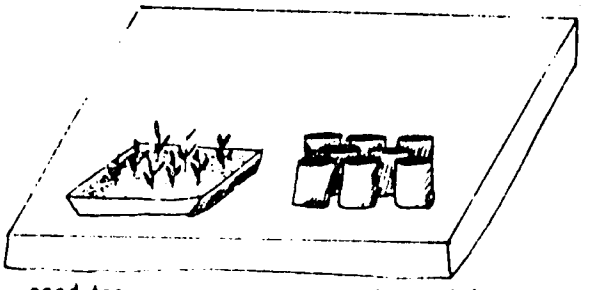
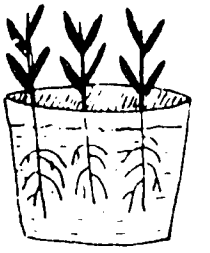
Step 1



seed tray empty containers

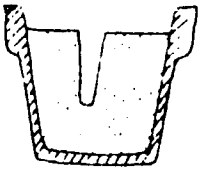
Lift out seedlings from pots or seed tray media with stick or small shovel.

Step 2



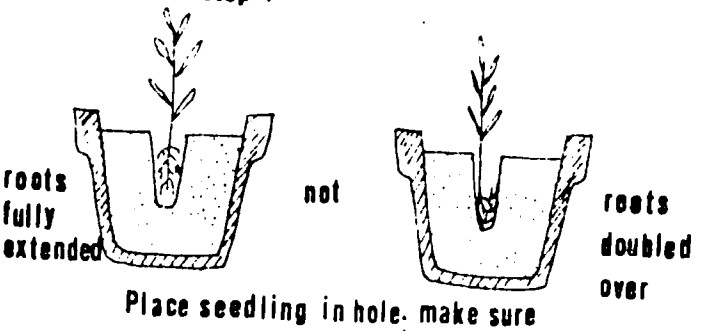
Place small seedling bundle in bowl of water to keep roots moist; if necessary trim roots with scissors to 3–5 cm length.

Step 3



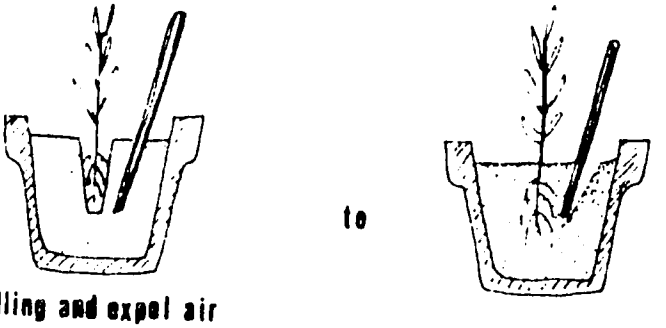
Prick small hole in center of pot or container cavity with sharpened stick, dowl or pencil.

Step 4



Place seedling in hole; make sure root system is fully extended lenghtwise, <u>not doubled over in J–shape</u>

Step 5



After firming up, remove stick.

Firm up seedling and expel air from hole by putting stick next to hole and pushing soil towards seedling.

Figure 7.12 Transplanting or pricking-out procedures.

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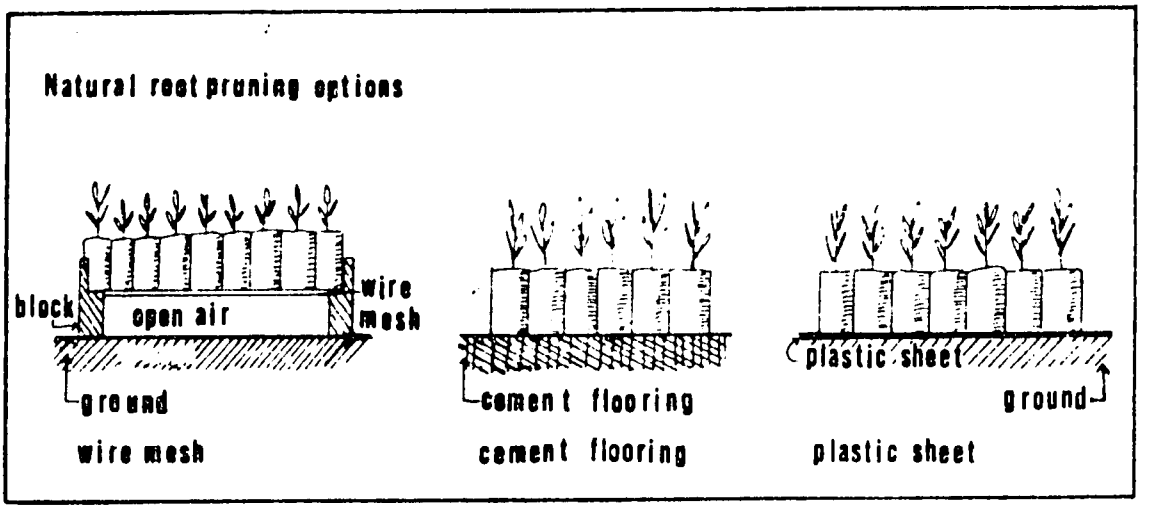
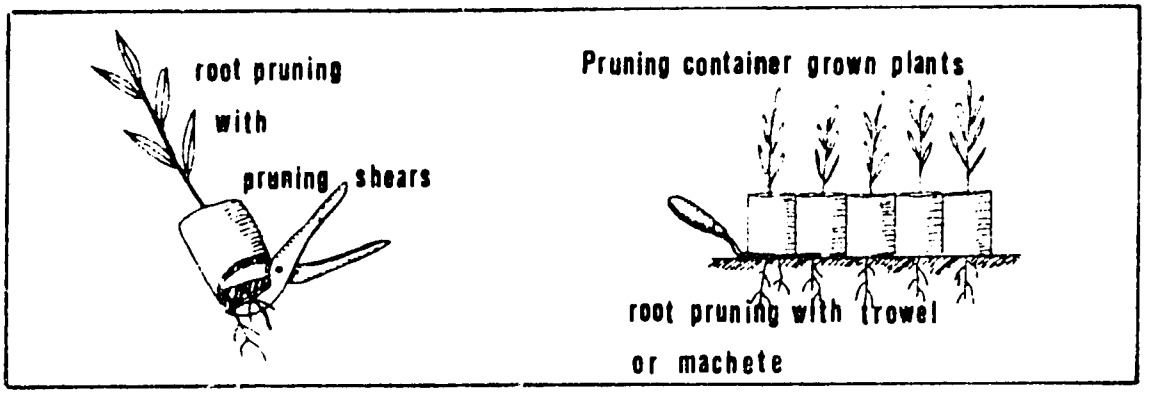
A



B



C

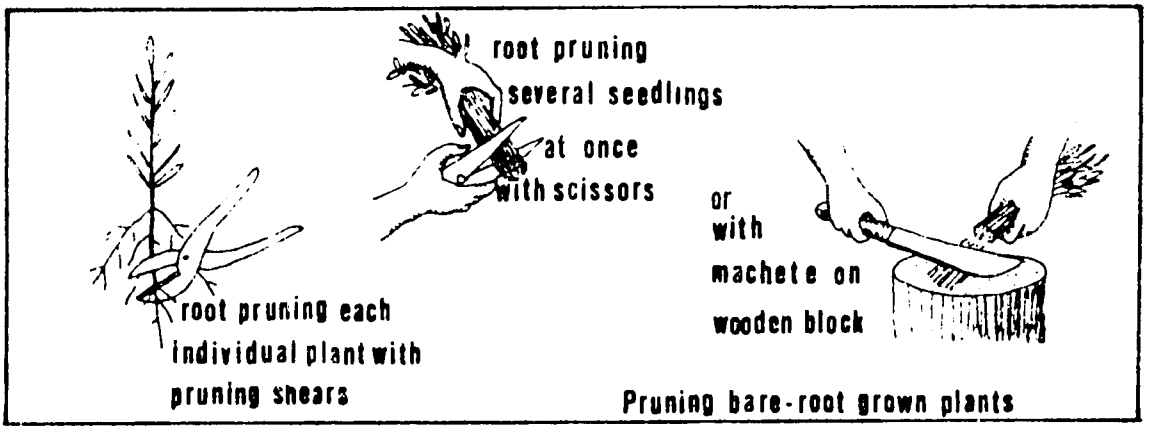


Figure 7.13 Pruning and lifting of seedlings. Adapted from German Technical Agency (GTZ), 1975.

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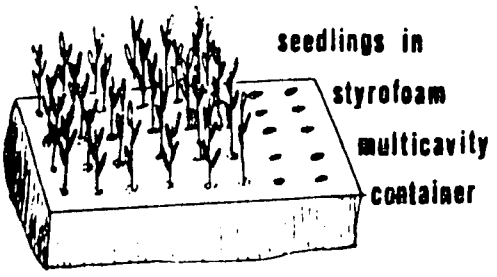
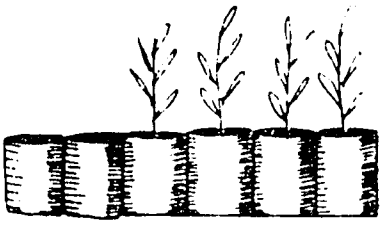
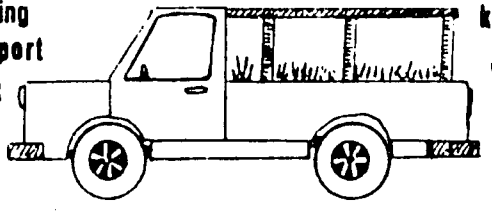
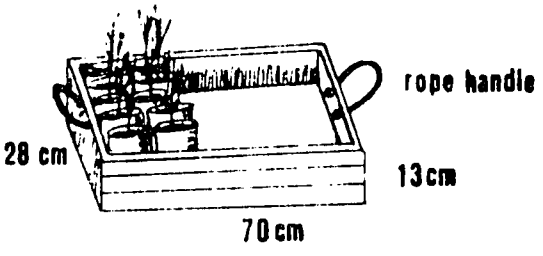




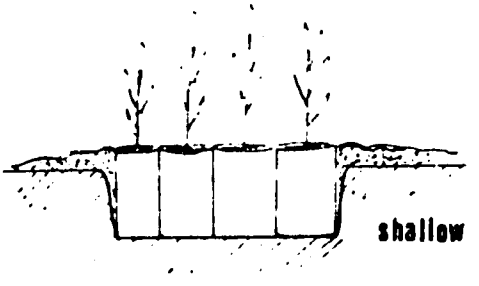
repacked seedlings in
plastic sheet with tear-away
packets



keep transport vehicle covered
with tarp or sheet to avoid
sun damage and reduce transpiration
loss by wind



wooden carrying tray



shallow trench

plant inmediately at site or "heel in" within
trench if planting must be delayed.

Figure 7.14 Transporting of nursery seedlings to field outplant sites.

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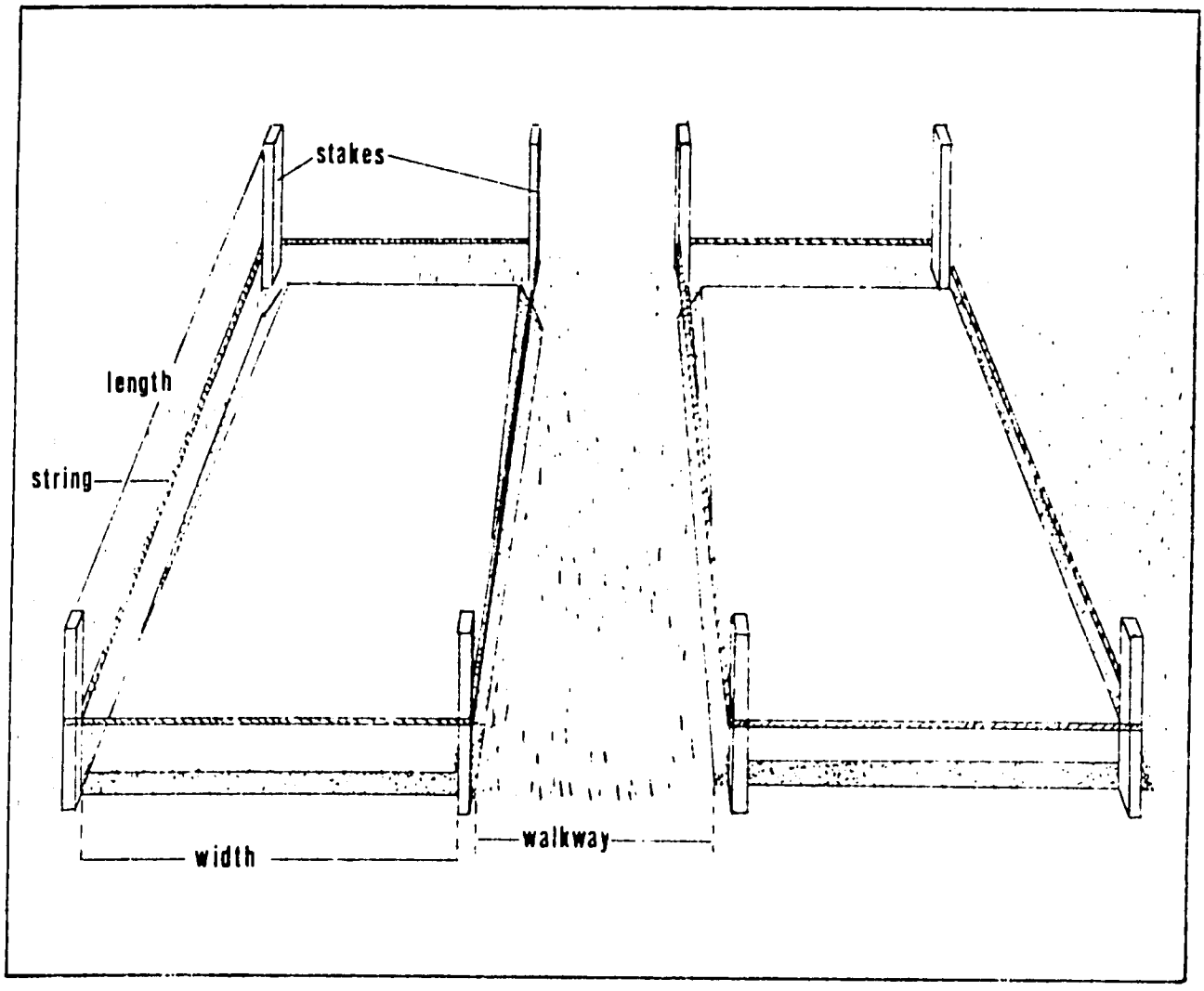

Figure 7.15 Proper method of laying-out small, ground-level seed beds for bare-root nursery stock. Adapted from Peace Corps, 1982.

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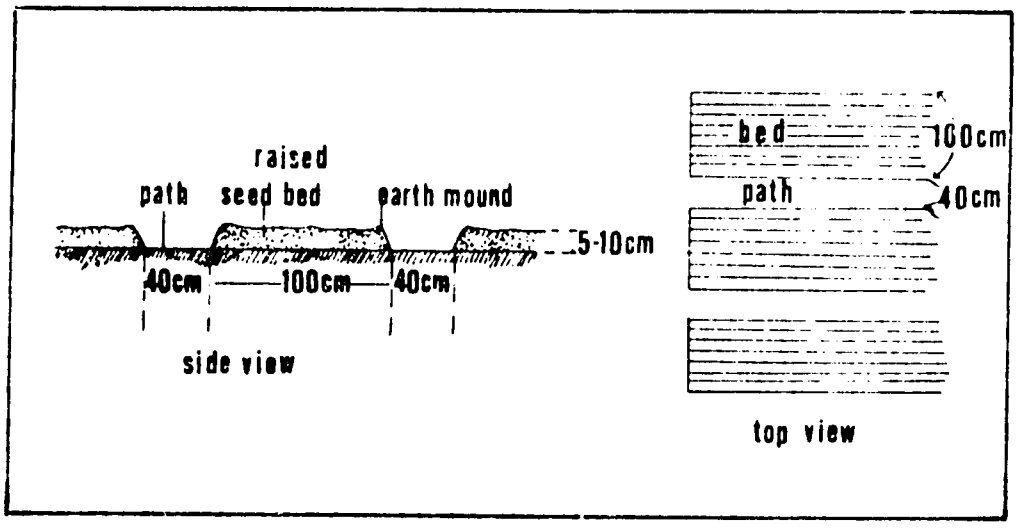
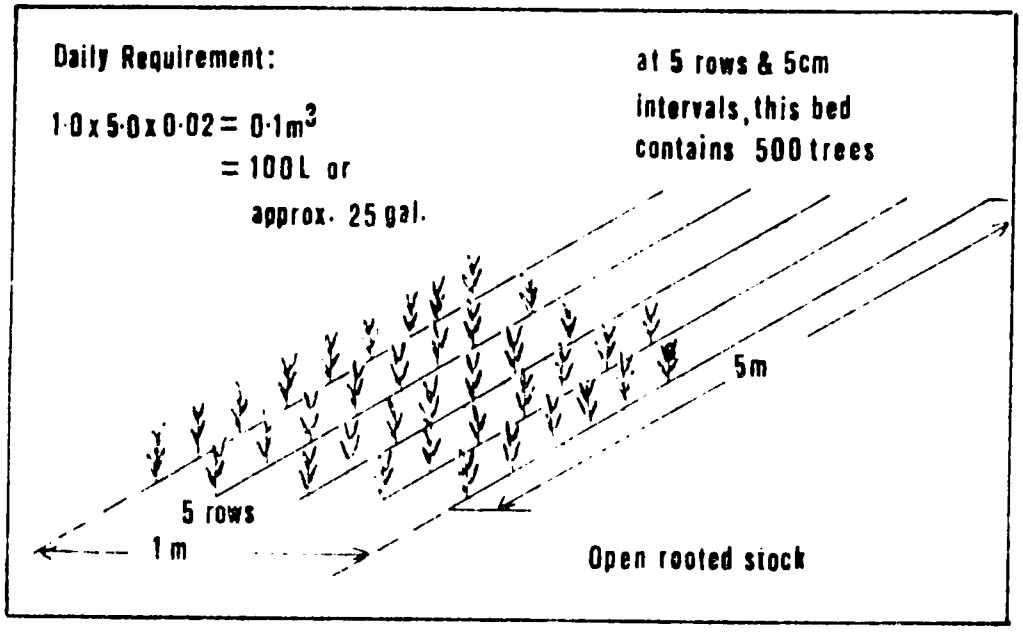


A. Raised seedbed for overhead irrigation.



B. Water need calculations.

Figure 7.16 Nursery bed irrigation considerations. Diagram B from ACTION/Peace Corps, 1977.

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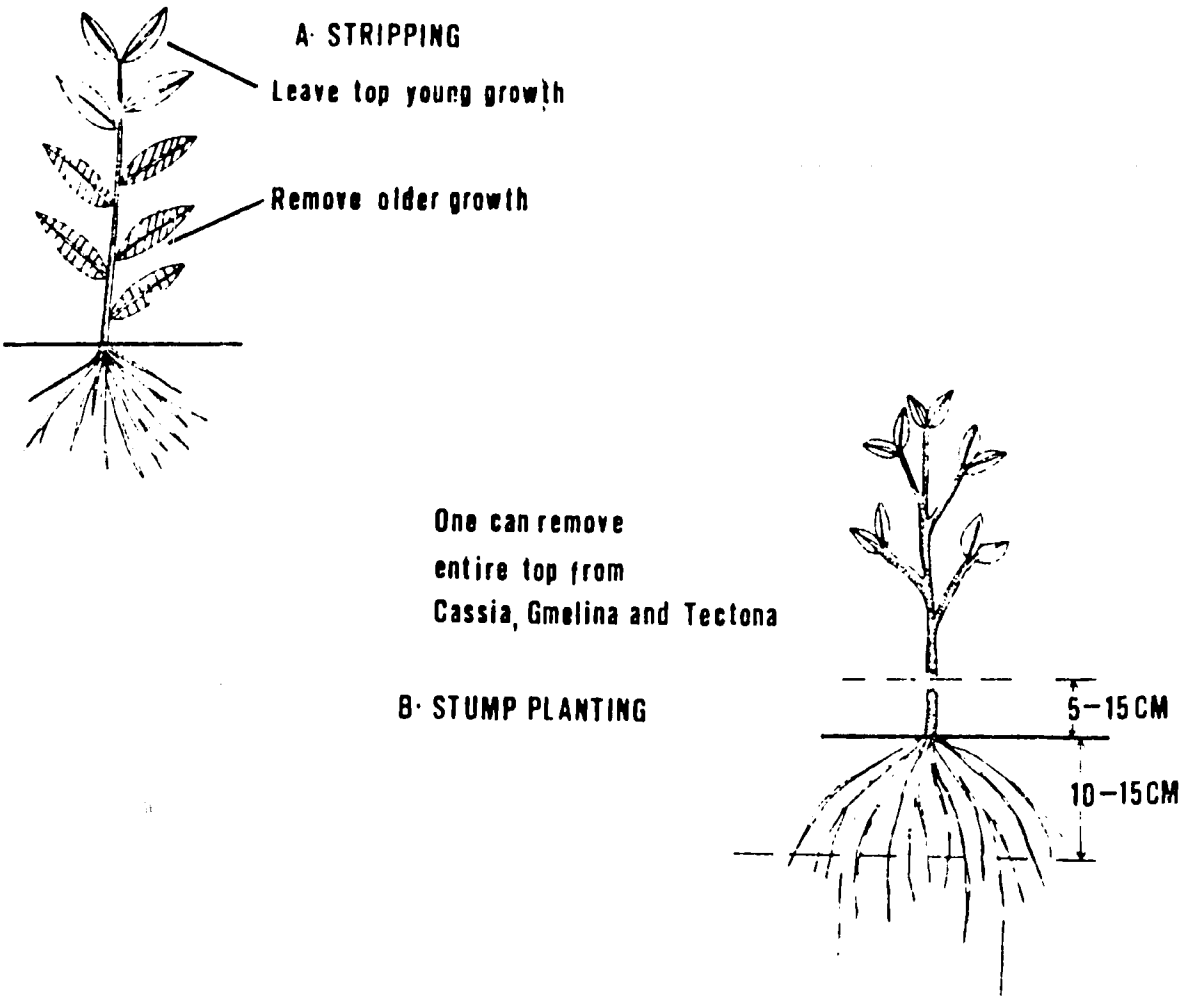

Figure 7.17 Procedures for stripping seedlings before transplanting to field (A) or making stumps for outplanting (B). ACTION/Peace Corps, 1977.

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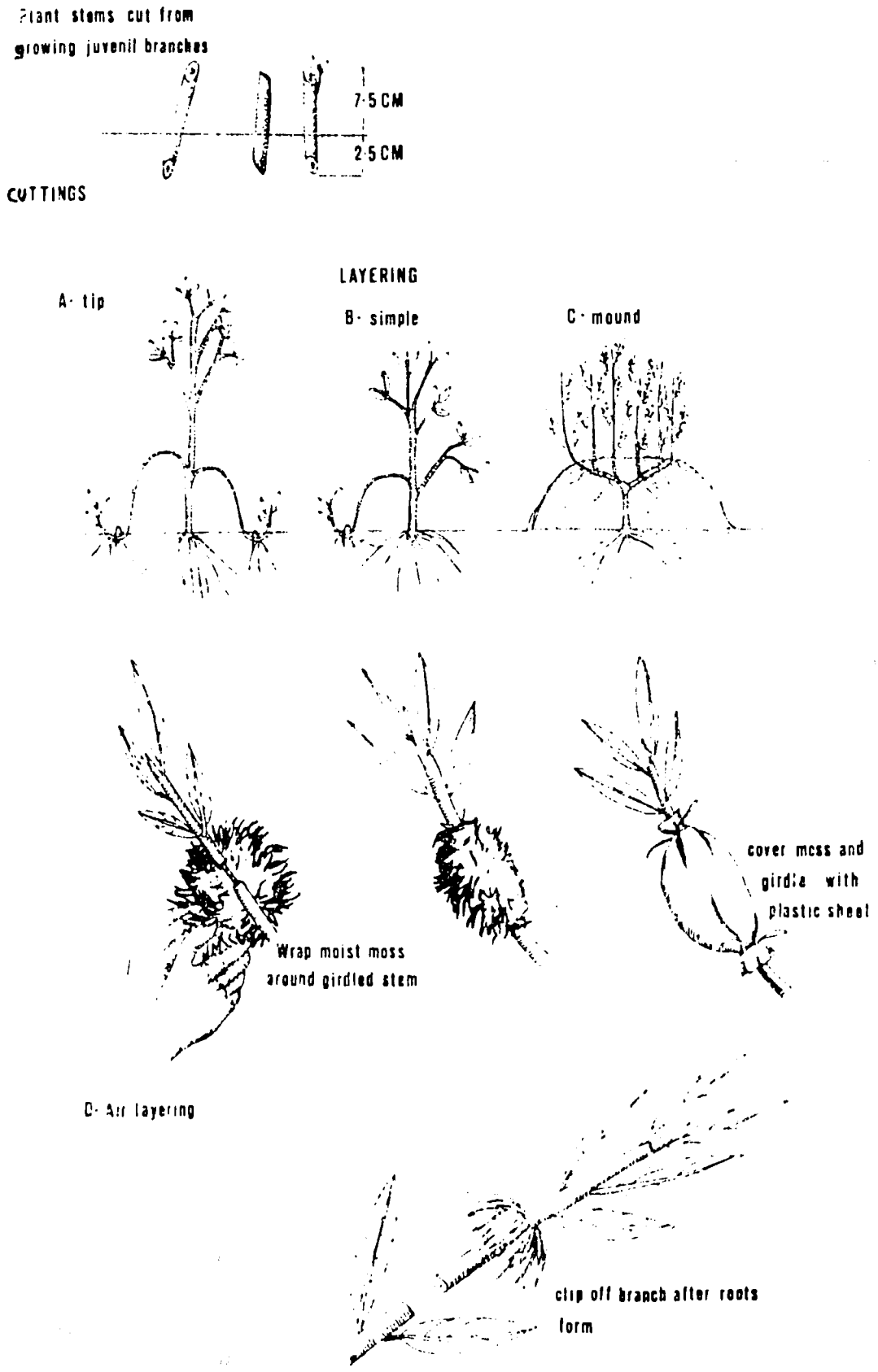

Figure 7.18 Vegetative propagation techniques. Adapted from K.W. Dorman, 1976, and Peace Corps 1982.

Best Available Document

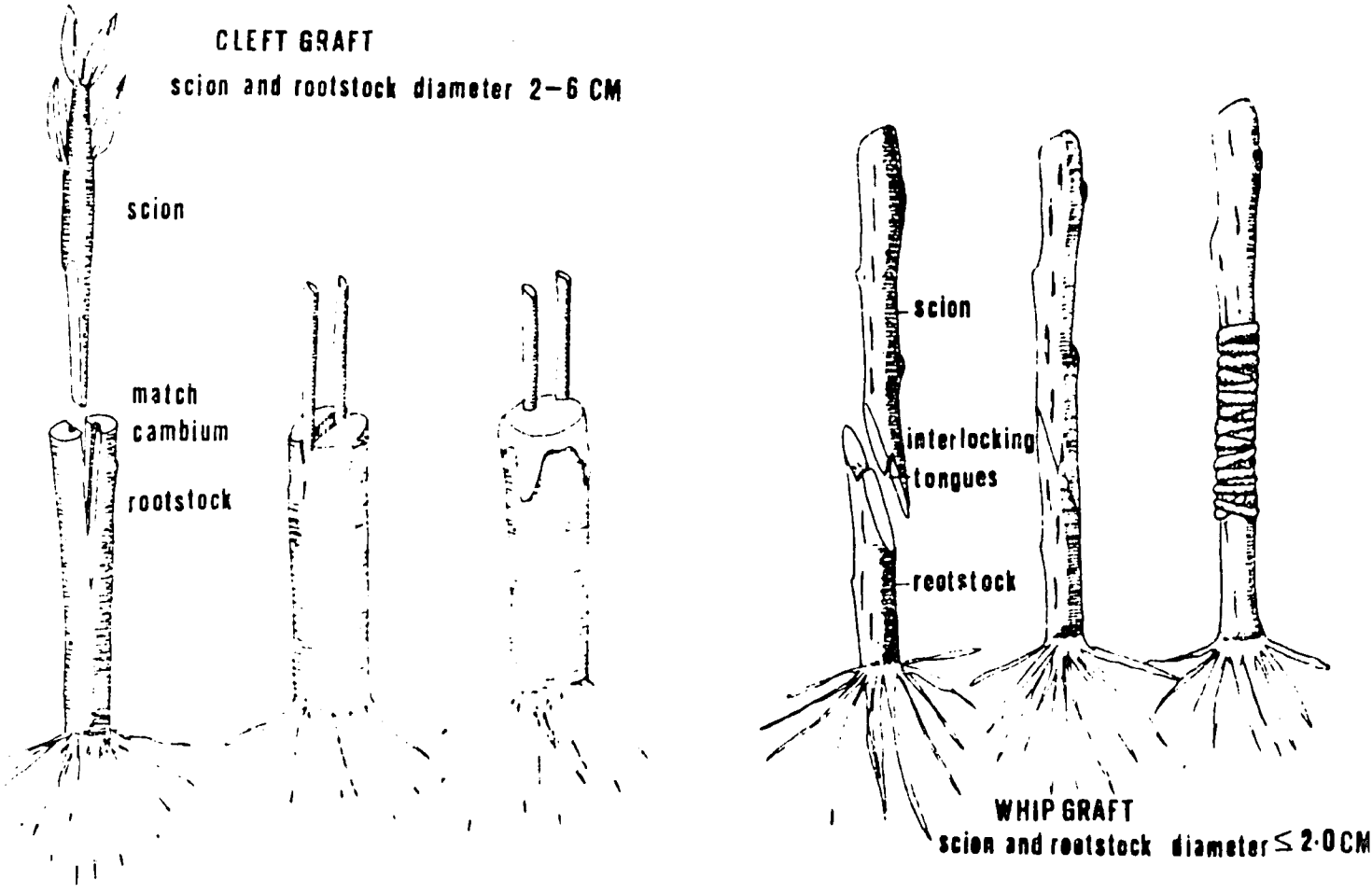

Figure 7.19 Vegetative propagation by grafting. Adapted from Peace Corps, 1982.

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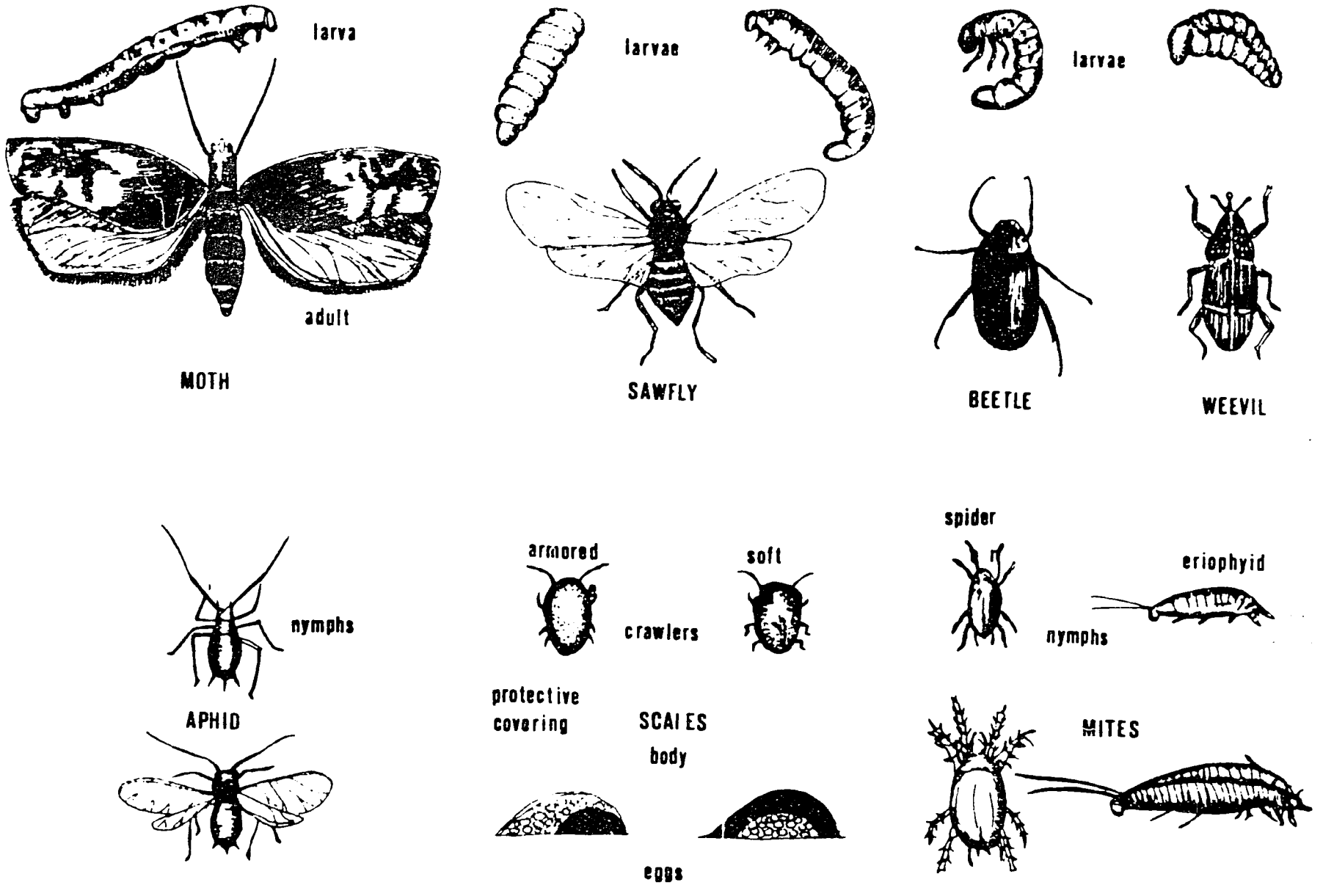

Figure 7.20 Common nursery insects.

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Appendix - Nursery Management

SPECIFIC PESTICIDES

The accompanying list is a generic list; most of the time the item will be sold under a trade name. The package label will have to be checked to see if it contains any of the suggested chemicals. Another point in the use of chemical sprays is compatability, or will two different ones mix together effectively without damage to the plants being treated. Dealers can help answer this question. The list given is a very small part of the large number of control materials available, but include the most commonly sold in all parts of the tropical world.

In any sort of application when equipment is used, be positive the tank is thoroughly cleaned before as well as after use. Follow carefully all directions for mixing, applying, and use of the materials. Empty bags should be buried. All chemicals should be kept in as secure storage as is possible to avoid accidental injury.

Some generic chemicals useful for nursery pest controls:

Insecticides

Malathion - widely available, sometimes odorous, useful to control aphids, scale, mealybugs and some chewing insects.

Metaldehyde - useful for control of snails and slugs.

Nicotine sulfate - an old, reputable and effective control for aphids and other sucking insects.

Supracide 2E - a miticide.

Ethion - useful in controlling leafhopper, mites and thrips.

Rotenone - a plant material used both as a contact and stomach poison, and has no toxicity to man.

Carbaryl - the use of the compound should be avoided, as it is tremendously toxic to the bee population.

Miticides

Ovex - extremely effective but use requires special care.

Chlorobenzilate - used for mites with good results.

Fungicides

Methyl thiophanate - effective for the control of soil fungi, used as a soil drench.

Bordeaux mixture - probably the most practical fungicide available, and with a little soap long lasting even under rainy conditions. For very small amounts dissolve 4 ounces of copper sulfate in one gallon of water. The simplest way to do this is to tie the crystals in a cloth bag and hang them at the top of the water. When the copper is in two gallons of water, then add the bleu copper sulfate solution to the lime solution, making three gallon of a 4-2-50 Bordeaux mix. Use immediately because the effectiveness is lost if it stands around. A little sop mixed in with the final solution will make it stick and spread even more than it does on its own.

Formaldehyde or formalin - can be used on bare ground prior to planting as it is enormously toxic to plants, but is excellent as a preplanting drench to control soil borne fungi. Fumes are toxic to people!

Lime sulfur - used to control mildews, it is also as a miticide.

Maneb - useful in controlling spot diseases, i.e., leaf spot.

Soil fumigants

Ethylene dibromide - one of the most effective of the soil fumigants, it is used to control soil insects and nematodes. Soil treated with this material cannot be planted for at least three weeks as it is very toxic. It is sold under a very great variety of commercial names. It is toxic.

Nicotine - sold under trade names, it is safe to use and effective for soil borne insects.

Spreaders

Substances to increase the adherence of sprays to plants. A few shavings of ordinary soap will serve the purpose, as will a small amount of detergent.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

SOILS AND PLANTATION RESEARCH COURSE
July 20-22, 1983

Wednesday, July 20

OFFICE

30 min.	A -	Introduction to Soils: Differences between tropical and temperate areas?
10 min.		Slide Show: Soils in the Caribbean
5 min.		Discussion/Questions
30 min.	B -	Introduction to Plantations: Plantations vs. natural forests vs. both?
10 min.		Slide Show: Major plantation species in the Caribbean
5 min.		Discussion/Questions
15 min.	C -	The 3 R's of Research: Restrict, Randomize, Replicate
5 min.		Discussion/Questions

9:20 - 9:30 AM Break

FIELD

9:30 - 10:15 AM	Travel to Cubuy area
10:15 - 11:00 AM	Pine/Soils/Nutrient Cycling
11:00 - 11:45 AM	Natural Forests/Soils
11:45 - 12:30 AM	Lunch/Discussion
12:30 - 12:45 PM	Travel to Caracol site
12:45 - 1:15 PM	*Pinus caribaea* var. *hondurensis* spacing trial
1:15 - 3:00 PM	Island-wide adaptability trial
3:00 - 4:00 PM	Travel back to ITF/Río Piedras

Itinerary for March 16, 1983

1:45 - 2:10	PM	Travel to El Verde
2:10 - 2:40	PM	Natural Forest/Soils/Nutrient Cycling
2:40 - 2:50	PM	Travel to Harvey plot
2:50 - 3:30	PM	Old Mahogany/Soils/Nutrient Cycling
3:30 - 4:30	PM	Travel back to ITF/Río Piedras

SOILS AND PLANTATION RESEARCH COURSE

Thursday, July 21

OFFICE

	A -	Tree improvement/genetics in plantation management
25 min.		Discussion/Questions
	B -	Phenology and flowering in pines
25 min.		Discussion/Questions
	C -	Pine/Hardwood provenance trials
25 min.		Discussion/Questions
15 min.		Slide Show: Flowering/seed production considerations in small islands

9:00 - 9:15 AM Break

FIELD

9:15 - 10:15 AM	Travel to Yabucoa - Finca Berríos
10:15 - 11:00 AM	*Pinus caribaea* provenance trial
11:00 - 11:45 AM	Water percolation/infiltration study
11:45 - 12:30 AM	Lunch/Discussion
12:30 - 2:00 PM	Eucalyptus provenance trial: field plot orientation and assessment
2:00 - 3:30 PM	*Pinus caribaea* var. *hondurensis* seed orchard and soil sampling techniques
3:30 - 4:30 PM	Travel back to ITF/Río Piedras

SOILS AND PLANTATION RESEARCH COURSE

Friday, July 22

OFFICE

30 min.	A -	Growth and yield methodologies in Puerto Rico/Caribbean
30 min.	B -	Disturbances and damage assessments
30 min.		Slides: Growth and yield data and hurricane damage assessment for pine plantings in Puerto Rico
9:00 - 9:10 AM		Discussion/Questions
9:10 - 9:20 AM		Break

FIELD

9:20 - 10:15 AM	Travel to Guzmán site
10:15 - 11:00 AM	*Pinus caribaea*, *P. kesiya*, *P. merkusii*, *P. oocarpa* provenance trials and hurricane damage assessment
11:00 - 11:45 AM	*Pinus caribaea* var. *hondurensis* spacing trial
11:45 - 12:30 AM	Lunch/Discussion
12:30 - 12:45 PM	Travel to lower Guzmán site
12:45 - 2:00 PM	*Pinus caribaea* var. *hondurensis* growth and yield
2:00 - 3:30 PM	Plantation/natural forest soil pit descriptions
3:30 - 4:30 PM	Travel to ITF/Río Piedras

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

SOILS COURSE
July 20, 1983

Major Reference: Harpstead, M.J. and F.D. Hole. 1980. Soil Science Simplified. Iowa State Univ. Press. Ames, Iowa. 121 p.

I. Major factors in soil formation
   A. Parent material
   B. Climate
   C. Organisms
   D. Topography
   E. Time

   (p. 5, Figs. 1.4 and 1.5)

II. Soil parent material/rock types and influence on chemical composition
   A. Crystalline rocks: granites (quartz-light colored)
      gabbro (dark-coarse grained)
      basalt (dark-fine grained)
      (p. 9, Fig. 1.8)

   B. Sedimentary rocks: limestone, sandstone, shales
      (p. 10, Fig. 1.9)

   C. Cover deposits: alluvial sands and silts
      glacial drift
      volcanic ash
      (p. 10, Fig. 1.10; p. 11, Fig. 1.11)

III. Physical properties and plant growth
   A. Texture - field tests for % sand, % silt, % clay
      (p. 13, Fig. 2.1; p. 14, Fig. 2.2)

   B. Structure - granular, platy, blocky, prismatic, columnar
      (p. 17, Fig. 2.6)

   C. Color as indicator of iron, humus, and drainage properties
   D. Density and effects on root penetration and soil water retention or movement

IV. Clay mineralogy and nutrient absorption
   A. Montmorillonite (2:1) - high nutrient holding capacity but shrink/swell problems when dry or wet
      (p. 22, Fig. 3.4)

B. Hydrous Mica (2:1) - low nutrient holding capacity and minimum shrink/swell
(p. 23, Fig. 3.6)

C. Kaolonite (1:1) - low nutrient and water holding capacity
(p. 23, Fig. 3.7)

V. Humus or organic matter
A. Origin from leaf litter, plant roots, and soil animals
B. Humus and soil structure/aggregation
C. Humus and soil chemical reactions
(p. 26, Fig. 4.1; p. 27, Fig. 4.2)

VI. Cation Exchange Capacity (CEC)
A. Both mineral soil particles and humus attract soil nutrients
(p. 32, Fig. 5.1; p. 33, Fig. 5.2)

B. Absorption of soil nutrients by plants
(p. 34, Fig. 5.3)

VII. Soil Reaction (pH)
A. Acid vs. basic soils
(p. 68, Fig. 8.14; p. 69, Fig. 8.15)

B. The pH scale
C. Base saturation

VIII. Soil water and erosion
A. Infiltration: entrance of water into the soil
(p. 38, Figs. 6.2 and 6.3; p. 39, Fig. 64)

B. Percolation: downward movement of water within the soil
C. Soil cover and evaporation/temperature relations
(p. 40, Figs. 6.5 and 6.6)

D. Erosion in moist and dry climates

IX. Describing a soil
A. The soil profile
B. Leached vs. accumulation horizons
C. Horizon designations
(p. 8, Fig. 1.7)

X. Soil classification
A. Why classify soils?
(p. 93, Fig. 11.9)

B. Classification systems
C. Benefits or world-wide, national, regional, and local soil surveys

XI. Conclusions:

Major soil forming processes are the same in both temperate and and tropical areas. However, the importance of any one factor like organisms may be greater or lesser, if they can be active all year long, because of warmer temperatures and more moisture in moist and humid tropical areas. Different countries or regions may have unique ways of describing soil horizons and soil properties, either chemical or physical. No matter what the descriptive system is, if it successfully predicts tree growth and response well, on the local sites being studied, it is a good system.

Required Reading:

- Determining field texture by the "feel" method.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

Essentials of Plantation Management:
On Small Caribbean Islands or Elsewhere

References: Liegel, L.H. 1982. Major issues of plantation establishment on small Caribbean Islands. p 83-92 In A.E. Lugo and S. Brown (eds.). Forestry in the Caribbean. Proc. First Workshop of Caribbean Foresters, (May 24-28, 1982), Castries, St. Lucia. U.S. MAB Report No. 7. Institute of Tropical Forestry, Río Piedras, P.R.

Evans, J. 1982. Plantation forestry in the tropics. Clarendon Press. Oxford, England. 472p.

I. Advantages of plantations

A. Exotics are easily incorporated into reforestation or afforestation programs. Some of their particular advantages are:
- fast growth rates
- favorable and known wood properties
- supplementation of local flora
- match species or provenances to local soil, climate, and elevational variation
- concentrating wood production on non-natural forest land takes pressure off natural forest ecosystems

B. Regeneration practices are usually easier than for natural forest species.
1. Exotics and some native species grown in plantations are easily propagated by container or bare-root nursery techniques.
2. Many native species, on the other hand, grow best in mixed forest conditions only.
3. Many exotic hardwoods like eucalypts and *Gmelina arborea* reproduce by coppicing, eliminating nursery to outplanting phases.

C. Integrated land use, or growing crops within plantations in agro-forestry activities, is possible, as in natural forest regeneration systems.

D. Tree improvement potential for exotics is usually much greater than for native (hardwood) species.

II. Plantations also have certain disadvantages that must be considered, especially from the long-term effects of management on natural ecosystems.

A. Indiscriminate destruction of natural forests for plantations reduce local flora and fauna or ecological diversity; yet, quantitative proof is rarely evident that this occurs, e.g. Puerto Rico being ± 85% deforested by late 1800's and no detectable plant species extinction being found.

B. There is a high theoretical potential loss from insects or diseases in tree monocultures; but actual losses may not be greater than those seen in native monocultures, e.g. conifer forests of southern U.S. and temperate boreal forests of the world.

C. Whole-tree utilization for short rotations of fuelwood or biomass may reduce inherent site fertility; proving such reduction or significant changes are difficult because
- each species and provenance can have different nutrient uptake rates,
- for long-term plantings, assumptions on uptake/replenishment rates may not be valid; they are certainly hard to quantify, and
- for certain soil nutrients, laboratory methodology can influence calculations of amounts stored or removed

D. Replacing natural forest with plantations is costly and wasteful, particularly when heavy machinery is used to exploit few trees in native forest.

III. Other important considerations in assessing merits or disadvantages of plantations are:

A. Reduction of yields in successive coppiced stands is most likely caused by reduction of stump numbers per unit area, from physiological deterioration and death by elimination in harvesting.

B. Long-term or cyclical changes in climate, particularly near outplanting date, can affect productivity adversely, for the duration of the planting.

C. Improvements in volume production of 15 to 30% from the first to second generation can easily overshadow declines in site deterioration.

D. Using superior nursery stock or modifying planting densities or thinning schedules all influence productivity potential of any site.

E. Poor harvesting techniques can reduce future yields at any site because of adverse influences on the soil, e.g. compaction, creation of gullies.

IV. There may be key local restraints that influence success or failure of plantations more so than all the preceding factors. For small islands in the Caribbean, at least, in the 1980's, these factors are:

A. Steep topography and diverse soils both complicate plantation alternatives.

B. Past lack of information exchange has hindered many countries from learning by the mistakes or successes of neighboring islands.

C. Localized but powerful and destructive disturbances from hurricanes and volcanic eruptions can completely eliminate costly investments in plantations

V. Conclusions:

There are both advantages and disadvantages of plantations; generalizations are hard to make, particularly for determining short- or long-term nutrient removals and effects on site productivity. Each island or mainland area has a unique complex of inherent soils, topography, native species, and local economic-marketing-social welfare situations. The successful reforestation project attempts to balance all of these factors as judiciously as time, money, and personnel permit.

L.H. Liegel
March 1983

FORESTRY/SOILS EXPERIMENTATION

1.0 Planning the Experiment

Experiments are usually included in long-term reforestation efforts. If started early in the project, they produce data and information that managers can use to develop managerial or technical guidelines at later stages in the project. For example, experiments can help decide which tree species are most suitable for charcoal production when grown between rows of corn or other crops. Experiments can also determine trees or shrubs most effective for erosion control on steep slopes or on disturbed sites ravaged by landslides or hurricanes.

Experimentation is all too often excluded from reforestation efforts because the purpose of experimentation is misunderstood or because experimentation is confused with statistics. Experimentation is the systematic observation, classification, and analysis of facts and data; it emphasizes the why and how of what is done. Statistics, on the other hand, are mathematical measures that describe organized raw experimental data. The most commonly used measures are the mean, standard deviation, variance, and coefficient of variation.

The commonly used statistical measures are outlined in Table E1. A hypothetical experiment is now discussed here to illustrate and emphasize that experimentation is an important component of effective decision making for reforestation projects.

1.1 Traits Assessed

Experiments can be done in the field or in the nursery. Many measurement traits or variables can be measured or assessed. Examples are:

Table E1. Summary statistics for two data sets, I and II.

Statistic	Data Set I			Data Set II		
	A	B	C	A_1	B_1	C_1
	8	5	1	8	5	1
	8	6	2	9	7	5
	9	8	5	9	9	8
	10	10	10	10	10	10
	11	12	15	10	11	12
	12	14	18	11	13	15
Sum	70	70	70	70	70	70
Mean ($\bar{x}$)	10	10	10	10	10	10
Standard deviation (s)	1.7	3.9	7.5	1.3	3.4	6.1
Variance (s^2)	2.9	15.2	56.2	1.7	11.6	37.2
Coefficient of Variation (CV-%)	17	39	75	13	34	61

$\bar{x}$ - The sum of individual observations divided by total number (n) of observations in a sample or set of values. Each of the six groups above has an n of 7 (observations); thus each of the six sums is divided by 7 to obtain the mean.

s - A summarization unit for interpreting whether individual observations are clustered around or spread away from the mean. Symbolically it is calculated:

$$\frac{x^2 - \frac{(x)^2}{n}}{n - 1}$$

For group A of Data Set I:

$$\frac{(8)^2 + (8)^2 + (9)^2 + (10)^2 + (11)^2 + (12)^2 + (12)^2 - \frac{(70)^2}{7}}{6} = 1.7$$

Group A has the lowest s in Data Set I; thus observations in group A are very clustered around the mean of 10. Observations in Data Set II are all more clustered around their means since the s of groups in Set II are all lower than those in Set I.

s^2- The square of s, or for data group A, $(1.7)^2 = 2.9$. Statisticians use s^2 in analysis of variance for testing whether various treatments are significantly different from one another.

CV- It is used to evaluate results from several experiments measuring the same variable or trait. It is calculated: $CV = \frac{s}{\bar{x}} \times 100$ For data group A, $\frac{1.7}{10} \times 100 = 17$.

In field experiments, CV values usually range from 15 to 50%; if values are higher than this, there was too much variability in plant materials or site and the experiment should be conducted again.

Nursery Traits	Field Traits
Average seed weight and size	Height in cm or m depending on seedling, sapling, or tree age
Mean germination time for seeds	Diameter at breat height in cm, usually after trees are 2 to 3 m tall
Percentage of seeds germinated within stated periods of time	Survival, as a percent of those originally planted, according to stated measurement times or after unusual events like hurricanes or disease
Seedling height to nearest mm, specifying to top of shoot apex, apical bud, or tip of tallest leaf or cotyledon	Stem form according to some predetermined class interval scale
Number of cotyledons	Longest length of useable bole in m
Nursery height in cm, at stated periods of time or before outplanting	Crown characteristics like length or width in m, assessed before canopy closure
Nursery diameter in mm, using calipers, at the base of a plant or at its root collar, if prominent	Branch habitat, including diameter, angle, number of branches per node, or coarseness; assessments usually made only once or twice in life of a trial
Nursery survival in percent	

In each instance, events or traits are recorded or measured according to previously formulated plans and designs.

1.2 Experimental Procedures

Developing an overall research plan is a must when conducting experiments. It can have the same component as the project plan and should always answer: Why? What? Where? How? When? How much?

The first step is determining the objectives and questions to be answered. Always restrict objectives to few and simple ones. Written objectives and an overall research work plan are critical for maintaining longer trials that continue after their originator has left.

Consider an area where eucalyptus are to be planted. Two important questions are: "What species will grow best?" and "On which sites will a certain species outgrow others?" Obviously, all species and sites cannot be tested. How, then, do we limit the scope of the proposed research on eucalyptus?

Restricting objectives can be done by considering available data on eucalyptus growth from elsewhere. Local conditions of climate, altitude, and elevation are also important for correctly matching species to sites. After reviewing available information, it might be decided to test E. saligna, E. robusta, and E. deglupta. A concise statement of the experiment objectives would be:

> To test height and diameter growth and survival of three eucalyptus species on valley, slope, and ridge topographic positions for 5 years.

Height, diameter, and survival data are the three most commonly assessed traits in reforestation. Whatever traits are selected, they should be stated clearly in the objectives.

The question of "Where to plant?" has not been completely answered in this eucalyptus example. Numbers could be assigned to all valleys, slopes, and ridges in the reforestation area and a certain number could be picked randomly from a hat or container as the experimental sites. This is seldom possible and is probably impractical because certain sites would be included where soil, geological, or other factors actually precluded planting. Most frequently it is best to limit sites to those covering the range in rainfall, elevation, past land use, or other factors that affect tree growth within the reforestation area.

A word of caution! Avoid confounding two or more factors. For example, if eucalyptus were planted on deep clay soils receiving 3000 mm of rainfall and on sandy soils receiving only 1500 mm, it would be impossible to tell if measured growth differences were caused by rainfall or soil factors. If these two soil types predominated throughout the reforestation area, most reliable data would be obtained by establishing experiments at high, medium, and low extremes in rainfall or elevational differences within the two soil types. This phase is called replicating the experiment at different potential planting sites.

The next step is actually establishing the experiment at the three different sites within each of the two soil regions. Seedlings would be randomly assigned to blocks containing all three species. Small row plots of 3 to 7 trees could be replicated up to 10 or 12 times for each of the three species; or larger plots using 10 to 49 trees could be used, depending on trial objectives or availability of planting stock. The most common outplanting design is the randomized complete block, as shown in Fig. E6.

In summary, experimentation is not an abstract concept but an important and integral component of decision making in reforestation projects. When conducting experiments, follow these three cardinal rules (the 3 R's):

1. Restrict objectives to simple and manageable ones
2. Replicate research plots on several sites and in several blocks at each site
3. Randonly assign treatments to each experimental block at each site

2.0 Data Recording/Record Keeping

If experiments are important enough to install and maintain, accurate record keeping is even more important. Insufficient field data or data not recorded properly will not allow experimental questions to be answered adequately. Thus, work plans for the experiment should include examples of field or nursery data sheets for the traits to be assessed, instructions on how assessments will be made, and guides on summarizing raw field data. Also, each research site should have its own field map, clearly indicating blocks, replications, and position sequence for trees located in rows or larger plots. Examples of field and data recording sheets are shown in Figs. E1, E2, and E3.

The following is a list of data recording Do's and Don'ts. Individual items may seem trite or picky, but many experiments have been abandoned or were useless because planting or measurement dates were not recorded or were recorded illegibly.

2.1 Data Recording Do's and Don'ts

No matter what format is used, ALL DATA SHEETS SHOULD CONTAIN:

1. Species or provenances measured;

2. Date of assessment -- write out the month and day instead of using a number system which is not uniform in many parts of the world, e.g. March 4, 1982 instead of 3/4/82 which could also be written as 4/3/82. Recording the exact data is particularly critical for calculating growth rates or volumes at later ages;

3. Names of person(s) who made the assessment as well as the parameters they were responsible for, e.g. John Doe: heights, Jane Doe: data recorder, Jack Jones: bark thickness and diameters;

4. Notations on whether data are given in metric or English units;

5. Proper and complete identification codes for all treatments, including proper block and plot numbers for replicated experiments; and

MEASUREMENTS ON STANDING TREES OR NURSERY SEEDLINGS

PLOT IDENTIFICATION
SPECIES AND PLANTING DATE

DATE OF ASSESSMENT — DATE OF LAST ASSESSMENT

TREE NUMBER	DBH	NOTES	TREE NUMBER	DBH	NOTES	TREE NUMBER	DBH	NOTES
1			21			41		
2			22			42		
3			23			43		
4			24			44		
5			25			45		
6			26			46		
7			27			47		
8			28			48		
9			29			49		
10			30			50		
11			31			51		
12			32			52		
13			33			53		
14			34			54		
15			35			55		
16			36			56		
17			37			57		
18			38			58		
19			39			59		
20			40			60		
						TOTAL NUMBER OF LIVING TREES		

DOMINANT HEIGHT							
TREE NUMBER	HEIGHT		TREE NUMBER	HEIGHT		TREE NUMBER	HEIGHT
SUMMARY	AGE	N	D	H_{dom}	$\bar{H}$	% Survival	ASSESSED BY:

N = stems per ha/acre
D = diameter of mean-basal-area tree
H_{dom} = dominant height (i.e. mean height of 100 trees of largest diameter per ha/acre)
$\bar{H}$ = mean height (i.e. arithmetic mean of all, or a systematic sample of all trees)

$$\% \text{ Survival} = \frac{\text{No. of trees (or seedlings) surviving at assessment}}{\text{No. of trees planted (or seeded)}} \times 100$$

Fig. E1. Example of the information required on the peirodic assessment form.

Best Available Document

PINE PROVENANCE DATA SHEET

Site _____
Study No. _____

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

	Height	DBH	Broken/ Cut	Foxtail	Insect/ Disease	Cones/ Pollen	Sprouts	Form	Branch Angle	Lean	
1											
2											
3											
4											
5											
6											
7											
$\bar{x}$											
SD											

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

Height	DBH	Broken/ Cut	Foxtail	Insect/ Disease	Cones/ Pollen	Sprouts	Form	Branch Angle	Lean	

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

Fig. E2. Field data recording sheet for international pine provenance trials in Puerto Rico.

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CEDRELA

FIELD STAGE DATA SHEET

SITE:_____ DATE:_____

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Other: No. for branches
B for borers
C for cut
T for top broken
Etc.

Fig. E3. Field data recording sheet fo *Cedrela odorata* used in Puerto Rico

Best Available Copy

6. A separate column or space for unusual things observed in any plot or at the research site, e.g. insect attacks, fire damage, wind damage with trees all leaning towards the northwest;

7. Write out all numbers clearly and distinctly -- handwriting differs from one person to another but if numbers are not recorded clearly, summarization at later data by someone other than the recorder may be next to impossible;

8. Summarize and analyze field data as soon as possible after it is actually taken -- waiting months or years is not recommended because the data become "cold" and their importance is diminished.

Finally, before leaving the research site, be sure that all appropriate items have been completed on the data sheet and that assessment dates appear on each page. Catching errors and correcting them before returning to the office can save a 1/2 to 1-day trip back to the field site to correct simple omissions or inconsistencies that can be spotted if the time is taken to do so.

3.0 Basic Statistics and Data Recording

The most commonly used statistics to summarize or categorize experimental data, from field or nursery environments, are the mean, standard deviation, variance, and coefficient of variation. A definition for each and an example of its calculation is shown in Table E1.

Raw data summarization can be a simple matter if data are coded correctly onto field or nursery data sheets. Examples are shown in Figs. E1, E2, and E3. Format will vary, depending on study design and traits that are assessed. The format of Fig. E1 is more suited for individual tree heights or diameters taken in plantations and natural forests, or from seedlings in nurseries. Formats in Figs. E2 and E3 were developed in Puerto Rico for assessing 7- and 4-tree row plots, respectively for *Pinus caribaea* and

Cedrela odorata provenance trials. Data recorded on the form shown in Fig. E2 is much more detailed than that recorded on sheets shown in Fig. E1 and E3. Any data sheet should be developed for the particular objectives and traits to be measured for specific studies.

4.0 Experimental Design Considerations

4.1 Plot Shape

Regular and compact experimental blocks have less microsite variation and are preferred over irregular shaped ones (Figure E4). When there is known moisture or other site quality variation at a field site, place the long side of blocks perpendicular to the gradient (Figure E5). Sometimes, outside factors may dictate block shape and orientation, e.g. locating blocks to accommodate rock outcrops (Figure E6). Making blocks or plots a convenient portion of a hectare (e.g. 0.2 or 0.5 ha) simplifies converting raw data to a whole hectare basis.

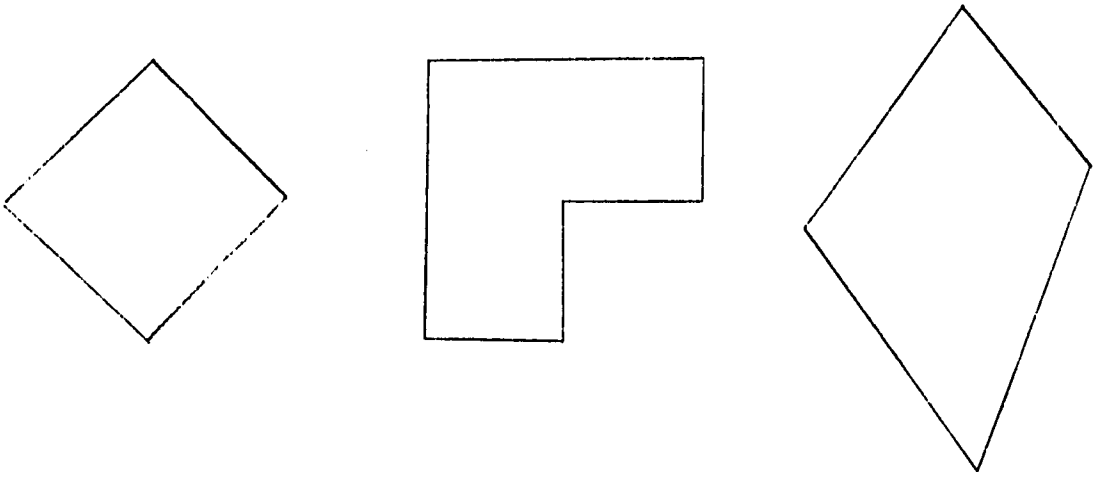
4.2 Plot Size

Optimum plot sized depends on several factors including available land and plant material, maximum allowable costs for land clearing and planting, desired spacing, experiment duration, required cultural treatments like thinnings, and whether nursery or fild trials are conducted. For example, 2-year field trials testing potential charcoal volumes for three species will be much smaller than 50-year trials assessing sawnwood obtained from teak, mahogany, and Spanish-cedar requiring thinnings. Similarly, provenance trials planted at 3 x 3 m require more area than do biomass trials planted at 0.5 x 0.5 or 1 x 1 m.

Desirable Experimental Block Shapes:

(regular and compact)

Undesirable Experimental Block Shapes:



(irregular and non-compact)

Fig. E4. Desirable and undesirable plot shapes used in forestry experimentation.

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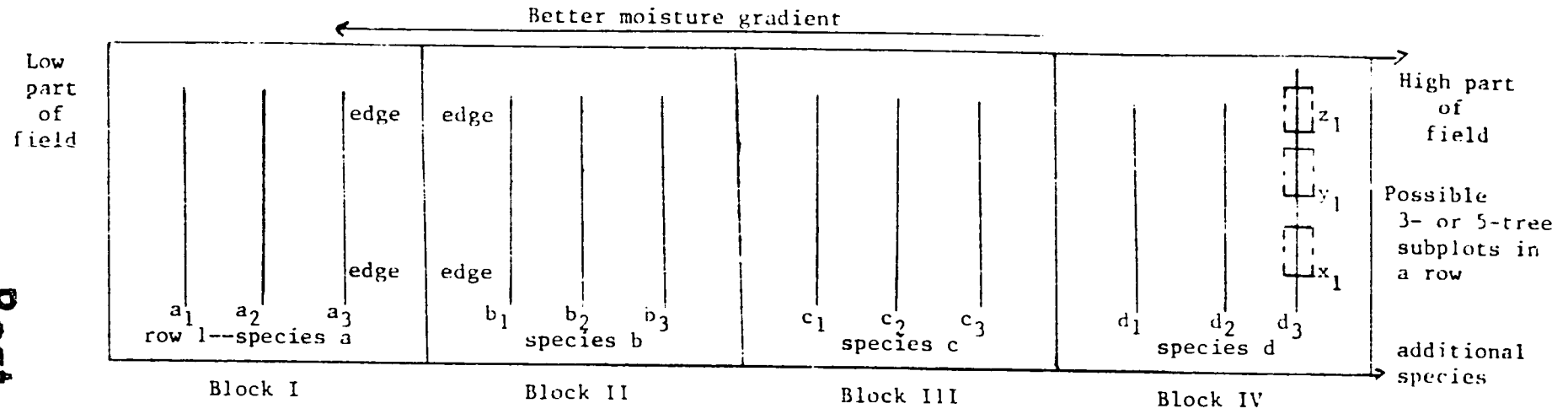
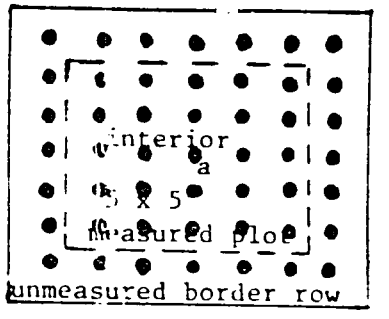


3 - a

Blocks	I	II	III	IV
	b	a	d	a
	c	d	a	c
	a	c	b	b
	d	b	c	d

Better moisture gradient

3 - b



3 - c

Fig. E5. Outplanting considerations for agroforestry research/demonstration trials:
2-a) Single blocks for species a, b, c, and d. Trees are tested between corn in long row plots of 25 or more trees per row; subplots are possible in each row of trees but the trial is unreplicated, with all rows receiving considerable border effect; species a and b probably have more available soil moisture during the year than do species c and d.
2-b) An improved design in which the moisture gradient effect is taken into account by using four randomized complete blocks, positioned perpendicular to the gradient; this allows each species to be tested over potentially different soil moisture regimes.
2-c) A 49-tree plot having one border or unmeasured row and 25 interior or measured trees to equalize edge effects.

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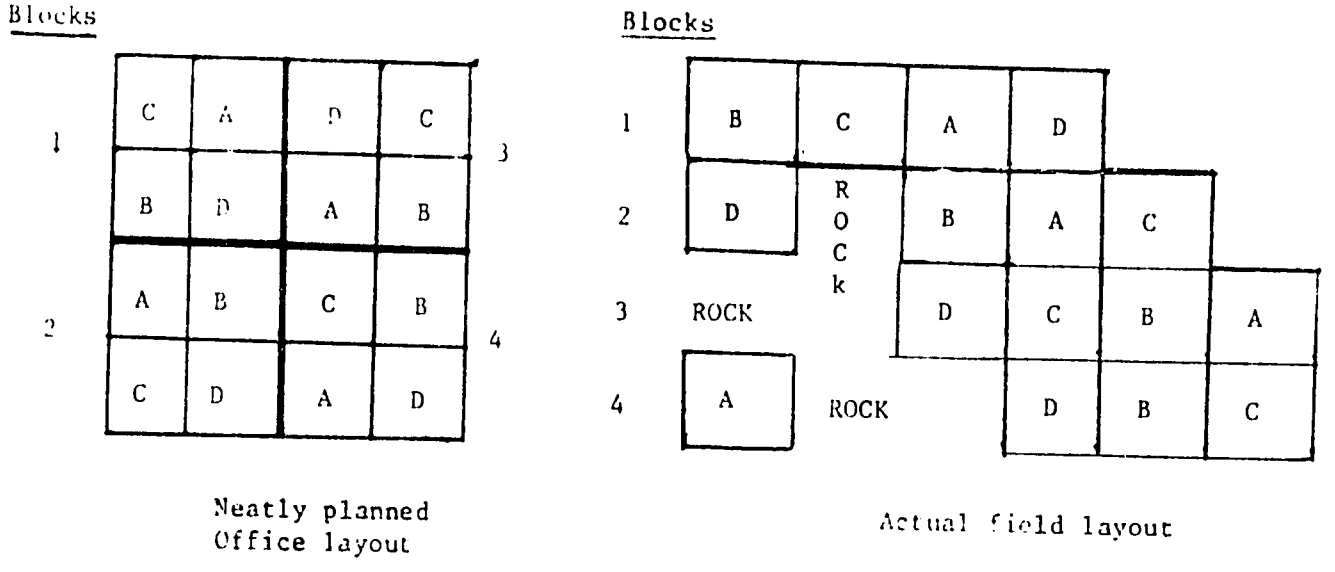

Fig. E6. A randomized complete block outplanting design testing growth performance of 4 species or provenances (A, B, C, and D) in four blocks; treatments are assigned randomly to each block. Frequently, actual field layouts must be modified from office layouts to accomodate outside factors like rock outcrops or access roads to the site.

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Where available area is limited, small row plots of 3-, 4-, and 7-trees, replicated ten or more times, are effective (Figure E7). When demonstration is an important objective, then larger plots, with fewer replications, are possible (Figure E5). Larger plots are very appropriate for community projects where visual effects are important in convincing landowners to adapt particular species or practices.

4.3 Border or Surround Rows

Edge trees of experimental plots have better moisture, light, and fertility than do trees in plot interiors where competition effects are greater. Consequently, edge tree growth, especially for diameters, is usually superior to that of interior trees. Including edge tree measurement data in assessments can significantly bias volume estimates upward over those made from interior tree data only.

The edge phenomenon is eliminated from field experiments by planting one or more rows around the interior or measurement plots (Figure E5) and recording data for interior trees only. Edge effects must be considered when designing trials for testing fuelwood/charcoal species in tree/crop mixtures since certain crops may be much more shade intolerant than others. Therefore, for a very shade intolerant crop like sweet potatoes, a fast-growing, open-crown species of *Casuarina* would be more suitable than a dense crown species of *Leucaena* or *Azadirachta indica* (neem).

4.4 Outplant Design

The most commonly used design in reforestation or other biological/agricultural experimentation is the randomized complete block. An experimental site is divided into a number of blocks having similar site quality; the same number of treatments are randomly assigned to each block (Figure E6).

Replication								
2	F	A	E	C	H	G	B	D
5								
9								
3								
6								
8								
10								
1								
7								
4	D	G	F	A	E	C	H	B

4-tree plot of Provenance D

Fig. E7. Field layout for 4-tree plot outplanting design, using 10 randomized complete blocks with 8 treatments (A to H) that represent different provenances of one eucalyptus species being tested for super-short rotation biomass/bioenergy potential. For brevity, only treatments assigned to blocks 2 and 4 are shown. Depending on availability of plant materials, 3-, 5-, and 7-tree row plots could be used instead of 4-tree plots. It is assumed that one border row would be placed around the entire planting perimeter.

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Three blocks are frequently used and 4 or 5 are recommended, especially if a small number of trees are used in 5- or 7-tree row plots. Using 49-tree plots in each block allows one surround row around the plot and is an effective design for demonstration purposes (Figure E5).

A typical example is one in which four tree species or provenances (A, B, C, D) are tested in four blocks (Figure E6).

Each species is randomly assigned to each block. Physical limitations of the site (e.g. rock outcrops) often preclude office-made layouts.

Prepared by: Leon H. Liegel
March 1983

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

TREE GENETICS/TREE IMPROVEMENT
July 21, 1983

I. Definitions

A. Forest (tree) genetics: studying resemblances and differences exhibited by trees related by descent. In other words, that science dealing with variation and heredity in trees (pines or hardwoods).

B. Tree improvement: using genetic and silvicultural information to increase yields.

C. Phenotype: the visible characteristics of tree growth, e.g. tall and straight, small and shrubby, many or few cones per tree.

D. Genotype: the invisible components of tree growth representing actual genetic constitution, e.g. dominant versus recessive genes.

E. Selection: choosing individuals or populations with desirable growth or wood quality characteristics in order to achieve genetic improvement.

II. Genetic Variation: Kinds and Causes

KINDS

A. Geographic (regional) areas - Some tree species are restricted to large areas, others to very small areas, e.g. *Pinus caribaea* is wide-ranging whereas *Pinus occidentalis* (on Hispaniola) is not. Certain traits like growth pattern, flowering cycles, and wood density can vary greatly in wide-ranging species.

B. Sites: Within specific geographical areas, there are usually differences in survival and growth of trees planted on upland or lowland and wetter or drier sites, as well as between individual stands of larger sites where agricultural practices have created artificial modifications of stand structure, e.g. old field regeneration from roadside or fence rows.

C. Individuals

1. Between trees - on the same site, individuals of some species exhibit significant differences in form, growth, wood quality, and resistance to insects, disease, and pathogens.

2. Within tree - for single trees, there may be differences in wood properties between core wood and outer wood and differences in cones, needles, and leaves between various crown positions.

CAUSES

A. Environmental factors
   1. Such things as soil/ambient temperature and moisture, day length, and soil chemical and physical properties all influence growth. Also important for planted stands are cultural techniques, including spacing, thinning, and fertilizing.
   2. Environmental factors are important in causing variation between geographic areas and between sites in the same area.
   3. Environmental factors, over the very long-term, help mold genetic material through the process of natural selection and survival of the fittest.

B. Genetic make-up
   No two individuals in a plantation or natural forest are exactly alike. Variation in individual form, growth rate, etc. are caused by factors inherent in the individuals themselves, i.e., by genes or factors passed on to offspring by their parents.

C. Genetic vs. environmental factors
   1. Genetic and environmental effects are never usually separate but interdependent or related.
   2. The genetic potential or make-up for a certain type of development may never be realized or realized only partially, depending on the environment to which it is subjected.

      Examples (for volume growth):
      a. Good genetic make-up/poor site. Under such conditions, individuals will never reach their full potential because of some limiting factor like soil moisture or nutrients, too dry or too cold growing conditions, etc.
      b. Poor genetic make-up/good site. Here, no matter how good the site, it is impossible to produce good or superior trees without having the proper genetic matetial to do so.
      c. Differences in genetic make-up. A mature P. caribaea will never produce the same volume as mature teak or mahogany because the genetic potential is dissimilar for each gene pool in the base population.

III. Tree Improvement Overall Objectives

A. Provide desired improved seed in commercial quantities, for use in individual states/countries/regions or for sale on open markets; individuals grown from improved seed grow faster or have better wood quality traits than the same species growing in wild or natural stands.

B. Develop a broad genetic base for the species desired; one purposely tries to include parents, from many areas and environments, that are well adapted (i.e. grow well) or have specific worthwhile traits (i.e. higher wood density, straight bole, narrow crown, etc.)

C. Develop strains for special problem areas or for specific products:
   1. adaptability to wet, dry, or marginal sites;

2. have special resistance to insects and disease;
3. has wood quality traits desirable for bags, tissues, newsprint, or glossy writing paper.

D. Obtain maximum gains or improvements in the shortest time possible, for the particular species/area being worked in. Each species has a certain inherent genetic make-up and grows well under certain environmental conditions; the successful tree improvement program takes these specific considerations into account, in initial and subsequent operations.

IV. Tree Improvement Techniques

A. Know the silvics and silviculture of the species worked on, especially seed production.
   1. Leaving seed trees not practical for a species whose seeds stay viable while on the ground for many years: yellow poplar.
   2. Comparing a superior phenotype with several neighbors to find extent of superiority in volume is not valid for species that have interrelated root stocks: sweetgum.

B. Naturally regenerated stands will have limited genetic improvement potential because of uncontrolled outcrossings in pollination.

C. Seed production areas are natural stands or plantations that are opened up (i.e., thinned heavily) for the production of seeds from good phenotypes.
   1. most influence will be in improving form and disease resistance, not wood (volume) production, in future generations;
   2. there is a time-lag in realizing seed production increase in pines because of flowers/conelets produced before thinning is done;
   3. do not create seed production areas in stands where past high-grading has occurred (i.e. best-formed trees were cut out earlier, leaving inferior growing material = dysgenic selection);
   4. seed production areas are only temporary measures of producing improved seed until seed orchards begin production;
   5. the true genetic worth of parent trees in seed production areas is seldom determined.

D. Seedling seed orchards
   1. Plant seedlings from seed of superior phenotypes (tree parents) to produce mass quantities of genetically improved seed.
   2. Advantages of method:
      a. can include many initial parents, using a broad genetic base;
      b. avoids vegetative propagation of species that are difficult to graft;
      c. easy to establish if only open-pollinated progeny are used;
      d. two cycles of selection can be completed in one operation; and
      e. seed production can b combined with progeny testing.

3. Disadvantages of method:
   a. Producing seed and testing progeny is often difficult on the same site since cultural techniques (spacing, fertilizing, etc.) are different for each;
   b. related mating (selfing) can occur in the orchard;
   c. flower production is usually slower for seedlings than from grafts; and
   d. outstanding genotypes are represented by single trees.

E. Vegetative (clonal) orchards
1. Establishing a collection of superior individuals reproduced by vegetative means: grafting, rooted cuttings, air-layers, or tissue culture, not by seedlings from seed.
2. Advantages of method:
   a. Both flower and seed production begin soon after orchard is established;
   b. orchard can be located in most economic and convenient place for seed production;
   c. outstanding genotypes are used many times to produce large amounts of seed; and
   d. related matings in orchard are minimized.
3. Disadvantages of method:
   a. Some species exhibit graft incompatibilities;
   b. progeny testing is carried out as a separate operation; and
   c. the number of parents represented is more limited, possibly reducing the genetic base.

V. Wood Quality Considerations
A. Wood properties are those factors which influence the quality or quantity of wood used for manufacturing, lumber, plywood, and pulp and paper; what interests the lumberman may not concern the pulp producer.

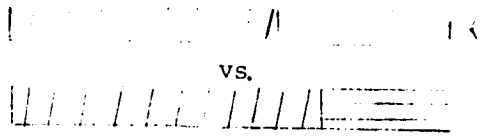
B. Important Generalizations
1. Many wood properties have a strong genetic component, i.e., can be bred for;
2. height growth is controlled genetically more strongly than diameter growth; and
3. straightness of stem is controlled genetically more strongly than height growth.

C. Specific gravity is composed of a combination of characteristics than can be bred for; for calculations, it is expressed:

$$\frac{\text{dry weight (grams)}}{\text{green volume (cubic centimeters)}} = \text{specific gravity (g/cc)}$$

1. Thus, specific gravity (or weight of dry wood per unit volume) is vital to both lumberman and pulp producer.
2. Factors affecting specific gravity
   a. % summer wood: the higher the % summer wood with thick-walled cells, the higher the specific gravity;

e.g. spring summer



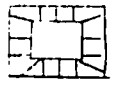
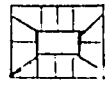
higher

vs.

b. larger cells with a certain cell wall thickness have higher specific gravity than smaller cells with smaller cell wall thickness; e.g.

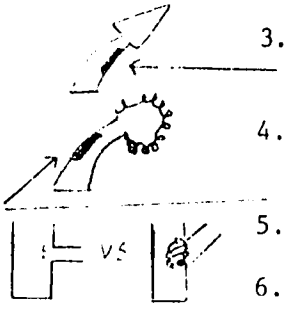
higher → vs.

c. in cells of similar size, that with thicker cell wall has highest specific gravity; e.g.

 vs.  ← higher

D. Effects of form on wood

1. Bole straightness is highly inherited.
2. Straight stems (boles) have more useable volume and give better structural material than crooked and/or for ed stems.
3. Conifers that lean have compression wood at underside of stem; compression wood has high lignin content, short tracheids, and abnormal latitudinal shrinkage.
4. Hardwoods that lean have tension wood on the top side of the stem; tension wood has high cellulose and low lignin --- tension wood is not found in conifers.
5. Horizontal branching has less compression wood and produces firmer knots than non-horizontal branching.
6. Resin content can be high in some species (or provenances), making wood unsuitable for pulping.



E. Juvenile/mature wood implications

1. Juvenile wood is characterized by
   - low specific gravity
   - short cells and thin cell walls
   - flat fibril angles

normal

vs.

more longitudinal shrinkage

   - high moisture content

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2. Juvenile wood occurs in the central "cylinder" or core of any tree; i.e. top section of tree has more juvenile wood than base of tree.
3. When comparing wood between species, or between trees of the same species, one must use material of the same age.
4. For some products, total dry weight yields of wood per unit area are more important than volume (wet or dry) produced per unit areas.
5. Conifers generally have considerable botton-to-top specific gravity differences in the bole; hardwoods do not.
6. For sampling wood properties (fibers and tracheids), a large increment borer (11 or 12 mm in diameter) or wedges of cross-sections must be used.

F. Effects of disease on wood properties
1. There can be 2 to 3 times as much resin in infected wood.
2. Diseased cells usually have thin-walled cells of low specific gravity.
3. Infection galls in wood cannot be removed and cause imparities on paper products.

VI. Designs and Field Testing

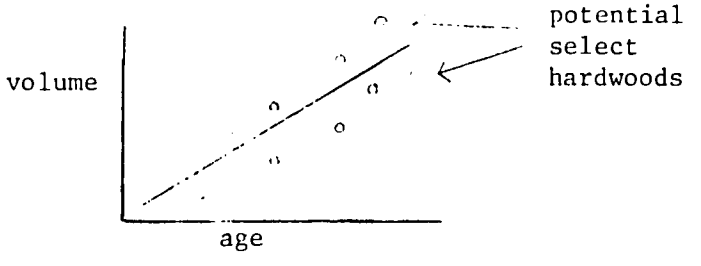
A. Follow the 3 R's of Research procedures: restrict, randomize, and replicate.

B. Early research on genetics in U.S. in 1920's and 1930's was not good because there was:
- non-randomization of rows
- there were soil gradients parallel to rows, and
- some provenances were always planted on outside edge and were always in the sun whereas others were always in shade.

C. Replication must be done in time and space.

VII. Special Considerations for Hardwood Tree Improvement

A. Grading schemes for selecting superior hardwoods are usually more difficult than for pines:
1. less information genera ly known about variation in hardwoods;
2. check tree system cannot be used for species with related root stocks;
3. when natural stands are all-aged, there is difficulty in comparing potential select with check trees --- use regression technique of:



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4. In cut-over stands, only poor genetic material may be left.

B. Grafting vegetative propagation techniques are different and more difficult.
   1. Healthiest branches are hard to get from upper 1/3 of tree; small branches do not have adequate food reserves;
   2. only vegetative and no reproductive buds can be used - terminal buds are not the best.

C. Wood economics are different for hardwoods and pines
   1. Hardwoods yield more than pines since lignin and cellulose quantities are greater in hardwoods;
   2. hardwood stumpage may be cheap however when conifer material is readily accessible;
   3. a wide species mix with varying specific gravities for each species in mixed hardwood stands is undesirable.

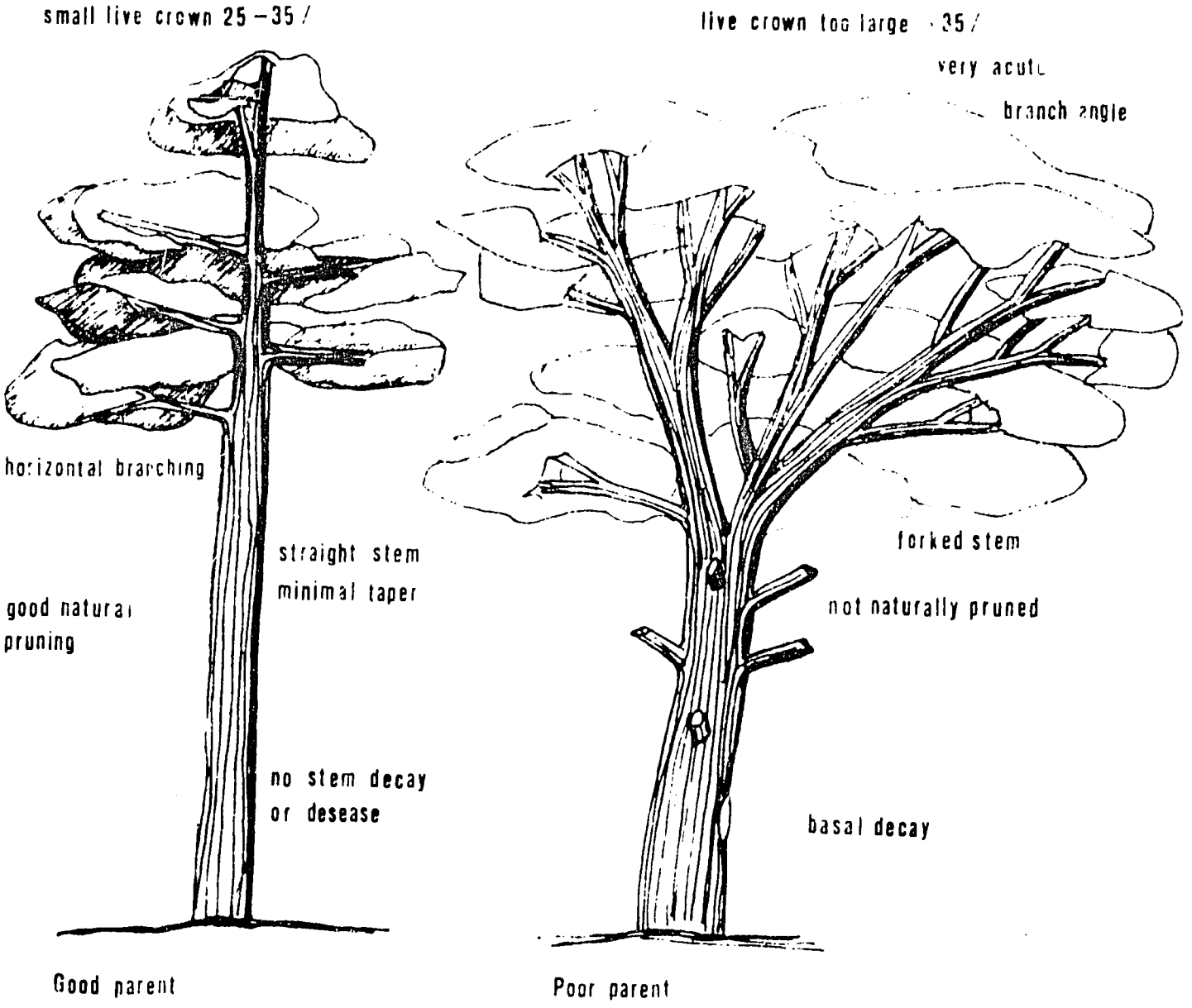
D. Site/silvicultural considerations
   1. Hardwoods are generally more intolerant of poor sites or grow well only on good sites;
   2. many good hardwood sites are prime sites for other land uses, e.g. farms, housing, etc.;
   3. many hardwoods are difficult to grow in plantation conditions;
   4. silvicultural systems for regenerating many hardwoods (e.g. gaps versus clear cutting) may prohibit hardwood reforestation because of unfavorable economics (for planting and harvesting).
   5. Epicormic branching is more of a problem in hardwoods than in pines.

E. Wood properties
   1. Most commercial hardwoods have higher specific gravity than do conifers.
   2. Geographic and between-tree variation in wood properties for hardwoods are less well known and less studied than is similar variation in conifers.
   3. Hardwood wood property studies are more difficult because of larger stems and higher specific gravity (more energy expended to obtain a given set of data).
   4. In short rotations, changes in specific gravity for hardwoods are low, but similar changes are usually great in the first 10 years for pine species.

VIII. Conclusions:

The major objective of tree improvement is to use knowledge of basic tree genetic principles to produce higher quality (improved) seed and wood products of specific physical and chemical composition. Overall techniques and approaches for hardwoods and conifers may be similar or different, depending on the stated objectives and needs of the area or region.

L.H. Liegel
March 1983



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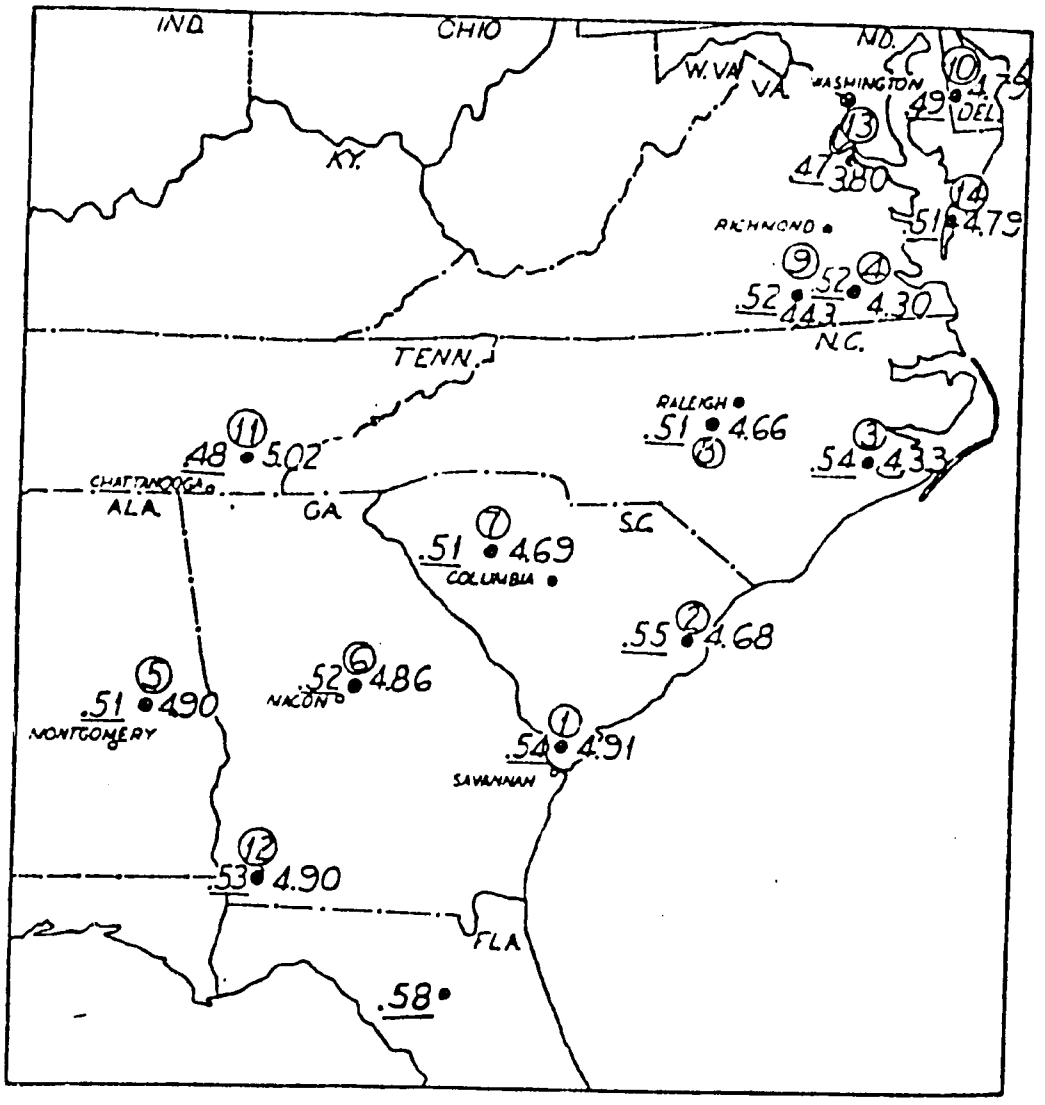

FIGURE 5. An illustration of variation in average specific gravity and tracheid length of loblolly pine with geographic location in the southeast. The tendency is for lower average specific gravity and shorter tracheids in the north of the species range. Values shown are averages for plots of 23 trees each — the underlined values are for specific gravity and the other values are tracheid lengths in millimeters.

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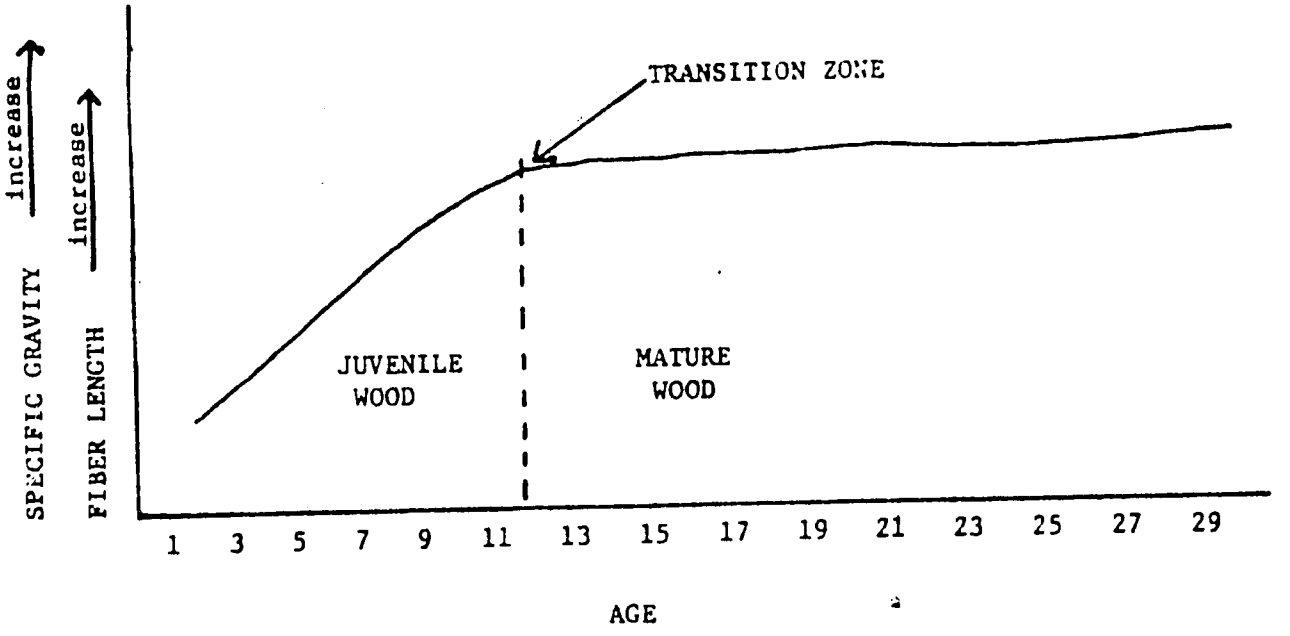

Figure 1. A schematic diagram illustrating the change of specific gravity with age, i. e., number of rings from the pith. In some trees specific gravity continues to increase, while in other trees it may fall. In most instances there is a year-to-year fluctuation caused by weather conditions.

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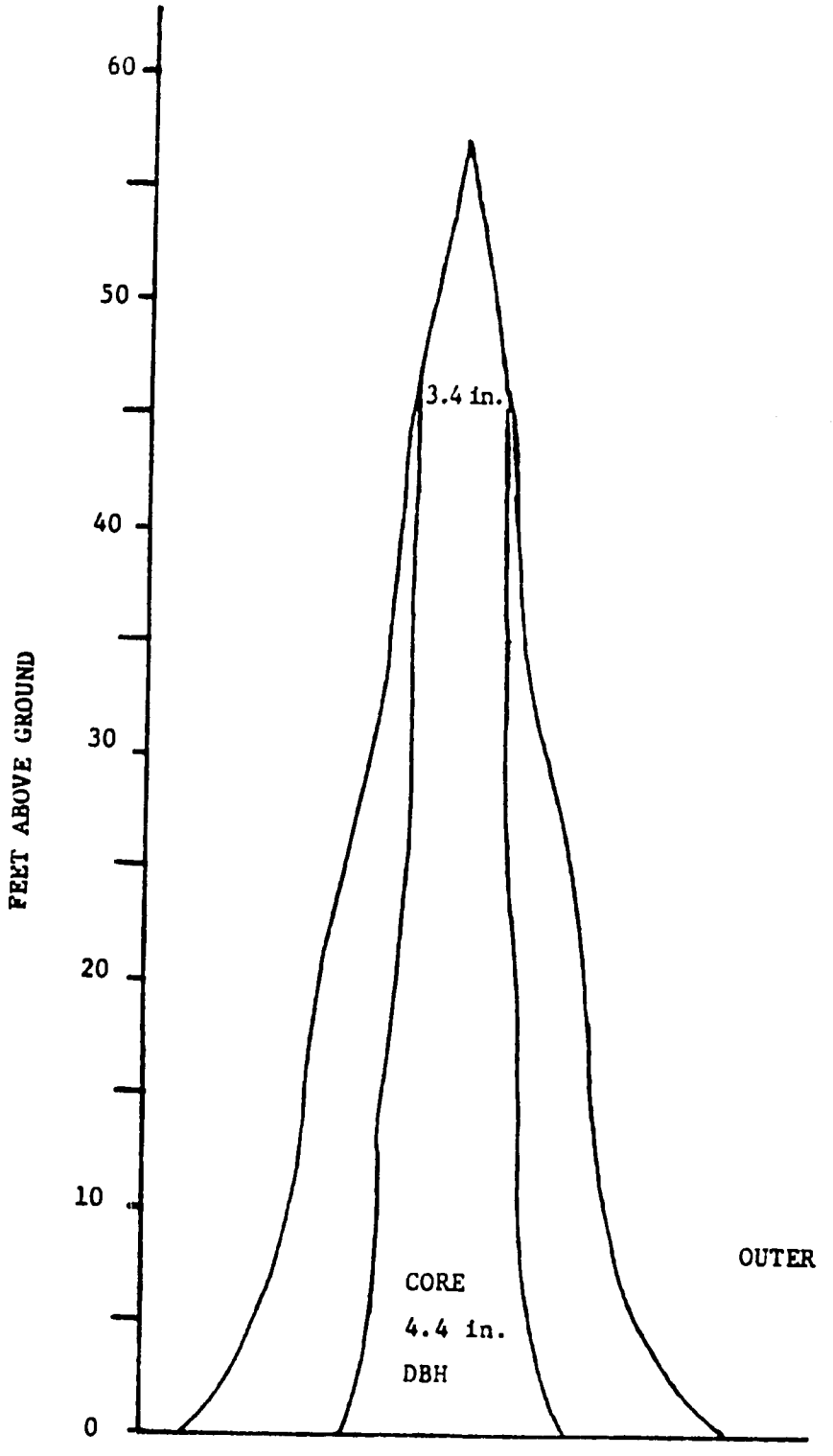

Figure 2. Diagram on core wood area averaged for several 17-year-old loblolly pine boles, showing its near cylindrical outline. Note that the top logs will consist mostly of the shorter-fibered, lower-specific-gravity core wood.

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

PHENOLOGY, FLOWERING, AND CONE/SEED PRODUCTION IN PINES

References: D.L. Bramlett et al. 1977. Cone analysis of southern pines - a guide book. USDA Forest Service General Technical Report SE-13. Southeastern Forest Experiment Station, Asheville, North Carolina, and Southeastern Area, State and Private Forestry, Atlanta, Georgia. 28 p.

USDA Forest Service. 1974. Seeds of woody plants in the United States. Agriculture Handbook No. 450. U.S. Government Printing Office, Washington, DC. 883 p. (See Chapters III, V).

I. The Flowering Cycle in Pines

A. Flowering and cone production for southern pines and *P. caribaea* takes 2 years to complete:

1. year 1: flower initials produced
   flower buds visible
   flowers mature/pollination occurs

2. year 2: pollen tube growth and slow conelet growth
   fertilization occurs
   cone and seed mature

   (Bramlett et al., p. 5, Fig. 2)

B. Pines produce two kinds of flowers or strobili:

1. male or pollen - producing catkins and

2. female or ovule - producing cones (or, commonly, conelets)

C. Most pines have both sets of flowers on the same tree:
   females, at the growing branch tips, usually in top part of tree, and

   males, further back on branch, normally in bottom part of tree.

D. First appearance of flowers varies with tree maturity.

1. females or conelets first 2 to 4 years

2. males later, at 4 to 6 years

E. In any growing season, one or the other set of flowers appears first, usually the females for *P. caribaea*

1. best seed production is when flowering occurs only at one time in any year.

2. for certain exotics, flowering occurs all year, e.g. *P. caribaea* in Puerto Rico lowlands.

F. Many other factors can influence flowering and/or pollination:
   1. external factors are:
      temperature, light, moisture, and nutrients, and cultural practices like thinning.

   2. internal (growth) factors are:
      hormones and other growth regulators.

II. Phenological Studies vs. Flowering
   A. Definition: Phenological studies are those that establish relationships between seasonal climatic changes and their influence on flowering, fruiting, leafing, and growth flushes of a species.

   B. Success or failure of flowering in exotics may be tied to local changes in elevation or climate that directly influence the flowering cycle, e.g., pollen shed in parts of Malaysia (and perhaps in Puerto Rico) is hindered by high humidity/large rainfall factors.

   C. Phenological studies are simple to conduct but long-term and therefore difficult to justify usually, for economic and human resource constraints.

   D. Avoid flowering problems by picking species and/or provenances from climates similar to that of country where new introductions are made.

III. Collection and Harvesting
   A. Always collect seed from good (select) phenotypes having:
      straight stems, no forking (conifers)
      small but healthy crowns (non-wolf trees)
      horizontal branching not abnormally coarse
      visible signs of vigor and health (disease free)

      (see class handout)

   B. Early estimate of yearly cone seed crop will indicate whether there will be adequate seeds for following planting season; if crop is small, outside seed suppliers must be used.
      1. Estimates can be made by counting cones on one or two sides of tree, with or without binoculars; calibrate, when possible, when trees are felled.

      2. Past experience is key to accuracy in estimates.

   C. Collect cones/fruits as early as possible.
      1. Changes in color, size, and appearance can often be used, e.g. ripening pine cones go from green to brown/red color.

2. Color changes can vary from region to region as well as from year to year.

3. In most cases, actual collections can be made before seeds fly/fall.

4. Test some cones on various mixtures of light motor oil, linseed oil or kerosene, of varying specific gravities: cones mature if they float, immature if they sink.

5. For large cone crops, immature cones can be picked and ripened later in wet burlap bags, buried in the ground.

6. In orchards, collecting time can be lengthened by using clones that flower (and produce ripe cones) earlier or later than other clones.

7. Collection is done by hand or mechanically.

D. Cone/seed yields and cone analysis

1. Cone slicers can easily be made by hand.

2. Cones sliced lengthwide reveal:
   normal seeds
   underdeveloped seeds
   infertile scales (no ovules)
   aborted ovules (1st or 2nd year)

3. For some species, there is an average "good seed count" on the exposed cone surface that bears strong relationship with actual number of full seed per cone.

4 Fully developed seeds are not always "full" or sound seeds.

5. Each scale, except for those at top and bottom of cones, has a potential for 2 full seeds; this potential is seldom reached e.g. P. taeda (loblolly) has potential for ± 175 full seeds but actual count is ± 40/cone.

6. Actual production is expressed in number of pounds of seed per bushel of cones and number of bushels or pounds of seed per acre,

   e.g. For loblolly pine, 1974 data

	bushels/acre	lbs. seed/bushel	lbs. seed per acre
Variation observed	2	0.4	7.0
	↓	↓	↓
Across southern USA	55	1.4	23.9

7. Seed yield per cone can vary greatly by parent; cone length, number of scales, and seed potential vary little.

IV. Insects and Diseases

A. Visible or external signs of cone/fruit damage are: deformed cones; presence of frass or pitch exudates; insect entry or exit holes; and blemished or off-color appearance.

B. Damage by seedbugs, fungi, and other insects/pathogens may be internal or not visible; they can be detected by X-ray or mechanically by determining "pops" (empty seed) with a hammer.

C. Birds and mammals can cause damage to ripe cones and seed.

D. Mechanical damage is caused by careless/poor harvesting techniques.

E. A few diseases infect developing female or male flowers.

F. Good seed can be damaged by improper storage techniques, usually failing to reduce seed moisture content to the proper level ($\leq$ 10%).

V. Conclusions:

Many factors, some of them man-controlled, will affect flowering and pollination. The controllable factors are used judiciously, to maximize seed production, in seed orchards. Before establishing seed production areas or seed orchards, be sure that species will respond to opening up of stand (to produce seeds) or that species can really complete entire flowering cycle, if it is an exotic or introduced species.

L.H. Liegel
March 1983

II. CONE AND SEED DEVELOPMENT AND MORPHOLOGY

A basic knowledge of cone and seed development and morphology is essential to understand cone analysis.

Pine trees produce two types of **strobili**: male or pollen-producing **catkins** and female or ovule-producing cones. The primordia of the **female cones** are initiated in the summer. The following spring **female flowers** emerge in an erect position from protective bud scales on the tips of new shoots (fig. 1A). The female flowers are composed of many soft, fleshy **scales** spirally attached at right angles to a central axis. Pairs of **ovules** originate as small protuberances at the bases of **scales** (fig. 1B). Not all scales produce functional ovules; only those in the central region of the cone have the potential to **produce** ovules and eventually seeds. These are called **fertile scales**. The lower scales and those at the tip of the cone are infertile and never bear seeds (**infertile scales**).

At the time of **pollination**, a single layer of cells (**integument**) covers the ovule. Pollination occurs when the **pollen grains** are carried by the wind from the male catkins to the female flowers. Pollen grains enter the ovule (fig. 1C) through an opening (the **micropyle**) in the **seedcoat**. Once in contact with the ovule, pollen grains germinate and **pollen tubes** grow from the pollen chamber into the ovule tissue (**nucellus**) (fig. 1D). The pollen tube develops slowly during the first growing season, and the winter is over before it reaches the mature egg cell of the ovule. For more than 1 full year, the **ovule** remains only a fraction of the size of a fully developed seed. During the year after pollination, the female flowers are called **conelets**.

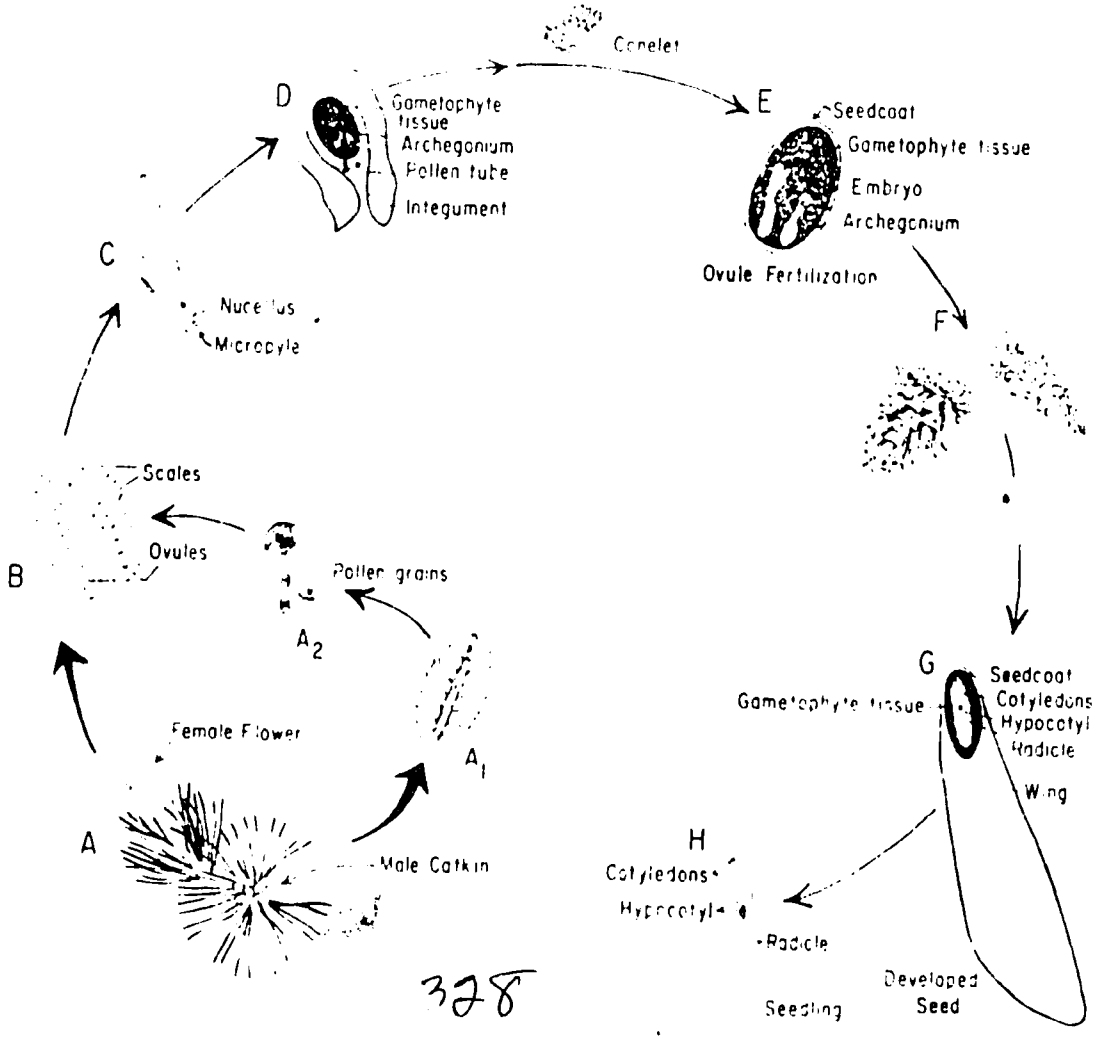

Figure 1 - Pine seed formation. Drawing adapted from one provided by Carolina Biological Supply Company

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When vegetative growth starts in the second spring the ovule also resumes development and enlarges From 12 to 16 months after pollination depending on pine species the pollen tubes grow far enough into the ovule to reach specialized structures (**arch** **ia**) containing the egg cells (fig 1E) Sperm cells from the pollen tubes fertilize the eggs, and embryos (2N tissues) for[illegible] gametophyte tissue surrounds the embryo and provides the nutritional reserves for the seed (1N tissues) During [illegible]ne the conelet enlarges rapidly to form a full-sized cone Seeds are full sized at the time of **fertilization**, but seeds and cones continue to mature until late summer or early fall

A mature fully developed seed (fig 1G) has an embryo composed of immature needles (**cotyledons**), immature stem (**hypocotyl**), and an immature root (**radicle**) The gametophyte tissue enveloping the embryo provides the food reserves for **germination**. The hardened seedcoat protects the seed

The sequence of pine seed development - from flower primordia formation to seed fall - is illustrated in figure 2 This development spans parts of three growing seasons

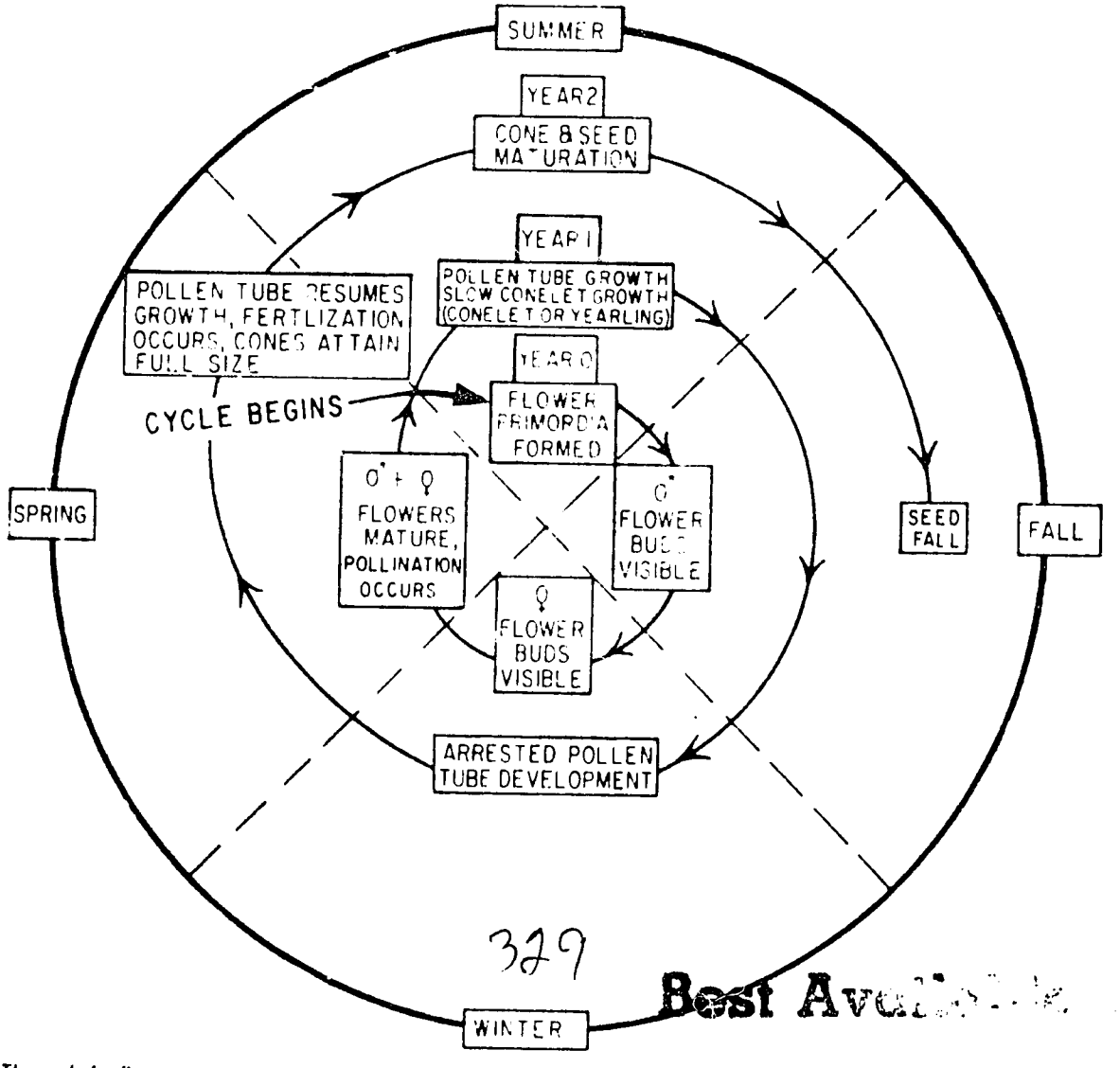

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Figure 2.-The cycle for flowering and seed production in southern pines

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

ADAPTABILITY AND PROVENANCE TESTING

References: North Carolina State University, School of Forest Resources, Industry Cooperative Program. 1977. Tree improvement short course. Raleigh, North Carolina. 156 p.

J. Wright. 1976. Introduction to tree genetics. Academic Press. New York, N.Y. 463 p.

I. Definitions

A. Provenance: the original geographic source of seeds or trees; usually represents a "promising" species.

B. Seed source: the locality where a seedlot was collected.

C. The terms in A and B are often used interchangeably, but are not equivalent when the source of seed is not within the boundaries of the native habitat.

D. Adaptability: the ability of a species to grow well (ht and dbh), and survive, and possibly to produce seeds, in areas outside its normal or original geographic source.

II. Kinds of Field Trials in Forestry

A. Arboreta

1. Keep and catalog living material;

2. number of individuals retained is small;

3. source is small seedlots acquired in travels or seed exchange.

B. Adaptability (species elimination) trials

1. Test overall growth and performance of many species on one or more sites.

2. Select a small number of all (i.e., promising) species tried for further testing.

3. Use a reasonable criteria for determining success or failure e.g., grow a minimum of 2.0 m in ht for first 2 years.

4. Number of species tried governed by availability of funds, planting sites, and human resources.

5. Test plots are small, often 3- to 9-tree row plots, or single-tree plots.

C. Species testing
   1. Compare growth of a restricted number of "promising" species;

   2. usually restricted to 5 or 10 species, tested on several sites;

   3. age of trials is 1/2 expected rotation age;

   4. use 7- to 9-tree row plots or small block (25-tree) plots.

D. Proving or management tests
   1. Test promising species under usual plantation conditions;

   2. plot size is large (49- to 100-tree plots in 7 x 7 or 10 x 10 tree configurations);

   3. reducing border effects critical for calculating true plot volumes;

   4. different cultural/management techniques can be incorporated too.

E. Provenance trials
   1. Test certain geographic sources of "proven" species;

   2. choose best provenances for adaptability to specific sites;

   3. choose provenances with better form, higher specific gravity, small limbs, etc.

   4. plot designs same as for species testing or proving/management trials.

F. Specialty plantings
   1. Developed for special uses like Christmas trees, erosion control, fuelwood/biomass, etc.;

   2. test species in specific, planned phases;

   3. plot size and layout same as for adaptability, species, or provenance trials.

III. Conclusions:

Time and money will be saved by choosing the most appropriate testing scheme. As a start, look
areas for help. Adapt results from other areas to local needs, particularly economic and social needs and realities.

L.H. Liegel
March 1983

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

GROWTH AND YIELD STUDIES
July 22, 1983

References: T.E. Avery. 1967 (1st Edition--available in 3rd Edition also). Forest measurements. McGraw-Hill, Inc. New York, N.Y. 290 p.

I. Definitions/Explanation

A. Forest Inventory: determine the number and kinds of species existing on an area.

1. term has been in existence for quite some time
2. characterized by low intensity cruises (e.g. 1 % of area)
3. usually conducted at one point in time, although it may be repeated at regular intervals: continuous forest inventory or CFI
4. records merchantable/non-merchantable volumes, using specific diameter thresholds
5. % stocking is variable and recorded for major species or species associations
6. information collected used for top-level management decisions and long range planning for large areas: states, several states (regional), or entire countries

B. Growth and Yield (G & Y): predicting volume yields at many points in time, usually for a single (plantation) species, most-often pines.

1. term is relatively new (late 1960's): for southern pines in USA
2. usually assumes full stocking, i.e. no unusual mortality
3. reports volume information for a given species by different diameter classes, densities (spacings), and site index (SI) classes
4. stands measured have been treated and managed alike
   e.g. all unthinned, unmanaged natural stands
   e.g. all planted, unmanaged stands
   e.g. all planted, thinned stands

II. Trends in G & Y in Southern United States

A. Large areas or compartments (say 40 acres), 1930-1950

1. usually even-aged, natural stands
2. more demonstration than research
3. sought long-term management or silvicultural system approach
4. no or little replication on different areas
5. not much attention paid to diameter distributions

B. "Small Plot" Studies, 1950-1960's

1. plots are small, 1/10 to 1/4 acre in size
2. established in pure, even-aged stands of pine primarily
3. usually in limited range of sites in a particular region
4. summaries not done by diameter distributions
5. growth determined for all stems above a single pubpwood size threshold, perhaps for sawtimber too
6. limited replication is incorporated

C. A + B (above) Were Point Studies

1. studies stand alone in objectives, analyses, and interpretation
2. incorporated erroneous idea that G & Y was not greatly altered over a large range in densities; this caused:
   - planting at wider densities to cut costs of planting
   - used heavier thinnings or reduced densities drastically if and when thinnings were incorporated into a management plan

D. New, Integrated Approach of the 1970's and 1980's

1. data pooled from many areas across the entire southern USA
2. quantify species' yields, using information from geographic areas, by land use (planted versus natural stands), different density combinations
3. fill out missing combinations of site, age, and density with thinning or other studies
4. pay more attention to diameter distributions
5. use flexibility in determining kinds of thresholds for diameter or upper stem limits, for various, not single products

III. Special Spacing/Thinning Considerations

A. Spacing can be critical for minimizing erosion and site disturbances in moist/humid tropical uplands, i.e. no unnecessary thinnings are conducted that will disturb the site.

B. The statement that dominants and codominants are not usually affected by spacings, except perhaps at very close (_ 5 ft) may not be true for *P. caribaea* var. *hondurensis* which had up to 5 and 8 m differences between dominants/codominants in 5 to 14 ft spacing trials in Puerto Rico.

C. Thinnings are conducted to put the same amount of wood on fewer stems to produce higher quality products.

- light poles need crowding and denser rings for 4 to 6 years prior to harvest for greatest strength properties

- using closer spacings for pulp rotations where entire crop is cut before competition begins and growth of stand declines

D. Timing of thinning may be very critical for some species like *P. caribaea* var. *hondurensis* where height and diameter growth were impacted (reduced) already by competition at age 3.5 to 4.5 years, on good sites in Puerto Rico.

L.H. Liegel
March 1983

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

DISTURBANCES OR CATASTROPHES IN PLANTATIONS
March 18, 1983

I. The only valid generalization about natural disturbances is: their arrival is unpredictable!

II. Even catastrophic events like hurricanes and volcanic eruptions have varying effects on the areas where they occur.

A. Damage can be total if there is a "direct hit."

B. Damage is of a lesser or partial degree as one moves away from the "center of activity."

e.g. recent small volcanic eruption in Hawaii
e.g. forest damage in Puerto Rico from Hurricane David as compared to that in Dominica from the same storm

III. Survival and adaptability is governed more by the extremes, not the average conditions.

e.g. the rainy season starting 4 to 5 weeks late

e.g. first day of frost coming 1 month early

IV. Hurricane damage, for plantation species and natural forests, seems to be affected by at least three major factors: the three S's of cyclonic storm damage in forest ecosystems

A. Storm factors

B. Site factors

C. Silvicultural factors

(see handout, prepared by L.H. Liegel, based on research on hurricane damage to *Pinus caribaea* and *Pinus oocarpa* provenances in Puerto Rico, 1979)

V. One does not know when a disaster will occur; but when making assessments of damage to forest ecosystems, if there is time and money to do so, develop a sound planning strategy, before commencing any field work!

(see handout, prepared by L.H. Liegel)

L.H. Liegel
March 1983

III. Other Activities Before Field Work

A. What kinds of damage classes are possible for identification besides:

Breakage: branches and main stem(s)

Windthrow, blowdown, uprooting (different names for the same thing)
roots showing or shearing off at ground level

Lean (1 - 10°, 11 - 20°, 21 - 30°, 30 - 45°, or others)

Defoliation
hardwoods only or pines too

B. Obtain local weather reports and/or briefings about storms from individual islands, especially track records for storm movement across the island for different hurricanes

C. Information, when possible, regarding wind speeds, duration, intensity, etc. and unusual phenomenon associated with wind, e.g. trees all leaning in one direction or blown down in all directions, as spokes in a wheel.

D. Collect any quantitative assessments of damage to other tree crops, like coffee, ginger, medicinal plants, etc., including extent of damage to agricultural crops (e.g. all plantains or bananas destroyed in the country) These data can in turn be related to known or observed damage to trees.

E. How is tree damage best expressed:

Basal area lost by damage classes or diameter classes
No. of trees lost in relation to an entire stand or plantation (%)
Volume by diameter classes
Others (?)

F. How are damage results best summarized?
tables (simple or matrix)
figures
others (something creative and innovative, but not necessarily too technical)

IV. Based on answers and comments to all of the above, develop appropriate field data sheets as well as analyses and interpretation sheets for summarizing the field data collected.

V. Based on answers above, develop new guidelines for remeasuring the plots assessed in Dominica in 1979, and maybe the plots (pine) assessed in P.R., also in 1979.

5 January 83 Planning Strategy

G. Charles
F. Gregoire
L. Liegel

I. The 3 S's of Cyclonic Storm Damage in Forest Ecosystems (tentative)

Storm Factors

Proximity of area to eye or storm center

wind intensity of storm

wind duration during storm

relationship to storm quadrant

Site Factors

Elevation

Mean annual rainfall

Aspect

Lee vs. windward slopes

Slope %

Rain amount during storm

Distance from affected site to the coast

Soil properties (chemical or physical)

Erodability index

Silvicultural Factors

Species and/or provenance differences:
- root systems
- branching habit (single or multiple stems)
- foliage type: needles or leaves

Species composition (monoculture vs. mixed forest)

Stand density:
- thinning vs. unthinned
- time of thinning before storm
- thinning intensity (or past mortality)
- single tree effects (roadside vs. in a stand)

II. Planning Strategy for pre-Field Activities in St. Lucia and Dominica

- identify plantation or natural forests stands with past cyclonic storm history on topo or other maps; state species mix and known silvicultural factors
- determine as many site factors as possible
- make notes on other observations from storms, e.g. extent of roadside damage
- collect data or observations from other small islands and elsewhere
- assemble and analyze all internal reports relating to damage surveys for St. Lucia and Dominica

Part [illegible]

Diameter Classes (inches)										
1	2	3	4	5	6	7	8	9	10	11

Edge Trees			Form							Superior Trees in Sub plot	Cone Data		
											Type		
No	DBH	Cones/Tree	Epicormic Branches	Fortail	Forked Stem	Butt Swell	Stem Leaning	Crooked			Tree No	New	Maturing (this season)

Subplot Dimensions

Length ft

Width ft

Other Data or Calculations

Original No of Trees Planted

Within Row	Between Row

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Form ITF-2474

Growth and Development of *Pinus caribaea* on Diverse Soils in Puerto Rico

/Location & Ownership/

(2-3)_____ (Barrio) (4-7)_____ (Road) (8)_____ (Ownership)

/Climate & Related Factors/

(9)_____ (Life Zone) (10-12)_____ (Rainfall-inches) (13-16)_____ (Elevation-feet)

/Geology & Soils/

(17-20)_____ (Soil series) (21-23)_____ (Parent Material) (24)_____ (Slope) (25)_____ (Erosion Factor)

/Plantation Characterization/

(26-28)_____ (Area) (29)_____ (Spacing) (30-32)_____ (BA-Prism) (33-34)_____ (Form) (35)_____ (Self-Pruning)

(36-38)_____ (Height--Site index--dbh) (39-41)_____ (42)_____ (Foxtail %) (43)_____ (Epicormic branching) (44)_____ (Natural Reproduction)

(45-47)_____ (BA: x of 20 trees) (48-50)_____ (height---Edge trees---diameter) x of 5 trees

/Seed Production Factors/

(54)_____ (Maturing cones/tree) (55)_____ (Young cones/tree) (56)_____ (No. of superior trees)

(57)_____ (Branch angle) (58)_____ (Flowering) (59)_____ (Edge trees) (60)_____ (Cone Position)

/Past & Present Stand History/

(61-63)_____ (Age) (64)_____ (Burned) (65)_____ (Windthrow) (66)_____ (Other damage)

(67)_____ (Mycorrhizae) (68)_____ (Understory) (69)_____ (Litter thickness) (70)_____ (Litter composition)

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(71-80)---Open
Remarks or Comments

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Fig. 1.2. Soils are natural features of the landscape.

NATURE AND USES OF SOIL

Soil is a loose mass of broken and chemically weathered rock mixed with organic matter. Humus is decomposed organic matter and is present in some soils on uplands. In many wet places plant remains have accumulated in a rather undecomposed state to form peaty soil. Most people think of soil as a support for growing plants in gardens, farm fields, and forests. To the farmer who tills the land each season and smells the unique earthy odor of a freshly turned furrow, the soil is a producer of foodstuff. Engineers are concerned with the soil as a foundation for such uses as roads, airports, and buildings. In intertropical regions millions of people live comfortably in homes built chiefly from locally excavated soil. Such earthen houses are common in West Africa. A compound dwelling for an extended family may be quite an impressive earth structure. The adobe houses of southwestern North America and the pioneer sod houses of the prairies are other examples.

Fig. 1.3. Earthen houses are common in West Africa.

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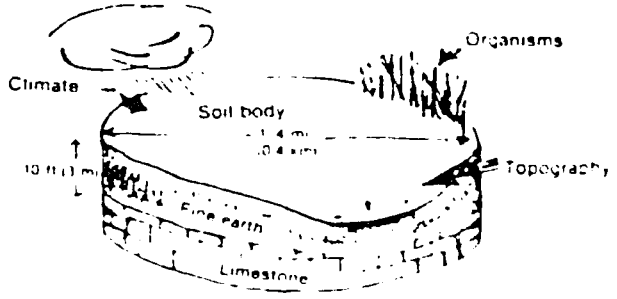

Fig. 1.4. Parent material is acted on over time by soil-forming factors.

Soils differ from place to place. Several factors influence the soils and account for their variability.

FACTORS OF SOIL FORMATION

Soil scientists prefer to think of soils as natural bodies that have length, breadth, and depth. Each soil body occupies a portion of the landscape. This means that soils are more than simply the product of rock weathering; they are natural features of the landscape just as rivers, forests, marshes, and prairies are. Thousands of years have been required to make our present-day soils. Five factors that have influenced their formation are:

1. *Parent material.* This is the bedrock that has either [illegible] up at a site or has been transported there by water or other agents. Soil has developed from this parent material.

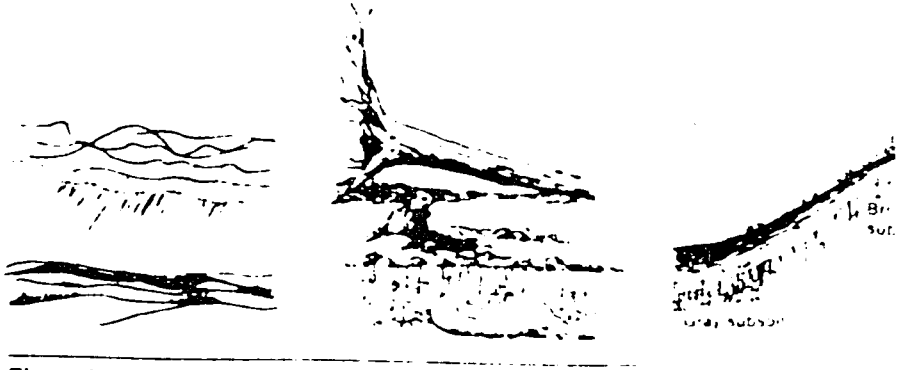

Fig. 1.5. Climate, living organisms, and topography contribute to soil formation

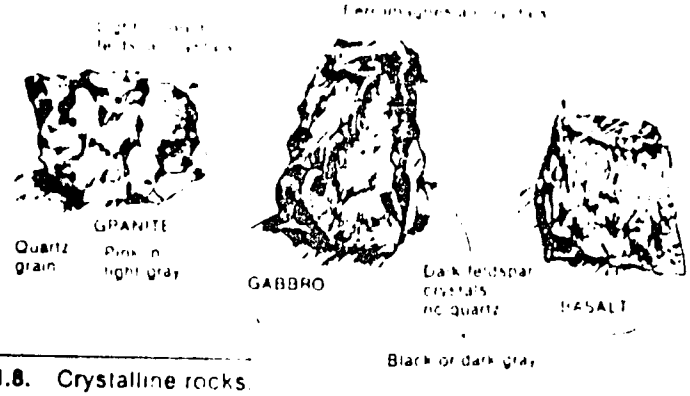

Fig. 1.8. Crystalline rocks.

SOIL PARENT MATERIAL

CRYSTALLINE ROCKS. Crystalline rocks include ancient granites, gabbros, basalts, and associated metamorphic rocks that make up the foundation of the continents. These rocks are buried out of sight for the most part, often to great depths under beds of sandstone and shale. Crystalline rocks (so named because of the beautiful crystals in them) underlie the regolith on about one-quarter of the land area. They are used for building stone and monuments. Pink and light gray granite in particular is prominent in buildings and monuments. It outcrops dramatically at Mount Rushmore in the Black Hills of South Dakota, where the heads of four U.S. presidents have been carved in it.

Soils that have formed from granite contain a full range of particle sizes, from gravel and sand to the finest clay. The quartz mineral grains (somewhat like bits of glass) in granite are very resistant to weathering and so become the gritty sand in the soil. The other less resistant minerals in this rock—such as feldspars (a word meaning field crystal because it is so abundant) and dark minerals rich in iron and magnesium (ferromagnesian minerals), including black mica—are altered by weathering to fine clay particles.

Black and dark gray crystalline rocks include gabbro (coarse grained) and basalt (fine grained). Since these contain no quartz, the soils formed from gabbro and basalt are not sandy but are clayey and sticky and commonly quite red and rather fertile.

SEDIMENTARY ROCKS. Regolith is underlain by sedimentary rocks on about three-quarters of the land area of the earth. These rocks were deposited as soft layers of sediment on the bottoms and shores of ancient seas. Sand was deposited near the shores, gray mud farther out, and limy

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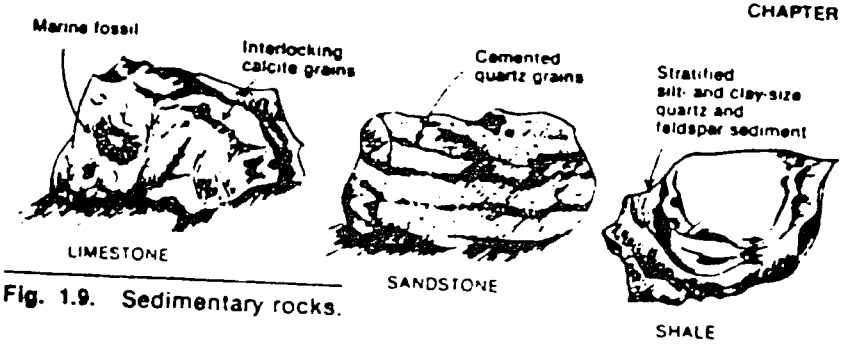

Fig. 1.9. Sedimentary rocks.

white mud very far from the shore in clear water. These layers gradually hardened to rock in most places, becoming sandstone, shale, and limestone. The sea bottom, slowly uplifted, became dry land. Weathering and erosion of the sedimentary rocks began, and soils formed from them in the process.

Soils on sandstone are sandy; those on shale are clayey. Soils on limestone consist largely of insoluble shale materials that were included as gray mud in the otherwise soluble rock mass. Therefore, soils on limestone are commonly clayey.

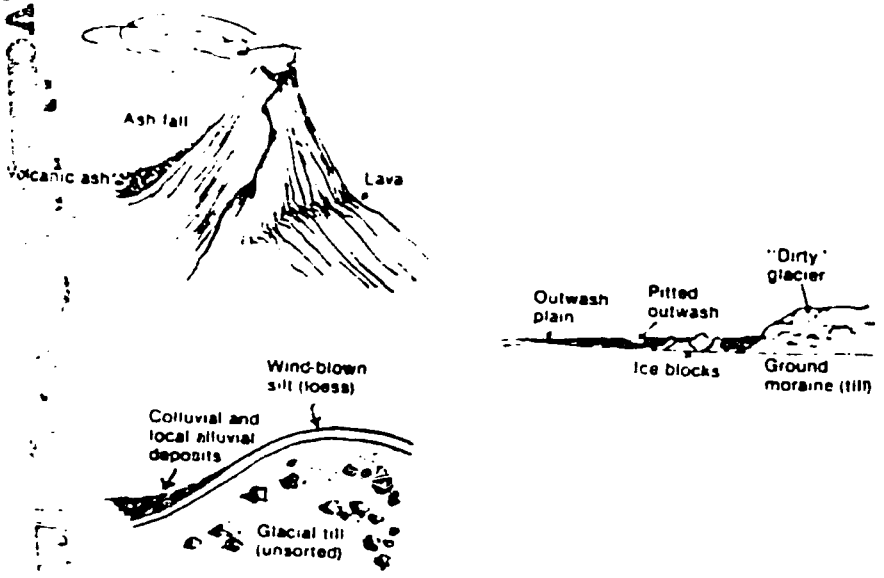

Fig. 1.10. Bedrock may be blanketed by sediment from several sources.

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RECENT COVER DEPOSITS. Cover deposits are blankets of recent sediments that overlie the bedrocks just mentioned. These include cover sands, cover silts, volcanic ash, glacial drift, alluvium (deposited by rivers or streams) and colluvium (collected at the foot of a slope).

Cover sands, both windblown and water-laid, are extensive in [illegible] and subhumid areas such as the Sand Hills of Nebraska.

Cover silts are windblown deposits, called loess, in which [illegible] agricultural soils of the world have formed—in China, [illegible] River valley, and many other places.

Volcanic ash soils are productive in Indonesia (Java), Japan, [illegible] and Washington in the United States, Mexico, and many other [illegible] tainous areas.

Glacial deposits, often with a covering of loess, are parent materials of soils of much of the corn belt in North America and the wheat [illegible] Eurasia. The glacial drift was left by ice sheets of [illegible] which were extensive over northern parts of North America [illegible] between 1 million and 10,000 years ago. The glaciers carried [illegible] debris collected from their grinding action over the terrain and [illegible] made of "dirty" ice. A mixture of unsorted stones, sand, [illegible] (till) was deposited by the ice in blankets or ridges (moraines). [illegible] flowing meltwaters built sheets of outwash sand and gravel. Where large ice blocks were buried and later melted, we see deep pits today. Many lakes once existed near the big glaciers. Today the ancient [illegible] are almost level farmlands with productive silty and clayey soils.

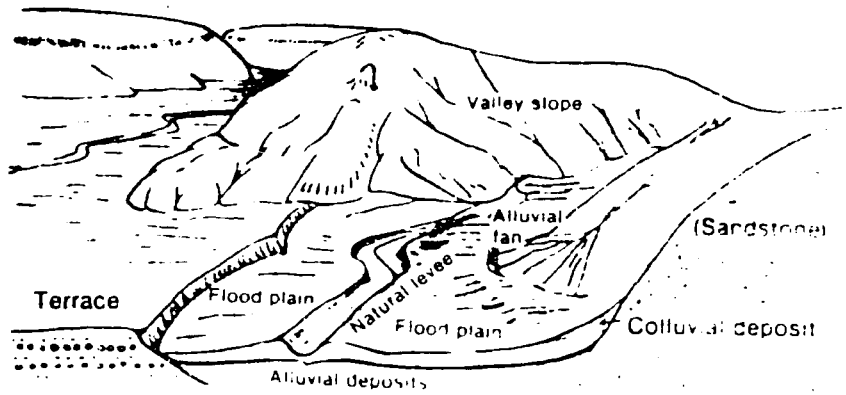

Fig. 1.11. Representative landforms

2 SOIL PHYSICAL PROPERTIES

The soil properties that we can see or feel are physical, and several will be discussed in this chapter. People are often misled into thinking that chemical properties are more important because they are detected with sophisticated scientific instruments. In fact, we can alter many chemical properties to our needs with soil amendments. On the other hand, physical properties are much more permanent and should receive greater consideration in land-use planning.

SOIL TEXTURE

For untold centuries people have rubbed soil between their fingers as a simple field test. If the soil feels harsh and coarse grains are visible, it is classified as a sandy soil. If moist soil feels slippery but not really sticky, it is a silty soil; if it is very sticky and can be rubbed into a cohesive ribbon that will extend from the fingers like a blade of grass, it is a clay soil. A

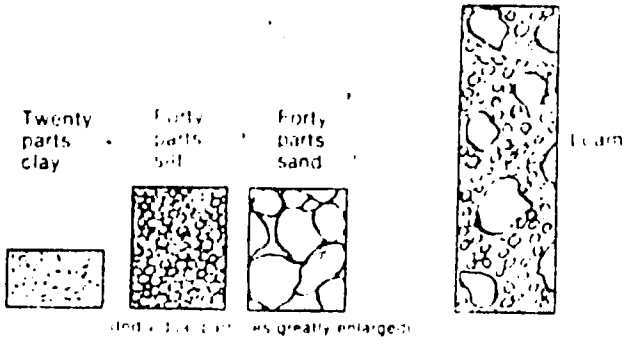

Fig. 2.1. Loam is a combination of clay, silt, and sand

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mixture of the proper amounts of these three components, which are called soil separates—sand, silt, and clay—is called a loam. We speak of various kinds of loam according to the degree of grittiness, smoothness, and stickiness—sandy, silt, and clay loam. A simple loam without excessive amounts of any ingredient has about 20% clay, 40% silt, and 40% sand. Compared to silt and sand, clay is so sticky that not much is required to give the soil a special textural quality. Soil texture is the degree of fineness or coarseness of the soil.

A textural triangle can be used to show the domains of the various soil textures. The term "loam" applies to the central area in the lower part of the triangle. We can see that equal amounts of sand, silt, and clay define a clay loam. A soil with 50% sand, 20% silt, and 30% clay is a sandy clay loam. Additions of humus to a soil (not shown in the triangle) modify soil behavior; sandy soils seem finer textured and clay soils seem coarser textured than they really are.

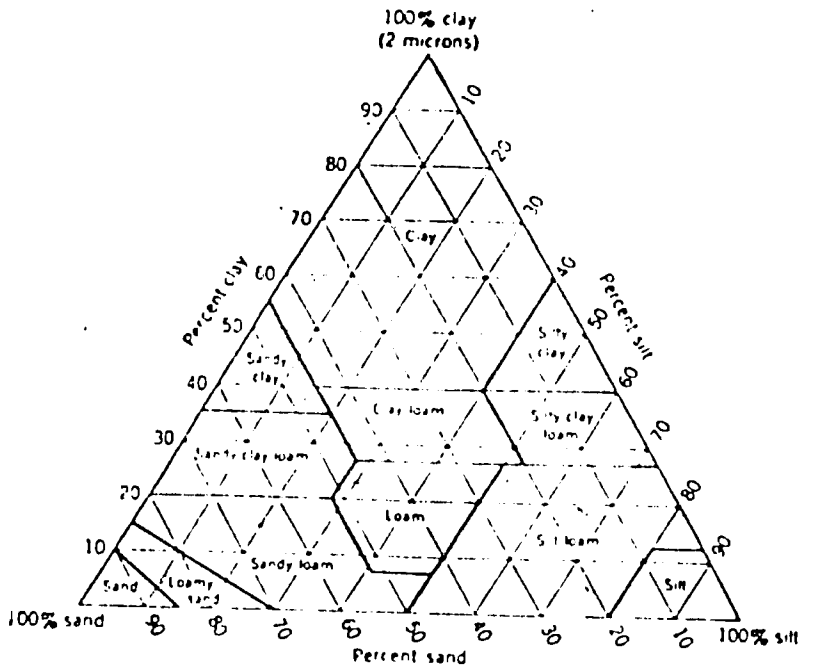

Fig. 2.2. A textural triangle shows the limits of sand, silt, and clay content of the various texture classes.

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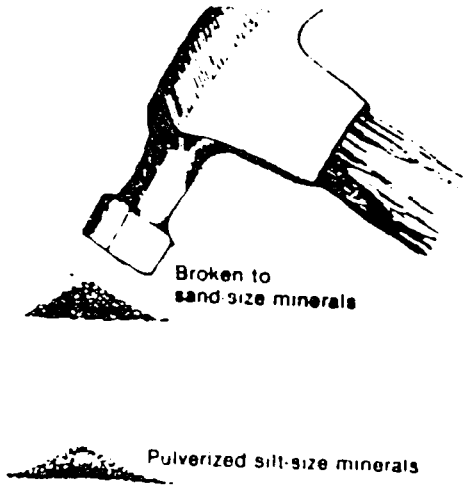

Fig. 2.5. The same mass of mineral when pulverized has much greater surface area.

PARTICLE SIZE ANALYSIS. To make an exact measurement of the amounts of sand, silt, and clay in a soil, we need to shake up a sample in distilled water to which a detergent has been added. The mineral particles settle out at different rates; the sand falls to the bottom first, the silt next, and the clay settles out only after many hours or days. A bulblike float, called a hydrometer (developed by Boujoucos in 1928 and modified by Day in 1956), is placed in the column of water. It floats highest when the most soil is in suspension. The hydrometer sinks gradually (but never completely) as the soil settles out. The position of the water surface as seen against a scale on the side of the hydrometer indicates how to calculate the texture of the soil according to the time elapsed. Directions for making this kind of analysis of particle size in a soil sample may be obtained from agricultural laboratories and many soil science textbooks.

Texture of a soil does not tell us how it got that way. Did wind or water or glacial ice drop the particles of sand, silt, and clay at a particular site? Such questions about the processes of soil landscape formation were discussed in Chapter 1.

SOIL STRUCTURE

Individual soil particles of sand, silt, and clay tend to become clustered into units of various shapes. This clustering is referred to as soil structure, which is defined as the arrangement of soil particles. The resulting structural units may be called aggregates or peds. Structural arrangements result from physical forces that cause some movement within the soil. Among these forces are the action of expanding roots, shrinking and swelling from moisture variation, freezing and thawing, and action of earthworms and other soil organisms. The weak cementing agents that hold aggregates together may be clay, organic compounds, oxides (particularly of iron), and various salts.

Soil structural units are classified according to shape, as shown in Figure 2.6.

SOIL COLOR. There are primarily two coloring agents in the soil: humus and iron. Most people recognize the dark surface soil as being humus enriched. The varying shades of red, yellow, and gray of soils are usually due to the quantity and form of iron present. Red means that the iron is oxidized and not hydrated with water. Yellow indicates hydration and sometimes less oxidation. Gray indicates chemical reduction due to wetness and the lack of oxygen.

Soil color has an effect upon the amount of absorption of solar radiation, but it is even more important as an indicator of natural drainage conditions.

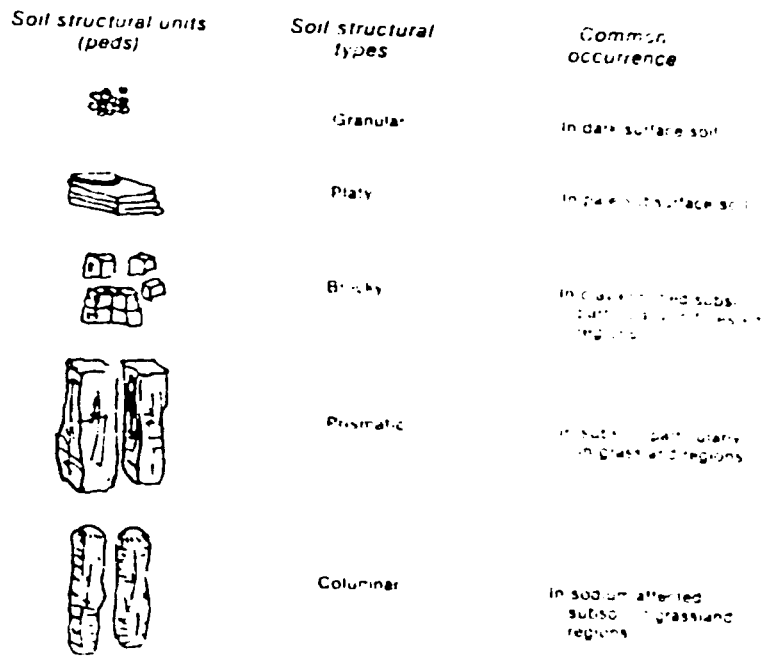

Fig. 2.6. Soil structural units (peds) are classified according to shape.

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Fig. 3.4. Layer lattice crystals of montmorillonite clay have a high capacity to hold plant nutrients and to adsorb water and swell

humid regions, they are generally in soil formed from shale or in the from basic rocks.

is interesting to note that on a farm where this clay abounds, poultry may become immobilized in the mud after rains. One of the farm chores is to rescue the helpless chickens and free them by washing their feet.

Fig. 3.5. Sticky clay can cause problems for farmers.

HYDROUS MICA GROUP. Hydrous mica has a rather slight structural difference from the primary mineral, mica, that is found in granite. Hydrous mica is probably derived by weathering from the primary form. A member of this group is called illite after a location in Illinois where it was found. Hydrous mica is like montmorillonite in that it has a 2:1 lattice structure, but the lattice layers are held together by a mutual bond with potassium ions between them. This bonding minimizes the swelling and shrinking and results in good bearing strength of this clay and in reduced

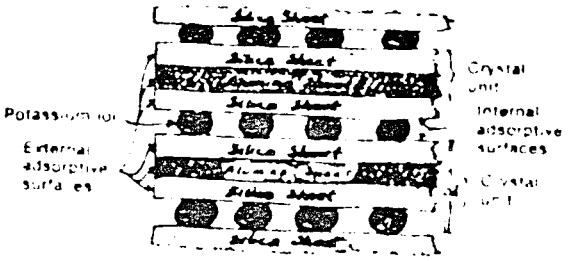

Fig. 3.6. Layer lattice crystals of hydrous mica clays have a low capacity to hold plant nutrients and to adsorb water

stickiness when wet. Clays of this type have a low capacity to hold plant nutrients.

Presence of this kind of clay in a soil does not make the soil unstable in the way that montmorillonite does. Predominance of hydrous mica in a soil indicates a lack of severe weathering. It is likely to be found in the cool climatic zones where precipitation is high enough to remove soluble salts from the soil.

KAOLINITE GROUP. The lattice of kaolinite clays is made up of one silica and one alumina layer (1:1 type). It can be seen that kaolinite has the least silica of any of the silicate clays. This is the result of the intense weathering that is characteristic of warm regions of the world. One important property of kaolinite is the fixed spacing between the lattice layers. This is due to the attraction of the hydrogen in an alumina layer for the oxygen in the adjacent silica layer. The bond between these lattice layers is on a microscopic level, but it is of great importance because it renders these clays less sticky and gives them a greater bearing strength than the other two types of silicate clays. These clays have a very low capacity to hold plant nutrients and to adsorb water.

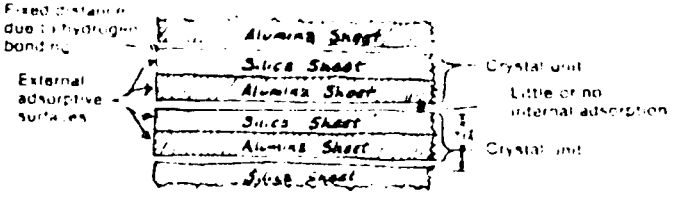

Fig. 3.7. Layer lattice crystals of kaolinite clay have a very low capacity to hold plant nutrients and to adsorb water.

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4 HUMUS

Most soils that have not developed in wet boggy areas consist largely of mineral particles. But even so, the surface soil, the "plow layer," contains considerable organic matter. The soil organic matter is the partially decomposed residue of plants and animals that live in the soil; it is called humus. In Figure 4.1 we see patches of humus in pores between roots and particles of mineral soil. Humus gives soil the dark color widely associated with high fertility, although this assumption is not necessarily true for soils that have been heavily cropped or for naturally infertile soils. In most surface soils of temperate humid regions the humus content lies between 2% and 6% by weight (or twice that by volume); but this small quantity has a great influence on the physical, chemical, and biological reactions that take place in the soil.

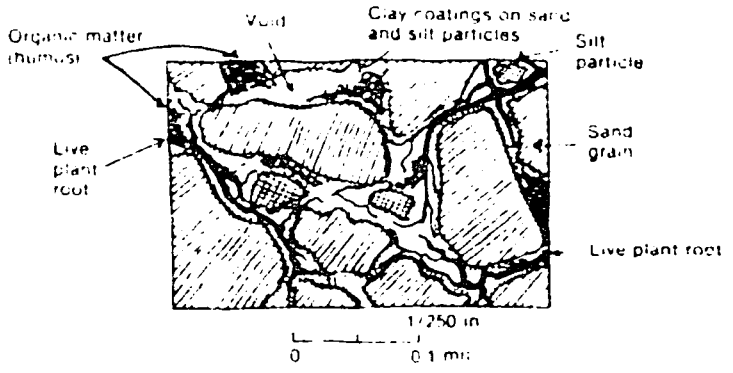

Fig. 4.1. The surface soil contains mineral particles and organic matter.

ORIGIN OF SOIL HUMUS

Most humus is derived from roots of plants (flora) in the soil, with only a very small fraction coming directly from soil animals (fauna). Soils formed under prairie grasslands generally have greater amounts of humus than those formed under forest vegetation because of the high density of grassland vegetation and the fibrous root systems of grasses. In the forest the vegetation at ground level is not nearly so dense, and most of the organic residue from living plants accumulates on the surface of the ground as leaves in the autumn. Much of the humus in the surface 5 or 6 inches (12 or 15 cm) of forest soils results from incorporation of this plant residue into the soil by insects, worms, and other forms of soil fauna.

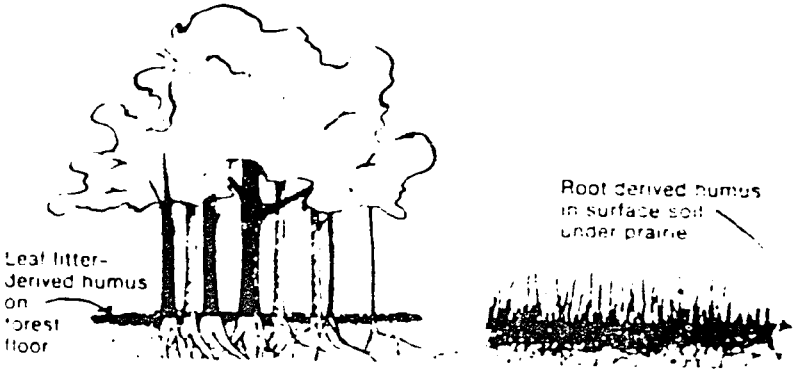

Fig. 4.2. Humus, shown as a dark layer, can be derived from leaf litter on the forest floor or from roots in surface soil.

ROLE IN PHYSICAL REACTIONS

Humus plays a major role in the structure of soils, which is the clustering together of soil particles. Without humus most soils become very dense and cloddy when they are tilled repeatedly. Humus does much to promote the formation of soil aggregates, which are clusters of mineral grains held together by a combination of clay and humus. A well-aggregated soil is said to be in good "tilth" because its looseness allows movement of roots, air, and water and resists the formation of soil crusts that can prevent the emergence of seedlings.

Water enters a well aggregated soil more easily, and more is stored in a form available to plants in the pore system of this type than in poorly ag-

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5 CATION EXCHANGE

Cation exchange is the natural "barter" system by which plant roots get plant nutrient ions, such as calcium (Ca^{++}), which cling to the negatively charged surfaces of soil particles. Commonly, hydrogen ions (H^{+}) in the soil solution, where they have been deposited by plant roots, exchange places with calcium ions. This puts the calcium ions in solution where the hydrogen ions were. Then the roots can take in the calcium.

smallest clay particles are colloidal in size (<0.0001 mm) and have most cation exchange capacity of any part of the soil. It takes 254,000 of these partic , side by side, to cover 1 inch (2.54 cm).

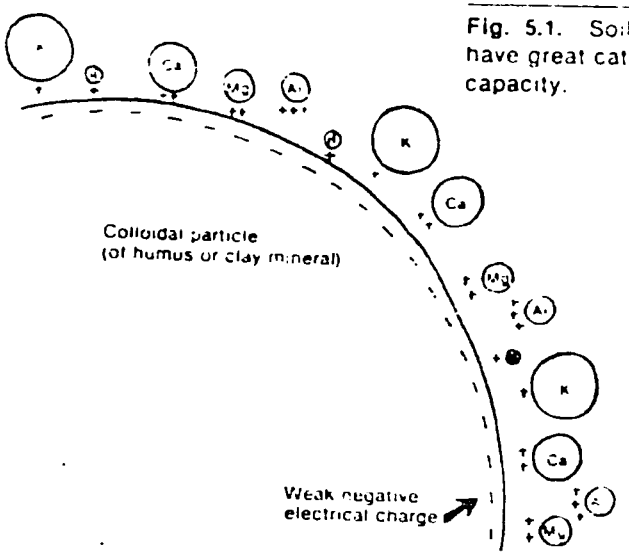

Fig. 5.1. Soil colloidal particles have great cation exchange capacity.

Cation exchange capacity is the number and weight of nutrient ions—calcium (Ca^{++}), magnesium (Mg^{++}), and potassium (K^{+}) especially—that a given weight of soil can hold in available form. When we say that a soil has 25 milliequivalents (meq) of cation exchange capacity (CEC) per 100 grams (3.5 oz) (dry weight) of soil, we are giving a figure that can be translated into pounds per acre (or kilograms per hectare). For example, the plow layer of 1 acre of Iowa prairie soil that has a cation exchange capacity of 24 meq per 100 g may hold a little more than 3 tons of available nutrients, of which calcium amounts to 2¾ tons. Such information obtained through soil tests tells us what nutrient supplies if any a soil needs to satisfy requirements of plants such as maize (corn), alfalfa, or pine trees.

SWARM IONS

Soil cations are sometimes called "swarm ions" because they resemble a swarm of bees around a hive, with the greatest concentration of bees close to it. In a soil colloidal system the ions with two (or more) positive charges (like calcium) and a small diameter are attracted close to the colloid, while monovalent cations (such as sodium with one positive charge) with large diameters tend to migrate farther. All the attracted cations are in constant motion, but attraction holds them tightly enough s they are not readily lost to water that is moving through the soil. This action is very important to plant life because it keeps nutrients within the root zone of the crops.

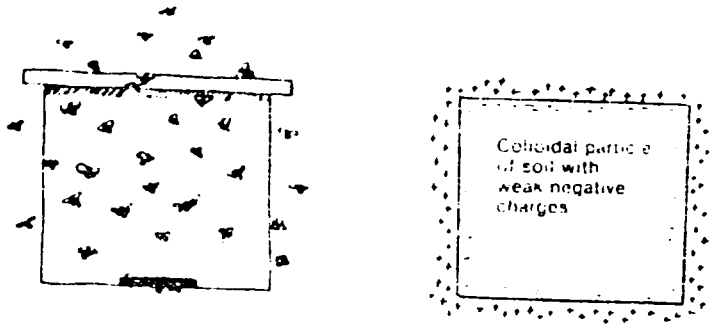

Fig. 5.2. A "swarm" of positively charged ions around a negatively charged soil particle resembles bees around a hive.

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MOVEMENT OF NUTRIENTS FROM MINERAL FRAGMENTS TO PLANT ROOTLETS

Metallic cations (M), Ca^{++} is an example, in a mineral fragment are released by weathering into the soil solution where they are attracted to particles of clay, around which they "swarm." By exchange with hydrogen ions coming from around roots, the nutrient ions finally reach the roots. There is an area, called the oscillation zone, in which ions are moving around roots and clay particles. This is the place of exchange, where one cation is replaced by another in an equivalent amount. For example one divalent ion (like Ca^{++}) may replace another divalent ion (Mg^{++}), or it may replace two monovalent ions (K^{+} and K^{+}). When a plant takes cations from the soil, it releases hydrogen ions (H^{+}) in exchange. For example, when one calcium ion is taken into the plant, two hydrogen ions are given off into the soil. Thus electrical neutrality is maintained.

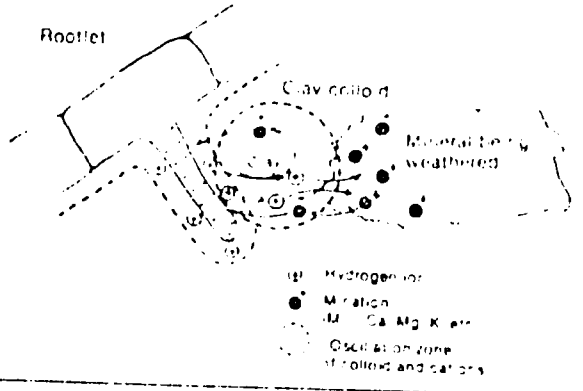

Fig. 5.3. Metallic cations move into the plant rootlet through ion exchange

EXCHANGE REACTIONS

Although colloids have a negative charge, no electrical charge in the soil goes unbalanced for very long. A soil colloidal system has a double layer of charges. The inner layer is the negative charge of the colloidal particle; the outer layer is formed by cations in the soil solution, which are attracted to the colloidal surface in proportion to the negative charges available. This means that a divalent cation such as calcium (Ca^{++}) or magnesium (Mg^{++}) will neutralize two negative charges of the colloidal particle, whereas monovalent ions such as potassium (K^{+}), sodium (Na^{+}), or hydrogen (H^{+}) will neutralize one negative charge each. In very acid soils aluminum ions (Al^{+++}), which may be combined with one or two hydroxyls (OH^{-}), can be attracted to colloidal surfaces. There may be

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ps that are properly treated with commercial fertilizers and tone to correct acidity produce such vigorous crop growth that large amounts of organic matter are added to the soil in the form of roots and above-ground residues. In this sense, so-called nonorganic farming is actually a combination of commercial fertilization and organic farming. Crops grown in fields and gardens where the soil has been supplied with a balance of nutrients from commercial fertilizers and good soil structure is maintained by addition of organic materials are indistinguishable from those produced by total organic gardening.

SOIL REACTION

For fertilizer to be effective in improving crop yields, it is important in humid regions to correct the acidity of many soils in accordance with crop requirements.

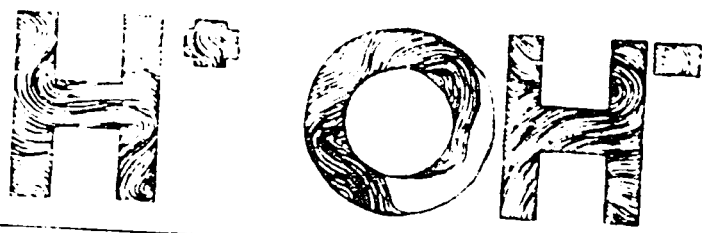

Fig. 8.14. Hydrogen ion concentration is expressed as pH.

The term "soil reaction" refers to the concentration of hydrogen ions (H^+) in the soil solution. This concentration is expressed on a hydrogen potential (pH) scale, which shows how acid or basic a soil is. Reference was made to this scale in the discussion of soil humus in Chapter 4. Sometimes acid soils are spoken of as "sour" because any acid substance has a sour taste. Some crops such as cranberries thrive in acid soils. Other crops, including alfalfa, are less tolerant of such conditions. Most crops do best if the pH is about neutral.

Basic (alkaline) soils have a concentration of hydroxyl ions (OH^-) in excess of hydrogen ions. Soils that create a problem by being too alkaline are found scattered in dry areas, but even in arid and semiarid regions most soils have a favorable pH unless abundant sodium was inherited from the parent material.

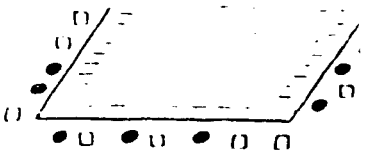

Fig. 8.15. A colloidal clay particle has exchangeable cations around it. Each ● (acid) or ○ (base) represents billions of ions.

BASE SATURATION. Most cations in the soil are associated with the c ion exchange complex of colloidal clay and humus discussed in Chapter Under acidic conditions comparatively few basic ions (calcium, magn sium, potassium) are attracted to the exchange complex, but there a many hydrogen ions there. Aluminum ions in the exchange complex al give an acid reaction. In a laboratory, soil scientists can replace the nat rally occurring cations in a soil sample with another kind in such a w that the original cations can be collected and analyzed. The amount basic exchangeable cations found is compared to the total amount of e changeable cations. This is the means for calculating the percent base s uration. For example, on the colloidal clay particle in Figure 8.15 the are twenty-five cations, fifteen of which are basic. Therefore, the perce base saturation is (15 ÷ 25) x 100 = 60%.

REASONS FOR ACID OR BASIC SOIL. In arid and semiarid regio most soils are basic (alkaline) or nearly neutral for two reasons: the io derived from weathering of minerals are dominantly base forming, a there is not enough precipitation to leach them from the soil.

In the humid regions of the world the leaching by precipitation can the bases to be translocated deeper into the soil, and ultimately re return to the sea. We can see the effect of this process over the long sp

Fig. 8.16. Leaching of the soil ultimately returns bases to the sea.

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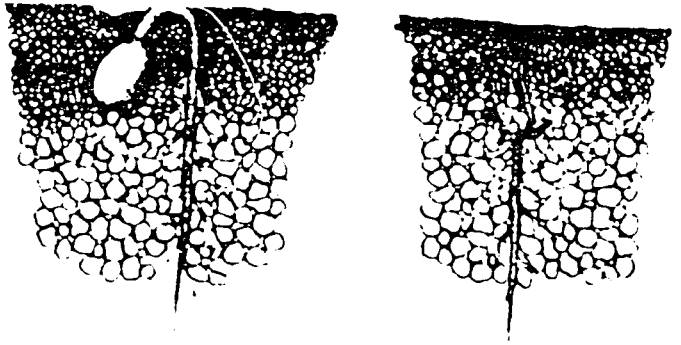

Fig. 6.5. If a plant seedling is not strong enough to lift the soil crust, it will die.

when plenty of organic matter is present and rather gentle tillage practices are used. The farmer who depletes the soil of organic matter by removing crops without returning plant residues is likely to be unsuccessful. Spongy aggregates do not form. When raindrops strike exposed soil, the soil is beaten to a paste, which forms a kind of seal or crust. This tends to shed water like a roof.

When the sealed off surface becomes dry, it forms a brittle crust that can inhibit emergence of seedlings. Strong emerging seedlings such as those of beans and potatoes are able to break through, lifting pieces of the crust like so many trapdoors opened from below. But seedlings of small-seed crops like oats and even corn may perish without ever emerging. Sometimes farmers have to break up this crust with light tillage after planting the crop, but this may be only partially successful at best.

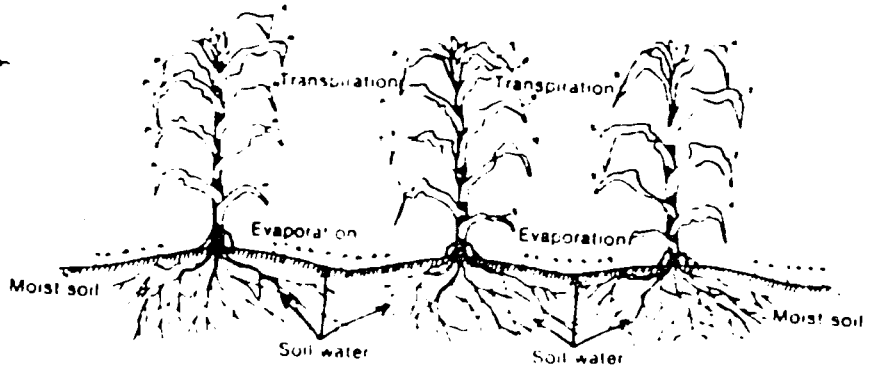

Fig. 6.6. Soil water returns to the atmosphere by evaporation from the soil surface and transpiration from plant leaves.

It may not be possible to completely avoid crusting on some soils if hard rains fall when the land has been made bare by tilling in preparation for seeding. However, the maintenance of strong aggregates through the incorporation of organic matter is very helpful in preventing serious crusting.

EVAPOTRANSPIRATION

What becomes of water that enters soil? Some of it percolates down to the water table and eventually flows into rivers. Most of it, however, goes in the opposite direction—back to the atmosphere in gas or vapor form. This happens in two ways. One is by evaporation of water into the air from the surface of the soil itself and at the same time by movement of farmland air out of soil pores. The other is by transpiration through plant leaves. The surfaces of the leaves are perforated by numerous openings called stomata, through which moisture escapes. These two processes, evaporation and transpiration, are usually referred to together as evapotranspiration.

In the midwestern United States at least half the water lost as vapor from farmland reaches the atmosphere by evaporation from the soil. This is a real waste of valuable water from cropland. The practice of planting crops in narrow rows helps decrease this evaporation loss.

MULCHES

In small plots of high-value crops, mulches can be used to hold the soil moisture for the plants and thus reduce evaporation. Many kinds of mulches have been used: straw, corncobs, gravel, and, more recently, plastic. All have been quite effective. The selection of one over the other depends on the specific use and the availability of the material.

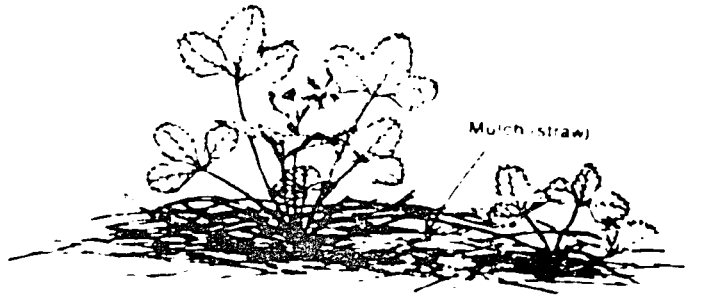

Fig. 6.7. A mulch will help prevent evaporation of moisture from the soil.

INFILTRATION AND PERCOLATION

Soil acts as a sponge to soak up water and retain it (along with some air) in the plant root zone and below. The process of entrance of water into the soil is called infiltration. Downward movement of water, once it is in the soil, is called percolation. During a heavy rain, water may infiltrate and percolate so abundantly as to force air out of the pores and saturate the soil. Gravity pulls the water down through the soil. During a light rain, water infiltrates and percolates more slowly by seeping through the small pores, leaving the large pores still full of air. In saturated soil both gravity and the "suction" power of the small soil pores move the water.

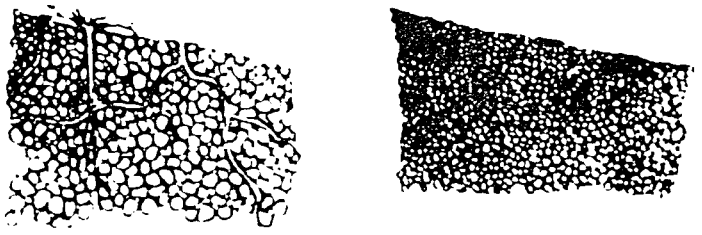

Fig. 6.2. Large aggregates and large pores provide easy infiltration (left). Small aggregates and small pores provide slow infiltration (right).

Since water is a valuable resource, it is important that some be stored in the soil for plant use and that some percolate through to the groundwater reservoir.

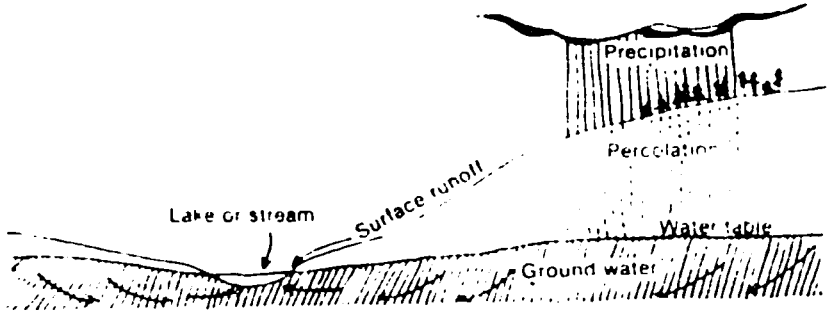

Fig. 6.3. Precipitation reaches the water table by percolation to recharge the groundwater.

GROUNDWATER RECHARGE

The water that fills large soil pores moves downward under the force of gravity. We have already spoken of this gravitational water. It percolates until either it is absorbed by drier soil below and is very much slowed in its movement or it reaches the water table. The water table is the plane in the porous substratum below which all pores are filled with water. This may be within the surface soil or in the deep bedrock. Groundwater is the term for the water below the water table. The water table surface has high and low positions, as does the land surface, but with less vertical range. Wetlands, lakes, and streams are places where the water table comes to the surface and where discharge is taking place. Wetlands in humid regions are actually not recharge areas, for water is being lost from them in the form of stream flow and evapotranspiration. Porous rock layers such as sandstone may be saturated and can be important sources of well water. Such layers are called aquifers.

In arid regions, wetlands fed by mountain streams recharge distant lowlands that have no other major water source.

RUNOFF

In a productive soil the soil pores need to be large enough to permit water to enter and move freely. If the soil pores are very small because of soil compaction or a natural "tight" soil condition, much water will run off. This takes water away from plant roots. Runoff water may also erode, carrying soil with it.

A gardener or farmer can have a good influence on the soil by keeping it under a protective vegetative cover and maintaining absorption capacity. This is a way to conserve both water and soil. The farmer or gardener keeps the topsoil full of "crumbs," which are stable spongy aggregates into and through which rainwater moves easily. Such aggregates form

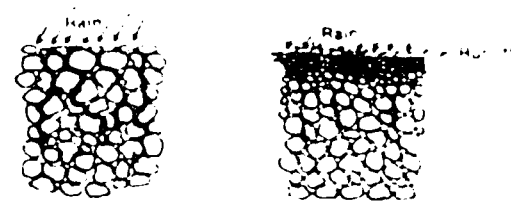

Fig. 6.4. Well-maintained soil provides adequate channels for infiltration and percolation of rainfall (left). Compacted topsoil permits only slow infiltration of rainfall through the crust (right).

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grains of sand and silt and weak cementation cause this horizon to be brittle when dry or moist, but not when wet.

Duripans are more durable than petrocalcic horizons because the cement in duripans includes much silica (SiO_2). This horizon is reported from desert regions and also from landscapes blanketed with volcanic ash under moderate rainfall.

In warm humid regions where iron is abundant in parent materials, the iron has concentrated and crystallized into a continuous layer called plinthite. This may be best developed on lower slopes. Plinthite hardens irreversibly into an iron pan (petroferric layer) when exposed to repeated wetting and drying. Much of what is called ironstone or laterite seems to have originated from plinthite. These iron-rich layers are found on old upland surfaces, which may have been affected by higher rainfall than occurs today.

MODERN CLASSIFICATION SYSTEM

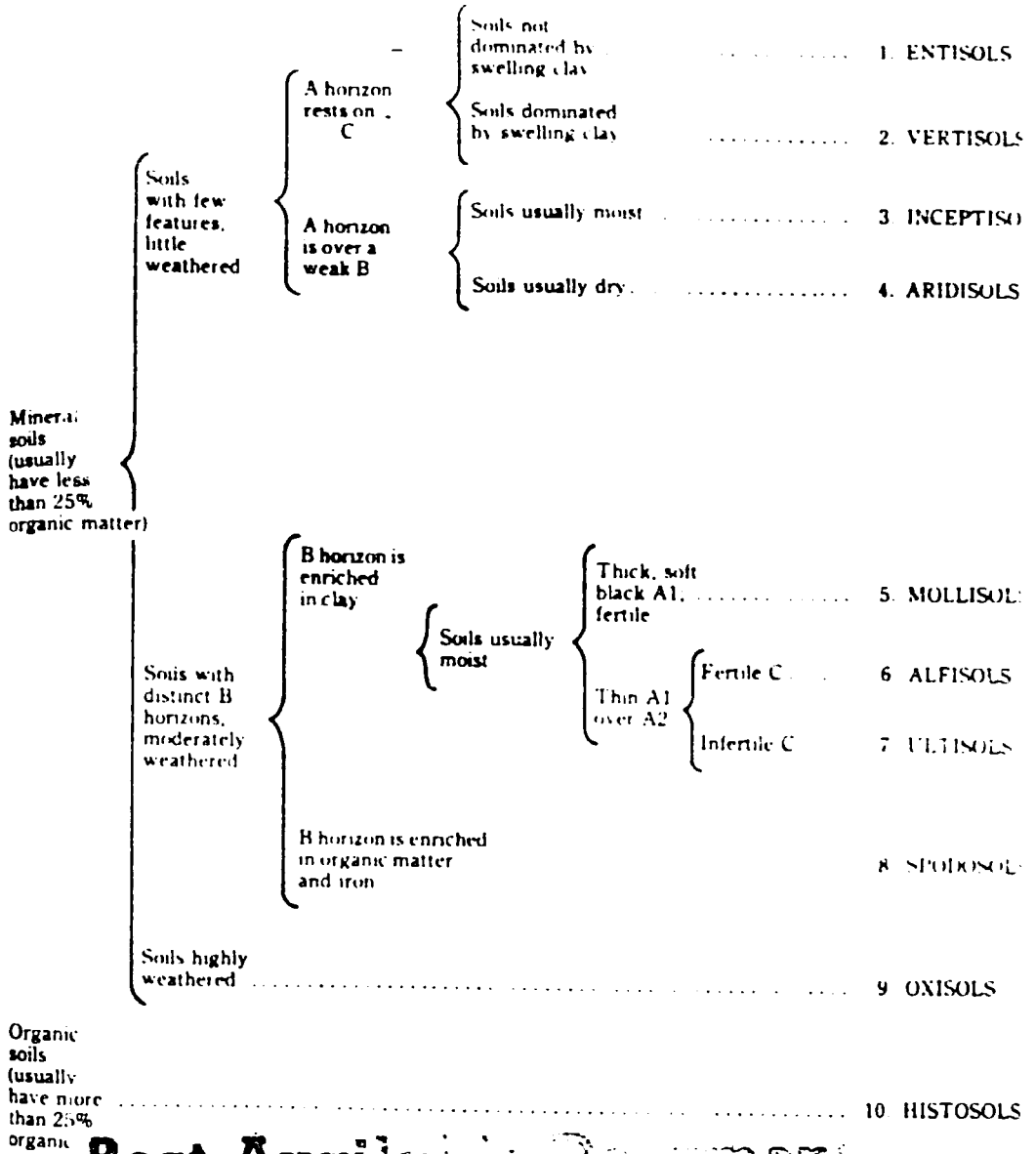
By means of modern classification, information about soils of any a[illegible] may be organized in a way to characterize and name the soils and [illegible]ct behavior regarding agricultural, silvicultural, or engineering ac[illegible]ties on them.

The latest classification of soils of the world was published in 1975 by the soil survey staff of the U.S. Department of Agriculture through the Soil Conservation [illegible]rvice program that is cooperative with the agricultu[illegible]ges and universities of the fifty states. The details of this system are presented in the book, *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*, which is available from the U.S. Government Printing Office in Washington, D.C. Our soil classification system has six categories that reflect levels of detail in a manner similar to the botanical system for the plant kingdom. At the highest level are ten soil orders. Other categories are suborder, great group, subgroup, family, and series.

Figure 11.9 gives a simple classification of world soils based on the ten orders. A world map showing distribution of these orders and various soil horizons is given in Figure 11.10.

THE TEN SOIL ORDERS

1. ENTISOLS: PRIMITIVE SOILS. The order Entisol includes soils that are so weakly developed they have only A and C horizons. There are two reasons why these soils lack greater development: the parent material has such highly resistant minerals that rate of weathering is very slow; or the exposed land surface is young as a result of erosion or burial under new



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*Some Mollisols have a weak B horizon; not enriched by clay.

Fig. 11.9. Simple classification of mineral and organic soils of the world based on *Soil Taxonomy* by the USDA.

takes place at a given site. This biocycling keeps the soil from becoming infertile by rapid leaching. Weathering continues in the true soil (A and B horizons) as well as below it. The older a soil gets, the more clay it is likely to have because clay results from the physical breakdown and chemical alteration of larger particles.

When a pit or an excavation exposes these horizons down into the relatively unweathered underlying material, the cross section is called a soil profile. The portion of the soil profile that has been altered by the soil-forming factors is called the solum and is made up of the A horizon (topsoil) and the B horizon (subsoil). On the surface of the A horizon there may be a thin layer of organic matter called an O horizon. The underlying consolidated material is called the C horizon; if bedrock is within a few feet of the surface, it is called the R horizon. These notations may be subdivided in many ways (for example, A1, A2, A3) because of the diverse nature of soils. This provides notation for making more concise and detailed descriptions. The letter symbols are a type of shorthand to the soil scientist; they reveal much about the soil properties. The principal soil horizons are further grouped into diagnostic horizons, which will be discussed in Chapter 11.

Although no single set of soil horizons can be selected to apply to all soils, one that is useful in the region of hardwood forests of the eastern United States is shown in Figure 1.7.

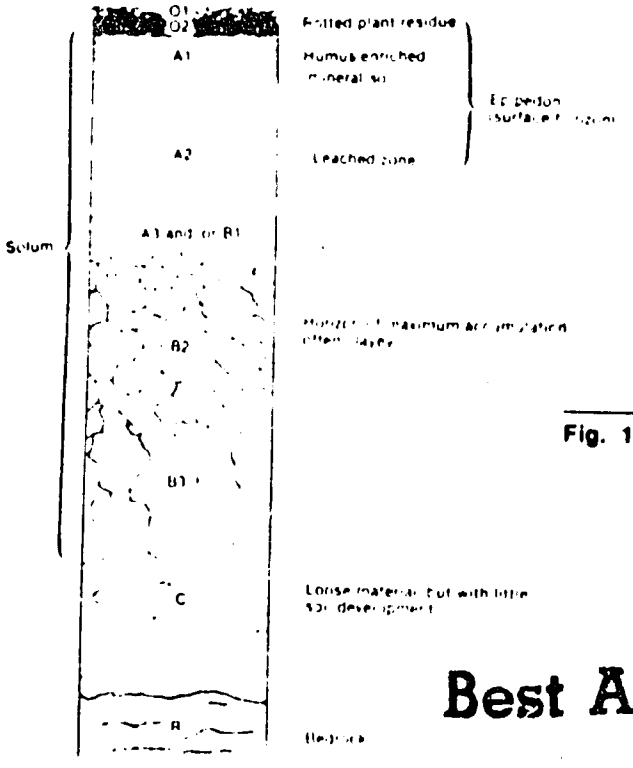

Fig. 1.7. A soil profile.

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Checking Out Soil Texture in the Field

Don't worry about distinguishing all the textural types, but you should be able to tell the difference between a SANDY, LOAMY, and CLAYEY soil. You can do that and then some by using the guidelines below:

SOIL TYPE	Visual Appearance	Squeeze Test	Feel When Moist
SAND	Loose, single grained	When dry and squeezed, it falls apart when released. If wet, it crumbles readily when touched.	Gritty
SANDY LOAM	Loose	When dry and squeezed, it falls apart readily when released. If wet, if forms a cast that crumbles w/o careful handling.	Gritty
LOAM	Few Clods	When dry and squeezed, it forms a cast that needs careful handling. If wet, the cast can be freely handled w/o breaking.	A bit gritty but slightly plastic.
SILT LOAM	Cloddy but clods are easily broken.	Same as above.	Only slightly gritty and plastic; has a talcum like feel.
CLAY LOAM	Cloddy and lumpy when dry.	When wet and squeezed, it forms a cast that holds together under heavy handling.	Plastic; forms a ribbon when pinched between thumb and forefinger but it breaks easily.
CLAY	Hard lumps or clods when dry.	The wet cast can be tossed and caught repeatedly w/o breaking.	Very sticky & plastic; forms a ribbon easy.

THE PROS AND CONS OF SANDY, LOAMY, AND CLAYEY SOILS

Sands (Coarse Textured Soils)

Sandy soils are easily tilled, resist compaction, and have good drainage and aeration - all good qualities for encouraging root growth. However, they have a low water holding capacity, tend to dry out quickly, and are likely to be low in natural fertility. They tend to be low in clay and humus, making for little negative charge to keep plus charged nutrients from leaching (see p. 37). Another reason leaching is a serious

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Table 2. Provenances of *Pinus caribaea* and *Pinus oocarpa* planted at Añasco, Puerto Rico, in October 1973.

PINUS CARIBAEA			PINUS OOCARPA		
CFI NO.	SEED STORE NO.	ORIGIN	CFI NO.	SEED STORE NO.	ORIGIN
K 66	47/71	Melinda, Belize	K 1	1/70	Camelias, Nicaragua
	46/71	Byfield, Queensland Australia	K 6	6/70	Zapotillo, Honduras
K 61	45/71	Santa Clara, Nicaragua	K 11	11/70	Conacaste, Guatemala
K 65	44/71	Mountain Pine Ridge, Belize	K 16	16/70	Agua Fria, Honduras
K 60	40/71	Potosi, Honduras	K 20	22/70 1/	Alamicamba, Nicaragua
K 57	37/71	Culmi, Honduras	K 31	1/71	Junquillo, Nicaragua
K 54	34/71	Briones, Honduras	K 34	3/71	Bucaral, Guatemala
	24/71 2/	El Burén, Cuba	K 36	5/71	Zamorano, Honduras
	19/71 2/	Los Palacios, Cuba	K 42	6/71	Yucul, Nicaragua
K 24	28/70	Guanaja Island, Honduras	K 45	7/71	Siguatepeque, Honduras
K 23	27/70	Brus Lagoon, Honduras	K 43	8/71	Jakuitila, Guatemala
K 29	26/70	Poptun, Guatemala	K 47	10/71	San José, Guatemala
K 22	24/70	Río Coco, Nicaragua	K 44	27/71	Rafael, Nicaragua
K 20	22/70	Alamicamba, Nicaragua	K 48	29/71	Malacatancit, Guatemala
K 19	21/70	Karawala, Nicaragua	K 49	30/71	Mountain Pine Ridge, Belize
	69/7296 2/	Andros Island, Bahamas	IM 70	31/71	Jitotil, Mexi

1/ This *P. caribaea* var. *hondurensis* provenance included as a "standard" against which *P. oocarpa* growth could be measured.

2/ 24/71 and 19/71 are provenances of *P. caribaea* var. *caribaea* Morelet; 69/7296 is a provenance of *P. caribaea* var. *bahamensis*; the other 13 provenances are all *P. caribaea* var. *hondurensis*.

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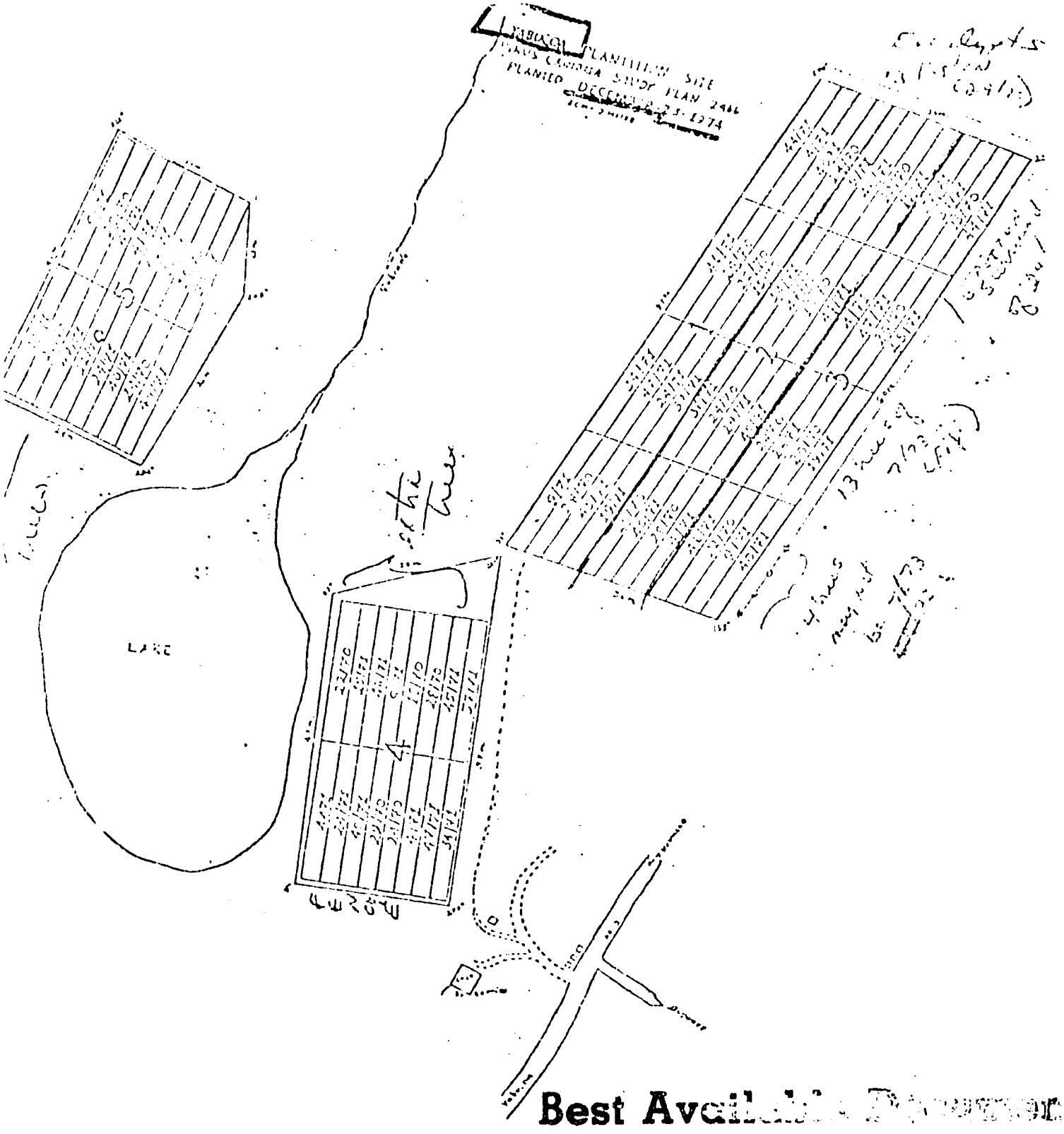

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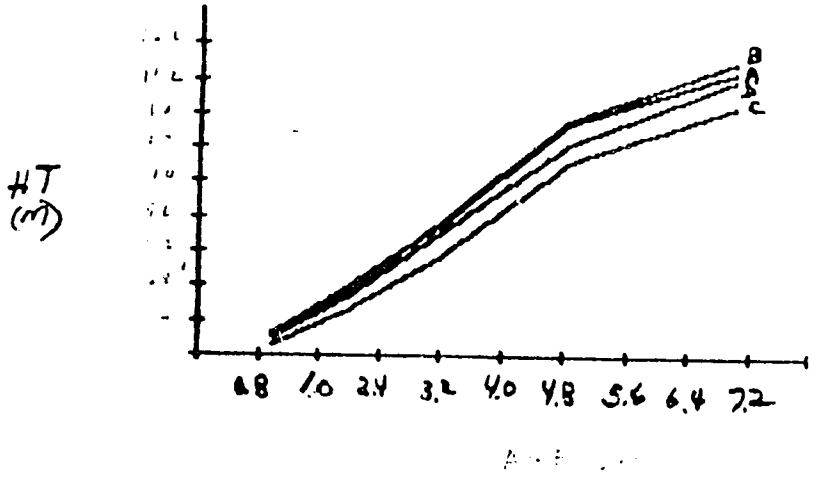
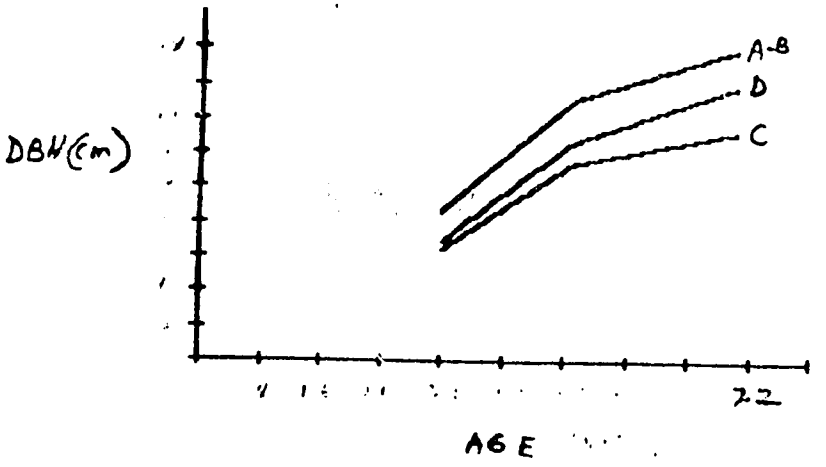
Pinus caribaea, Oxford
Prov. Trial
2-tree plots replicated
5 times

LE:PC 2466 YABUCOA
M:I= Y=
CALE= .8 Y SCALE = 1.4



LE:PC 2466 YABUCOA
:I= Y=
CALE= .8 Y SCALE = 2



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OXFORD

PC 2466 YASUCOA 30X25 L7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
IFORD SEED #	HT(M) AG 1.0	SURV(%) AG 1.0	HT(M) AG 1.0	SURV(%) AG 2.0	HT (M) AG 3.2	DBH(CM) AG 3.2	SURV(%) AG 3.2	HT (M) AG 4.9	DBH(CM) AG 4.9	SURV(%) AG 4.9	HT (M) AG 7.0	DBH(CM) AG 7.0	SURV(%) AG 7.0		
C47-71	0.67	83	2.5	69	4.4	8.5	60	9.7	13.8	57	10.5	15.9	57		
C40-71	0.90	66	3.1	63	5.6	9.3	63	7.6	16.7	60	11.9	20.1	57		
C28-70	0.98	89	3.0	86	5.8	9.1	86	10.0	16.6	80	11.9	19.4	77		A = Coastal
C24-70	0.73	71	2.7	57	5.3	7.7	54	9.7	14.1	49	11.5	16.7	49		
C22-70	0.76	71	2.8	69	5.6	8.2	66	9.7	13.9	66	11.9	17.2	51		
I44-71	0.90	57	3.0	43	5.8	8.9	43	10.5	15.7	43	12.7	19.5	37		
I37-71	0.80	86	2.7	86	5.2	8.2	74	9.8	14.7	74	11.6	17.2	74		
I34-71	0.67	71	2.5	69	5.5	8.8	54	9.1	13.9	54	12.7	19.1	51		B = Interiors
I46-71	0.72	57	2.4	57	5.3	8.3	57	9.8	15.7	57	12.1	19.1	57		
I45-71	0.72	86	2.7	83	5.4	8.4	83	9.4	14.6	83	11.6	17.2	77		
I29-70	0.73	57	2.2	51	5.4	8.7	51	8.7	15.5	51	10.6	17.0	46		
I24-71	0.48	69	1.9	60	4.1	6.5	60	8.5	12.1	60	11.2	13.8	57		C = Small Islands
I19-71	0.42	86	1.8	77	3.9	6.2	74	7.3	10.9	74	9.0	12.6	71		
P09-71	0.64	60	1.9	49	4.0	6.2	37	7.3	11.7	34	10.1	14.7	34		
P04-71	0.83	63	2.6	54	4.9	6.7	51	8.9	12.3	46	11.2	15.6	34		D = P. caribaea
O15-70	0.75	71	2.8	63	5.9	7.9	60	9.5	14.2	60	12.3	17.0	54		

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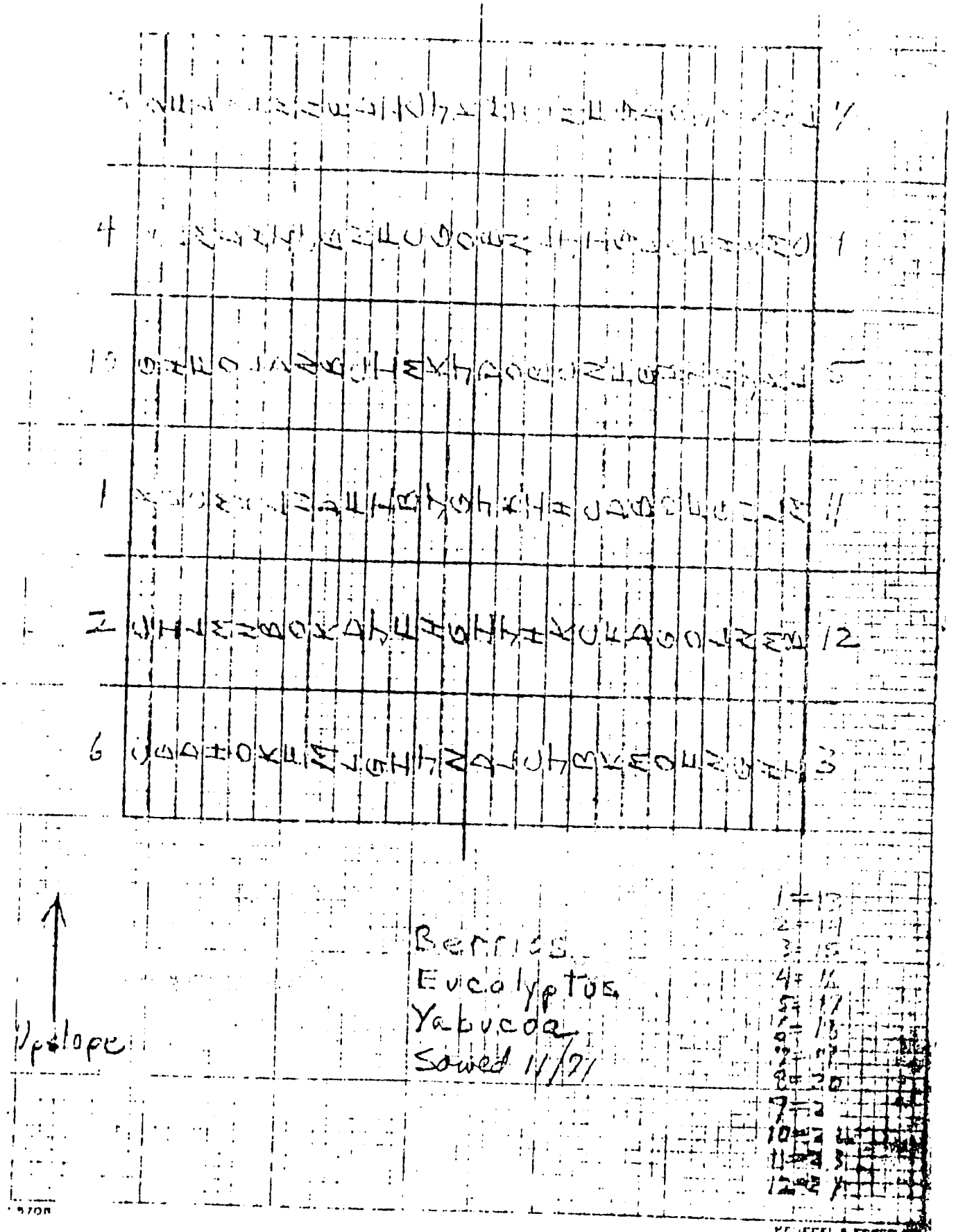

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Eucalyptus Provenances

Study #2453

Yabucoa site

Subtropical moist forest life zone Mayo sandy loam (Typic Dystropept).

Elevation: 50 meters

Rainfall : approximately 2000 mm

Outplanted: November 1971

Five provenances of *E. decaisneana*, five of *E. deglupta* and two of *E. alba* were planted in 4-tree plots, replicated 12 times. At the end of 2 years in the field, mean height of the three species ranged from 3.2-3.8, 2.2-3.2, and 3.0-3.1 meters, respectively and survival ranged from 79-85%, 67-92%, and 75-85%, respectively.

See: Whitmore and Macía. 1975. Forest Science 21(4):410-412.

Table 1

Origin of *Eucalyptus* provenances tested in Puerto Rico
(Forestry and Timber Bureau of Australia, 1969)

SPECIES	ITF CODE	PROVENANCE	LATITUDE	ALTITUDE	SOIL	F C
E. deglupta	B	Papua New Guinea (Goroka)	6°02' S	1815 m	-	8
E. deglupta	C	Papua New Guinea (Raba Raba)	9°58' S	150 m	-	8
E. deglupta	D	Philippines (Mindanao)	7°36' N	515 m	Sandy-silty sand, alluvial fan	9
E. deglupta	F	New Britain (Keravat)	4°19' S	0-90 m	River flat	93
E. deglupta	G	Philippines (Mindanao)	6°15' N	390 m	Sandy loam	94
E. urophylla	H	Indonesia (Timor)	8°37' S	635 m	Schist	89
E. urophylla	I	Indonesia (Timor)	8°47' S	1090 m	Schist	90
E. urophylla	J	Indonesia (Flores)	8°40' S	420 m	Recent volcanic	90
E. urophylla	K	Indonesia (Timor)	9°37' S	1240 m	Limestone	90
E. urophylla	L	Indonesia (Timor)	8°39' S	575 m	Schist	901
E. alba	M	Indonesia (Timor)	8°42' S	360 m	Slate pH 8	899
E. alba	N	Indonesia (Flores)	8°40' S	120 m		900

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Table 3

Height (m), diameter (cm) and survival (%) trends using 2nd, 5th, and 8th year data, by site and provenance. Final column shows wind damage (number of trees damaged). These are trees damaged beyond possible recovery, are considered dead, and are excluded from height and DBH calculations. Note that the Yabucoa site was directly affected by Hurricanes David and Frederick just prior to measurement in 1979. DBH was not measured in 1973. Trees planted in 1971.

Site	Provenance	Height 1973	Height 1976	Height 1979	DBH 1976	DBH 1979	Survival 1973	Survival 1976	Survival 1979	Damage as of October 1979
RIO ABAJO	DEG B	4.9	17.1	25.7	14.5	22.2	73	54	29	9
	DEG C	3.7	15.3	20.8	11.5	14.9	90	60	46	3
	DEG D	5.7	17.9	26.9	16.0	24.2	73	70	57	1
	DEG F	5.0	16.3	22.0	14.2	20.1	82	67	55	4
	DEG G	3.8	15.2	25.2	14.7	22.8	81	40	33	1
	URO H	3.4	14.1	21.6	13.7	19.2	83	55	38	3
	URO I	3.2	10.3	13.3	9.3	12.6	73	48	48	1
	URO J	5.3	14.7	19.3	12.7	16.4	79	68	68	1
	URO K	4.5	13.3	16.8	10.6	13.3	65	69*	48	6
	URO L	3.8	10.8	13.3	9.6	10.6	68	39	39	0
YABUCOA	DEG B	2.2	12.5	18.1	11.4	16.7	67	56	33	5
	DEG C	2.2	11.6	16.0	9.5	13.9	67	58	35	2
	DEG D	2.7	15.1	19.8	14.0	17.6	92	92	83	1
	DEG F	3.0	14.5	19.4	11.2	18.4	69	67	58	3
	DEG G	2.4	12.5	18.0	14.1	15.7	77	60	52	2
	URO H	3.8	14.9	20.5	16.2	25.2	81	79	44	15
	URO I	3.2	14.3	17.9	14.5	18.7	79	83*	54	11
	URO J	3.6	17.0	21.6	16.3	23.2	85	88*	56	10
	URO K	3.5	14.3	18.3	13.4	18.2	81	79	69	4
	URO L	3.7	15.4	22.0	16.8	23.7	79	79	62	7
	ALB M	3.1	10.9	14.0	9.3	12.8	85	69	40	11
	ALB N	3.0	11.7	13.9	9.7	12.5	75	73	56	4

*A few trees that were "dead" in 1973 were alive and well in 1976.

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Reading sheet

S: surrounds; large number [illegible]

Measurement plots: [illegible]

Number 0 in lower right corner of a square means [illegible] not included [illegible] (i.e., not transplanted) Number 1 [illegible] plot [illegible] from [illegible] (i.e., [illegible]), E means [illegible] to complete the plot; V [illegible]

TFG 383

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Pinus caribaea Progeny Test

(Study #2451)

YABUCOA

Subtropical moist forest life zone Mayo sandy loam (Typic Dystropept).

Elevation: 50 meters

Rainfall : approximately 2000 mm

Outplanted: December 1971

Seedlings of 16 superior phenotypes from Belize were planted in 12 replicated plots. Objective was to produce improved seed (combined seedling seed orchard/progeny test).

See: Geary and de Barros. 1973. Commonwealth Forestry Review 52(2): No. 152.

Directions for Scoring

1. Straightness. To be scored on an absolute scale of 0-5 points. Obvious, single, sharp mechanical bends should not degrade too much if the rest of the stem is straight.

2. Crown. To be judged subjectively for the individual select tree. Visual comparison with neighboring trees will be made than possible. However, each individual will be judged on crown (radius, density, shape). Usefulness of this score will increase as familiarity with the species increases. Score 0-5.

3. Limb Angle. To be judged objectively for variation from the horizontal position. Angle to be determined from young limbs near crown top. Lower, larger limbs tend to flatten with age. Score 0-2.

4. Pruning Ability. To be judged, not only on absence of limbs, but on absence of limb scars on the bark. A smooth bark is essential to rate as a good pruner. Score 0-3.

5. Presence of Epicormic Branches. To be judged as well as possible from the tree position. Many trees produce epicormic branches as soon as the stand is opened up and light hits the tree bole. This branching is very degrading for veneer. This characteristic is much a matter of judgment of the grader. Score -2 to -3.

6. Height. To be judged on height for a given age. Curves will be built up for this.

7. Volume. Same as height. Score one point for each 10% superiority.

8. Leader Dominance. To be judged on the tendency for formation of a main leader. Care must be exercised to assess mechanically destroyed leader versus tendency to forking or ramicorn-type branching. Score 0-4.

Detailed Location & Sketch:

_____

_____

_____

_____

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2. Volume - For[illegible] $\frac{V_s}{V_c}$ [illegible] check -- Average of 5. The select tree is [illegible] one point for each 10% [illegible] in volume over the checks.

3. Crown - To be judged subjectively from the standpoint of the individual select tree as compared to the 5 checks and scored as follows:

   a. Crown radius avg. to small for pole [illegible] and competition under which tree has grown: 0 to 5 points depending on superiority. Based also on conformation, density of foliage, [illegible]

4. Form Class - Form class determined by the form point method. The select tree to be given 1 point for each form [illegible] greater than the avg. of the 5 checks less 1. Example - select tree 3 f.c. above checks' score, 2 points.

5. Straightness - Judged subjectively for the individual select tree and not compared to the checks. No tree accepted [illegible] spiral; any crook in two planes; or a crook in one plane which will not allow a line from merchantable top to stump to stay within the confines of the bole. Scored subjectively allowing 0 to 3 points, the number of points allowed dependent upon the relative straightness of the individual. Thus, a tree which contains [illegible] spiral and [illegible] crook in one plane receives 0 points while a perfect [illegible] straight individual [illegible] no spiral receives 3 points.

6. Pruning ability - [illegible] of select tree to shed its lower limbs (dead and alive) as compared to checks.

   a. Average for checks - 0 points.

   b. Above average for checks 1 to 3 points, depending on superiority, judged subjectively.

7. Branch Diameter - Judged subjectively - select vs. checks.

   a. Branch diameter average 0 points.

   b. Branch diameter relatively small 1 or 2 points.

8. Branch Angle - Judged subjectively - select vs. checks.

   a. Branch angle average 0 points.

   b. Branch angle flat 1 or 2 points.

If, in any of the above eight categories excepting straightness the select tree is poorer than the checks, points are deducted by the same scale as they are added when the select tree is superior to checks. Normally a tree with minus score in more than one characteristic is not acceptable.

9. Age - No tree is acceptable which is apparently more than 3 years older than the checks of breast height. Those trees which are apparently younger than the check trees are given a bonus of 1 point for each year younger than the average age of the checks, less 2 years, i.e., a tree 5 years younger than the checks, receives 3 points.

10. Specific Gravity - No points [illegible] are given for specific gravity, since the desires of each company differ. The value of a tree for specific gravity is judged by two criteria:

    (1) Comparison of the select tree with its five check trees. This gives an indication of the tree's position when compared to trees growing under the same environmental conditions.

    (2) Comparison of the select tree with the regional average for that particular company.

These comparisons are shown on the Final Recommendation Sheet, and are taken into account (dependent on the desire of the company) in making the final recommendation for use in the seed orchard.

Best Avail[illegible]

HARDWOOD

Company [illegible] Timber Co.

State [illegible] No.

State N.C.

Company Number

County [illegible]

Date

Grader [illegible]

Tree Data

Species [illegible]

Age 13

DBH

Height: Total 57 Merch. 36 L.C. 23

Cubic Volume

Specific Gravity: [illegible] [illegible] [illegible]

Fiber Length: 15 30

Percent Heartwood

Tree Score

1. Straightness 4
2. Crown 3
3. Limb Angle 2
4. Pruning Ability 2
5. Presence of epicormic branches
6. Weight
7. Volume
8. Leader Dominance 3

Total Score

Comments:

Tree Location

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N. C. State Univ.
Cooperative [illegible]
Selected Tree Rating [illegible]
Form S-1

The grading system described below replaces the original system devised in 1956*

Company _____ N. C. State Accen. No. _____

State _____ Company Number _____

County _____ Species _____

Grader _____ [illegible] _____

Date _____ DBH _____

5 Dominant Crop Trees

	Ht.	DBH	Form Class	Age	Sp. Gr.	Vol.
1						
2						
3						
4						
5						
Total						
Avg.						

Selected Tree Scores

1. Height _____
2. Volume _____
3. Crown _____
4. Form Class _____
5. Straightness _____
6. Pruning Ability _____
7. Branch Diam. _____
8. Branch Angle _____
9. Age Adjustment _____

TOTAL SCORE _____

REMARKS:

	Avg. Crop Tr. (a)	Select Tree (s)
Vol.		
Ht.		
F. C.		
Sp. Gr.		

DIRECTIONS FOR GRADING

1. Height - Formula: [illegible] s = select
c = check - average of 5

The height ratio is determined by the above formula is then converted to tree score by the following scale:

Site Index 76 and below

	Age 5 to 15 yrs.	Age 20-30 yrs.	Age 35 yrs. & up
Less than 10%	0 points	0 points	0 points
10% - 11%	1 "	1 "	2 "
12% - 13%	2 "	2 "	4 "
14% - 15%	3 "	3 "	6 "
16% - 17%	4 "	4 "	8 "
18% - 19%	5 "	7 "	9 "
20%	6 "	8 "	10 "
Over 20%	7 "	9 "	12 "

Site Index 76 and above

Less than 10%	0 points	0 points	0 points
10% - 11%	2 "	1 "	2 "
12% - 13%	2 "	2 "	3 "
14% - 15%	2 "	3 "	4 "
16% - 17%	3 "	4 "	5 "
18% - 19%	3 "	5 "	7 "
20%	4 "	6 "	8 "
Over 20%	5 "	7 "	9 "

*In essence, the systems are the same, but the method of assigning points has been slightly revised. Only specific gravity grading has been drastically changed. Grades of trees as determined by the original and revised systems are comparable.

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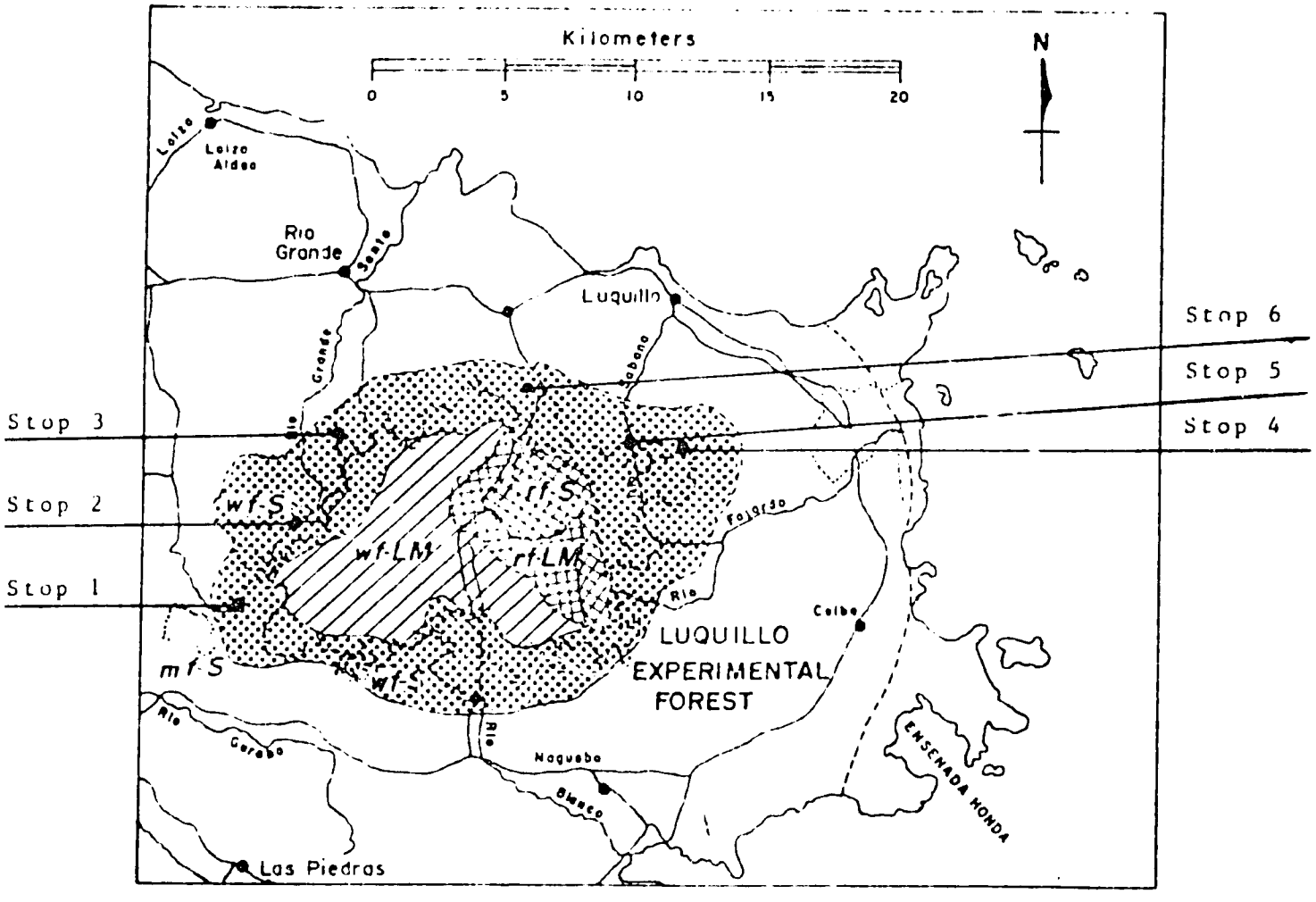

LEGEND

mf-S	Subtropical moist forest	Stop 1	Cubuy
wf-S	Subtropical wet forest	Stop 2	Caracoles
rf-S	Subtropical rain forest	Stop 3	Guzman
rf-LM	Lower montane rain forest	Stop 4	Rio Chiquito
wf-LM	Lower montane wet forest	Stop 5	Sabana
		Stop 6	Catalina

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S&PF Demonstration

Location	Caribbean National Forest-Cubuy plantation P. R. Highway No. 186, Km. 11.4
Species	Pinus caribaea var. hondurensis
Planted	June 1962-July 1963
Spacing	10' X 10' (3 x 3 m)
Elevation	450-580 m
Precipitation	2150 mm (est.)
Life Zone	Subtropical wet

The area covers approximately 8.6 ha and is the second largest pine planting in Puerto Rico. In 1972 the plantation was thinned by poisoning 25% of the trees using a hypo-hatchet and Sylvisar 550.

From 1980-1983 a 0.2 ha area will be monitored to study changes in soil N,P, K, Ca, and Mg, organic matter, and understory composition. The same five elements will be studied in leaf fall and litter samples collected monthly. Biomass will be estimated for the age classes present. The study is made possible by a grant from MAB to study nutrient cycling within tropical plantations and to determine what changes, if any, plantations have on selected soil properties that are also being monitored in adjacent natural forested areas. One younger pine planting and two mahogany plantings (Harvey and Rio Chiquito) are also included in the MAB study.

4110
PS-80-1152-2501
(Problem 1)

Study Plan Summary

A.E. Lugo and L.H. Liegel - Río Piedras, Puerto Rico

DYNAMICS OF TROPICAL TREE PLANTATIONS IN A MAB BIOSPHERE RESERVE

The establishment of fast-growing timber plantations is an alternative to the dual problem of increasing rates of deforestation in the tropics and the increasing human demands for forest products. Many officials advocate the establishment of plantations, primarily of exotic species, as one of the highest priorities of tropical forestry programs. Over 400 native and exotic tree species have been tested for their suitability as timber species in Puerto Rico alone. Nursery, growth, and spacing tests have been conducted for many promising timber producers. Yet, in spite of the long research tradition on plantation forestry (since the 1920's in Puerto Rico and earlier in the British West Indies), there is little quantitative information on the dynamics of tree plantations, including their nutrient cycling pathways, their impact on site quality, and their influence on understory vegetation. Without this information it is difficult, if not risky, to endorse monoculture plantings in tropical environments known for their inherent species diversity. This study will begin the systematic collection of such information in young and old plantations and adjacent natural forest stands.

The primary study objective is to trace the cycling of N, P, K, Ca, and Mg, along with organic matter, within four plantations located within the Luquillo Experimental Forest, a biosphere reserve with environments that are representative of other areas in the humid tropics. The plantations studied represent two internationally popular timber species, *Pinus caribaea* var. *hondurensis* (Honduras pine) and *Swietenia* sp. (mahogany). Aboveground and root biomass will be determined, using dimensional analysis and allometry; differences in soil fertility for five elements and organic matter between plantations and adjacent natural forested areas will also be determined. Sample plots will be 0.2 ha in size. Diameters and heights will be measured on all trees within the plots; roughly 10 percent of the trees will be harvested in each plot. Soil pits will be dug in each plot and in adjacent nonplantation areas. Soil samples will be taken from the A, two B, and one C horizon.

Spacing Trial of Pinus caribaea var. hondurensis in Puerto Rico

Compartment D (Caracoles)-CNF

Planted	1961.7
Soil	Los Guineos clay
Life Zone	Subtropical wet forest
Elevation	520 m
Rainfall	2200 mm

Growth results after 13.6 years as reported in: J.L. Whitmore and L.H. Liegel. 1980. Spacing trial of Pinus caribaea var. hondurensis. USDA Forest Service Res. Pap. SO-162. Southern Forest Experiment Station. Institute of Tropical Forestry. Rio Piedras, P.R. (in press):

Table 3. – *Age, survival, and growth data summaries for triangular spacing trials of* Pinus caribaea *in Puerto Rico. Based on measurement of the 12-tree interior plots*

Site	Age *years*	Spacing *feet*	Survival *percent*	Basal Area Total ft²/acre	Basal Area Total m²/ha	Basal Area Mean annual increment ft²/acre	Basal Area Mean annual increment m²/ha	Volume Total ft³/acre	Volume Total m³/ha	Volume Mean annual increment ft³/acre	Volume Mean annual increment m³/ha
Caracoles	13.6	5	83	381	87	28.0	6.4	11,477	803	844	59
		7	79	259	60	19.0	4.4	8,257	578	607	42
		10	88	247	57	18.2	4.2	7,531	527	554	39
		14	79	163	37	12.0	2.7	5,238	367	385	27
			x̄ = 82								
Utuado	12.5	5	71	260	60	20.8	4.8	7,199	504	576	40
		7	100	278	64	22.2	5.1	8,291	580	663	46
		10	100	206	47	16.5	3.8	7,310	512	585	41
		14	92	170	39	13.6	3.1	4,715	330	377	26
			x̄ = 91								
Guzmán	12.3	5	71	311	71	25.3	5.8	9,322	646	751	53
		7	96	282	65	22.9	5.3	8,518	596	693	48
		10	88	205	47	16.7	3.8	6,470	453	526	37
		14	83	125	29	10.2	2.4	3,827	268	311	22
			x̄ = 84								
Lares	11.5	5	96	311	71	27.0	6.2	8,988	629	782	55
		7	96	268	62	23.3	5.4	8,779	614	763	53
		10	88	225	52	19.6	4.5	8,130	569	707	49
		14	100	193	44	16.8	3.8	6,946	486	604	42
			x̄ = 95								

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Species Adaptability Trial

Compartment D (Caracoles)-CNF

Planted	1961.9
Soil	Los Guineos clay
Life Zone	Subtropical wet forest
Elevation	500 m
Rainfall	2200 mm

Growth Results after 7.4 years:

Species	Total Height (m)	MAI Height (m)
Pinus caribaea var. *hondurensis*	9.7	1.3
Hibiscus elatus	9.4	1.3
Eucalyptus ex bangalore	8.8	1.2
Anthocephalus chinensis	7.9	1.1
Pinus oocarpa	6.5	0.9

This study was also repeated at 25 other locations in Puerto Rico and the U.S. Virgin Islands, on sandy, shallow clay, and limestone soil groups. The single-tree plot design was meant for rapid adaptability testing of tropical species. Height measurements would be terminated 5-7 years after any trial was established. Later, the fastest growing species, also having high survival rates, could then be tested in larger experimental plots, using many more individuals. Results from the upland sands are published in:
T.F. Geary and C.B. Briscoe. 1972. Tree species for plantations in the granitic uplands of Puerto Rico. USDA Forest Service Res. Pap. ITF-14. Institute of Tropical Forestry. Rio Piedras, P.R.

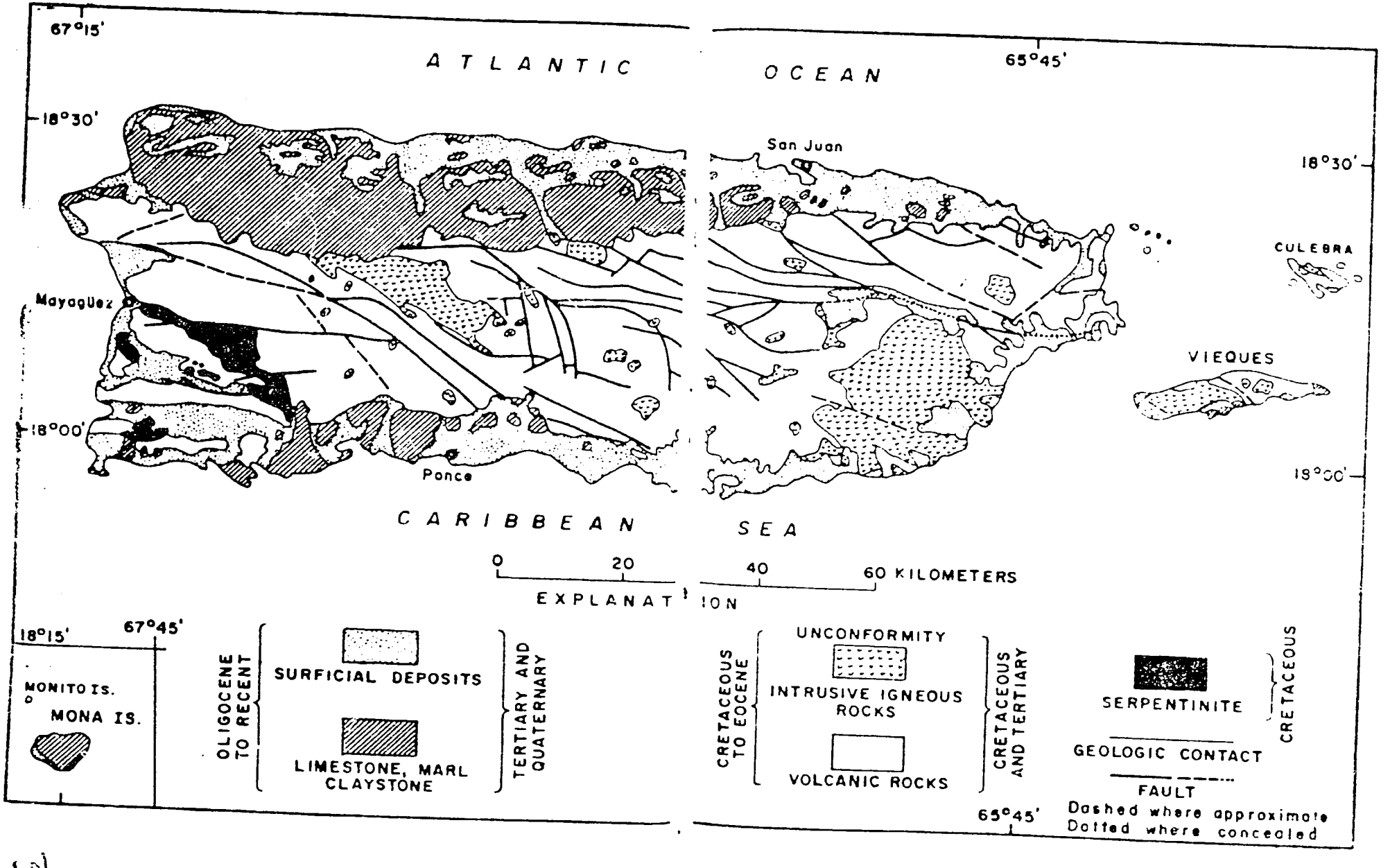

Figure 3.15. Generalized Geologic Map of Puerto Rico. (Reprinted from Reginald P. Briggs, "Mineral Resources of Puerto Rico," *Revista del Colegio de Ingenieros de P. R.* 19, no. 2 [April-June, 1969].)

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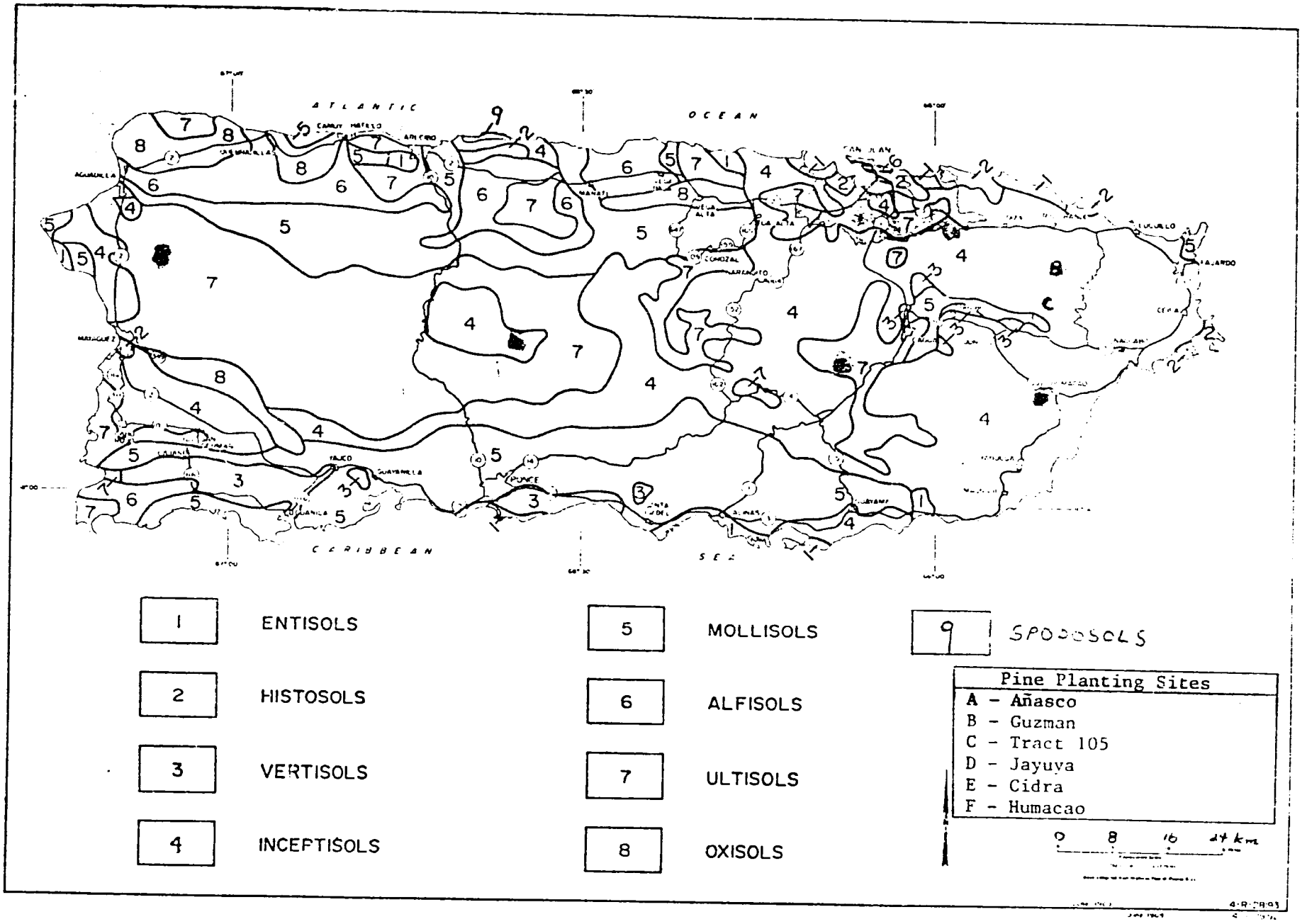

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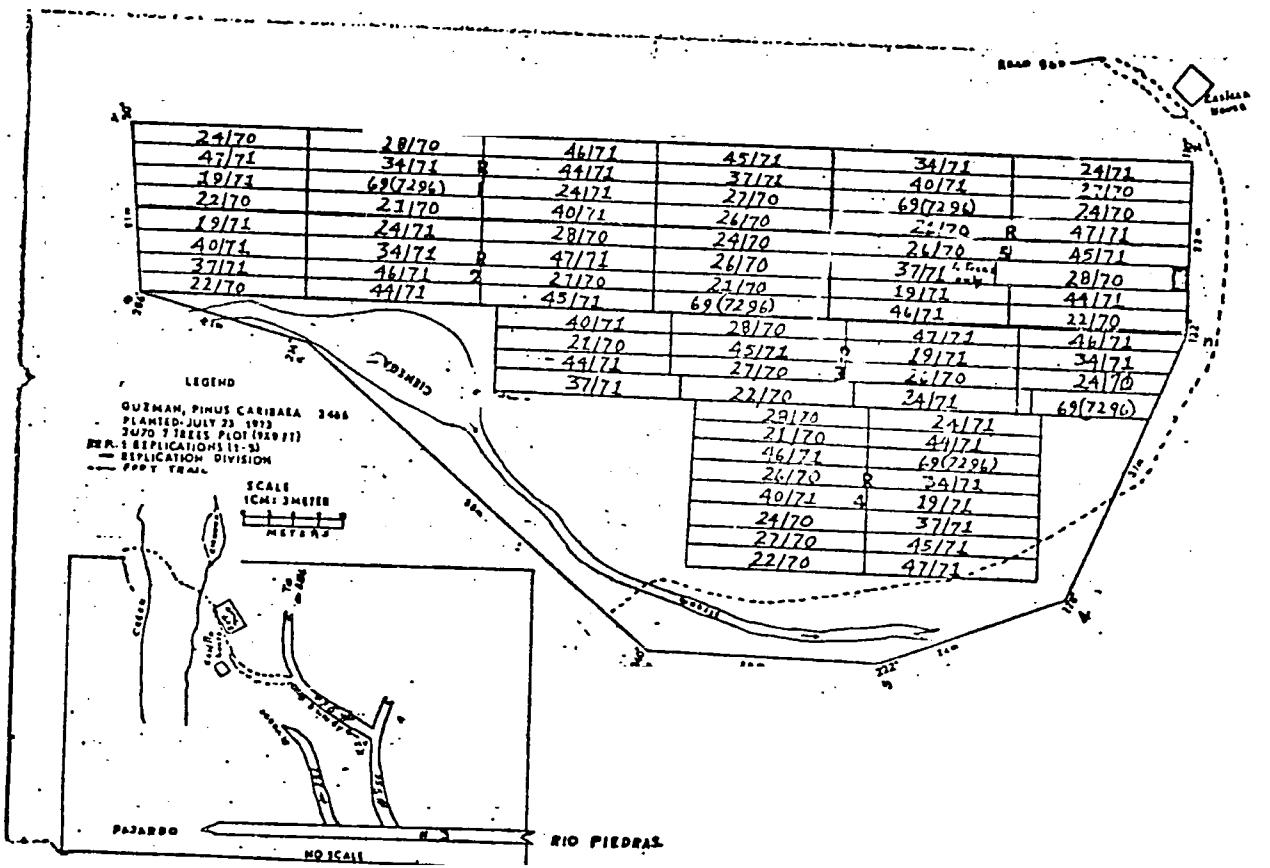

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Table 2. Provenances of *Pinus caribaea* and *Pinus oocarpa* planted at Añasco, Puerto Rico, in October 1973.

PINUS CARIBAEA			PINUS OOCARPA		
CFI NO.	SEED STORE NO.	ORIGIN	CFI NO.	SEED STORE NO.	ORIGIN
K 66	47/71	Melinda, Belize	K 1	1/70	Camelias, Nicaragua
	46/71	Byfield, Queensland Australia	K 6	6/70	Zapotillo, Honduras
K 61	45/71	Santa Clara, Nicaragua	K 11	11/70	Conacaste, Guatemala
K 65	44/71	Mountain Pine Ridge, Belize	K 16	16/70	Agua Fría, Honduras
K 60	40/71	Potosi, Honduras	K 20	22/70 1/	Alamicamba, Nicaragua
K 57	37/71	Culmi, Honduras	K 31	1/71	Junquillo, Nicaragua
K 54	34/71	Briones, Honduras	K 34	3/71	Bucaral, Guatemala
	24/71 2/	El Burén, Cuba	K 36	5/71	Zamorano, Honduras
	19/71 2/	Los Palacios, Cuba	K 42	6/71	Yucul, Nicaragua
K 24	28/70	Guanaja Island, Honduras	K 45	7/71	Siguatepeque, Honduras
K 23	27/70	Brus Lagoon, Honduras	K 43	8/71	Lagunilla, Guatemala
K 29	26/70	Poptun, Guatemala	K 47	10/71	San José, Guatemala
K 22	24/70	Río Coco, Nicaragua	K 44	27/71	Rafael, Nicaragua
K 20	22/70	Alamicamba, Nicaragua	K 48	29/71	Malacatancito, Guatemala
K 19	21/70	Karawala, Nicaragua	K 49	30/71	Mountain Pine Ridge, Belize
	69/7296 2/	Andros Island, Bahamas	EM 70	31/71	Jitotil, Mexico

1/ This *P. caribaea* var. *hondurensis* provenance included as a "standard" against which *P. oocarpa* growth could be measured.

2/ 24/71 and 19/71 are provenances of *P. caribaea* var. *caribaea* Morelet; 69/7296 is a provenance of *P. caribaea* var. *bahamensis*; the other 13 provenances are all *P. caribaea* var. *hondurensis*.

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Guzman

PC-2466 GUZ 30X25 L7

	1	2	3	4	5	6	7	8	9	10
1	OXFORD	HT(M)	HT(M)	HT(M)	HT(M)	HT(M)	DBH(CM)	DBH(CM)	DBH(CM)	DBH(CM)
2	SEEDS	AG 0.9	AG 2.8	AG 3.8	AG 6.2	AG 8.0	AG 2.8	AG 3.8	AG 6.2	AG 8.0
3										
4										
5	C47-71	0.45	3.18	5.96	12.9	14.8	3.7	9.9	18.4	22.4
6	C40-71	0.43	3.16	5.84	11.6	13.1	4.7	9.1	17.0	19.4
7	C28-70	0.50	3.11	6.41	12.5	14.7	4.0	10.2	18.4	22.4
8	C27-70	0.40	2.77	5.65	12.0	14.0	3.8	8.1	14.8	17.6
9	C24-70	0.53	3.49	6.32	12.7	14.2	4.2	9.9	16.8	20.0
A 10	C22-70	0.50	3.39	6.36	12.7	14.5	4.4	9.7	18.3	22.7
11	C21-70	0.53	3.56	6.20	13.1	14.8	4.2	9.5	18.0	21.4
12	I46-71	0.50	3.70	7.12	13.0	15.1	4.9	11.1	17.9	20.9
13	I45-71	0.55	3.70	6.70	13.3	15.0	4.7	9.7	17.0	19.0
14	I44-71	0.41	3.32	6.21	12.7	14.9	4.3	10.4	17.2	20.6
15	I37-71	0.44	3.79	5.99	12.4	14.8	3.8	8.6	17.5	21.0
B 16	I34-71	0.49	3.75	7.31	12.7	14.8	4.6	11.8	20.6	25.1
17	I26-70	0.44	3.67	6.84	12.9	14.7	4.4	10.8	17.4	19.7
18	S124-71	0.26	1.81	4.19	9.7	11.7	3.0	5.9	11.8	13.8
19	S119-71	0.22	2.09	4.26	9.3	10.7	4.1	6.3	11.3	12.4
20	S169-72	0.26	2.44	4.26	10.3	11.0	3.6	8.0	12.7	13.6

Coastal P. caribaea hondurensis

Interior sources

Island sources

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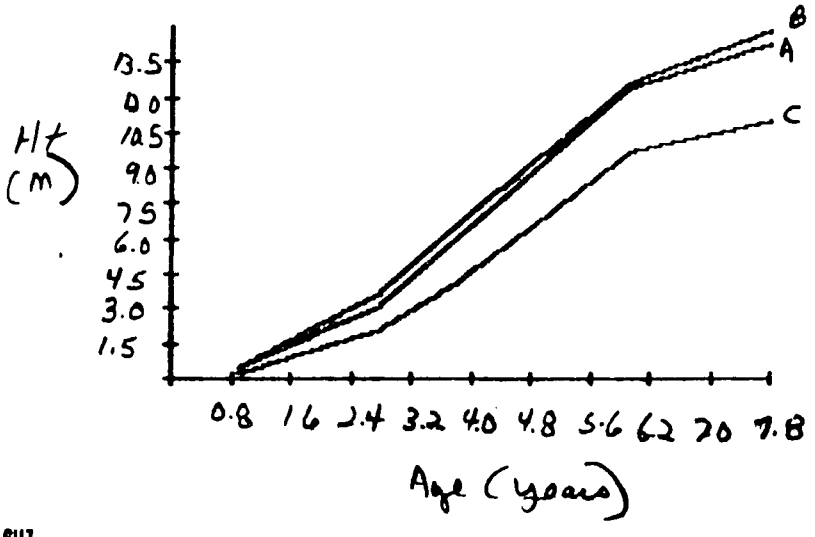

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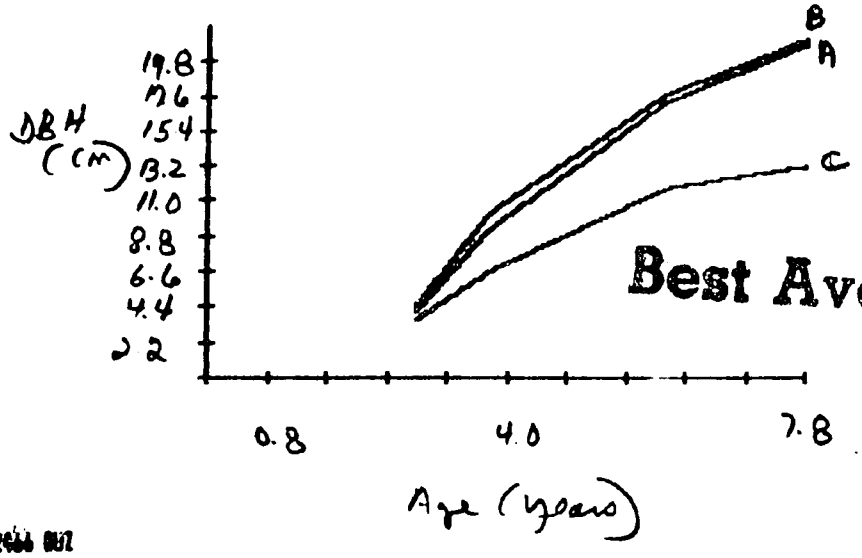

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Spacing Trial of Pinus caribaea var. hondurensis in Puerto Rico

Guzman Arriba-CNF

Planted	1962.9
Soil	Los Guineos clay and Catalina clay
Life Zone	Subtropical wet forest
Elevation	330 m
Rainfall	2400 mm

Growth results after 12.3 years as reported in: J.L. Whitmore and L.H. Liegel. 1980. Spacing trial of Pinus caribaea var. hondurensis. USDA Forest Service Res. Pap. SO-162. Southern Forest Experiment Station. Institute of Tropical Forestry. Rio Piedras, Puerto Rico. 9 p.

Table 3. – *Age, survival, and growth data summaries for triangular spacing trials of* Pinus caribaea *in Puerto Rico. Based on measurement of the 12-tree interior plots*

Site	Age *years*	Spacing *feet*	Survival *percent*	Basal Area Total ft²/acre	Basal Area Total m²/ha	Basal Area Mean annual increment ft²/acre	Basal Area Mean annual increment m²/ha	Volume Total ft³/acre	Volume Total m³/ha	Volume Mean annual increment ft³/acre	Volume Mean annual increment m³/ha
Caracoles	13.6	5	83	381	87	28.0	6.4	11,477	803	844	59
		7	79	259	60	19.0	4.4	8,257	578	607	42
		10	88	247	57	18.2	4.2	7,531	527	554	39
		14	79	163	37	12.0	2.7	5,238	367	385	27
			x̄ = 82								
Utuado	12.5	5	71	260	60	20.8	4.8	7,199	504	576	40
		7	100	278	64	22.2	5.1	8,291	580	663	46
		10	100	206	47	16.5	3.8	7,310	512	585	41
		14	92	170	39	13.6	3.1	4,715	330	377	26
			x̄ = 91								
Guzmán	12.3	5	71	311	71	25.3	5.8	9,322	646	751	53
		7	96	282	65	22.9	5.3	8,518	596	693	48
		10	88	205	47	16.7	3.8	6,470	453	526	37
		14	83	125	29	10.2	2.4	3,827	268	311	22
			84								
Lares	11.5	5	96	311	71	27.0	6.2	8,988	629	782	55
		7	96	268	62	23.3	5.4	8,779	614	763	53
		10	88	225	52	19.6	4.5	8,130	569	707	49
		14	100	193	44	16.8	3.8	6,946	486	604	42
			95								

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TABLE 3. SURVIVAL AND TOTAL VOLUME: POOR SITES.

AGE	SPACING (M)	SURVIVAL (%)	TOTAL* VOLUMES M^3/HA	TOTAL* VOLUMES FT^3/AC
		CARACOLES		
20	1.5	71	740	10,531
	2.1	71	737	10,534
	3.0	79	782	11,178
	4.3	88	613	8,758
		GUZMAN		
19.1	1.5	58	960	13,720
	2.1	88	990	14,146
	3.0	83	741	10,594
	4.3	83	518	7,402

* FROM SURINAM VOLUME TABLE.

TABLE 3. (CON.) SURVIVAL AND TOTAL VOLUME: GOOD SITES.

AGE	SPACING (M)	SURVIVAL (%)	TOTAL* VOLUMES M^3/HA	TOTAL* VOLUMES FT^3/AC
		UTUADO		
19	1.5**	17	186	2,605
	2.1	46	653	9,339
	3.0	79	584	8,348
	4.3	75	640	9,152
		LARES		
18	1.5	87	888	12,694
	2.1	87	858	12,257
	3.0	92	867	12,394
	4.3	92	807	11,540

* FROM SURINAM VOLUME TABLE.

** HURRICANE DAMAGE, 1979.

TABLE 3 (CON.) MEAN ANNUAL VOLUME INCREMENTS: POOR SITES.

AGE	SPACING (M)	INCREMENT* M^3/HA	INCREMENT* FT^3/AC
		CARACOLES	
20	1.5	37	529
	2.1	37	527
	3.0	39	559
	4.3	31	438
		GUZMAN	
19.1	1.5	50	718
	2.1	52	741
	3.0	39	555
	4.3	27	388

* FROM SURINAM VOLUME TABLE.

TABLE 3 (CON.) MEAN ANNUAL VOLUME INCREMENTS: GOOD SITES.

AGE	SPACING (M)	INCREMENT* M^3/HA	INCREMENT* FT^3/AC
		UTUADO	
19	1.5**	10	140
	2.1	34	491
	3.0	31	439
	4.3	34	482
		LARES	
18	1.5	49	705
	2.1	48	681
	3.0	48	689
	4.3	45	641

* FROM SURINAM VOLUME TABLE.

** HURRICANE DAMAGE, 1979.

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Location: Guzmán Arriba - Caribbean National Forest
PR Highway 960

Elevation: 350 m

Life Zone: Subtropical Moist

Soil: Los Guineos silty clay loam
20-40% slopes
clayey, mixed, isothermic
family of Epiaquic Tropohumults

Study 2457

Variation in Philippine Provenances of *Pinus kesiya* and *Pinus merkusii*
(part of FAO/FRI/CFI International Provenance Trial)

Planted: June, 1972

Design: 3 tree plots replicated 12 times for 17 provenances:
13 of *P. kesiya* from entire range in Philippines plus one from Zambia (original source from Vietnam),
3 of *P. merkusii*, and one of *P. caribaea* var. *hondurensis*

Spacing: 3 x 3 m

Additional site with same planting near Las Piedras, P.R., on pandura loam; loamy, mixed, isohyperthermic, shallow family of Typic Dystropepts--Limestone soil site eliminated in 1973 due to cattle damage.

Fire passed through Guzmán site in May, 1973.

Two year data being worked up by J.L. Whitmore; generally, *P. merkusii* not doing well and *P. kesiya* holding its own against *P. caribaea* standard.

Results from measurements of April 19, 1978:

P. caribaea had greater height and diameter growth and higher survival than all *P. kesiya* or *P. merkusii*. However, growth differences for two of the *P. kesiya* provenances were not statistically different at the .05 level from the(best)*P. caribaea* provenance. This indicates that more research is needed on *P. kesiya* as a possible complement to *P. caribaea*.

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Table 2

Pine provenance trial: *P. kesiya* and *P. merkusii* vs. *P. caribaea* var. *hondurensis*. Mean height, DBH and survival after 6 years in the field. Except for *P. merkusii*, few significant differences among means were detected.

Seed Lot #	Species	Guzman			Las Piedras		
		Ht. (m)	DBH (cm)	% Surv.	Ht. (m)	DBH (cm)	% Surv
54	P. kesiya	6.2	11.1	58	5.2	8.7	25
55	"	5.9	11.4	44	5.2	9.1	36
56	"	6.2	11.9	61	5.2	9.1	42
58	"	6.2	12.6	50	5.2	8.4	31
61	"	7.2	13.4	53	5.6	9.9	53
62	"	6.2	12.2	61	5.6	9.6	28
63	"	6.4	11.4	56	5.1	8.2	31
64	"	6.1	10.5	50	6.8	10.9	47
66	"	6.2	11.1	47	5.8	10.2	25
67	"	6.4	13.1	39	5.9	9.9	39
70	"	7.7	14.1	61	5.7	11.0	28
72	"	7.4	15.1	50	5.5	10.0	25
33	"	6.6	12.8	42	5.0	8.9	36
74	P. merkusii	-	-	0	5.6	12.5	3
75	"	-	-	0	6.0	13.4	3
76	"	2.5	7.2	14	3.8	6.6	6
24	P. caribaea	8.9	15.2	69	7.3	12.9	67

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Ulzmai

Pinus occidpa

PO-2466/SUB 30125 L7

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	DIFORD	HT(M)	SURV(%)	HT(M)	DBH(CM)	SURV(%)	HT(M)	DBH(CM)	SURV(%)	AGE	HT	DBH	SURV
2	SEEDS	AG 0.8	AG 0.8	AG 4.4	AG 4.4	AG 4.4	AG 6.1	AG 6.1	AG 6.1		(M)	(CM)	(%)
3													
4													
5	N 1-70	0.25	91	6.0	10.2	43	10.6	16.4	43	0.8	0.23	N	90
6	N 1-71	0.22	91	6.1	7.7	40	9.6	13.3	40	4.4	6.3	8.2	89
7	N 6-71	0.23	89	8.9	9.7	63	13.4	20.2	60	6.1	10.2	14.4	48
8	N 27-71	0.20	89	7.8	10.9	49	12.6	18.3	49	0.8	0.23	N	91
9	N 6-70	0.22	83	5.9	8.0	43	10.0	16.6	43	4.4	5.3	7.1	94
10	N 16-70	0.26	91	4.0	5.1	46	7.8	10.2	46	6.1	9.1	12.2	53
11	N 5-71	0.23	89	4.6	6.7	54	8.4	10.0	54	0.8	0.23	N	93
12	N 7-71	0.22	94	5.1	7.1	54	9.4	12.1	51	4.4	7.9	10.3	69
13	G 11-70	0.27	94	4.9	6.9	63	8.9	11.3	57	6.1	13.4	17.6	66
14	G 3-71	0.24	83	5.7	8.0	54	9.6	13.9	51				
15	G 8-71	0.22	94	5.2	6.2	63	9.6	11.2	63				
16	G 10-71	0.20	89	5.2	6.2	63	8.9	10.7	63				
17	G 29-71	0.18	97	3.3	5.4	43	6.3	8.4	43				
18	D 30-71	0.26	83	7.8	10.7	60	12.6	18.1	60				
19	N 31-71	0.19	94	3.3	6.3	31	8.3	11.3	31				
20	CZZ-70*	0.23	95	7.9	10.3	69	12.9	17.6	66				

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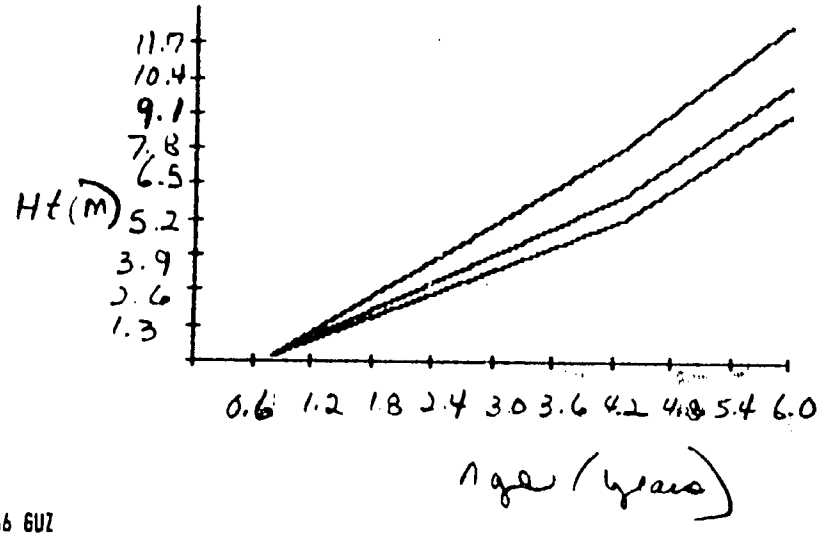

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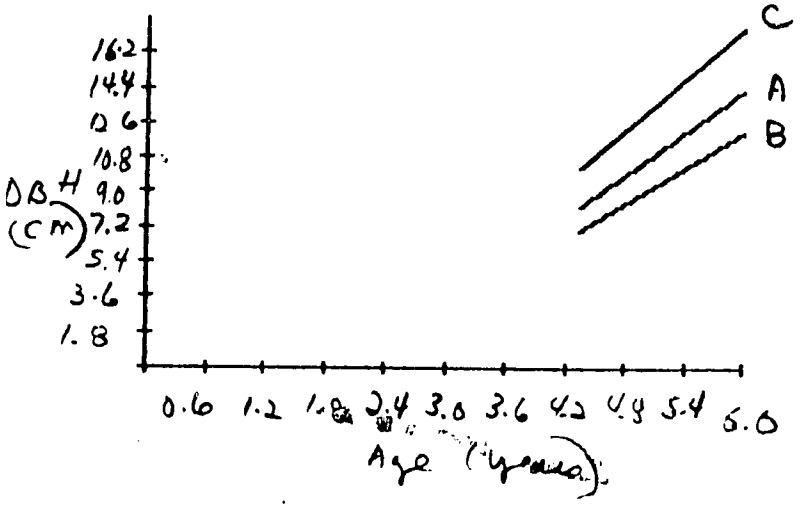

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Hurricane David & Tropical Storm Frederick
August 30 - Sept. 4, 1979

Hurricane Damage Summary

Pinus caribaea vs Pinus oocarpa

Species	Sites: Barasco	Guzman	Tracy-Los	Jayuya	Cidra	Humacao	Species $\bar{X}$	Damage
P.C. 1/	0	3	3	1	1	3	2	Blow-down Mortality (%)
P.O. 2/	3	31	13	3	5	22	13	
P.C.	4	23	30	28	34	4	20	NON-MORTALITY DAMAGE 3/ (%)
P.O.	16	49	65	29	53	13	38	
P.C.	4	26	33	29	35	7	22	Total Damage 4/ (%)
P.O.	19	80	78	32	58	35	52	
P.C.	26	33	9	16	20	23	21	Foxtail %
P.O.	4	0	2	4	4	3	3	
P.C.	8	30	28	32	23	69	32	Pre-Hurricane Mortality (%)
P.O.	12	49	28	45	29	69	39	

1/ P.C. = Pinus caribaea provenances (16), representing all 3 varieties
2/ P.O. = Pinus oocarpa provenances (15).
3/ Includes leaning trees (from 5 to ≥45°) and trees with broken tops.
4/ Includes all trees blown down, leaning, or having broken tops caused by hurricane winds/rain.

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1979 Hurricane Damage Assessment - Data Categories

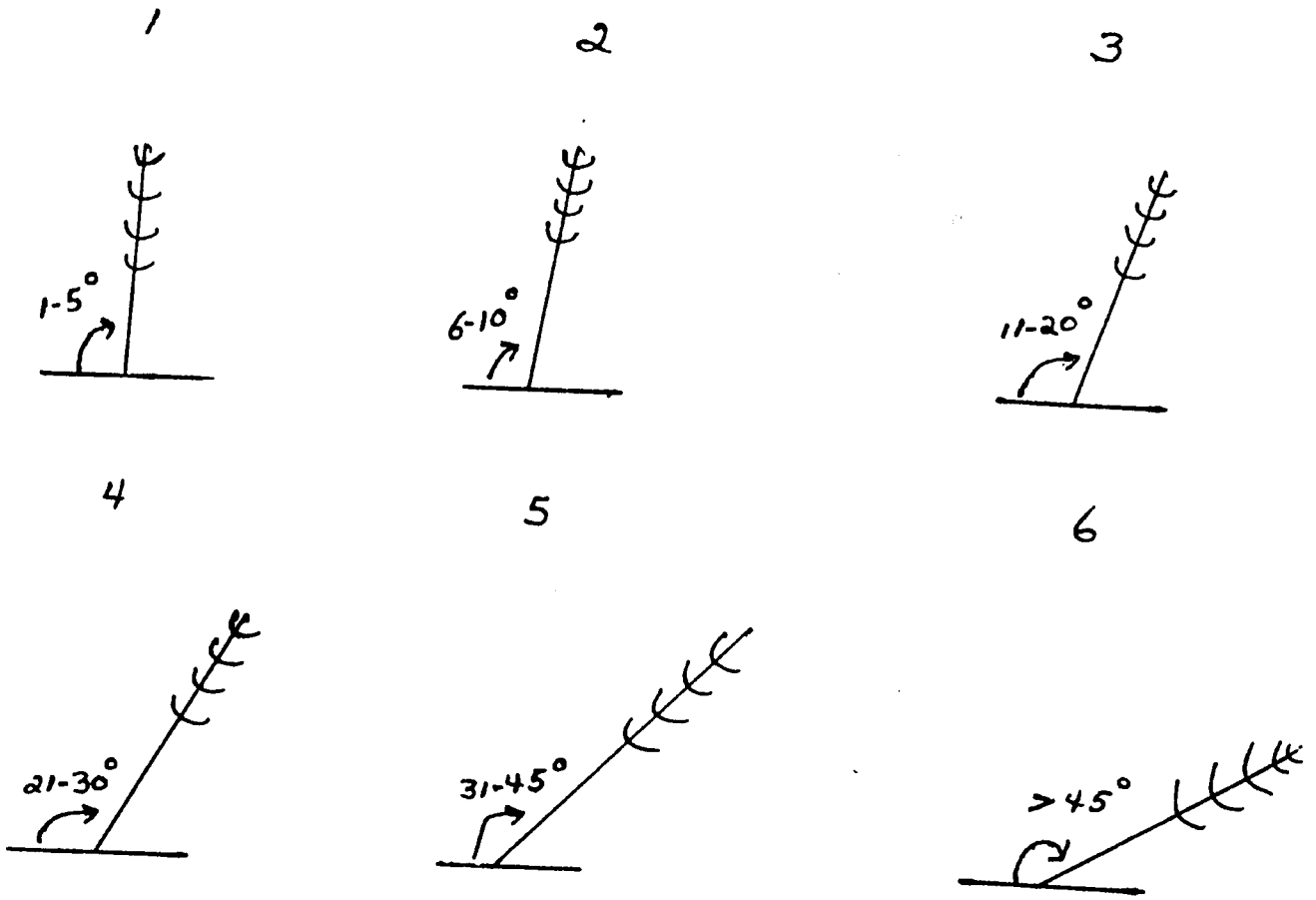
X Pre-hurricane mortality

BD Blown down

BT Broken top (upper 1/3 of crown)

BO Broken off (lower 2/3 of crown)

Lean Classes:



Seminar Summary Classes for *Pinus caribaea* + *P. occarpa*:

A. Blow-down mortality damage (%)

B. Non-mortality damage (%)

C. Total damage = A + B

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as a variable. For this reason, the shaking should be begun immediately after adding the extracting solution to the soil; however, after shaking, the suspension should be filtered as soon as possible. It is not necessary to collect more than 75 ml. of the clear filtrate.

It is important that the standards and unknowns be heated for the same length of time and at the same temperature. The water in the bath should be above the level of the solution in the flasks. Boiling water should be added to the bath from time to time to compensate for evaporation. The use of a water bath made of sheet copper, provided with a ½ inch mesh wire screen to hold 24 flasks so that an inch from the bottom, is very convenient for both heating and cooling the flasks.

Unfortunately this method of color development is not sufficiently sensitive for use on soils containing less than 50 pounds of P_2O_5 per 2,000,000 pounds of soil. When dealing with such soils the method of Truog (14), utilizing stannous chloride for reduction, may be preferable. In applying Truog's stannous chloride method for use with a photoelectric colorimeter, the time of color development and the quantity of stannous chloride added must be carefully standardized.

DETERMINATION OF pH

Procedure

To a 20 gm. sample of soil in a 50 ml. beaker, add 20 ml. of distilled water and stir the suspension several times at regular intervals for about an hour. Measure the pH of the soil suspension with the glass electrode, stirring well just prior to immersing the electrodes deep into the suspension.

Comments

Soil-water ratios ranging from 1:0.5 to 1:10 have been proposed for the determination of the pH of soils. The pH of most soils increases with dilution, usually attaining approximately a constant value at 1:5 soil-water ratio. There is little justification for using soil water ratios wider than 1:1. The pH measurements of soils at moisture contents below that of the moisture equivalent are subject to several inherent errors, as recently pointed out by Davis (4), and also make mandatory the use of a special glass electrode and pH meter.

DETERMINATION OF ORGANIC MATTER

Reagents

1 N potassium dichromate.—Dissolve 49.04 gm. of reagent grade $K_2Cr_2O_7$ in water and dilute to 1 liter.

0.5 N ferrous sulfate.—Dissolve 140 gm. of reagent grade $FeSO_4.7H_2O$ in water, add 40 ml. concentrated H_2SO_4, cool, and dilute to 1 liter. Standardize this reagent each day by titrating against 10 ml. of N potassium dichromate, as directed in the method given below.

Ne → Barium diphenylaminesulfonate.—Prepare a 0.16 percent aqueous solution.

o-phenanthroline ferrous complex (optional).—Prepare 0.025 M solution of one of the phenanthroline ferrous complex indicators.

Sulfuric acid; not less than 96 percent.

pe → Phosphoric acid; 85 percent, U. S. P. grade.

(o-Phenanthroline is used)

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MECHANICAL ANALYSIS FOR SOILS

Sift sample thru a 20 mesh screen (2 mm)

Place 50 g. sample in electric stirrer container (approx. 1000 ml.), filling with distilled water up to 2 inches from the top of the container.

Add 5 ml of a saturated solution of sodium oxalate ($Na_2C_2O_4$) } Calgon 5%

Add 5 ml of 1 N sodium hydroxide (NaOH)

Stir in mixer for 5 min. or more.

Transfer the suspension thus formed to a cylinder [for use in measuring particle size distribution in soil suspensions (3545-G10, A.H.T.)], graduated at 1000 ml, and fill to the mark.

Cover cylinder with a rubber stopper or with the palm of the hand and shake by turning the cylinder upside down a few times.

Place cylinder on table and mark the time.

Place the hydrometer inside the suspensions, and take a reading after 40 secs. and record the temperature.

Remove the hydrometer carefully.

After 2 hrs., repeat the reading and record the temperature again.

Correct the hydrometer readings as follows:

For each Farenheit degree over 67°, add 0.2

For each Farenheit degree under 67°, substract 0.2

Ions:

1. Saturated solution of sodium oxalate ($Na_2C_2O_4$)

2. 1 N sodium hydroxide solution (NaOH)

Relations:

% Sand = 100% - Reading obtained at 40 secs. x 2
% Clay = Reading obtained at 2 hrs. x 2
% Silt = 100 - % sand + % clay
% Silt = 2 [illegible]

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ITF Soil Mechanics Analysis

Recording Form

Date	Soil #	Hydrometer RL reading	Dispersion	Soil weight (gr)

Time	Hydrometer uncorrected	Temp °C	Hydrometer reading - corrected
40 sec			
2 hrs.			

Investigator:

Process by:

Texture:

% Sand = 100 - ____ (reading corrected obtained at 40 sec × 100 / soil weight ____ gr)

% Sand =

% Clay = (reading corrected obtained at 2 hrs ____ / soil weight ____ gr) × 100 =

% Silt = 100 - (% sand ____ + % clay ____) =

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special research [illegible] boundaries between classes so that they have the maximum practical use for soil definitions and interpretations. It may the results of this research had the effect of some [illegible] modification in the old definitions of class names in terms of actual percentages of sand, silt, and clay as determined in the laboratory, and some modifications in field definitions based upon feel [illegible] laboratory data from mechanical analyses. [illegible] researched as general guides only to soil textural [illegible] are not as absolute guides to soil [illegible] in the United States. At the same time one [illegible] percent. Especially may further improvement be expected in the designations used for the textural classes of Florida soils and of Latosols in which the clays generally have different mineralogical compositions from those [illegible] in temperate regions. Textural class names must be defined with [illegible] in terms of size distribution, however, and not used to express differences in consistence or structure, which [illegible] be treated separately.

Definitions of the basic classes are set forth in graphic form in figure 58, in terms of clay, [illegible] 0.002 mm., silt, 0.002 to 0.05 mm;

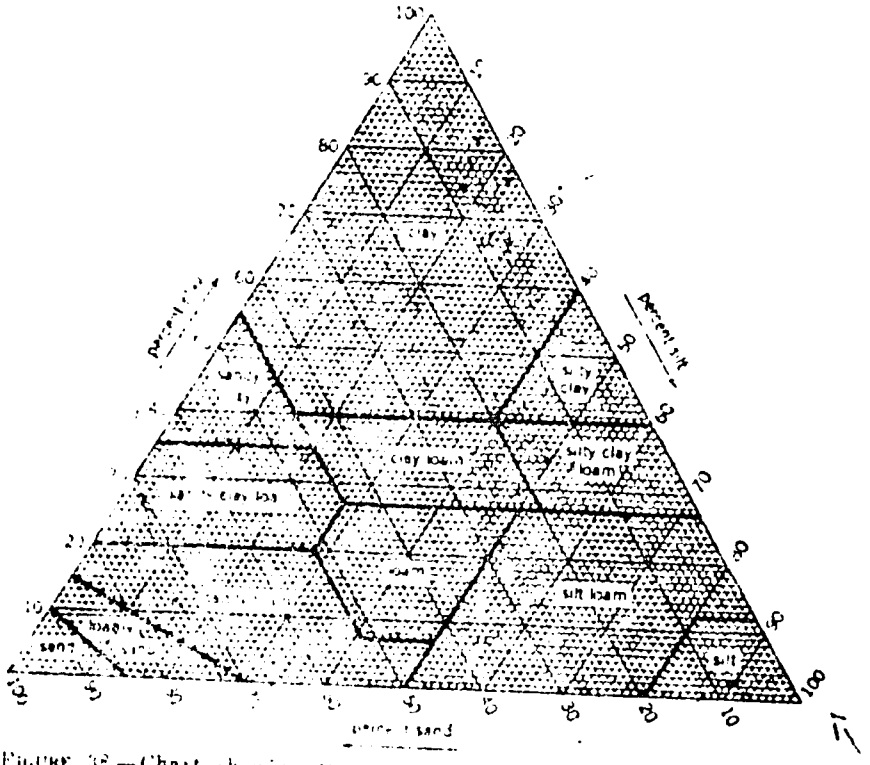

FIGURE 58.—Chart showing the percentages of clay (below 0.002 mm.), silt (0.002 [illegible] 0.05 mm.) and sand (0.05 [illegible] 2.0 mm.) in the basic soil [illegible]

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Experimentation

Experiments are usually included in long-term reforestation efforts. If started early in the project, they produce data and information that managers can use to develop managerial or technical guidelines at later stages it the project. For example, experiments can help decide which tree species are most suitable for charcoal production when grown between rows of corn or other crops. Experiments can also determine trees or shrubs most effective for erosion control on steep slopes or on disturbed sites ravaged by landslides or hurricanes.

Experimentation is all too often excluded from reforestation efforts because the purpose of experimentation is misunderstood or because experimentation is confused with statistics. Experimentation is the systematic observation, classification, and analysis of facts and data; it emphasizes the why and how of what is done. Statistics, on the other hand, are mathematical measures that describe organized raw experimental data. The most commonly used statistical measures are the mean, standard deviation, variance, and coefficient of variation.

The commonly used statistical measures are outlined at the end of this appendix along with special experimental design considerations for determining desireable plot size, shape, significance of border rows, and useful outplanting designs. A hypothetical experiment is now discussed here to illustrate and emphasize that experimentation is an important component of effective decision making for reforestation projects. The different kinds of plantation experiments possible has already been discussed in Chapter V, The nature of reforestation.

1. Traits Assessed

Experiments can be done in the field or in the nursery. Many measurement traits or variables can be measured or assessed. Examples are:

Nursery Traits

-Average seed weight and size.

-Mean germination time for seeds.

-Percentage of seeds germinated within sta ed periods of time.

-Seedling height to nearest mm, specifying to top of shoot apex, apical bud, or tip of tallest leaf or cotyledon.

-Number of cotyledons.

-Nursery height in cm, at stated periods of time or before outplanting.

-Nursery diameter in mm, using calipers, at the base of a plant or at its root collar, if prominent.

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-Nursery survival in percent.

Field Traits

-Height in cm or m depending on seedling, sapling, or tree age.

-Diameter at breast height in cm, usually after trees are 2 to 3 m tall.

-Survival, as a percent of those originally planted, according to stated measurement times or after unusual events like hurricanes or disease.

-Stem form according to some predetermined class interval scale.

-Longest length of useable bole in m.

-Crown characteristics like length or width in m, assessed before canopy closure.

-Branch habit, including diameter, angle, number of branches per node, or coarseness; assessments usually made only once or twice in life of a trial.

In each instance, events or traits are recorded or measured according to previously formulated plans and designs.

2. Experimental Procedures

Developing an overall research plan is a must when conducting experiments. It can have the same component as the project plan and should always answer: Why? What? Where? How? When? How much?

The first step is determining the objectives and questions to be answered. Objectives should be limited in number and straigth forward. Written objectives and an overall research work plan are critical for maintaining longer trials that continue after their originator has left.

Consider an area where Eucalyptus are to be planted. Two important questions are: "What species will grow best?" and "On which sites will a certain species outgrow others?" Obviously, all species and sites cannot be tested. How, then, do we limit the scope of the proposed research on Eucalyptus?

Restricting objectives can be done by considering available data on Eucalyptus growth from elsewhere. Local conditions of climate, altitute, and elevation are also important for correctly matching species to sites. After reviewing available information, it might be decided to test E. saligna, E. robusta, and E. deglupta. A concise statement of the experiment objectives would be:

-To test height and diameter growth and survival of three

Eucalyptus species on valley, slope, and ridge topographic positions for 5 years.

Height, diameter, and survival data are the three most commonly assessed traits in reforestation. Whatever traits are selected, they should be stated clearly in the objectives.

The question of "Where to plant?" has not been completely answered in this Eucalyptus example. Numbers could be assigned to all valleys, slopes, and ridges in the reforestation area and a certain number could be picked randomly at the experimental sites. This is seldom possible and is probably impractical because certain sites would be included where soil, geological, or other factors actually precluded planting. Most frequently it is best to limit sites to those covering the range in rainfall, elevation, past land use, or other factors that affect tree growth within the reforestation area.

A word of caution! Avoid compounding two or more factors. For example, if Eucalyptus were planted on deep clay soils receiving 3,000 mm of rainfall and on sandy soils receiving only 1,500 mm, it would be impossible to tell if measured growth differences were caused by rainfall or soil factors. If these two soil types characterized the reforestation area, most reliable data would be obtained by establishing experiments at high, medium, and low extremes in rainfall or elevational differences within the two soil types. This phase is called replicating the experiment at different potential planting sites.

The next step is actually establishing the experiment at the three different sites within each of the two soil regions. Seedlings would be randomly assigned to blocks containing all three species. Small row plots of 3 to 7 trees could be replicated up to 10 or 12 times for each of the three species; or larger plots using 10 to 49 trees could be used, depending on trial objectives or availability of planting stock. The most common outplanting design is the randomized complete block (discussed below).

In summary, experimentation is not an abstract concept but an important and integral component of decision making in reforestation projects. When conducting experiments, follow these three cardinal rules (the 3 R's):

-Restrict objectives to simple and manageable ones.

-Replicate research plots on several sites and in several blocks at each site.

-Randomly assign treatments to each experimental block at each site.

3. Data Recording/Record Keeping

If experiments are important enough to install and maintain, accurate record keeping is even more important. Insufficient field data or data not recorded properly will not allow experimental questions to be answered adequately. Thus, work plans for the experiment should include examples of

field or nursery data sheets for the traits to be assessed, instructions on how assessments will be made, and guides on summarizing raw field data. Also, each research site should have its own field map, clearly indicating blocks, replications, and position sequence for trees located in rows or larger plots. Examples of field and data recording sheets are shown at the end of this appendix.

The following is a list of data recording Do's and Dont's. Individual items may seem trite, but many experiments have been abandoned or been useless because planting or measurement dates were not recorded or were recorded illegibly.

Data Recording Do's and Dont's

No matter what format is used. <u>ALL DATA SHEETS SHOULD CONTAIN</u>:

-Species or provenances measured.

-Date of assessment--write out the month and day instead of using a number system which is not uniform in many parts of the world, e.g. March 4, 1982 instead of 3/4/82 which could also be written as 4/3/82. Recording the exact date is particularly critical for calculating growth rates or volumes at later ages.

-Names of persons(s) who made the assessment as well as the parameters they were responsible for, e.g. John Doe: heights, Jane Doe: data recorder, Jack Jones: bark thickness and diameters.

-Notations on whether data are given in metric or english units.

-Proper and complete identification codes for all treatments, including proper block and plot numbers for replicated experiments.

-A separate column or space for unusual things observed in any plot or at the research site, e.g. insect attacks, fire damage, wind damage with trees all leaning towards the northwest, etc.

-Write out all numerals clearly and distinctly-handwriting differs from one person to another but, if numbers are not recorded clearly, summarization at a later date by someone other than the recorder may be next to impossible.

-Summarize and analyze field data as soon as possible after it is actually taken-waiting months or years is not recommended because their importance is diminished.

Finally, before leaving the research site, be sure that all appropriate items have been completed on the data sheet and that assessment dates appear on each page. Catching errors and correcting them before returning to the office can save a 1/2 to 1 day trip back to the field site to correct simple omissions or inconsistencies that can be spotted if the time is taken to do so.

4. Basic Statistics and Data Recording

The most commonly used statistics to summarize or categorize experimental data, from field or nursery environments, are the mean, standard deviation, variance, and coefficient of variation. A definition for each and an example of its calculation is shown in Table I1.

Raw data summarization can be a simple matter if data are coded correctly onto field or nursery data sheets. Examples are shown in Figs. I1, I2, and I3. Formats will vary depending on study design and traits that are assessed. The format of Fig. I1, is more suited for individual tree heights or diameters taken in plantations and natural forests, or from seedlings in nurseries. Formats in Figs. I2 and I3 were developed in Puerto Rico for assessing 7 and 4 tree row plots respectively for Pinus caribaea and Cedrela odorata provenance trials. Data recorded on the form shown in Fig. I2 is much more detasiled than that recorded on sheets shown in Figs. I1 and I3. Any data sheet should be developed for the particular objectives and traits to be measured for specific study plans.

5. Plot Shape

Regular and compact experimental blocks have less microsite variation and are preferred over irregular shaped ones (Fig. I4). When there is known moisture or other site quality variation at a field site, place the long side of blocks perpendicular to the gradient (Fig. I5). Sometimes, outside factors may dictate block shape and orientation, e.g. locating blocks to accomodate rock outcrops (Fig. I6). Making blocks or plots a convenient portion of a hectare (e.g. 0.2 or 0.5 ha) simplifies converting raw data to a whole hectare basis.

6. Plot size

Optimum plot sizes depends on several factors including available land and plant material, maximum allowable costs for land clearing and planting, desired spacing, experiment duration, required cultural treatments like thinnings, and whether nursery or field trials are conducted. For example, 2 year field trials testing potential charcoal volumes for three species will be much smaller than 50-year trials assessing sawwood obtained from teak, mahogany, and Spanish-cedar requiring thinnings. Similarly, provenance trials planted at 3 x 3 m require more area than do biomass trials planted at 0.5 x 0.5 m or 1 x 1 m.

Where available area is limited, small row plots of 3, 4, and 7 trees, replicated ten or more times, are effective (Fig. I7). When demostration is an important objective, then larger plots, with fewer replications, are possible (Fig. I5). Larger plots are very appropriate for community projects where visual effects are important in convincing landowners to adapt particular species or practices.

7. Border or Surround Rows

Edge trees of experimental plots have better moisture, light, and

fertility than do trees in plot interiors where competition effects are greater. Consequently, edge tree growth, especially for diameters, is usually superior to that of interior trees. Including edge tree measurement data in assessments can significantly bias volume estimates upward over those made from interior tree data only.

The edge phenomenon is eliminated from field experiments by planting one or more rows around the interior or measurement plots (Fig. I5) and recording data for interior trees only. Edge effects must be considered when designing trials for testing fuelwood/charcoal species in tree/crop mixtures since certain crops may be much more shade intolerant than others. Therefore, for a very shade intolerant crop like sweet potatoes, a fast-growing, open-crown species of Casuarina would be more suitable than a dense crown species of Leucaena or Azadirachta indica.

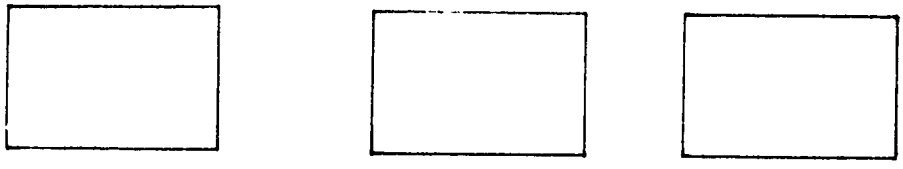
8. Outplant design

The most commonly used design in reforestation or other biological/agricultural experimentation is the randomized complete block. An experimental site is divided into a number of blocks having similar site quality; the same number of treatments are randomly assigned to each block (Fig. I6). Three blocks are frequently used and 4 or 5 are recommended, especially if a small number of trees are used in 5 or 7 tree row plots. Using 49 tree plots in each plot in each block allows one surround or around the plot and is an effective design for demonstration purposes (Fig I5).

A typical example is one in which four tree species or provenances (A, B, C, D) are tested in four blocks (Fig. I6).

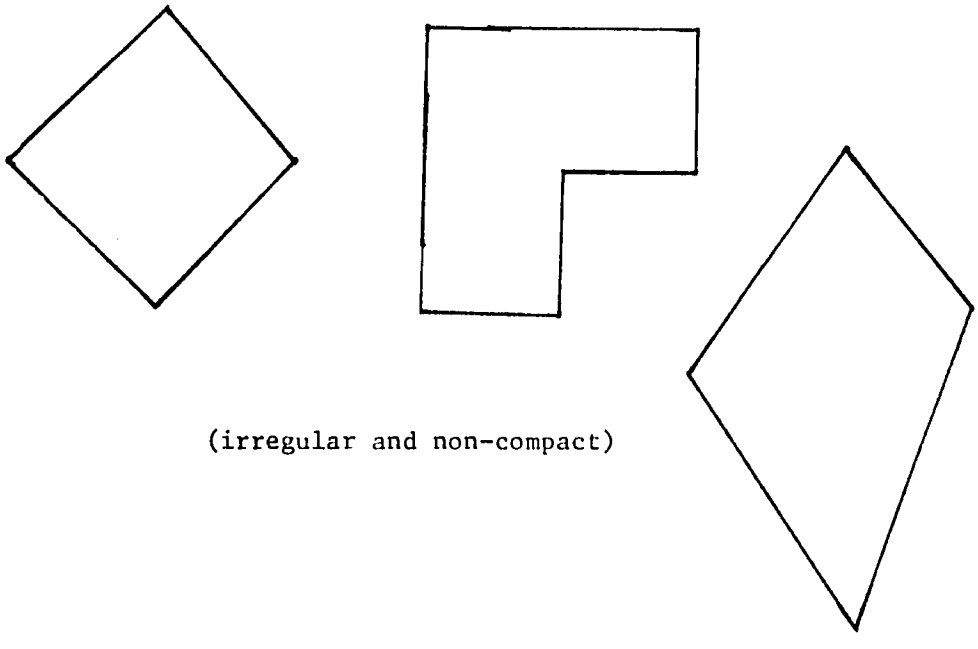
Each species is randomly assigned to each block. Physical limitations of the site (e.g. rock outcrops) often preclude office-made layouts.

Desirable Experimental Block Shapes



(regular and compact)

Undesirable Experimental Block Shapes



(irregular and non-compact)

Figure I 1. Desirable and undesirable plot shapes used in forestry experimentation.

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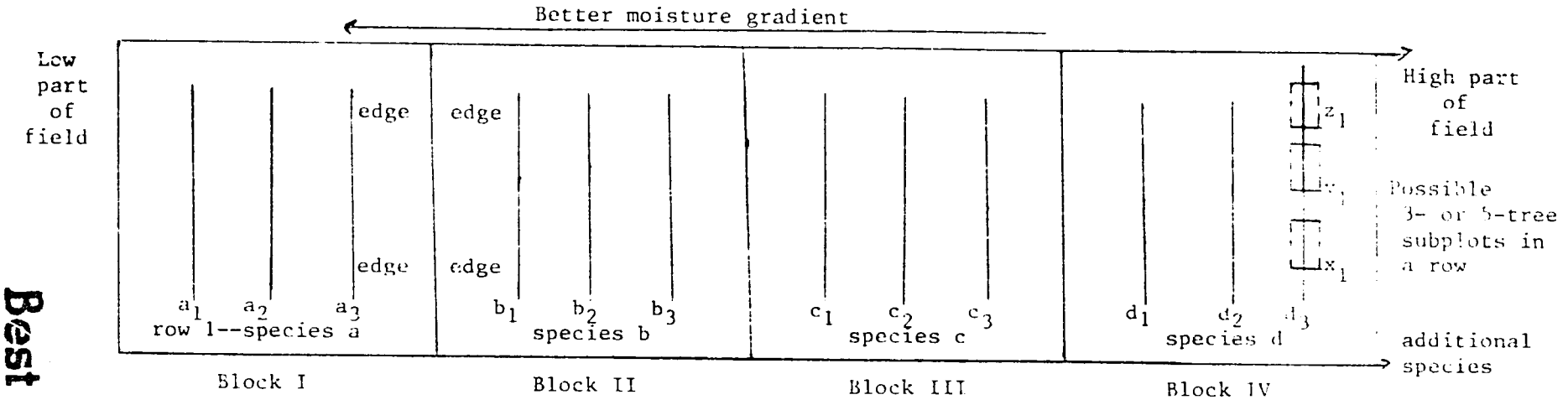
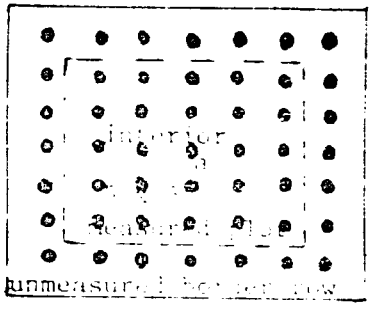


3 - a

Blocks	I	II	III	IV
	b	a	d	a
	c	d	a	c
	a	c	b	b
	d	b	c	d

Better moisture gradient

3 - b



3 -

Figure I2. Outplanting considerations for agroforestry research/demonstration trials:

3-a) Single blocks for species a, b, c, and d. Trees are tested between corn in long row plots of 25 or more trees per row; subplots are possible in each row of trees but the trial is unreplicated, with all rows receiving considerable border effect; species a and b probably have more available soil moisture during the year than do species c and d.

3-b) An improved design in which the moisture gradient effect is taken into account by using four randomized complete blocks, positioned perpendicular to the gradient; this allows each species to be tested over potentially different soil moisture regimes.

3-c) A 49-tree plot having one border or unmeasured row and 25 interior or measured trees to equalize edge effects.

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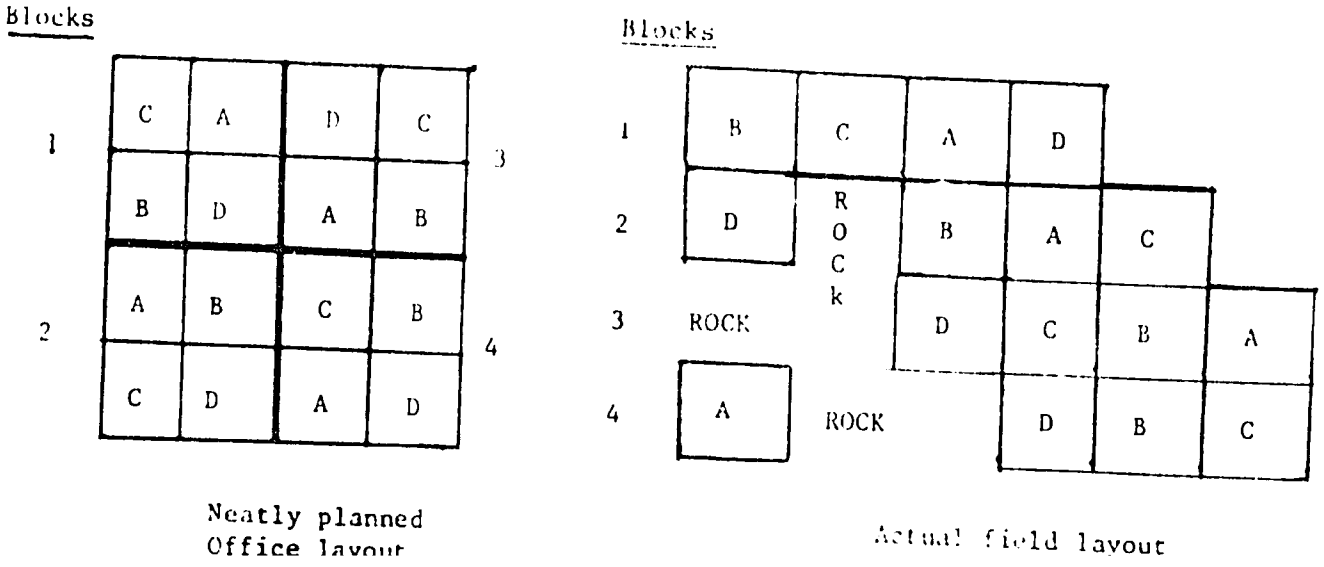

Fig. I3. A randomized complete block outplanting design testing growth performance of 4 species or provenances (A, B, C, and D) in four blocks; treatments are assigned randomly to each block. Frequently, actual field layouts must be modified from office layouts to accomodate outside factors like rock outcrops or access roads to the site.

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Replication								
2	F	A	E	C	H	G	B	D
5								
9								
3								
6								
8								
10								
1								
7								
4	D	G	F	A	E	C	H	B

4-tree plot of Provenance D

Fig. I4. Field layout for 4-tree plot outplanting design, using 10 randomized complete blocks with 8 treatments (A to H) that represent different provenances of one eucalyptus species being tested for super-short rotation biomass/bioenergy potential. For brevity, only treatments assigned to blocks 2 and 4 are shown. Depending on availability of plant materials, 3-, 5-, and 7-tree row plots could be used instead of 4-tree plots. It is assumed that one border row would be placed around the entire planting perimeter.

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Figure 15. Measurements on standing trees or [illegible]

Plot identification species and planting date

Date of assessment					Date of last assessment			
Tree number	DBH	Notes	Tree number	DBH	Notes	Tree number	DBH	Notes
1			21			41		
2			22			42		
3			23			43		
4			24			44		
5			25			45		
6			26			46		
7			27			47		
8			28			48		
9			29			49		
10			30			50		
11			31			51		
12			32			52		
13			33			53		
14			34			54		
15			35			55		
16			36			56		
17			37			57		
18			38			58		
19			39			59		
20			40			60		
						Total number of living trees		

Dominant height

Tree number	Height	Tree number	Height	Tree number	Height

Summary	Age	N	D	H_{dom}	$\bar{H}$	Survival	Assessed by:

N = stems per ha/acre
D = diameter of mean basal area tree
H_{dom} = dominant height (i.e. mean height of 100 trees of largest diameter per ha/acre)
$\bar{H}$ = mean height (i.e. arithmetic mean of all, or a systematic sample of trees)
Survival = $\frac{\text{No. of trees (or seedlings) surviving at assessment}}{\text{No. of trees planted (or seeded)}} \times 100$

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CEDRELA

I6

FIELD STAGE DATA SHEET

SITE:_____ DATE:_____

REPL.

REPL.

REPL.

REPL.

REPL.

REPL.

Ht.	Dia.	O

Other: No. for branches
B for borers
C for cut
T for top broken
Etc.

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PINE PROVENANCE DATA SHEET

Site _____
Study No. _____

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

	Height	DBH	Broken/ Cut	Foxtail	Insect/ Disease	Cones/ Pollen	Sprouts	Form	Branch Angle	Lean	
1											
2											
3											
4											
5											
6											
7											
$\bar{x}$											
SD											

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

Height	DBH	Broken/ Cut	Foxtail	Insect/ Disease	Cones/ Pollen	Sprouts	Form	Branch Angle	Lean	

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

Rep. _____ Block _____ Plot _____
Provenance _____ Date _____

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Table II. Summary statistics for two data sets, I and II.

Statistic	Data set I A	B	C	Data set II A_1	B_1	C_1
	8	5	1	9	5	1
	8	6	2	9	7	5
	9	8	5	9	9	8
	10	10	10	10	10	10
	11	12	15	10	11	12
	12	14	18	11	13	15
	12	15	19	12	15	19
Sum	70	70	70	70	70	70
Mean ($\bar{x}$)	10	10	10	10	10	10
Standard deviation (s)	1.7	3.9	7.5	1.3	3.4	6.1
Variance (s^2)	2.9	15.2	56.2	1.7	11.6	37.2
Coefficient of Variation (CV-%)	17	39	75	13	34	61

$\bar{x}$ - The sum of individual observations divided by total number (n) of observations in a sample or set of values. Each of the six groups above has an n of 7 (observations); thus each of the six sums is divided by 7 to obtain the mean.

s - A summarization unit for interpreting whether individual observations are clustered around or spread away from the mean. Symbolically it is calculated:

For group A of Data set I: $\dfrac{x^2 - \frac{(x)^2}{n}}{n - 1} =$

$$\frac{(8)^2 + (8)^2 + (9)^2 + (10)^2 + (11)^2 + (12)^2 + (12)^2 - \frac{(70)^2}{7}}{6} = 1.7$$

Group A has the lowest s in Data set I; thus observations in group A are very clustered around the mean of 10. Observations in Data set II are all more clustered around their means since the s of groups in set II are all lower than those in set I.

s^2 - The square of s, or for data group A, $(1.7)^2 = 2.9$. Statisticians use s^2 in analysis of variance for testing whether various treatments are significantly different from one another.

CV - It is used to evaluate results from several experiments measuring the same variable or trait. It is calculated: $CV = \frac{S}{\bar{x}} \times 100$

For data group A, $\frac{1.7}{10} \times 100 = 17$

In field experiments, CV values usually range from 15 to 50% ; if values are higher than this, there was too much variability in plant materials or site and the experiment should be conducted again.

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WILDLIFE RESEARCH AND MANAGEMENT

INTRODUCTION

This part of the course deals with conservation of wildlife populations. Although many of the principles of wildlife conservation are similar to those used in managing other natural resources, animals have several traits (e.g., migration, territoriality, social interactions) that are unique in resource management and must be understood before sound conservation strategies can be implemented.

To provide a very basic outline of these background principles, the information here has been divided into five sections. The first summarizes some basic principles of wildlife ecology. The second section reviews some of the research techniques useful in the study of wildlife biology. Some principles and methods of managing wildlife populations are described in the third section . Next, I have presented some suggestions and sources for obtaining funding for wildlife research and management programs for this region. Finally, I have compiled a list of references that would be useful to the wildlife research biologist or manager in the Caribbean region.

INTRODUCTION TO WILDLIFE ECOLOGY

Wildlife and Its Environment

Just as plants are dependent on the soils for nutrients, climate for moisture, and sun for energy, animals are dependent upon these and other components of the environment. The Environment is all of the physical and biological surroundings of an organism, including the plants and animals

with which it interacts. Within that environment, an organism occupies a specific Habitat, which is the place where an animal or plant normally lives. An organism's habitat is often characterized by a dominant plant form or physical feature (e.g., shrimp would live in a stream habitat, parrots in a forest habitat dominated by a species of large tree that forms nesting cavities, ducks in a wetlands habitat).

Each organism has a specific Range of Tolerances over which it can survive. Within that range of tolerances, there are areas where the organism is better able to survive or "be comfortable" than in other areas. These areas or conditions that are optimal to the organism will have more animals (or plants) than conditions or sites that are less favorable to the species (Fig. 1). In areas where the conditions are extremely unfavorable the organism might be absent altogether; i.e., each organism has a certain tolerance range where it will be found, but outside of which conditions are not optimal for the species' presence and few to none will occur.

-Fig. 1-

This tolerance range may depend on many environmental factors, such as the climate, the suitability of foods available, and the presence of nesting sites. However, if only one of these factors is not present in the organism's environment that species could not survive there. The missing factor is considered a Limiting Resource, or a resource that is scarce relative to the demand for it. If water were absent from an area, that environment would be unsuitable habitat for most animals, even if there were suitable food, shelter, nesting, and all other resources for the species' survival. In this example water would be a Limiting Resource. All organisms have certain characteristics that enhance their ability to

cope with their environment. These characteristics are called Adaptations. Certain species of animals or plants are better able to survive under hot, dry conditions than others. Normally those species are more abundant in areas that are characterized by those conditions than in areas that are cooler and wetter. The species that survive best under hot and dry conditions have certain adaptations that enable them to exist on the limited water resources. For example, desert plants have adaptations to conserve the small amounts of water available to them or animals might be able to get their water from the foods they eat rather than from open pools that are not available in desert areas.

Wildlife Habitats in the Caribbean Region

There are several general categories of habitat types in the Caribbean region. The two broadest categories are the Aquatic habitats and Terrestrial habitats. Most animals are either associated primarily with either the water or land habitats although some forms, called Amphibious organism, may regularly use both habitats or may depend primarily on one habitat type for a part of its life history and another during another stage in its development. Sea turtles spend most of their lives in the open sea, but return to land to lay their eggs. Because of their dependency on the terrestrial habitat they must be able to tolerate the very different conditions of this environment in addition to the open ocean where they spend most of their lives.

Within the Aquatic category there are Freshwater and Marine habitats. The Marine environment can be further divided into the Open Sea, usually characterized by deeper water and distanc from land, and the Coastal Zone where the water is shallower or only intermittently flushes an otherwise terrestrial habitat, such as in mangrove forests. Freshwater habitats

include Rivers, Lakes, Ponds, and Freshwater Swamps.

Terrestrial habitats are basically divided by the types of vegetation and amount of rainfall for the area. Forests and woodlands are dominated by trees or scrub, respectively. These areas can be further divided into dry or wet forests. Normally woodlands occur in drier sites. Savannas, or grasslands, are also typical of drier sites. Each of these habitat types is characterized by a certain species of animal: Open Sea by sea turtles, humpback whales, and sharks; Coastal Zone - white-crowned pigeon, egrets, manatee; Lake - turtle, duck; River - shrimp, goby fish; Freshwater Swamp - grebe, rails; Savanna - short-eared owl; Wet Montane Forest - parrots, screech owl.

Environment and Distribution of Wildlife in the Caribbean

The West Indies are characterized by a predominance of birds and lizards. This is due to a number of factors related to the environments present in the region, but more importantly to the geography of the region. Because the islands of the West Indies are separated from the continental land masses by barriers of water, certain species have not been able to reach these islands. Some species, such as birds, have excellent powers of dispersal; i.e., they can fly to the islands and the water barriers are of little consequence. Other species, like larger mammals, have little chance of reaching the distance islands as they are poor swimmers and have no specialization for crossing the water barriers. A few of these individuals may be able to cross the barriers on "rafts" yet, unless they are able to tolerate the harsh conditions in transit to the island, they will be unable to survive the trip. Some groups, like lizards, are better able to make such crossings than others (like mammals), and are therefore more abundant in the West Indies. However, the farther an island is from the source of

dispersion (mainlands where there is a great variety of species and larger populations of those species), the less chance there is for an animal to reach that island alive, and even less chance for two or more organisms, need to reproduce, to reach the island. Thus the Caribbean islands farthest from the mainland centers of dispersal (North, Central, and South America) have the fewest species (Fig. 2).

-Fig. 2-

Another important factor to consider in wildlife diversity patterns in the West Indies is the size of the island. Because different organisms normally specialize on different habitat types or environments, the greater the diversity of habitats, the larger greater should be the potential for a more diverse fauna. Whereas small, low islands have relatively little diversity in habitat types, the larger islands (e.g., Hispaniola, Jamaica), with their mountainous relief, have a greater variety of habitat types and also a greater variety of wildlife. Even if a large number of animal species were able to reach a small island there would be a high rate of extinction as it is unlikely there would be sufficient suitable habitats to support all of those species (Fig. 2). The result of these factors is that the closer to the mainland and the larger the island, the more diverse will be the fauna (Fig. 2).

Ecology of Wildlife Populations

Elements of Population Dynamics

A Population of animals is the number of some species living in a particular area. A population is an aggregation of similar individuals in a continuous area which contains no potential breeding barriers; that is,

all of the individuals in the population can interbreed.

Several elements of population dynamics (e.g., movement, reproduction, mortality) are important to understanding wildlife biology. The biologist needs to determine if the wildlife population is stable, increasing, or decreasing in order to assess the health of the population. To do so the biologist needs to examine four characteristics of the population: (1) population size, (2) population density (animals per unit area), (3) age and sex structure of the population, and (4) productivity of the animals.

Population Growth and Regulation

Wildlife populations increase at a rate related to the birth rate, but population size is regulated by the death rate. Natality (birth rate) is the rate of the additional of new individuals to a population by birth. Just the opposite is Mortality (Death Rate), the rate of removal of individuals from a population by death. The rate of population growth is determined by subtracting mortality from natality; this is termed the Natural Increase of the population (Natural Increase = Natality - Mortality). Different species show different population growth patterns related to their life history strategies. Some species, like the larger mammals (e.g., man) have very high early survival and most individuals have long lives. Other species, like fishes, may have a very high rate of early mortality (Fig. 3).

- Fig. 3 -

Wildlife Movements

Most animals are capable of some degree of dispersal (movement from area of origin). This ability to disperse is of importance to the population dynamics of a species. Most animals have daily movements to

reach a water or food source. Many have seasonal movements, such as migration when animals from North or South America may pass through or spend a substantial part of their lives in some of the West Indies. Other species may disperse from one area to another periodically in response to a regularly occurring, but not seasonal, change in the environment. Animals may also disperse because of an irregular environmental occurrence, such as a drought year causing an absence of water in the region.

Regulation of Numbers

There are several factors which regulate the numbers of animals. Naturally, without these checks on wildlife populations, the animals would soon eat all food, drink all water, and occupy all space available. Normally this does not occur. There is a limited number of individuals that can be supported (i.e., "carried") on a given area for a period of time; i.e., the Carrying Capacity. Certain factors that are important in the regulation of animal numbers are dependent on the size of the wildlife population and are called "Density Dependent". Stress is a characteristic of overcrowding resulting from too many individuals per unit area. Food resources are limited in any area, but the more animals depending on those sources, the fewer food items are available per individual.

Other mechanisms of population regulation are not conditioned by the size of the animal population; i.e., they are Density Independent. Climatic conditions, such as rainfall, may regulate a wildlife population's size. This control is not related to how many individuals there are in the population but to something independent of the population size.

Each animal has a Home Range, whic is an area to which an individual restricts most of its normal activities. The animal's home range contains all of the elements needed for its survival; e.g., shelter, food, water,

mates. A home range may be defended against other animals to protect the resident's resources. Other individuals may be excluded from the owner's home range. Size of home ranges varies directly with body size of a species; i.e., larger species generally have larger home ranges than do smaller related species (Fig. 4).

- Fig. 4 -

A Territory is any area defended by one or more individuals against intrusion by others of the same or different species. The territory may serve to preserve the resident's exclusive rights to food, water, or breeding resources. Many species (e.g., many birds and lizards) have strong territorial behaviors, whereas others show no territorial defense.

Competition is the use or defense of a resource by one individual that reduces the availability of that resource to other individuals. If two species depend on the same species of fruit for food and the supply of that food is limited, there will be competition between the two species (and among individuals) for that food resource. Over time one species may be able to develop more efficient means of locating and harvesting the food, and would thus "out compete" the other species for the resource. That species would thrive whereas individuals of the other species would become rarer (Fig. 5).

- Fig. 5 -

Predation

A Predator is an animal that kills and eats other animals.

Unfortunately, many predators are condemned because of these habits although predators are often beneficial animals. Normally, predators live on the annual surplus produced by a prey species. Except under very unusual circumstances, no predator except man is capable of exterminating a prey species. The most destructive predators, when occurring only sparsely, can have little effect upon the total numbers of desirable prey species. A reduction in the number of predators does not necessarily mean predator pressure on a prey animal will be reduced. Predation may be beneficial -- because herbivorous animal populations tend to increase toward self-destruction, if not held in check by various counterforces, predation may be considered a beneficial service for most prey species of this type. Availability of prey governs the diet of most predatory animals

Evolutionary Responses

Most undisturbed wildlife populations are in an Evolutionary Equilibrium; i.e., there are no major fluctuations in numbers of individuals in the populations. Normally predator-prey and parasite-host systems do not result in drastic declines in the prey or host populations as to do so would mean that the dependent predators or parasites would also decline substantially. As prey individuals become rarer, so do predators, which allows the prey populations to again grown, and so on.

A loss of a species from a local or global population is termed an Extinction. Extinction results from a failure of an organism to change in response to a changing environment.

Community Ecology

Community Organization

A Community is an association of interacting populations, usually

defined by the nature of their interaction of the place in which they live. One of the ways the members of the community interact is through the passage of energy among the organisms. There are many ways to visualize the pathways of this energy flow. Perhaps the simplest way is to consider the components of the community as forming a pyramid related to their position in the energy flow of the community (Fig. 6). At the base of the Food Pyramid are the Producers, or the plants, that are able to convert with solar energy various raw materials into food that can be used by Consumers (animals), which form the upper part of the pyramid. There are different levels of consumers, as we know that certain animals eat only plants and others (predators) eat only animals. Energy flow in a community has often abeen characterized as a chain; i.e., plants are eaten by insects, insects are eaten by lizards, lizards by birds, and so on. However, energy flow is not as simple as suggested by the food chain. More often it must be depicted by a Food Web (as in Fig. 7) because of the many interactions among consumers.

- Figs. 6 & 7 -

Concept of Niche

Two other terms should be presented here: Ecosystem and Niche. An Ecosystem is all the interacting parts of the physical and biological worlds. One can speak in terms of broad or very specialized ecosystems depending on the resolution one is concerned with in their wildlife work. Hence, one could be concerned with a system as broad as the tropical wet forest ecosystem, or as narrow as the tabonuco tree (*Dacryodes excelsa*) canopy leaf ecosystem.

A Niche is a very narrow part of the ecosystem and refers to the specific components of the environment with which an organism or population interacts. This may sound familiar to the Habitat of an organism but

differs in that you can consider an animal's niche as all those components that make up the animal's occupation, whereas its habitat may be considered the species' or population's address.

Behavior

Behavioral attributes are exclusively animal traits. Movement is an fundamental behavior characterizing wildlife populations. Animals may move as individuals or as social groups. Another important division of behavior is habitat selection; i.e., an animal's behavioral characteristics interact with other components of the animals physical and physiological makeup to determine what specific habitat elements are used. Feeding may be done in a solitary fashion or with a group of animals of the same or different species. Animals also have characteristic escape and defense behaviors used in aggressive interactions. Territoriality, as described earlier is also an important component of an animal's behavior. Many wildlife species develop tightly structured social ranks, wherein there are dominant and subordinant individuals. The dominant animals may have a better chance of survival as they have the pick of the feeding areas. Reproductive behavior includes courtship displays and parental care.

WILDLIFE RESEARCH TECHNIQUES AND NEEDS

Why do we Need Investigations of Wildlife?

Before we can institute a working conservation program to preserve a species, population, or community we need to determine basic ecological or behavioral characteristics of that group to better assure that the program will meet the needs of the problem. Studies of wildlife ecology and behavior are needed to provide the manager with information necessary to manipulate habitats or populations in preserving the group. Finally,

research can provide answers simply to satisfy human curiosity.

What are the Basic Needs of Research?

Fundamental to all wildlife research is a knowledge of the animal and its ecosystem; i.e., one must first know how does animal interrelate with its environment. Through carefully structured experiments the research biologist tries to determine what happens when man manipulates wildlife populations or habitat. In accomplishing that, the research biologist can make recommendations to the manager as to how best to make changes to improve wildlife populations.

The Scientific Approach in Wildlife Research

There is a standard approach to all research that generally follows the sequence below:

1. Observation
2. Hypothesis (an unproved theory tentatively accepted to provide a basis for further investigation).
3. Tests of the Hypothesis
    a. Further tests of hypothesis
    b. Logical deduction
    c. Experiment
    d. Components of tests
        1. Collection of data
        2. Organization of data
        3. Analysis of data
4. Interpretation of results
5. Conclusion
6. Reporting of results

Planning Wildlife Research

Wildlife research planning begins with a problem statement which reflects the needs for the program. Next, the state of knowledge for the problem at hand is investigated through literature searches and personal contacts with other workers in the field. Finally, the planning process is conducted wherein the objectives, procedures, and final product are developed.

Making Observations and Keeping Records

There is a vast difference between watching and observing. One can watch an animal without observing what it is doing. All wildlife investigations require the investigator to be alert to all of the animal's activities and to interpret these as to their importance to the individual's (or species') biology. The observer should think about what is happening and write down ideas that come to his mind as he is watching the animal. Observations should be recorded accurately and completely in a field notebook, and not left to memory.

Field notes may be in any style, but should provide the most information needed for the type of study being conducted. Narrative notes are sometimes the only way to get all categories of information needed, but it may be difficult to extract data at a later date. Sampling only a few categories of observation may prove to be much more useful for some types of field work. For some field work special field forms may be useful. These forms allow the observer to quickly note specific data into preassigned category blanks. A daily journal should be kept of the field observations for cross-referencing other notes. Other types of documentation useful in wildlife work include photography, tape recording, and portable field computers.

Whatever type of notes are taken, they should always be written with waterproof ink on good quality paper in a notebook. It is a good idea to follow a particular format (see Fig. 8 for an example). Do not trust your observations to memory. Write observations down in the notebook when you make them. Include the following information in the notes:

1. Page number - number consecutively for the notebook. (Number notebooks consecutively).

Fig. 8. Sample field note page.

	Page no. Your name Locality Date
Other observers Weather Habitat type Time into field	
Time: Observations and remarks. Time: Observations and remarks.	
Time out of field Summary	

2. Locality - specific locality, direction and estimated distance from known point (e.g., east tip of Machos Bay, 3 km northeast of Ceiba, Puerto Rico.

3. Date - Date of observation, trave , etc.

4. Other observers - Provides for later verification and elaboration by coworkers.

Other equipment for capture and monitoring wildlife are mentioned below.

Habitat Analysis and Evaluation

The distribution and character of habitat determine the characteristics of wildlife populations. For this reason it is important for the wildlife biologist to determine habitat characteristics as they relate to the wildlife under study or being managed. Habitat consists of the sum total of the environmental factors (food, cover, water) that an animal needs to survive and reproduce in an area. Before the investigator can properly appraise habitat components the investigator must know something of the animal's ecology, or how the animal interacts with its environment.

Habitat may be studied in many ways but, unless one is studying a very small population of animals or a population restricted in distribution to a local area, the biologist must sample only a representative portion of the animal's habitat rather than try to analyze the entire area over which the species is found. Reconnaissance-type evaluation of habitat is probably the most economical in time and expense and adequately serves most wildlife investigation purposes. In these habitat inventories, the biologist would like to know (1) how much habitat is available for the wildlife populations, (2) where the habitat is located, (3) the pattern of the habitat (e.g., small patches of habitat in a scattered mosaic or extensive tracts of a suitable habitat), (4) quality of the habitat, and (5) trends of change of the habitat over time.

Maps are the most convenient and universally understood means currently used to show graphically the spatial relations between the various features and structures on the earth's surface. Maps are ideal for

5. Weather - Rain, percent cloud cover, wind speed and direction, temperature. Insert changes in your notes as weather changes through day.

6. Habitat type - General topography and vegetative cover.

7. Time into field - Time at which you begin your field-related activities (e.g., time you leave home or office for study area).

8. Time - Time of observation, both beginning and end; use military time (e.g., 13:45-15:10. Midnight = 00:00, noon = 12:00, 6:00 P.M. = 18:00).

9. Observations and remarks -

   a. Record the species, number, age, and sexes as possible.

   b. Describe behavior as accurately, clearly, concisely, and completely as possible.

   c. Include remarks such as unusual occurences, thoughts, and ideas about your observations.

10. Time out of field - Record time you left study area.

11. Summary - give a brief summary of the day's observations.

Equipment

There are many sophisticated types of equipment being used today in wildlife research. However, time most valuable piece of equipment for this work is still the binocular (usually 7 x 35 mm for most wildlife work). Other types of optical aids include a spotting scope of between 20 and about 60 power magnification and telescopes of even greater magnification.

Some recording devices are valuable in wildlife work. Portable tape recorders are used in recording animal vocal behavior and also to take notes on field observations when it is difficult to both watch and write.

recording and communicating the information related to a specific area. There are several types of maps that can be useful in wildlife habitat reconnaissance; these include maps created to show:

1. Cover types
2. Vegetative distribution
3. Land use patterns
4. Soil types and characteristics
5. Distribution and abundance of animals
6. Topography
7. Future land use plans

One of the most important components of an animal's habitat is the vegetative composition. Several aspects of the vegetative component are important to the investigator in his study of an animal's habitat: density of vegetation, cover quality, distribution of plants, amount of available food, food utilization by the animal, and prediction of fruit production. The methods for conducting wildlife habitat evaluations are many and vary considerably with the purpose of the study and the degree of resolution needed by the wildlife biologist. Several references to methods of collecting habitat data are included in the bibliography.

Food Habits Analysis

The wildlife biologist must know the kinds and quantities of foods eaten by animals in order to understand that species' ecology and to manage the species. The most important questions asked by the biologist in food habits studies are: (1) what foods are used, and (2) how, where, and when are such foods obtained. It is also important that the investigator realize that animals may vary their food requirements seasonally and thus food habits must be examined throughout the year to gain a clear

appreciation for the species' feeding behavior.

Data Collection

Information on a wildlife species' food habits can be obtained in many ways. Field observations of animal feeding behavior are an excellent source of information. Other methods may require the biologist to examine members of the wildlife population to see what types of foods they have been eating. Specimens for these kinds of food habits studies may be obtained from several sources, including (1) animals or parts donated by hunters, (2) accidental kills (e.g., road kills), and (3) samples collected specifically for the study. The source, number, and type of materials chosen for food habits studies must be determined by the goals of the study and the status of the wildlife population; e.g., one would not want to collect several specimens of an endangered wildlife species to examine stomach, but would use methods with minimum impact on the populations (observations of feeding behavior, collection of droppings or pellets).

Several types of materials are commonly used in food habits studies, depending on the kind of animal and the objectives of the study. The most commonly used materials for studies of bird food habits include:

1) crops (the preferred source for most species)

2) gizzards (e.g., waterfowl)

3) stomachs (especially predators)

4) droppings (e.g., seed eaters) and pellets (many raptors)

Stomachs or scats are typically used in studies of mammal food habits. Stomachs are the most commonly used material for the study of reptile and amphibian food habits.

Irregardless of the kinds of material examined or the kind of food habits studies being conducted, the biologist should develop a reference

collection from the specimens obtained. The collection should consist of representative parts of the food species to aid in future identification of wildlife food items. All specimens should be adequately preserved to ensure they retain the characteristics of the species that are useful in identification.

Unless the materials are examined within 12 hrs, they should be adequately preserved so the food items do not deteriorate and thereby make identification more difficult or impossible. There are three common methods for preserving food samples: wet (e.g., formalin or alcohol), dry (e.g., oven-dried seeds), and freezing. [See Appendix I for more details on preservation techniques.

Food Habits Analysis

Food habits analytical techniques vary with the objectives of the study; the analyses may be "rough" if the wildlife biologist only needs to know the major food types used by the animal, or it may be desirable to have very detailed analyses of foods used by the species ensure that the manager has a good comprehension of the nutritional requirements of the wildlife population. Analytic procedures typically consist of the following:

1. Preparation of the material (washing if it has been in preservative)
2. Segregation of food items into rough categories
3. Identification of food items to lowest possible category
4. Data records
5. Appraisal and presentation

Collection and Preservation of Biological Materials

There are many times when it is desirable to preserve specimens for

verification of a species' existence, as part of a reference collection for future comparison and identification of other specimens, or for scientific study. The means of preserving materials vary with the kind of specimen and with the intent of use of the animal or plant. The most common methods of preserving specimens are:

1. Refrigeration
2. Preservatives
3. Study skins
4. Preserving plants

Some of these methods are detailed in Appendix I.

Capturing and Marking Wildlife

Such wildlife studies as movements, growth, disease, and estimates of numbers may require that the animal be captured, examined, and perhaps marked for future identification. The first step in determining the most suitable method for capturing a species is to understand the ecology and behavior of that animal. The most efficient trapping strategies make good use of this knowledge to ensure that the target animal is the species captured. Depending on the type of investigation being conducted, the biologist may live trap the animal or collect specimens (e.g., by shooting or snap-trapping).

Marking Techniques

Natural marks

There are many studies of wildlife populations where individuals need to be distinguished from others in the population over periods of time. In some cases it is possible to recognize individuals without artificially marking the animal; i.e., the animals may have natural markings that can be

used to distinguish them from other individuals. Plumage or pelage patterns are useful for several animals, whereas others might show individual differences in color or shape. For example, Puerto Rican parrots (Amazona vittata) have facial plumage patterns that are different in each individual. In Africa, research biologists have used the shape and other characteristics of ears to tell one elephant (Loxodonta africana) from another. Biologists working on the endangered California condor (Gymnogyps californianus) are able to recognize individuals by the shape and pattern of wing feather molt and damage. Recognition using natural markings has its limits of reliability in that changes occur over time and there may be problems of duplication (i.e., each individual may not be unique).

Tagging

"Tagging" is a technique commonly used on many types of animals. Tagging may be either mutilative (i.e., permanent) or non-mutilating (marking device causes little or no physical damage to the animal and may eventually be lost). Mutilative techniques include:

1. Toe clipping
2. Ear notching
3. Tattoos
4. Freeze branding
5. Dyes
6. Branding
7. Painting.

Non-mutilating methods include:

1. Tagging (e.g., metal or plastic leg bands, patagial (wing) tags, neck streamers, and ear tags)
2. Radio tagging

3. Radioactive tags

Each species and its problem has to be assessed individually as to the kind of marking scheme needed for the study, but certain techniques are typically used on the different animal groups. Mammals are commonly marked using one of the following techniques

1. ear tagging
2. ear notching
3. tattoos
4. freeze branding
5. natural marks
6. radio transmitters
7. radioactive isotopes
8. Toe clipping
9. branding
10. Wing bands (bats)
11. Fur clipping
12. Tail docking

Investigators studying birds have used the following marking techniques for that group:

1. Leg bands
2. Patagial tags
3. Neck bands and streamers
4. Bill saddles & other nasal markers
5. Back tags
6. radio transmitters
7. Dyes
8. Natural marks

Marked populations of reptiles and amphibians have been studied using

mostly a number of mutilative techniques. Individual snakes have been identified by natural scale patterns, and by belly scale clipping and branding. Turtles are typically marked by cutting notches or holes in shell edges, affixing tags through shell holes, branding, or painting the shell with unique symbols. Toe clipping, paint, and tattooing have been used to mark lizards in field studies. Frogs have been studied using natural marks, tattoos, and freeze branding. Studies using radio telemetry have been conducted on each of these reptile and amphibian groups.

Fish marking techniques include tissue alterations (e.g., fin punches, fin clipping, fin ray clips), chemicals (e.g., dyes, radioactivity, fluorescence), branding, and tagging with internal tags (e.g., subcutaneous) or external tags, such as strap tags, flag tags, spaghetti tags, anchor tags, or radiotelemetry.

Age and Sex Criteria

It is often of great importance for the wildlife researcher or manager to understand the population structure of animals. There are several definitions that the wildlife biologist should be acquainted with:

Prenatal age - age of embryos and fetuses, usually expressed in days.

Postnatal age - follows birth or hatching and involves:

Year-class - actual chronological age in years or

Age-class - breeding condition of the individual:

Immature or juvenile - too young to breed but distinguishable from adults by external characteristics

Subadult - has not bred, but externally resembles adult

Adult - an animal which has bred.

The following terms are also used in classifying age categories:

yearling - over 1 but under 2 years of age

two-year-old - over 2 but under 3 years of age

Population turnover - length of time required for 1 year class to disappear from the population

Among birds, the following terms have specific meanings:

juvenal - name of plumage following natal down

juvenile - a bird after the downy stage and before sexual maturity

immature - from the post-juvenal molt to full adult plumage via postnuptual molt

The age and sex of the animals in the population can be determined in several ways, usually depending on the kind of animal one is working with and the type of investigation being conducted. The surest was of determining sex of an individual is through surgical means. However, this method is not always the most desirable as it requires capture of the animal, and also some degree of risk to the life of the animal.

Most methods for determining an animal's age or sex do not involve surgery, but rely on secondary sexual characteristics or morphological indicators of status. For birds, plumage characteristics sometimes can be used to distinguish juveniles from adults or males from females. Cloacal examinations are often used to determine age and sex of certain birds, whereas developmental state of the bursa of Fabricius may be used to distinguish adults from juvenile birds. The North American Bird Banding Manual, Vol. II (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1977) has complete descriptions of sexing and aging techniques for over 60 species.

Reptiles and amphibians, because they grow continuously (but at varying rates) are typically aged through weights and measurements.

Sex determination for mammals is generally more easily made than for

birds or herps because many mammals have external sex organs or sexually dimorphic secondary sex characteristics (e.g., males are larger, have horns or antlers). Mammals may be aged by tooth erruption or wear patterns, or through weights and measurements.

Estimating Status and Distribution of Wildlife Populations

In the assessment of the health of wildlife populations it is essential to determine the how many animals are in the area, where the animals are located, and trends in population size (e.g., growing or declining?). Status surveys are conducted to gain population and harvest information that can provide the background on which sound management decisions can be based. Once elements of population dynamics are known it is possible to predict and manipulate the wildlife populations.

Harvest Data

There are several types of status surveys, but most methods employ either counts of animals in the population or are harvest surveys. Harvest data are typically collected from animals killed by hunters. Often harvest data are the best sources of information on the size and productivity of a wildlife population and its ability to provide recreation through hunting. The wildlife investigator can develop population estimates based upon composition of the kill; i.e., kind and number of animals, and age and sex composition of the sample. Age and sex information collected from harvest data is used to draw conclusions about the well being of a population.

Various methods may be used to gather harvest data, but the most common are questionnaires mailed to a representative sample of license holders and check stations located in regularly-used hunting areas.

Population Counts

Population surveys normally involve making direct or indirect counts

of the wildlife within the area of interest. Several terms should be familiar to the wildlife biologist, including:

Census - A complete count or tally of animals over (a) a specified area at a specified point in time, or (b) a specified interval of time at a specified point in space (area).

Sample Census - A complete count or tally of animals over (a) a sample of a specified area at a specified point in time, or (b) a sample interval of time from a specified interval of time at a specified point in space.

Census Index - A count or ratio which is relative in some sense to the total number of animals in a specified population. A sample census is a special case of a census index.

Census Estimate - An estimate of the total number of animals in a specified population, obtained from a census index.

Survey - A sample census

Index - A condition which can be measured, and which varies as some other condition which cannot be measured. The former is used as an **Index** to the latter.

Complete counts may be used to determine population size in some special cases, such as when the number of animals is small, they are found in specific known areas, and they are detectable. Examples of direct count applications include:

1. Territory (or Home Range)-Mapping Methods; e.g., song birds.
2. Drive Counts (usually big game, which are easily driven and seen).
3. Temporal Counts, in which a count is made of all animals passing a point during some interval of time; e.g., counts made at roosts of congregating birds or of migrating animals.

4. Extermination or Total Capture, wherein all animals in the population are destroyed or removed from the area.

5. Complete Counts of Small Populations Restricted in Range; e.g., some endangered species such as Puerto Rican parrot and Puerto Rican plain pigeon

The most common approach now used to estimate wildlife populations is through Sample Area Counts, wherein a sample of the population is censused and then the results are projected over the total known range of the species for a total population estimate. The two main types of Sample Area Counts are (1) Quadrats and (2) Transects and Strip Censuses (e.g., Roadside counts of hawks).

Population surveys are also made by investigating animal signs and related objects. These techniques usually only sample a population. Three types of sign counts are often used: 1). pellet (droppings) counts, 2). track counts, and 3). Call Counts, as commonly used for song birds, pigeons and doves. Call counts tend to show great variability of results with weather, time of year, and behavioral aspects of the animals being censused.

Population Estimates Based on Marking Animals

In "Mark-Recapture" methods, the most commonly-used marking technique for determining wildlife populations, population estimates are obtained by marking a sample of the animals present in an area and then determining the fraction of the total population marked by either observing the population or capturing a sample in traps or by shooting.

$$\frac{\text{Tagged and released animals}}{\text{Total population}} = \frac{\text{Recaptured tagged animals}}{\text{Total recaptured animals}}$$

or

Total population =

$$\frac{\text{(Tagged \& released animals)} \times \text{(Total recaptured animals)}}{\text{Recaptured tagged animals}}$$

Example:

We mark 100 lizards on a small island. Many others escape and we are unable to mark them. Two weeks later we return to the island and attempt to capture all the lizards we can. We are able to capture 100 lizards, 35 of which are marked from our earlier visit and 65 are unmarked.

From the above formula we figure:

Total population of lizards =

$$\frac{\text{(100 tagged \& released lizards)} \times \text{(100 recaptured animals)}}{\text{35 marked recaptured animals}}$$

$$= \frac{(100)x(100)}{35}$$

$$= 10000/35$$

= 285.6 (286) lizards estimated in the population

Trend Counts

Trend counts are not conducted on carefully defined sample areas nor according to rigidly prescribed rules (as in sample area counts), but give a population index relating to relative population levels and changes in these levels. Trend counts are thereby most useful in monitoring wildlife populations from year to year.

Distribution Studies

Geographic distribution of wildlife populations is important in determining areas where management of animals must be performed (e.g., establishment of conservation areas, harvesting areas, preserves). Distribution related to habitat is also important in managing wildlife and the habitat on which it is dependent.

WILDLIFE MANAGEMENT

Wildlife Management Principles

In 1933 Aldo Leopold, who is considered the "founder" of modern wildlife management defined the management of game as "the art of making land produce sustained annual crops of wild game for recreational use." Leopold's definition has been modernized by Robert H. Giles (1969): "Wildlife management is the science and art of changing the characteristics and interactions of habitats, wild animal populations, and men in order to achieve specific human goals by means of the wildlife resource."

Modern wildlife management is based on a good understanding of the animal's ecology; i.e., the wildlife manager must know the animal and its environment. The Wildlife manager attempts to identify the factor(s) limiting the abundance of wildlife. By controlling this factor, more wildlife can be produced for recreational use.

Hunting

In most parts of the world hunting is a traditional pastime and means of bringing food home. Whereas some wildlife populations can sustain varying degrees of hunting pressures, others are sensitive enough so that no level of hunting pressure can be tolerated. Thus there must be a species-by-species determination of which animals can be hunted and which can not. Limitation of hunting usually is important to assure survival of a breeding stock of these species. Hunting may be self-regulating since hunting success and hunting pressures decline as the season progresses; i.e., hunted animals become more scarce and individuals grow more wary. It is essential that hunted populations are regularly surveyed to determine effects of harvesting and to develop and refine harvesting regimes; e.g.,

hunting seasons, bag limits (see below).

Refuges

Refuges are areas of good quality habitat preserved for the benefit of wildlife populations. Such refuges are particularly important to waterfowl and other wildlife experiencing restrictions in habitat availability; e.g., destruction of wetlands. There are several kinds of refuges, including those that offer complete sanctuary for all wildlife, those that provide sanctuary for only certain species (such as some endangered species), and those that offer game good habitat but where closely-regulated hunting is allowed.

Predator Control

Normally predators do not harm wildlife populations. However, there are occasional cases where control of an offending individual or family group may be advantageous. Endangered species also present a special case -- the reduced populations of some threatened and endangered wildlife species can not sustain a level of predation that could be normally sustained it the population was healthy, and it may be beneficial to the species' recovery to control the number of predators in a limited area.

The wildlife manager has to assess each case of predator damage to ensure that a management strategy does not upset the "balance" of the ecosystem. As an example, perhaps red-tailed hawks (*Buteo jamaicensis*) have been found to be an important predator of scaly-naped pigeons (*Columba squamosa*). Local hunters may ask that the agency responsible for game management kill the hawks so that more pigeo would be available to the human hunters. However, if hawks are eliminated from an area there is a good chance that pigeon populations may decline below their former level.

Hawks are also important predators of rats. Without this rat population control, these predators of pigeon eggs and nestlings may cause severe damage to pigeon reproduction. In this case (as in most), it may be best not to control the predator.

Artificial Stocking

Artificial stocking of wildlife on an area with depauperate populations of that species is a common practice in some countries. Most people are familiar with the stocking of fish in some lakes or streams to provide enough animals to meet the demands of fishermen. However, many game birds and even large game mammals are stocked in some areas to provide for hunting or passive recreation. Such stocking practices are a means of providing this resource in an environment wherein natural population growth can not meet the demands of the public.

Although some animals may be removed from other wild populations and transported to a managed area for stocking, usually the animals are produced from captive breeding stock at fish hatcheries or game farms. As such, the practice of game stocking is quite expensive. Also, in most cases, few of these captive-produced individuals survives for long in the wild unless special techniques are used to condition the animals to their new environment.

Carrying Capacity

The carrying capacity of a habitat is the sum of the environmental factors which make a wildlife range habitable; e.g., food, water, loafing areas, escape and nesting cover. There are upper limits to the carrying capacity of any wildlife habitat, beyond which no amount of environmental manipulation ("improvement") can increase the number of animals the area is capable of supporting. Wildlife cannot be "stockpiled" in excess of the

carrying capacity. Also, the carrying capacity of any area changes with time; e.g., seasonally, successionally.

Habitat Improvement

Habitat improvement includes any of the many means of changing the habitat (food, water, cover, space) to meet wildlife needs for reproduction and survival. projects must be justified according to biological needs based on preliminary investigations Any habitat change will affect most wildlife species and before any management is attempted, the probable effects on all wildlife in the area should be assessed. Most habitat manipulations are costly in time and money. The wildlife manager must assess the projected benefit to wildlife against the substantial commitment to the project. Improvements should simulate natural conditions. The greatest returns are achieved if the improvement does not interfere with the primary purpose for which the land is managed; e.g., farming, recreation. Periodic evaluation are an important part of any habitat improvement program.

There are a number of ways that habitat can be improved to benefit wildlife populations. Some of these are outlined below:

Food production

Food production for wildlife may take the form of plantings or conversions of existing habitats. The manager can plant small food patches or strips containing a mixture of a variety of foods. It is usually desirable to leave food trees in woodlots when cutting. Food trees can be planted in windbreaks around clearings for crops or recreation areas. Also, small patches of field crops can be left standing and unharvested for wildlife.

Plantings of food species by direct seeding or use of transplants may be feasible as a food production strategy. In some cases where native food trees have become rare, a program of propagation and planting of wild mast and fruit producing trees may be of great benefit to wildlife. Food species may be released from competition by a number of methods, including mechanical (e.g., chaining, tilling, cabling, scalping), chemical sprays, and controlled burning.

Water development

Wetlands are in tremendous demands for development as recreational, industrial, and urban sites. These uses of wetland habitats are not always compatible with wildlife needs and strategies for the improvement of water resources for wildlife must be developed. These strategies include: developing ponds and lakes for waterfowl, water birds, and other aquatic animals; providing floating logs or rafts as loafing sites for waterfowl; providing "potholes" and other small open water areas for nesting or resting waterfowl; and establishing watering places for wildlife in arid areas.

As in any habitat manipulation scheme, the wildlife manager must fully evaluate the potential for adverse, as well as beneficial, change to the environment. For example, in some arid areas hunters may argue that by increasing water resources, the number of doves and pigeons will increase, thereby improving the recreational value of an area. However, by providing improved water resources the manager may actually depress resident wildlife populations adapted to the natural water resources. Rats and mongooses, dependent on free water and predators of many native birds, may increase in number and range with water development. Nest predation by rats and mongooses could greatly depress populations of these native species.

Wetland improvement

Habitat manipulation practices for improving wetlands include: (1) water level control, (2) planting for food and cover, and (3) nesting and resting sites. Stream and river banks can be stabilized with plantings (also to improve food and cover resources). Buffer strips of vegetation can be established along streams to provide shade, insect food for fish, and shelter for aquatic animals. Controlling water levels in marshes can favor habitat for waterfowl and other waterbirds.

Cover improvement

Cover is one of the important habitat components required by all wildlife species. The manager can improve wildlife protective and nesting cover in several ways, including: (1) establishing living hedges around field boundaries to reduce soil erosion and provide nesting cover, travel lanes, and food; (2) establishing windbreaks along roads, around homesites, and between fields and crop strips; (3) planting areas not suitable for farming with trees, shrubs, and permanent cover crops; (4) saving den and nest trees in wooded areas; (5) maintaining ditch banks with cover of grasses and weeds; (6) encouraging vegetation growth in marshes, sloughs, and pond edges; and (7) providing artificial nesting and roosting structures for animals.

Protective cover may be provided as: (1) hedgerows, (2) natural and artificial roosts, (3) ground nesting cover, (4) nesting trees, and various nesting structures (e.g., nest boxes, nesting platforms, nest cones).

Structural improvements

Some situations require that habitat be protected by physical restraints to keep domestic animals or people out of areas with sensitive

wildlife. All of the introduced domestic animals (but particularly pigs and goats) cause severe habitat damage. Some habitat damage by these animals can be controlled by fencing against uncontrolled grazing and browsing to protect food and cover.

To determine the extent of domestic animal grazing and browsing damage to wildlife habitat, the wildlife biologist may establish study exclosures to keep these animals out of an area of habitat.

Interspersion

"Interspersion" is the positioning, configuration, and size of the kinds of vegetation needed to sustain the wildlife species. Wildlife numbers usually depend on the interspersion of habitat types and their relation to the species' cruising radius (the daily and seasonal movements).

The development of "edge" can have a positive effect on wildlife populations, because many wildlife species are a product of the places where two habitats meet. Examples are the borders of clearings, fields, meadows, woods, ponds, rivers, marshes, and swamps.

Territories

The wildlife manager attempts to increase the number while decreasing the size of territories, thereby increasing the number of animals that can use an area. The manager does this through changing vegetative components so all life's necessities are within the smallest range the species will inhabit.

Population and Harvest Surveys

Sound wildlife management requires a knowledge of (1) population levels and (2) harvest in order to efficiently provide maximum continued

recreation. This population and harvest information provides the background on which sound management decisions can be based.

Predation Control

The researcher and manager need to determine the exact relationship between predator and prey. Predators should be recognized as valuable in their own right, and a philosophy of giving the predator the "benefit of the doubt" should be adopted until studies prove its total ecological relationship. In situations where predators need to be removed, control should be specific for the target predator. Predator control may benefit a desire species on areas where other environmental conditions are favorable for increase, especially when the numbers of the prey species are well below normal; e.g., endangered species. The emphasis should be on control of damage rather than upon control of predators.

Wildlife Disease

Disease is any condition which jeopardizes the survival of an animal in a particular environment. The study of wildlife disease is important not only to insure survival of the wildlife species but also to safeguard livestock industries and the health of man. Abundance of healthy wild animals indicates a high quality environment.

Disease may be difficult to detect in wildlife populations. An indication may be a sudden decline in numbers. The effects of disease are often subtle and of long duration, and may be complicated by malnutrition and a high incidence of parasite infestations in a wildlife population. Diseased animals may be more susceptible to the debilitating effects of some environmental contaminants (e.g., pesticides) than healthy animals.

The wildlife biologists may want to collect specimens of individuals suspected to have disease problems in a population. These specimens can be

grossly examined for pathogenic signs by the wildlife biologist but the animal may have to be diagnosed by a laboratory specializing in wildlife disease problems. If a population is determined to contain diseased members, the wildlife biologist may have to control individuals or groups of animals by culling through eradication to save the other members of the population.

Wildlife Damage Problems

Steps in Treating Wildlife Damage

When the wildlife biologist receives a report of wildlife damage, the first step in treating the situation is to identify the problem and its source. Next, the scope of damage must be determined, including the seriousness and extent of the problem. Finally, the control strategy is planned and carried out, after economic, social, and moral evaluations.

Control Methods

The wildlife manager may want to reduce the numbers of offending animals to immediately stop damage, If the situation (and public opinion) warrants this strategy. However, many other techniques may be just as effective as removal of animals. Mechanical barriers can be used to stop animal access to crops. Frightening techniques can be used to scare problem animals from crops, airfields, other damage areas. The wildlife manager can encourage increased harvest of the offending species by hunters. Farmers and managers can develop strategies of adjusting agricultural practices to discourage wildlife use. Also, managers can establish wildlife feeding and resting areas on non-crop lands to "lure" animals away from agricultural areas.

There is considerable public interest in introducing exotic animals for sport hunting or aesthetic purposes. Such introductions may be beneficial, but there are many dangers in introducing species to non-native countries. One has only to consider the introduction of the small Indian mongoose (Herpestes auropunctatus) to the West Indies and its subsequent negative impact on native wildlife to appreciate the severe consequences that may result from introductions of non-native species. Before any introductions are made to an area, the manager must carefully consider the ecological morality of such a program. Also, the manager must assure that safeguards for control and, if necessary, removal are included in the introduction plan.

Law Enforcement

Enforcement is the basic tool of management. Without adequate law enforcement the best research and management programs would have little consequence; illegal kills would reduce or exterminate most wildlife. Aside from enforcement of wildlife laws the conservation officer has a responsibility for conservation education of the public.

OBTAINING FUNDING FOR WILDLIFE PROJECTS

What is a Grant?

A grant may be any form of financial assistance or support to carry on a wide range of activities; i.e., it is a means of transferring property, money, services, or anything of value to a recipient in order to accomplish a public purpose. Grants are made for research, management, education, travel, training, or conferences. As such, grants are excellent ways of financing some aspects wildlife programs that can not be supported by

government funds. However, grants are not easy to come by, and with funds shrinking everywhere it is becoming more competitive and difficult to obtain funding through grants. The information included below may help the wildlife biologist in locating sources of grants for wildlife, and in making the grant more competitive.

How to Find Out About Grants and Who Gives Them

Basic sources of information on grants can be found in libraries, institutional grants offices, subscription information services, workshops and institutes, journal newsletters, news media, and word-of-mouth. There are three main sources of grant funds: government agencies, foundations and community trusts, and business and industrial organizations. A list of potential grant sources that have interest in wildlife problems in the Caribbean is presented at the end of this section.

Writing the Proposal

A standard format for a grant submitted to an agency, foundation, or organization should have the following elements:

I. Cover page, that includes:

A. Name and address of organization to which the proposal is addressed.

B. Subject of the proposal and the type of support requested; e.g., grant, contract, or fellowship; for training, research, or other purpose.

C. Name of the applicant; i.e. the individual preparing the proposal, the project director or principal investigator; address, telephone number.

D. Name of the institution or agency endorsing the proposal.

E. Name, address, telephone number, and title of the official

authorizing the institutional or agency endorsement.

F. Name, address, telephone number, and title of the government agency or institutional fiscal agent to whom the grant funds will be paid.

G. Project period - beginning and ending dates. A statement that it is a new, renewal, or continuation application.

H. Amount of the request.

I. Signatures of the principal investigator and the institutional or agency representative

J. Date the application is submitted.

II. Abstract - A summary of the project containing all the key points necessary to give the reviewers an overview of what is being proposed in 100 to 300 words.

III. Project description - The main body of the proposal where the basic idea is expressed, the philosophy or premise underlying it is explained, the methods for developing it are described and its ultimate purpose is asserted and defended.

Components of the Description

A. Introduction

B. Objectives - State specific objectives and their relatin to the overall purpose of the proposed work.

C. Methods of Procedure - State the plan or design of the project in step-by-step sequence including time estimates, techniques or methodology to be used, use of subjects, collection and analysis of data, evaluation methods, and interpretion of results.

D. Significance of the work proposed

E. Facilities Available - list space, equipment, environmental factors that are available for the project

IV. Budget

A. Direct costs

1. Personnel - salaries and wages

2. Expendable supplies

3. Equipment

4. Travel

5. Publications - brochures, reports, page charges, reprints of articles

6. Additional costs

B. Indirect costs - Government or institutional overhead

V. Credentials of staff who will be performing proposed work

A. Training

B. Achievements

C. Experience

VI. Institutional endorsement

Funding Sources for Wildlife Projects in the Caribbean

Foundations and Other Organizations

American Museum of Natural History
Central Park West at 79th St.
New York, N.Y. 10024
Chapman Fund
Theodore Roosevelt Memorial Fund

Conservation and Research Foundation
Box 1445
Connecticut College
New London, Connecticut 06320

National Academy of Sciences
Office of the Home Secretary
2101 Constitution Ave., N.W.
Washington, D.C. 20418

National Audubon Society
950 Third Ave.
New York, New York 10022

Committee for Research and Exploration
National Geographic Society
17th and M Streets, N.W.
Washington, D.C. 20036

The National Wildlife Federation Endowment, Inc.
1404 Oliver Building
Pittsburgh, Pennsylvania 15222

New York Zoological Society
The Zoological Park
New York, New York 10460

North American Wildlife Foundation
709 Wire Building
Washington, D.C. 20005

Wildlife Management Institute
709 Wire Building
1000 Vermont Ave., N.W.
Washington, D.C. 20005

The World Wildlife Fund
1110 Morges,
Geneva, Switzerland

International Union for the Conservation of Nature
CH-1196 Gland
Geneva, Switzerland

International Council for Bird Preservation
Smithsonian Institution
Washington, D.C. 20560

United States Government Agencies

National Aeronautics and Space Administration
NASA Headquarters Information Center
Washington, D.C. 20546
- has supported research on migration, navigation, and orientation of animals

National Institutes of Health (NIH)
Division of Research Grants
National Institutes of Health
Bethesda, Maryland 20014

National Science Foundation
Central Processing section
Washington, D.C. 20550

Wiley - Wildlife AID Course

Smithsonian Institution
Office of Academic Studies
Room S1356
Washington, D.C. 20560

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D.C. 686pp. [A comprehensive and much recommended book on techniques and methods of wildlife management].

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482

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APPENDIX I. RECOMMENDED TECHNIQUES FOR PRESERVING BIOLOGICAL MATERIALS

All specimens should be fully labeled with the following information: 1) date specimen was collected, 2) locality where collected, 3) name of person who collected specimen, 4) name of organism (if known), 5) type of material preserved (e.g., digestive track, pellets, etc), and other information about the specimen, such as type of habitat, time collected.

Biological material	Recommended technique listed in order of preference
Mammals	
whole, small	Ethyl alcohol (70%) or 5% formalin
whole, large	Formalin (7-10%); also injection of preservative into internal organs by hypodermic
Skins, pelts	1) Clean thoroughly and air dry 2) salt thoroughly 3) use alum on pelts which appear to be "slipping"
Skins, study	1) Borax 2) arsenic trioxid-borax mixture in equal proportions 3) arsenical soap
Food material stomachs	Small stomachs - 5% formalin large stomachs - 5-10% formalin (wrap in cheesecloth)
Droppings	Dry quickly, fumigate with carbon disulfide
Reproductive tracts	1) AFA or Bouin's fluid

	2) 10% formalin
Birds	
whole	1) 70% alcohol
	2) 5% formalin
	Both with internal injection
Skins, pelts or study	1) Borax
	2) arsenic-borax mixture
Stomachs	5% formalin
Droppings and pellets	Dry quickly and fumigate with carbon disulfide
Reptiles and Amphibians	
whole	1) 35-40% isopropyl alcohol or 70% ethyl alcohol
	2) formalin - specimens should be slit or injected
Snake skins	Rolled flat, placed in 70% alcohol
Amphibian skins (to preserve color)	Kill with either; skin and place skin in water; float onto cardboard; dry quickly
Fish	1) Fix in 10% formalin for 1 week then wash in water and store in 70% alcohol
Insects	
Hard bodies	Kill with KCN bottle; store dry
Soft bodies	Kill and store in 5% formalin or 10% alcohol

Miscellaneous

Skeletons - field

1) Clean thoroughly and dry quickly; treat with arsenical soap for shipment
2) place in alcohol (formalin, unless neutralized, dissolves calcium of bones)

Skeletons - in laboratory

1) Boil gently in 3% hydrogen peroxide to remove meat and to bleach bones; degrease in carbon tetrachloride
2) clean by use of dermestid beetles

Parasites

Ectoparasites

Remove by hand or with aid of ether, chloroform, or sorptive silica powder (Dri Die).

1) ship live in non-airtight container with moist cotton, refrigerate if possible.
2) kill with ether, chloroform or HCN and ship dry between layers of cotton.
3) freeze and ship frozen.

Helminths

1) relax in cold water. Fix nematodes in hot 70% alcohol. Fix cestodes, trematodes in warm AFA.
2) alcohol 70%-95 parts / glycerol-5 parts

Protozoa

1) Refrigerate tissues, feces, citrated blood
2) make smears of blood, feces, tissue impressions
3) fix tissues in 10% formalin

Plants

Terrestrial	Place between folded paper, dry quickly between corrugated cardboards and with slight pressure in plant press.
Aquatics, or other plants with a mass of tissue	1) alcohol-acetic acid-formalin solution 2) 2 to 4% formalin

---

In this table several references are made to various concentrations of alcohol and formalin. Normally, alcohol is 95% strength, and formaldehyde solution (from which formalin is derived) is 40% solution in commercial quality. The formula used in diluting either of these chemicals is as follows:

$$\frac{\text{Desired concentration}}{\text{Concentration of stock solution}} \times \text{desired volume} = \text{Volume of stock solution to be diluted to desired volume}$$

Example: Suppose 200 ml of 60% alcohol is wanted and a stock solution of 95% alcohol is on hand. Then, according to the above formula:

$$\frac{60}{95} \times 200 = 126.3 \text{ ml of 95\% alcohol}$$

to which is added 73.7 ml of water to make 200 ml of 60% alcohol.

Example: We want to make 250 ml of 5% formalin from a stock solution of 40% formalin:

$$\frac{5}{100} \times 250 = 12.5 \text{ ml of stock formalin}$$

which is mixed with 237.5 ml of water.

APPENDIX II. WRITING A SCIENTIFIC REPORT

I. Scientific style

A. Title

B. By-line

C. Abstract

D. Introduction

E. Acknowledgments

F. Study Area

G. Materials and Methods

H. Results

I. Discussion

J. Literature Cited

II. Suggested procedure for writing the report

A. Prepare outline

B. Plan illustrations and tables

C. Assemble references to literature

D. Write

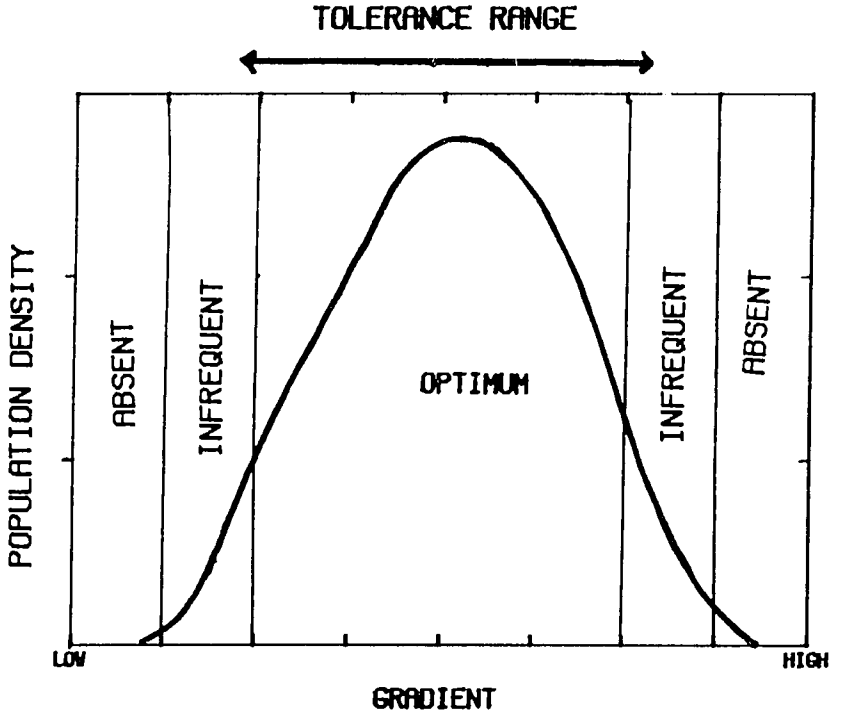
III. Writing tools

A. Good dictionary; e.g., Webster's Third New International Dictionary.

B. Thesaurus; e.g., The New Roget's Thesaurus in Dictionary Form

C. Good grammar text

D. Style manual; e.g., Style Manual for Biological Journals



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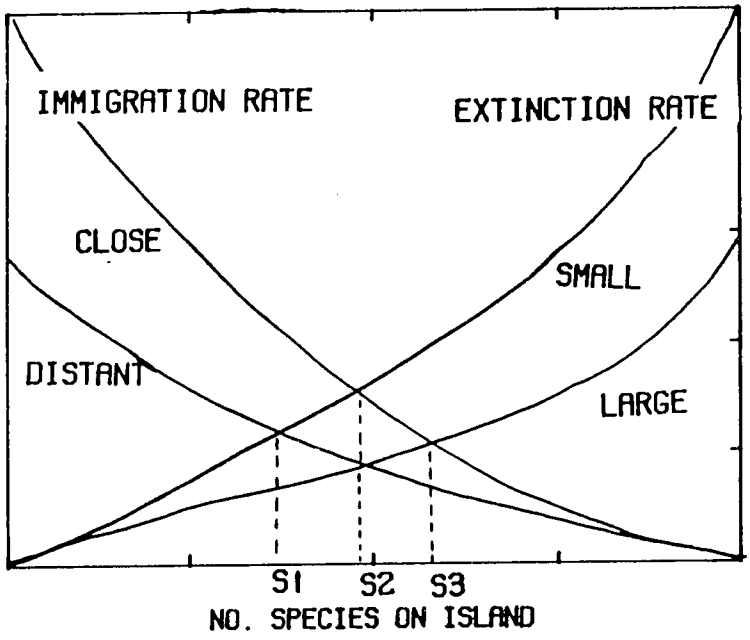
S = EQUILIBRIUM NO. OF SPECIES



S1 = DISTANT ISLAND

S3 = CLOSE ISLAND

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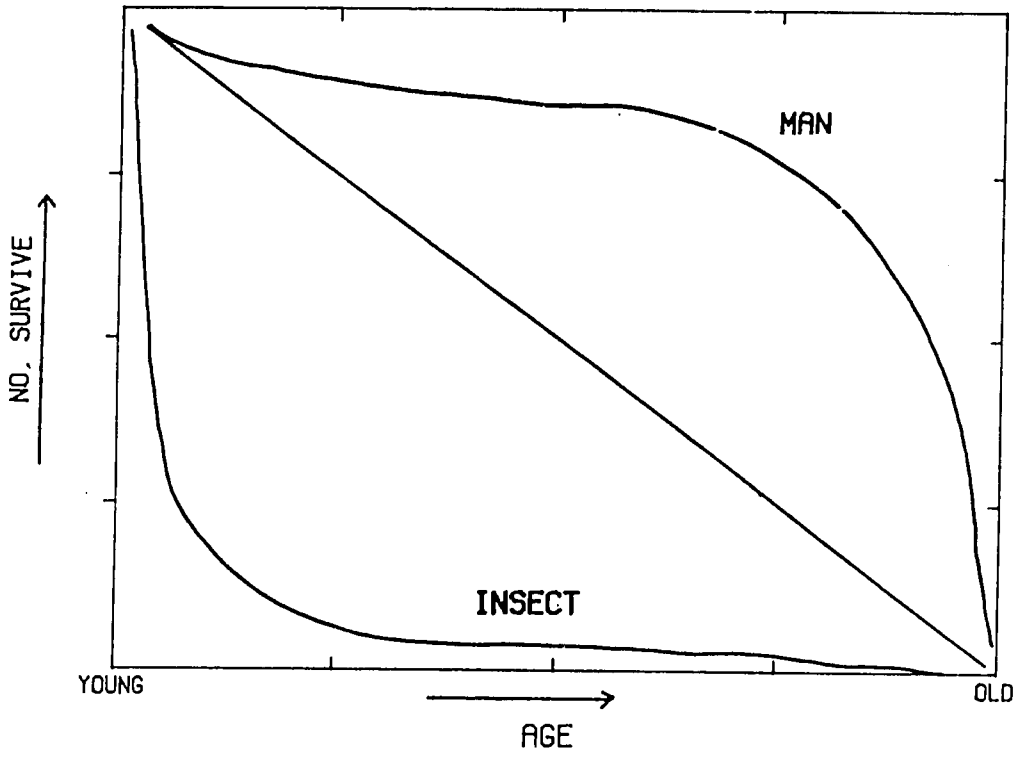
WILDLIFE POPULATION CHARACTERISTICS



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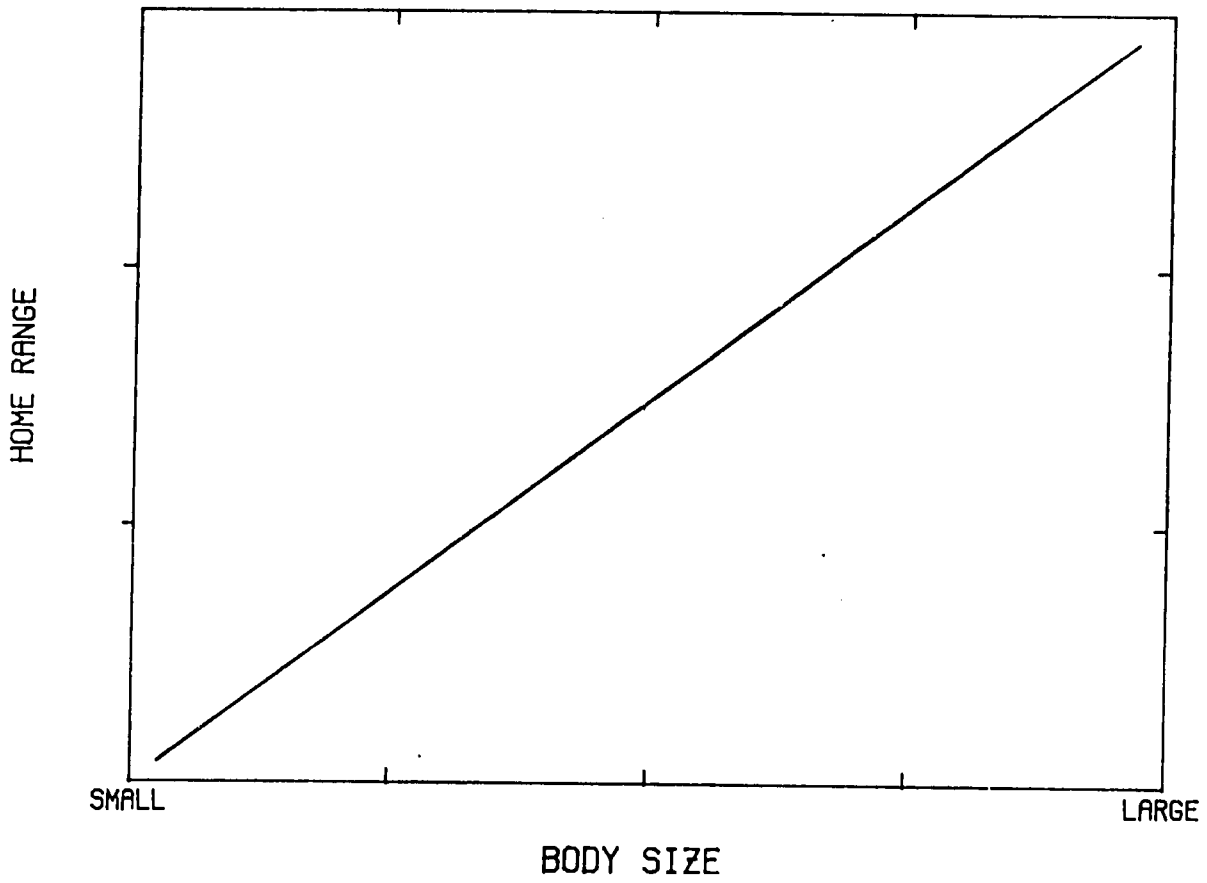
HOME RANGE SIZE VS. BODY SIZE



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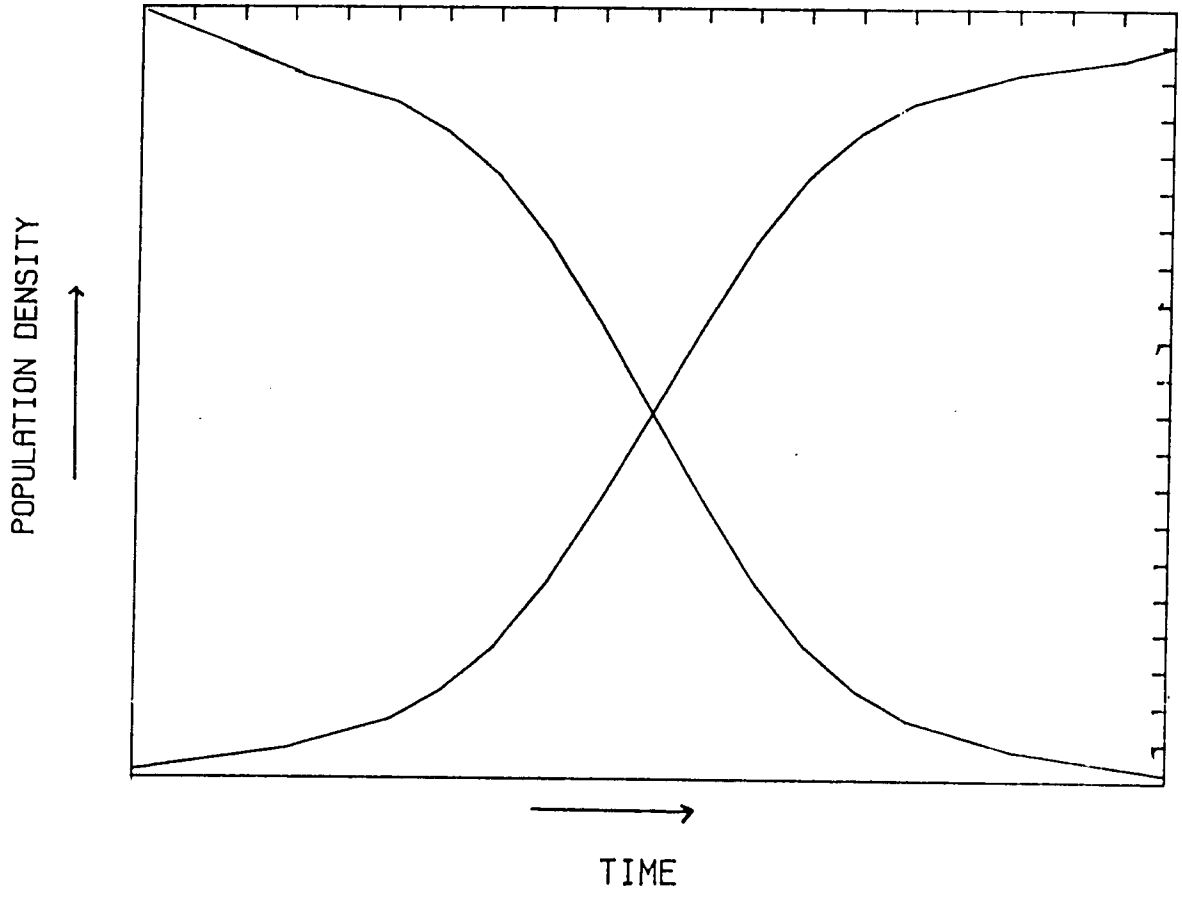
COMPETITION BETWEEN TWO SPECIES



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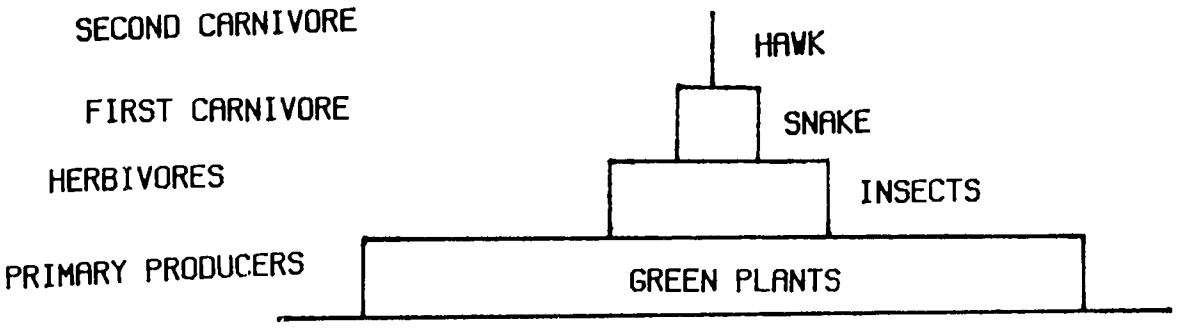

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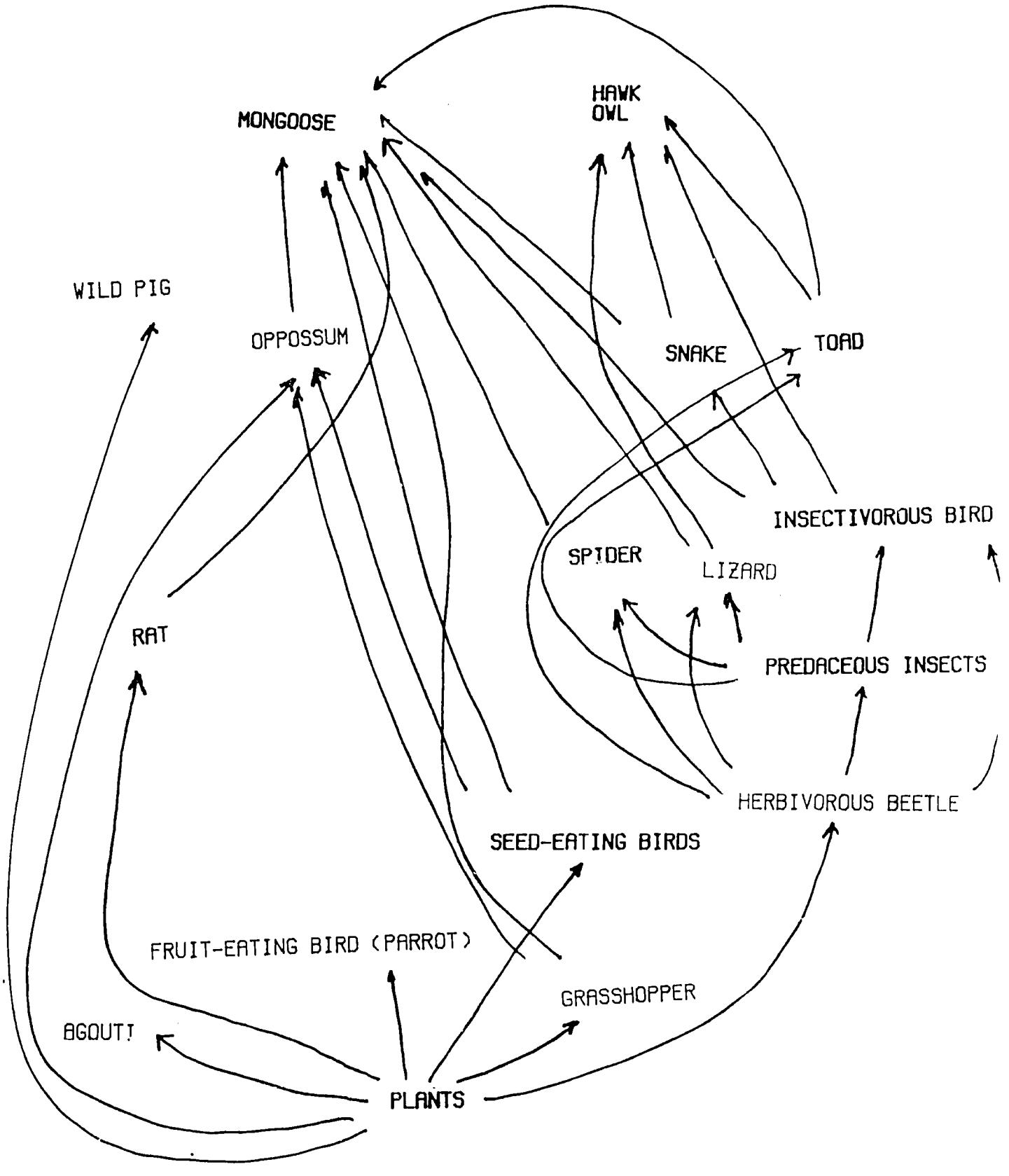

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SCHEDULE

1. LEGISLATION HISTORY & DEFINITIONS
2. BASIC CONCEPTS OF METEOROLOGY FOR P.R.
3. CONCEPTS OF AIR POLLUTION
4. AIR QUALITY AREA MANAGEMENT
5. AIR POLLUTION SITUATION IN P.R.
6. PRESENT ACTIVITIES
7. FUTURE ACTIVITIES
8. GENERAL DISCUSSION

A continuación discutiremos brevemente las unidades que componen el Area de Calidad de Aire, así como sus responsabilidades y deberes generales:

En la actualidad tenemos unas 7 unidades de trabajo, a saber:

1- División de Permisos e Ingeniería
2- División de Validación y Manejo de Datos
3- División de Muestreo de Aire (Red de Vigilancia de Calidad de Aire)
4- Oficinas de Control de Calidad (Muestreo y Aspectos Analíticos)
5- División de Planificación de Calidad de Aire
6- División de Querellas y Vigilancia
7- Oficina de Entrenamiento, Recursos Humanos e Información y Participación Pública

Además, el Area de Calidad de Aire cuenta con los servicios de la División de Laboratorio adscrito al Area de Política Pública.

Aunque estas unidades de trabajo gozan de cierto grado de autonomía administrativa, el tipo de actividades técnicas exigen cierto funcionamiento cohesivo para poder conseguir nuestros propósitos y cumplir con servicios públicos de forma completa y eficiente.

Nuestro trabajo y funcionamiento se programa cada año fiscal a través de las solicitudes para Fondos Federales y Estatales. Mediante estos documentos y escritos se establece el itinerario funcional del Area de Calidad de Aire. Con frecuencia nosotros mismos evaluamos el ritmo de trabajo y a mitad de año un equipo técnico de la Region II de APA nos visita para hacernos la evaluación completa.

En este volumen nos limitaremos a explicar el funcionamiento de las tres primeras unidades de trabajo.

La División de Permisos e Ingeniería tiene las siguientes funciones y responsabilidades básicas:

1- Evaluar y procesar todas las solicitudes para otorgar o denegar Permisos de Ubicación, Construcción y Operación de Fuentes de Emisiones según la Reglamentación vigente para el Control de la Contaminación Atmosférica (RCCA).

2- Vigilancia para determinar los cumplimientos.

3- Inspecciones a fuentes de emisiones motivadas por querellas.

4- Inspecciones de rutina de la operación de fuentes de emisiones para asegurar que cumplan con el RCCA.

ORGANIGRAMA ADMINISTRATIVO-AREA CALIDAD DE AIRE

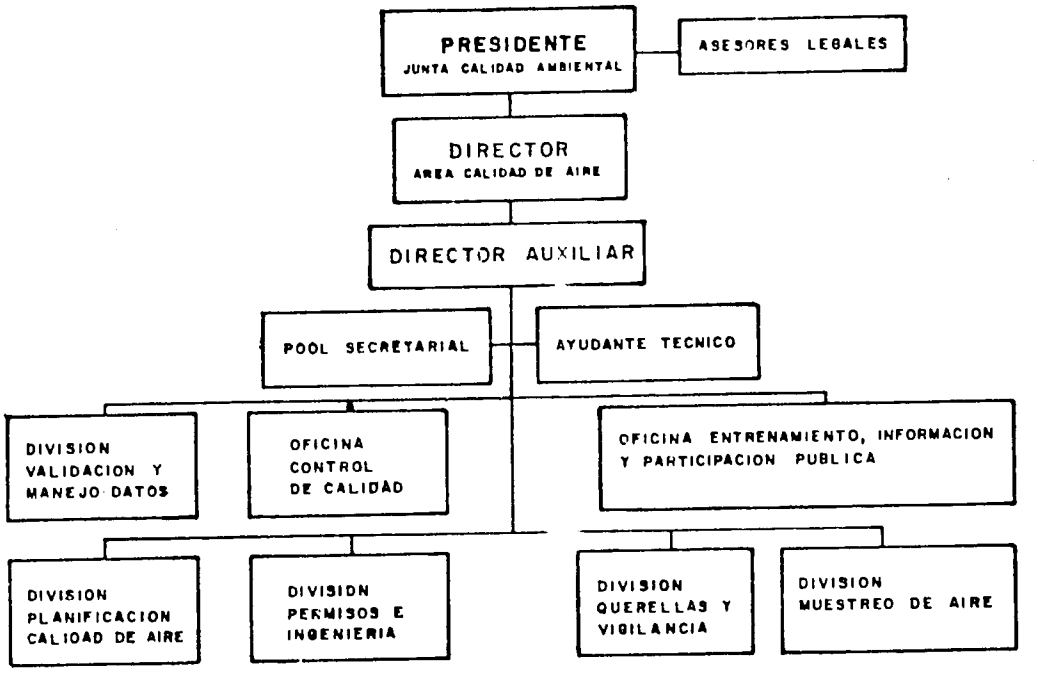

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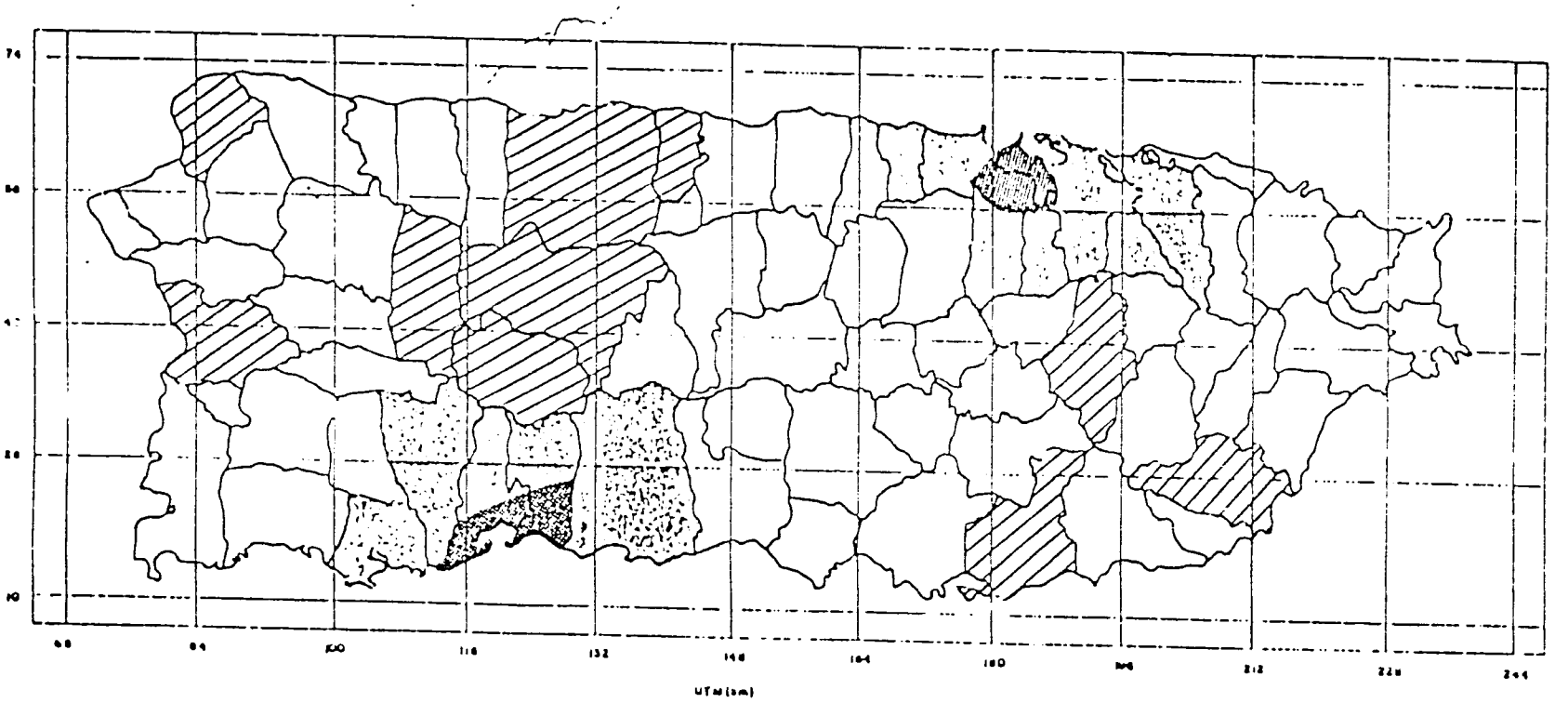
Figure 1-1

PUERTO RICO
DESIGNATED NON ATTAINMENT AREAS* AND STUDY AREAS



LEGEND

- Designated Non Attainment Areas
- Nonattainment Study Areas
- Maintenance Study Areas

*NOTE: *vide*, the Federal Register Vol.43, No.43 March 3, 1978, p. 9055.

FIGURE 1-1

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PUERTO RICO AMBIENT AIR QUALITY STANDARDS

Pollutant	Time/Period/Standard	Maximum Permissible Concentration
Total Suspended Particulates [TSP]	Annual, Secondary	60 ug/m^3
	Annual, Primary[a]	75 ug/m^3
	24-Hour, Secondary[b]	150 ug/m^3
	24-Hour, Primary	260 ug/m^3
Sulfur Oxides [Meassured as SO_2]	Annual, Primary	80 ug/m^3
	24-Hour, Primary	365 ug/m^3
	3-Hour, Secondary	1300 ug/m^3
Carbon Monoxide [CO]	1-Hour, Primary	40 mg/m^3
	8-Hour, Primary	10 mg/m^3
Oxidants/Ozone [O_x/O_3]	1-Hour, Primary	160 ug/m^3
Nitrogen Dioxide [NO_2]	Annual, Primary	100 ug/m^3
	Annual, Secondary	100 ug/m^3
Hydrocarbons [HC]	3-Hour, Primary, Secondary	160 ug/m^3
Lead [Pb]	Quarter Average, Primary	1.5 ug/m^3

[a]Primary: To Protect public health.

[b]Secondary: To protect public welfare.

[c]Hydrocarbons: Hydrocarbons standard does not have to be met if oxidant standard is met.

Figure 4

TSP SHORT TERM TRENDS

MAXIMUM 24 HOUR VALUES BY MONTH

GUAYANILLA NON-ATTAINMENT AREA

1977-1981

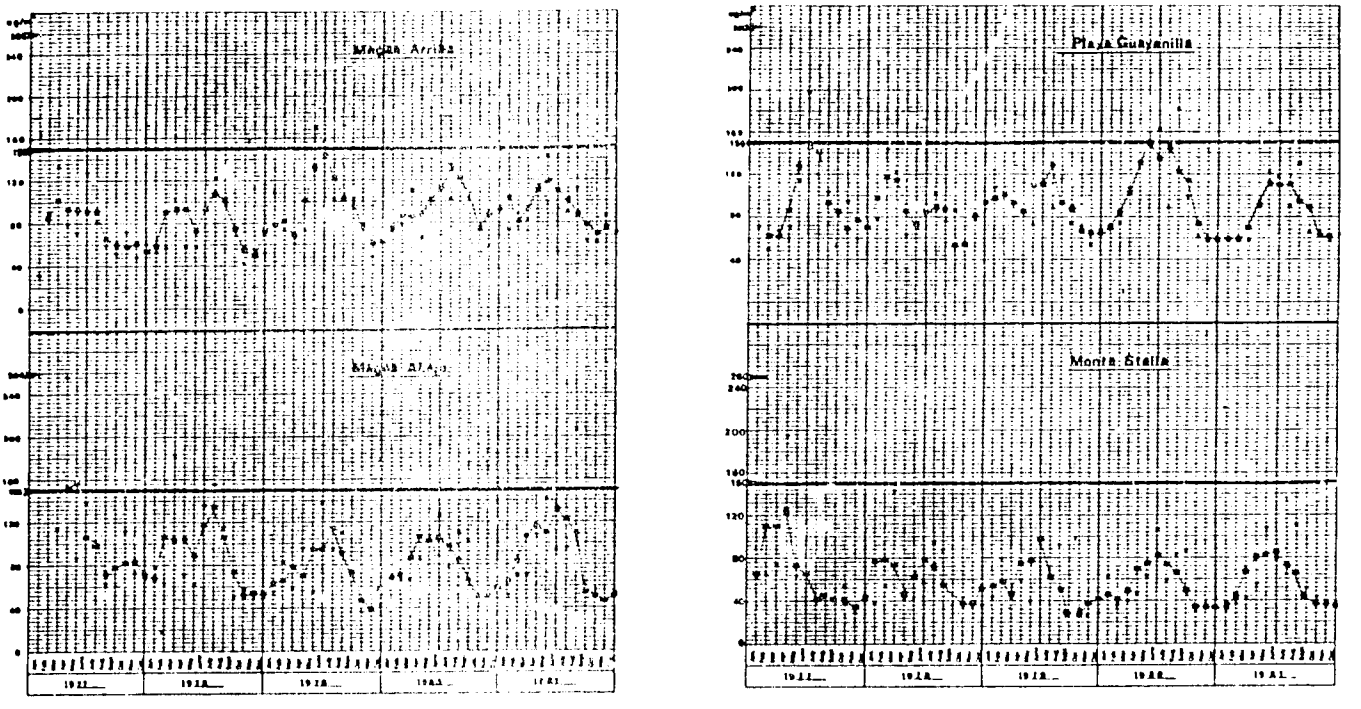


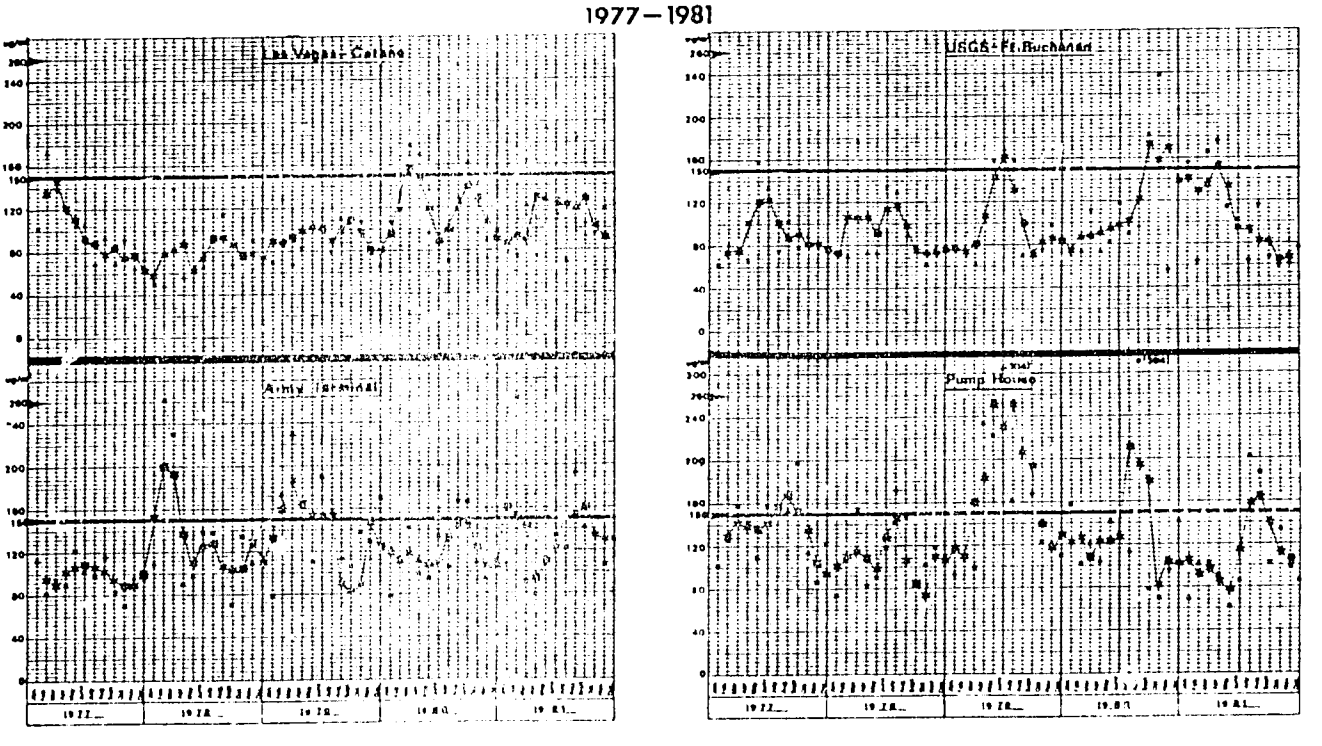
Figure 5

TSP SHORT—TERM TRENDS

MAXIMUM 24—HOUR VALUES BY MONTH

CATAÑO NON—ATTAINMENT AREA

1977—1981



• Maximum Concentration 3-Month Average Standard

500

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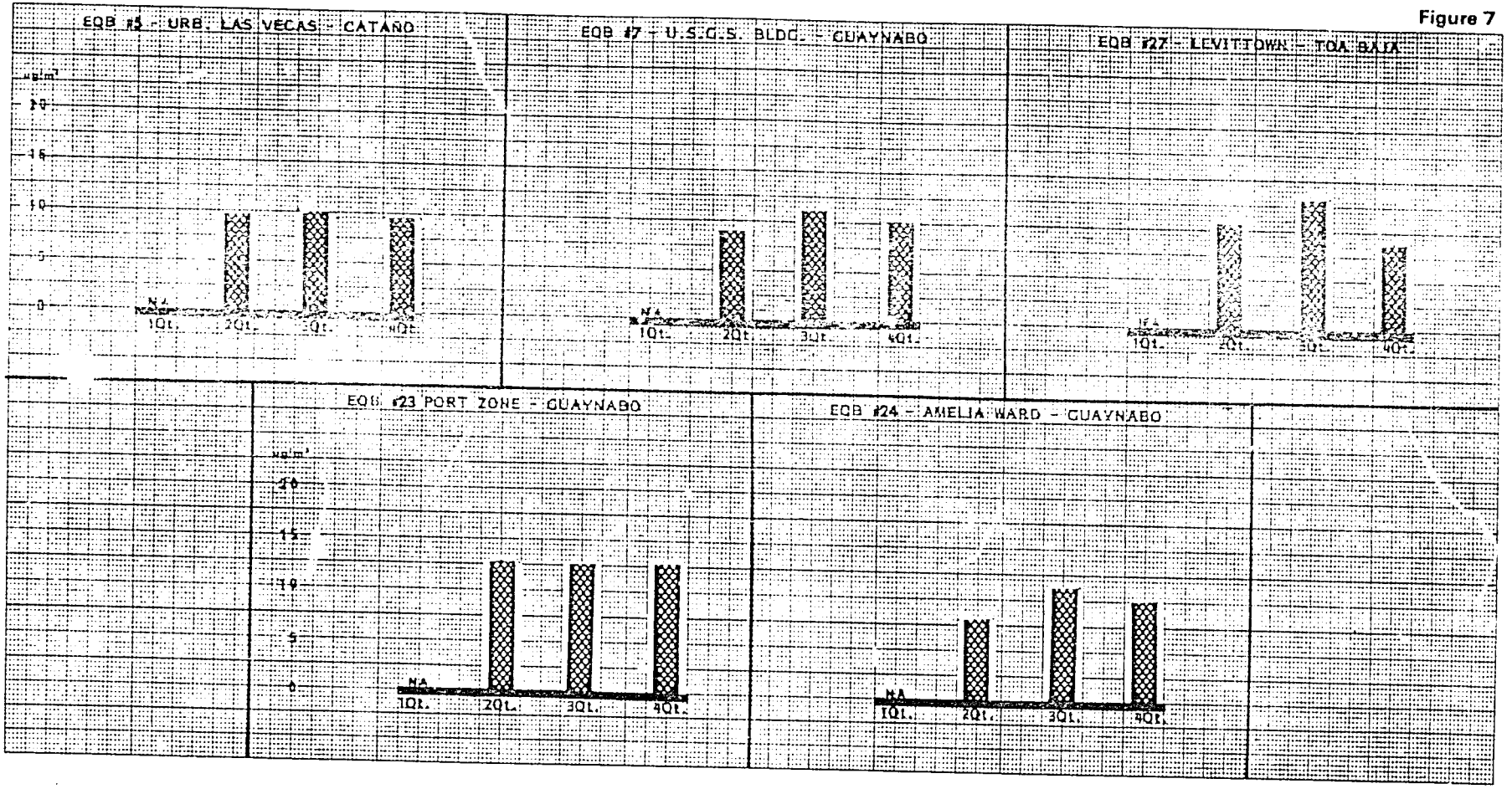
1 9 8 1 SULFATE QUARTER AVERAGES

CATAÑO - GUAYNABO SAMPLERS

Figure 7



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ESTADO LIBRE ASOCIADO DE PUERTO RICO / OFICINA DEL GOBERNADOR

Junta de Calidad Ambiental

8 de octubre de 1980

Ing. Juan Merced Mateo
Director
Area de Calidad de Aire
Junta de Calidad Ambiental
Santurce, Puerto Rico 00910

Estimado ingeniero Merced Mateo:

He leído con mucho interés su publicación Vigilante del Aire que servirá el propósito de informar al público y al personal de esta Agencia sobre las actividades y trabajos sobresalientes realizados por el personal del Area de Calidad de Aire de la Junta de Calidad Ambiental.

Deseo por este medio unirme al regocijo de todo el personal de Aire por el magnífico logro alcanzado mediante esta primera publicación de este Boletín. He podido escuchar comentarios muy favorables a esta primera edición y personalmente deseo felicitar nuevamente a cada uno de los funcionarios que participó en la confección del mismo. Espero que cada edición mensual se desarrolle un mensaje que sirva de orientación a nosotros y al público interesado en los problemas ambientales que afecta la atmósfera que respiramos, y espero que cada nueva edición supere siempre la anterior.

¡ENHORABUENA!

Cordialmente,

Pedro A. Gelabert
Presidente

WSA/PAG/smm

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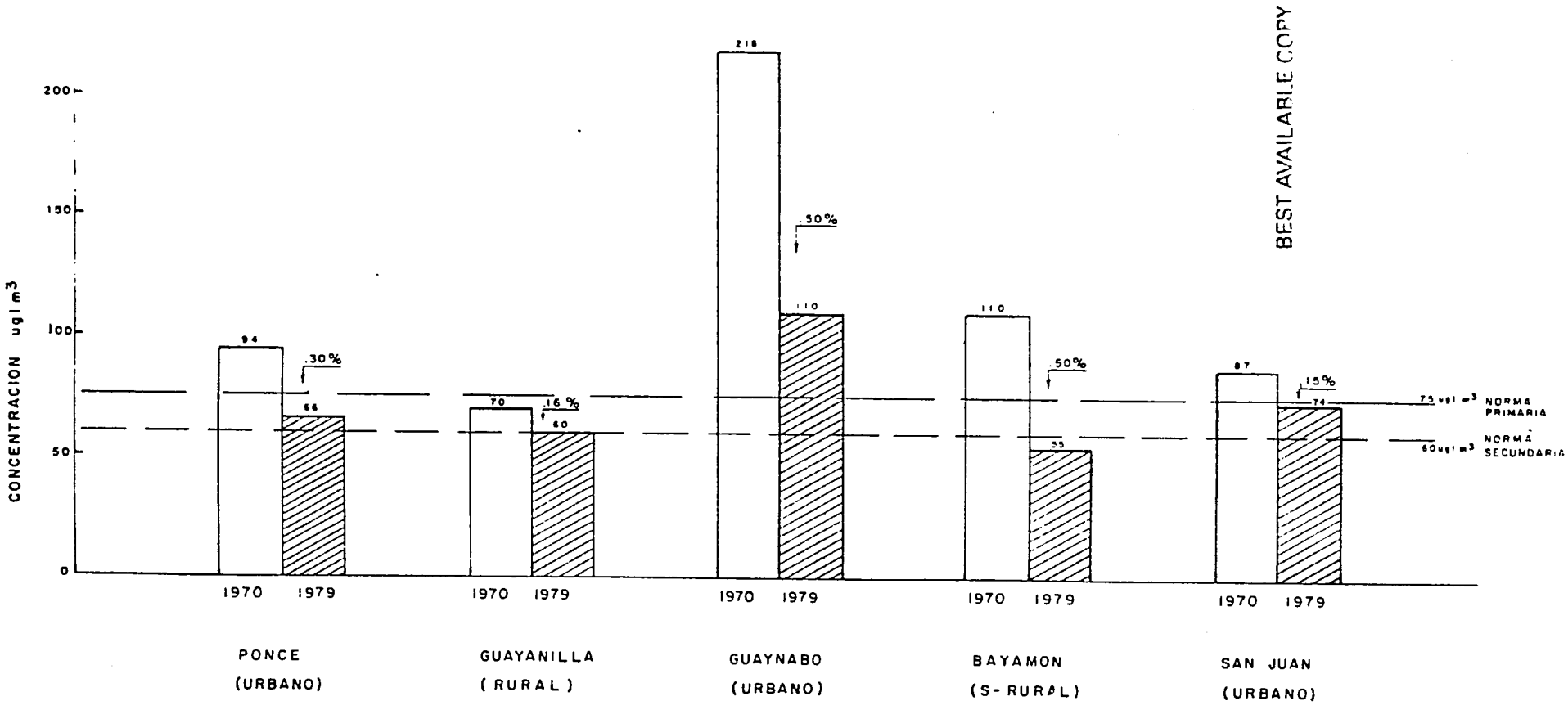
COMPARACION DE NIVELES PROMEDIO DE PARTICULADO
1970 - 1979



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Junta de Calidad Ambiental

VIGILANTE DEL AIRE

Volumen I—Núm. 4—Agosto 1982 AREA CALIDAD DE AIRE Apartado 11488, Santurce, P. R. 00910

MENSAJE DEL ING. CARL AXEL-P. SODERBERG Vicepresidente

Al igual que en la pasada década, la del 80, será una época de constante evolución en el campo ambiental. El idealismo por la protección del ambiente dio paso al establecimiento de instituciones gubernamentales dedicadas exclusivamente a este fin. Estas instituciones, a su vez, se dieron a la tarea de desarrollar reglamentación para controlar las fuentes más obvias de contaminación y resolver los problemas ambientales de primer orden.

En esta década veremos nuestros esfuerzos dirigidos hacia el control de otros problemas ambientales que fueron soslayados por la urgencia de resolver problemas ambientales de primer orden. Específicamente, se enfatizará el control de la disposición de desperdicios tóxicos y peligrosos al aire, al agua y al subsuelo.

Además, veremos como el control de fuentes dispersas de contaminación de agua y el control de fuentes indirectas de contaminación de aire será un factor clave para lograr el cumplimiento con las normas aceptables. La disposición adecuada de los desperdicios sólidos, incluyendo los cienos generados por las plantas de tratamiento de aguas usadas y el control del ruido no dejarán de quitarnos el sueño.

Estos problemas exhiben un grado de dificultad mucho mayor que los problemas que atendimos en la década del 70. La situación se complica al considerar que las soluciones requieren mayores recursos y que estamos sintiendo los efectos de una economía recesionaria.

Ante este formidable reto debemos redoblar nuestro empeño para afrontar con éxito, una vez más, los reclamos de nuestro medio-ambiente. Se requiere el más decidido esfuerzo de cada uno de nosotros para que la gestión llegue a un feliz término.

El Vigilante del Aire es un magnífico vehículo para mantenernos informados de las nuevas iniciativas para confrontar la tarea que nos resta por realizar. Felicito al Programa de Aire por tomarse la inciativa de publicar este boletín y compartir la divulgación de información con las demás unidades de la agencia.

NOTA DE REDACCION

Es nuestro propósito de que por medio del Vigilante del Aire llevarles saludos y/o mensajes de las personas que son responsables de las directrices y administración de la Junta de Calidad Ambiental.

Asimismo, hemos estado haciendo acercamiento a los Directores de las diferentes áreas; Agua, Terrenos, Política Pública, Relaciones con la Comunidad, Administración, Asesores Científicos, Personal y otros para solicitarles su aportación a nuestra publicación. Nuestro propósito es que el Vigilante del Aire se convierta en una publicación más amplia representativa de toda la Junta para así llevar un mensaje e información más completa y global de nuestras diversas actividades.

En el primer volumen de este Boletín publicamos un organigrama administrativo del Area de Calidad de Aire. Haciendo referencia a dicho organigrama queremos informar que no quisimos obviar la existencia en la Oficina del Presidente de tres (3) miembros asociados que para esa época lo eran el Sr. Santos Rohena, Ing. Pedro Marrero e Ing. Carl-Axel P. Soderberg. Posteriormente, esta organización fue modificada a una Junta de Directores compuesta por un Presidente, Sr. Pedro A. Gelabert, Vicepresidente, Ing. Pedro A. Marrero, Miembro Asociado, Sr. Santos Rohena y Miembro Alterno, Ing. Carl Axel-P. Soderberg.

Luego ante la renuncia del Ing. Marrero de su posición de Vicepresidente fue sustituído por el Ing.Soderberg y éste a su vez por el señor Wilfrido Soto de Arce. A esta fecha, así está constituída la Junta de Directores de la Junta de Calidad Ambiental.

Actividades sobresalientes del Area de Calidad de Aire, relacionadas con la Participación Pública.

En los pasados meses del año calendario 1982 el personal técnico del Area de Calidad de Aire realizó una serie de actividades sobresalientes aparte de las de rutina, que merecen mencionarse a saber:

1. Conferencias técnicas sobre Calidad de Aire y control de la Contaminación Atmosférica a estudiantes de Cursos Graduados de la Universidad Interamericana, Universidad Mundial y Colegio Regional de Humacao.

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2. Se inició un adiestramiento de organizar comités para Detección de Olores Objetables a personal del Area de Calidad de Agua.
3. Se ofreció el curso rutinario de cada seis meses sobre Lectura de Opacidad de Humo de Emisiones a Fuentes Estacionarias a los Técnicos de Calidad de Aire. Léase artículo más adelante.
4. Este mismo curso se le ofreció a un grupo representativo de industrias las cuales en su mayoría, tienen asignaciones de porciento de contenido de azufre en el combustible que usan.
5. Participamos en diferentes actividades de la celebración de la Semana de Salud Ambiental.
6. Participación de algunas de las actividades de la Semana del Ambiente.
7. Participación en las actividades de la Semana del Agua patrocinados por la Autoridad de Acueductos y Alcantarillados.
8. Se ofreció un seminario sobre Ecología Ambiental a un grupo de estudiantes de la Escuela Carlos Escobar de Loíza y cual culminó con "field-trips" a la Bacardi, Gulf Caribbean, Planta de Filtración de Aguas Sergio Cuevas, una planta de tratamiento de Aguas Negras o Usadas y el Relleno Sanitario de Desperdicios Sólidos de Fajardo.
9. Se hicieron varios documentales fílmicos de actividades de muestreo de agua del Area de Calidad de Agua.
10. Participación en Seminario a estudiantes Escuela Superior Jardines de Palmarejo de Canóvanas.
11. Se grabó un video-tape una demostración sobre técnicas de disposición de desperdicios en el relleno sanitario de San Juan.
12. Participación en Seminario sobre la Administración de los Desperdicios Sólidos.
13. Se sometió en su forma final el Informe Anual de actividades para edición final y presentación.

ORIGEN Y EFECTOS DE LA CONTAMINACION AMBIENTAL

El aire al que denominamos como Atmósfera comunal consiste mayormente de una mezcla de gases en las siguientes proporciones:

(a) Nitrógeno	(N_2)	—	78%
(b) Oxígeno	(O_2)	—	21%
(c) Otros Gases	———		1%

Puedes entender que nuestra atmósfera prácticamente consiste de nitrógeno y oxígeno. El aire se considera como una de las substancias o elementos naturales más barata y a la misma vez es indispensable para la consecución de la vida, tanto animal así como vegetal.

La atmósfera se puede considerar como un océano por lo que podemos decir que vivimos en un gran océano de aire. El hombre, así como, otros animales pueden vivir aproximadamente cinco semanas o quizás más sin agua y/o sin alimentos, pero diferente si es privado del aire, puede fallecer en cinco minutos. El hombre respira 22,000 veces al día, inhalando durante ese período unas 35 libras de aire. Es por ello que el aire se considera como el elemento más indispensable para la sobrevivencia del hombre. Pero este elemento aire, tan indispensable, ha estado contaminándose producto de las actividades humanas desde el mismo momento que empezamos a respirar, toser y estornudar.

A medida que nuestra sociedad ha ido mejorando su civilización, ha aumentado su actividad industrial y ha buscado tendencias de vida más cómoda y agradable, ha producido que la contaminación del aire haya aumentado en forma proporcional.

Podemos definir la contaminación ambiental, "como una condición de la presencia en la atmósfera de uno o más contaminantes o combinaciones de éstos en suficiente cantidad, concentración y por cierta duración que pueda afectar la salud del ser humano y animales, la propiedad, la vegetación y el libre disfrute de la vida normal".

Se pueden mencionar las siguientes actividades como fuentes **naturales** de contaminación ambiental:

1) Actividad volcánica
2) Fuegos forestales
3) Polvo fugitivo levantado por el viento
4) Descomposición biológica
5) Salitre-mayormente de agua salada o mar
6) Polen-de las flores
7) Radiación solar y cósmica
8) Ozono (O_3) — mayormente producida por descargas eléctricas

Si bien es cierto, como hemos mencionado, que hay fuentes naturales de contaminación ambiental,también hay fuentes artificiales, mayormente producidas por el hombre, y consideradas más peligrosas que las primeras. A saber algunas de ellas:

A. **Móviles**

1. Aeroplanos
2. Barcos
3. Vehículos de motor
4. Polvo fugitivo

B. **Estacionarias o Fijas**

1. Plantas de producir energía eléctrica
2. Industrias en general

3. Calentadores, incineradores y calderas
4. Quema a campo abierto
5. Actividades de construcción, edificios y carreteras
6. Actividades agrícolas
7. Actividades de minería
8. Deportes, etc.

Por acción natural, la atmósfera se limpia ella misma por la caída de lluvia y el viento. En Puerto Rico tenemos la buena suerte, que llueve a menudo y que los vientos alisios soplan todos los días evitando así concentraciones excesivas de contaminantes que puedan producir una condición de contaminación masiva del aire comunal. Cuando este proceso natural no sea capaz de ejercer estas funciones, probablemente debido a un alto grado de contaminación de la atmósfera y/o falta de la lluvia necesaria del aire, la humanidad tendrá un grave problema de esta índole como sucede en muchas grandes ciudades industriales en diversos sitios del mundo.

Podemos concluir que sin lugar a dudas el grado de contaminación ambiental ha sido el precio que hemos pagado por la abundancia, comodidad, plenitud y el alto nivel de vida que disfrutamos.

El problema de la contaminación del aire, que es la que en esta ocasión estamos enfocando más específicamente, se ha ido agravando en el transcurso de los años y la lucha del hombre por conseguir un control aceptable nos está costando muy caso.

Origen y Efectos de la Contaminación (Cont.)

Nuestras exigencias por obtener una vida cómoda y más placentera nos ha llevado a tal extremo que hemos empezado a retar la naturaleza para satisfacer estos deseos y propósitos desencadenados. Es por ello que las demandas de más trabajo mejor remunerado, más automóviles, más y mejores carreteras, más utensilios eléctricos domésticos, más recreación y entretenimiento, mejor y más educación académica, exigencias de actividades sociales, más productos de consumo y uso de carácter desechables, uso indebido y despilfarro de las fuentes energéticas y recursos naturales; etc. han sido principalmente los causantes del desequilibrio ambiental y ecológico que nos aqueja y nos tortura tanto físico, así como, sicológicamente.

Hemos siempre asociado la contaminación del aire con la existencia de las industrias, no obstante, han existido por años la tecnología y equipo de control aceptable y eficiente para un control a nivel de contaminación que no sea perjudicial a nuestra salud y propiedad.

Podemos decir que un cigarrillo encendido, un automovil, una chimenea, disposición adecuada de los desperdicios sólidos, el uso de enseres eléctricos y hasta un centro industrial pueden ser inofensivos si se usan y operan eficazmente y tomando las medidas de control necesarias.

Pero la apatía, negligencia y descuido de adoptar ciertas prácticas y medidas necesarias y adecuadas por parte de la ciudadanía nos ha llevado a la situación de la contaminación ambiental antes descrita.

La industria mediante sus diferentes fases de producción de sus productos deja una huella o evidencia de contaminación. Cada producto que se consume o usa, al momento de fabricarse o hacerse, al transportarse, al ser vendido, al usarse y al disponer de lo que no usamos o consumimos dejan en un orden cronológico desde gestionar la materia prima para su fabricación, hasta el uso y disposición final, los ingredientes necesarios para que se produzca la contaminación ambiental del aire, agua, terrenos y niveles aceptables de ruidos.

Ahora, quisiera que me contesten o nos contestemos la siguiente pregunta: ¿A quién podemos señalar como el más culpable de la contaminación del ambiente? será la industria productora o el ser humano que exige que se le produzcan para uso personal y general de los productos y servicios para tener una vida muy placentera y cómoda.

Si contestamos científicamente y con sinceridad las siguientes preguntas nos convenceremos de que podemos tener la respuesta indicada a la pregunta anterior.

(a) ¿Qué tipo de equipo de control adecuado debe instalarse en las diferentes fases industriales existentes?

(b) ¿Qué tipo de industria y dónde deben ubicarse para evitar el deterioro de la atmósfera?

(c) ¿Existe una alternativa viable, quizás un sistema adecuado en masa, para controlar la transportación de manera que no produzca contaminación?

(d) ¿Qué medios hay disponibles para el futuro desarrollo y/o limpieza de áreas contaminadas y convertirlas a Areas de Logro?

(e) ¿Qué podemos y debemos hacer en el presente para asegurar una mejor calidad de la atmósfera para el futuro de nuestra generación?

(f) ¿Deseas dejarles un buen recuerdo a tus descendientes?

Si podemos contestar y asumir una actitud positiva al contestar estas 6 preguntas, es posible que podamos asegurarles a los que nos sobrevivirán por ley natural, una atmósfera limpia y aceptable.

—Seguiremos en nuestra próxima edición

¿Por qué se Organizan los Comités para Detectar Olores Objetables y se hacen Lecturas de Opacidad de Humo de Emisiones a Fuentes Estacionarias?

Hemos ofrecido información de estos dos tipos de actividades en el sentido de que las mismas son rutina en el desempeño de hacer cumplir el Reglamento para el Control de la Contaminación Atmosférica. Citando la Regla 420 de esta reglamentación define los olores objetables de la siguiente manera: "Para los propósitos de este artículo, un olor será considerado "desagradable" (objetable) cuando en concenso de un grupo de por lo menos cinco personas elegidas por la Junta, se establece que el olor es desagradable al ser ellas expuestas al mismo".

Mucho se ha escrito, desde los tiempos inmemorables hasta el presente, sobre olores. De hecho se han diseñado e introducido en el mercado muchos instrumentos para medir olores, algunos de ellos bien sofisticados y costosos, pero se ha llegado a la conclusión que el instrumento más preciso es la "Nariz Humana". Es por ello la razón de ser de los "Comités para Detectar Olores Objetables" según dispuesto por la Parte B de la Regla Núm. 420.

Por primera vez en la historia de la Junta de Calidad Ambiental, recientemente quedó constituído formalmente un Comité para detectar olores objetables. El mismo está compuesto por los siguientes técnicos quienes trabajan para las Divisiones de Querellas y Vigilancia y Fuentes Dispersas del Area de Calidad de Agua:

1—Pedro R. Navarro
2—Milagros Rodríguez
3—Ahmed Valencia
4—Jorge Ortiz
5—Genaro Torres
6—Luz A. López
7—Nayda Alvarez
8—Luisa Cunningham
9—Miguel Maldonado

Estos técnicos participaron en cuatro sesiones académicas en que recibieron conocimientos básicos sobre olores, una práctica inicial de detección de olores usando como fuente de emisión una porqueriza, una prueba en el laboratorio para determinar la capacidad para detectar categoría ó clase de olores; así como, clasificación de los mismos usando la reacción humana. Luego realizaron una actividad formal usando como fuente de emisión una vaquería la cual motivó una querella de varios vecinos ante la Secretaría Auxiliar de Salud Ambiental del Departamento de Salud.

Luego fueron sometidos a un examen escrito final y discresión general de los aspectos académicos, así como, las prácticas logísticas de campo en cuanto a selección de estaciones de detección, información requerida tales como medidas de velocidad y dirección del viento, temperatura ambiental, entrevistas a querellantes y no-querellantes y evaluación final del proceso formal de la detección de olores.

Invitamos a personal de cualquiera de las áreas de trabajo de la Junta de Calidad Ambiental a que se cualifiquen mediante adiestramiento en este tipo de actividad. Estos adiestramientos se repetirán cada 6 meses como materia de cualificar y darle un mérito. Los interesados pueden llamar a la extensión 242.

"Los olores han llegado a ser tan considerados por muchos autores que hasta Shakespeare se inspiró y le escribió unos versos".

Emisiones Visibles

La Regla 403 del Reglamento para el Control de la Contaminación Atmosférica de Puerto Rico limita las emisiones visibles para Fuentes Estacionarias. Haga referencia a la primera parte del Artículo Origen y Efectos de la Contaminación Ambiental en el cual citamos ejemplos de emisiones artificiales; estacionarias (fijas) y móviles.

Usamos el método Núm. 9, del Código de Reglamentos Federales (Federal Registers) Título 40, Capítulo I, Sub-capítulo C, Sección 60; Determinación Visual de Opacidad de Emisiones Producidas por Fuentes Estacionarias.

Ya que este procedimiento es bien extenso, puede conseguir una copia en el Area de Calidad del Aire y a la misma vez le invitamos a que participe con nosotros como observador en la próxima incursión para cualificar nuestros técnicos lo cual anunciaremos próximamente.

Definición de la Mujer Criolla

Sabes a vida y esperanza
y haces del fiero tu esclavo,
cuando te das toda en la danza
y en la fiebre del güiro bravo
hades a canela y a clavo.

Luis Llorens Torres

505 B

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

BASIC HYDROLOGIC CONSIDERATIONS

HANDOUT NO. 1

Institute of Tropical Forestry
USDA Forest Service
Río Piedras, Puerto Rico

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BASIC HYDROLOGIC CONSIDERATIONS [1/]

The Watershed

A watershed is all the land area which drains into a stream system upstream from its mouth or other designated point of interest or measurement. The watershed of a stream not only has area, length, and width, but a third dimension as well - depth. Except for barren rock slopes, the depth of a watershed extends from the top of the vegetation to the confining strata beneath.

The circumscribing boundary which surrounds the watershed is called the divide. This line defines the limits of area which contributes survace runoff. The underground watershed divide which delineates the area of contributing groundwater runoff may coincide with the surface divide or may be quite different.

All land everywhere is part of some watershed. A watershed may be small as a footprint, or as large as a subcontinent, as is the case for such river basins as the Mississippi, the Amazon, the Congo, the Nile, or the Ganges. Practically, though, most watershed management is concerned with watersheds which range in size from perhaps an acre in area to several thousand square miles. Larger watersheds become increasingly complex in every respect, and for purposes of study and analysis are subdivided into smaller, more homogeneous subwatersheds.

1/ Adapted from Watershed Management. Food and Agriculture Organization of the United Nations, Rome. 1962. The principle contributor to this chapter was William C. Ackerman, Professor of Hydrology. University of Illinois, and Chief Illinois State Water Survey Division, U.S.A.

Every watershed in the world is an unique as a fingerprint. No two are exactly alike. It is easy to visualize that a timbered watershed high above the snow line is unlike the dry and dusty watershed of an arid country. But even two watersheds which lie side by side, and look alike, are actually different in detail.

Generalization is of course possible to a degree since the same physical laws apply everywhere. Given an understanding of these laws, and equipped with an intimate knowledge of the watershed and its environment, it is possible to predict hydrologic behavior with reasonable accuracy. This suggests taht measurements of the watershed an all relevant factors are essential to an accurate understanding of watershed behavior. Watersheds of great individual importance may warrant detailed, individual study, and this is sometimes done. However, not all watersheds in the world can be studied in hydrologic detail because their number is myriad. The answer, instead, lies in generalized research. Ultimately, man must conduct research in each physiographic province, in each climatic region, and with each vegetal type. The product of such research can then be transposed with confidence to other watersheds within the limits of reasonable homogeneity.

Hydrologic Cycle and the Watershed

The unending circulation of the earth's moisture is called the hydrologic cycle. Although familiar to many in a general way, it is being described here in barest outline to place watershed management in relation to the larger pattern of nature, and to define terms which will recur frequently throughout this course.

The hydrologic cycle has no beginning or ending, but we may think of it as originating with atmospheric moisture consisting of water vapor, clouds, and fog. Water vapor is the gaseous state of water, and is present in the atmosphere because of evaporation processes on the land and water surfaces. Clouds and fog are created by the cooling and condensation of water vapor upon small nuclei such as salt or dust particles in the atmosphere. When the resulting water droplets obtain a sufficient size, they fall as rain. If the raindrops pass through zones of temperature below freezing, hail results. If condensation occurs at temperatures below freezing, snow is formed. If condensation of water vapor takes place directly on a surface cooler than the air, either dew or frost is formed, depending upon whether the temperature at which condensation occurs is above or below freezing.

Of the toal precipitation, a very large proportion falls directly upon the oceans, large inland lakes, and other water surfaces such as rivers and ponds. That falling on the ocean, together with the water returned as runoff, maintains the equilibrium evidenced by the substantially constant sea elevation.

Rain or melting snow first tends to moisten the surface and then to enter the interstices of the soil. This process is called infiltration. Of the total infiltration, some percolates to the groundwater, some is utilized by vegetation and transpired back into atmosphere, and some is subjected to evaporation as a result of capillary uplift. On sloping terrain, with a thin soil mantle, infiltrating water may return to the surface through lateral movement.

When the rate of precipitation exceeds the rate at which water can infiltrate into the soil, surface runoff usually occurs. After filling the surface depressions, this rainfall excess finds its way over the surface of the ground until it reaches a definite stream channel system, through which it passes and is discharged ultimately into the ocean or some inland water body.

Water in the liquid state, when heated by solar energy or otherwise, passes into the gaseous state by a phenomenon called evaporation. This process of evaporation takes place from water, from wet surfaces such as vegetation, and from the ground and snow cover.

One of the basic functions in the life processes of vegetation involves the process of taking water from the soil through the roots, utilizing it in producing growth and maintaining life, and discharging it from pores into the atmosphere is called transpiration.

A portion of the precipitation penetrating the ground surface as infiltration will percolate into the ground. If not absorbed by soil deficient in moisture, or by porous rocks, this water eventually reaches a level which is completely saturated - the groundwater table. The slope and confining structure surrounding the groundwater body may be such as to prevent its immediate releases; or the groundwater body may intersect a stream bed where part of it will be returned to a body of surface water. Groundwater may also flow through porous strata and reach a level where it may be confined by tighter soils and thus subjected to pressure. If a well penetrates to this level, it may be artesian and the water discharged will likewise become part of the surface water. The same pressure zone may contact the ocean bed and discharge water into the sea.

Thus, the atmospheric moisture with which this description of the cycle started may follow paths of various lengths and complexity before it can complete the circuit.

Opportunities and Limitations

Watershed management is always aimed at specific objectives, and a program is designed to accomplish these objectives. The aims may be entirely or primarily concerned with use of the land, such as improved crop production, or reduced erosion. Even in such instances the hydrologic factors are important since some element such as temperature or available moisture may actually determine whether the desired program can be carried out. Also, even though use of the land may be the immediate consideration, it is important to know the hydrologic consequences of any projected change in watershed management. For example, the use of row crops on steep land in an area subject to intense rains will produce stream flow of poor quality, peak rates of runoff that are excessive and result in flooding and excessive erosion which will ultimately destroy the land.

In some instances, a change in the water regimen may be the primary objective of watershed management. These changes may include reduction of flood peaks, the increase of low flows or water yield, the increase of available soil moisture, raising groundwater levels, or the improvement of water quality for water supply. Any of these objectives can be accomplished to a degree, but not all may be mutually compatible or be consistent with the desired program of land use.

I must be remembered that the most important factors which control the hydrologic cycle are the forces and circumstances of nature, about which

man can do little. These include weather or climate which over the ages has shaped the landscape and determined the kind and depth of soil. If the soil is shallow there is little that man can do to increase soil moisture storage. If the soil is frozen in the winter, infiltration of moisture is certain to be insignificant. If the land is mountainous, man cannot lay it flat.

Precipitation is probably the single most important factor in day-to-day hydrology, and this remains largely outside of man's control. It is true that recent studies indicate the possibility of small precipitation increases through cloud seeding under favorable circumstances in mountain regions. Future developments in meteorology may further after this, but present reality is that precipitation must be accepted as nature provides it. Rainfall cannot be moved from one season to another, nor can it be increased or decreased in amounts or rates.

However, much can be done with factors which are subject to control. There is a variety of vegetation from which to choose, land use practices can be changed, and by engineering methods water can be stored for movement to places or seasons where it is not otherwise available. Man can cover the landscape with green vegetation which promotes infiltration and protects the soil, and by constructing engineering works he can confine or stem the flood tides.

The Role of Weather

Weather is a broad and inclusive term, and is the subject of a separate branch of science called meteorology. Weather in the lower atmosphere at the interface between air and land has important implications in watershed management.

Among the many weather elements, most important is precipitation. This is the moisture input of a watershed which must be controlled and can be put to beneficial use. Precipitation in turn occurs in various forms - some of which must be thought of here as minor. These include dew, hail, and sleet. This, then, leaves rainfall and snowfall as the most significant forms of precipitation. With respect to rainfall, it is of importance to know the amounts as expressed in inches or other linear measures of depth. The duration of rainfall, expressed in minutes, hours, or days, and the rainfall intensity which is commonly expressed in inches per hour is also needed.

Precipitation rates are highly variable. They may occur at such low rates as to be immeasurable with ordinary equipment in which case it also has little effect on the hydrology of a watershed. Rates in excess of one inch per hour are considered intense. Rates in excess of 10 inches per hour are infrequent or rare, and seldom continue for more than a few minutes.

Precipitation amounts are also highly variable from place to place on the earth, with some areas normally receiving less than 10 inches in a year and others more than 100 inches. Even in one location precipitation must be considered quite variable. In the humid and temperate zones, annual precipitation may vary as much as 50 percent from the normal, while in arid or semi-aird regions, the variation is frequently several hundred percent of normal. Precipitation follows a seasonal pattern, typical for the

locality, but barying above and below the average, and with greater variability associated with the more arid climates.

Rainfall is measured in rain gages, of which there is an infinite variety. Ideally, all rain gages would be of the recording type, from which not only amount, but duration and intensity as well can be determined. Practically this is seldom necessary or possible, and one or more recording gages are supported by more numerous non-recording gages, augmented by observer's notes and comments as to the variations of intensity and duration. A frequently used standard rain gage is 8 inches in diameter and contains an inner tube of one-tenth the cross-sectional area. Collected mounts are, therefore, amplified 10 times for greater ease and accuracy of measurement. However, any container with vertical sides and rigid shape can be used with little loss of accuracy. Some non-recording gages with diameters as small as one inch have been used successfully.

Rain gages are located in the open so that vegetation and buildings do not interfere with or intercept any of the fa-l.

The number of gages required to reasonably represent the average rainfall on an area, such as a watershed has been the subject of study. No fixed number can be stated since this varies with local meteorological conditions, topography, the desired accuracy, and financial and other limitations. However, any watershed being studied or managed should have at least one gage, preferably located at the geometric center of the area. A watershed of 1000 acres under intensive study might require about three gages for adequate coverage. Large watershed basins do not require such gage densities since minor variations in rainfall become less important, and a coverage of one gage for 50 or 10 square miles may be adequate if

one knows something about rainfall patterns in the area. It is often useful to begin a project with several rain gauges and reduce the number when some data has been collected.

Rainfall experience is represented and commonly published in tabular form by hours and days. A 5-day perid. The "pentad" is coming into use. For analysis purposes, amounts are normally entered on maps and lines of equal amount. Rainfall intensities may be represented as bar graphs for periods of minutes or hours, or rate may be plotted against time.

The unit of rainfall for hydrologic analysis is the storm. However, for many purposes rainfall and other hydrolo factors are also represented by days, weeks, months, seasons, or years.

Precipitation is ultimately disposed to percolation, runoff, and evapotranspiration* and in these processes it is affected by many factors such as the vegetation, the landscape, soils, and geology, as will be discussed subsequently. However, it is possible to generalize in a qualitative way the effect of precipitation variations as follows. Other things being equal:

Higher precipitation <u>amounts</u>	= greater runoff. greater evapotranspiration. greater percolation.
Higher precipitation <u>intensities</u>	= greater runoff and lower evapotranspiration and percolation.
Longer precipitation <u>duration</u>	= lower runoff and greater evapotranspiration and percolation.
Greater <u>areal extent of</u> precipitation	= greater runoff, greater evapotranspiration, greater percolation.
Greater precipitation in <u>cold season</u> (above freezing temperatures)	= greater runoff and percolation and lower evapotranspiration.

Greater precipitation in <u>warm season</u>	= lower runoff and greater evapotranspiration and percolation

Temperature is a second weather element, along with precipitation, which is of importance in watershed management. Temperature regulates the germination and rate of growth of vegetation which in term influence the hydrology. Air temperatures determine the form of precipitation, the rate of snow melt, and through its effect on viscosity, affects infiltration and runoff from rainfall.

Temperature is a more conservative element than precipitation in that it does not vary as greatly in time or space. Therefore, fewer instruments are required to adequately represent areal variations, at least in the absence of strong relief features in the watershed. Recording thermometers are desirable, but perhaps not essential to the most hydrologic analysis. Maximum and minimum thermometers which are read daily will serve for most purposes.

Many other weather elements can be mentioned, and upon occasion of detailed research studies may be observed and correlated. These include relative humidity, wind direction and velocity, and solar radiation.

The Role of Vegetation

It is assumed that vegetation is an indispensable part of watershed management in any climate where there is sufficient moisture and heat for plant growth. The only exceptions to this would be paved areas, being mined, and water surfaces. Vegetation is essential because it is through plants that land becomes productive. Secondly, vegetation is the only practical way in which land can be protected against the forces of erosion

through its action of shielding soil against the impact of rain. Finally, vegetation is important to watershed management because it represents one of the relevant influences which man can manipulate to his advantage. Man can also manage soil directly, but desirable soil qualities can be achieved more quickly and with less effort by allowing vegetation to create desirable surface conditions.

At the onset of storm precipitation, the first effect of vegetation is to intercept a portion of the rain through the process of wetting the leaves and branches, or a portion of the snow through storage. In dense vegetation such as in a mature forest with a complete overstory of trees and an under-story of herbaceous vegetation, this may amount to half inch, or more, of precipitation per storm. Following the end of precipitation, a portion of this moisture falls to the ground due to wind movement. This delayed precipitation, in effect, polongs the period of rainfall at the ground surface, and tends to increase infiltration into the ground. Moisture remaining on the leaves evaporates normally within a day. This evaporation must not necessarily be thought of as a moisture loss since during the period following a rain, when the landscape is saturated and the lower atmosphere is also high in moisture, solar radiation may be the limiting factor in evaporation. Therefore, the evaporation from leaf surfaces is probably compensated by reduced evaporation from the ground and transpiration from the vegetation.

The second influence of vegetation is to protect and shade the soil. Protecting the soil against the impact of direct rainfall is important in maintaining a desirable soil structure of loose aggregates or crumbs made up of individual soil particles. Direct impact also dislodges soil particles, the first step in the erosional process. Vegetation also

shades the soil the soil surface from direct sunlight and excessive evaporation, and thus promotes the growth of soil organisms which are at work breaking down organic materials into desirable plant foods and soil material.

Transpiration is evaporation from plant surfaces of moisture which has been taken up by the root system and utilized in the process of plant growth. This plant process which is not completely understood, rarely accounts for less than 1/3 of the precipitation in humid areas and effectively all in the lower rainfall areas. Little can be done to modify the transpiration of a particular vegetative type, but there is the option of substituting other plants with changed behavior. Transpiration fluctuates in a seasonal pattern with maximum rates being achieved during the warm growing season when ample moisture is present. Rates during the cold season may equal or approach zero. In addition to the seasonal cycle, transpiration varies with the depth of soil and the available moisture. When the moisture level falls to near the point at which plants wilt, the remaining water is held very tightly by the soil particles, and is not readily available to plant roots. Finally, transpiration varies with the rooting habits of the vegetation. Mature forests are generally considered to have the greatest transpiration because of the great leaf areas supported by extensive root systems which extract moisture to great depths each season. Shallow-rooted plants, such as certain annual grasses, must develop a new root system each year and extract soil moisture from a far shallower belt than trees. Vegetation with root systems extending 10-20 feet or more into the soil are considered deep, from 5-10 feet is intermediate, and from 2-5 feet is shallow.

In practical watershed management, transpiration takes place concurrently with and cannot be accurately separated from other evaporation. This includes the evaporation from residual moisture left by rains as well as that from the soil itself. Studies have shown that soil evaporation does not extend to great depths, and is usually limited to the top 12 to 18 inches. Evaporation, therefore, feeds off moisture in the upper layers which is supplied by periodic rains. Transpiration, on the other hand, tends to extract moisture to the limits of the root system, which in turn may be limited by the total depth of soil or soil moisture.

Evaporation and transpiration are normally considered together as evapotranspiration. There is evidence that total evapotranspiration in some localities may be limited by solar radiation, and therefore, if plant processes are operating at a high rate, ground evaporation may be small. During the dormant season, on the other hand, tanspiration may be insignificant and evaporation is limited by available moisture and heat.

Evapotranspiration rates are frequently measured in inches per day. Under optimim condition,s this may be in the range of 0.2 to 0.3 inch per day. Under growing season conditions in the temperate zones when transpiration is the dominant feature, about 0.15 inch per day is typical. During the dormant season or at times when the soil is dried to the wilting point, the rate may approach zero.

Vegetation has a large effect on infiltration, which was defined earlier in the chapter as the rate at which rain or melting snow enters the interstices of the soil. The vegetative influence operates in several ways; by shielding the surface from impact it maintains the important crub or aggregated structure which is essential to high infiltration. Secondly, roots open channels in the soil for transmission of water, and its foliage

annually becomes a mulch on the soil surface and an important ingredient in the soil building process. Finally, vegetation, through the process of transpiration, extracts soil moisture and creates a moisture deficiency or storage potential which is available when moisture infiltrates. Obviously, a soil which is saturated at any level can no longer absorb moisture faster than the transmissibility rate at which it percolates to a groundwater outlet.

Among all natural vegetal covers the mature forest has the highest infiltration rates. Even after extended rainfall rates of 0.30 to 0.50 inches per hour may be sustained during the growing season at a site with deep soil. These high rates may be closely approached by a thick sod cover which is lightly grazed and otherwise well managed, although rates are more typically intermediate at 0.20 to 0.30 inch per hour during the growing season, and lower in winter. Cultivated crops are associated with more variable and lower infiltration rates because of the seasonal variation in cover and because they are not conducive to the best soil structure and development of soil moisture storage through depletion. Bare soil has the lowest infiltration rates because of rapid surface sealing and lack of soil moisture storage capacity. These rates may typically be o.10 inch per hour or less in most soils. During periods of frozen soil or complete soil saturation, all infiltration rates may approach zero, although there is evidence that some advantage persists with forest soils which freezes in a honeycomb rather than solid form.

Infiltration and runoff are closely related, and to an extent are complementary. Runoff can be considered as a rainfall excess which remains after the infiltration rate and/or the soil storage capacity are satisfied. Sites with high infiltration rates have low surface runoff, and frequently

lower total runoff. In fact, research findings indicate that under optimum conditions of forest cover, surface runoff can be eliminated. The mechanics of runoff production will be discussed in greater detail in subsequent sections.

The Role of Topography

When rainfall takes place at rates in excess of the infiltration capacity of the soil, water accumulates on the soil as surface detention. Initially, such rainfall excess fills depressions in the surface. As further excess accumulates, sufficient head is developed to cause downslope movement , called overland flow (or surface run-off) Surface detention is commonly 0.10 inch or less depending upon the surface roughness, method of cultivation, the amount of litter, or mulch accumulated on the surface, and the land slope. In instances where contour plowing is practical or level terraces are constructed in a deliberate attempt to hold moisture, detention can be considerably larger and amount to the equivalent of one inch or more over the entire surface. Following the period of rainfall the residual water held in surface detention will infiltrate in part and evaporate in part.

Land slope has a marked effect on the velocity with which overland flow takes place, steeper slopes causing increased velocity. Under steep-slope conditions, runoff tends to concentrate more quickly in the stream channels and is a major cause of flooding, particularly along small streams. This increased velocity of overland flow is also a critical factor in land erosion. The capacity of flowing water to carry soil particles increases

more than proportionately with increased velocity. This accounts for the sensitivity of sloping land to erosion, and is one of the most critical factors in limiting the application of cultivated crops.

Although velocity of overland flow and erosion capacity vary directly with slope, volume of surface runoff does not. In other words, it has not been possible to demonstrate that steep slopes have a greater volume of runoff. This is tertatively explained on the basis that sloping land has more land surface to infiltrate rainfall than is indicated from mapped areas, since these are horizontal projections. Precipitation is measured over a horizontal plane also, but is actually spread over the greater surface of a sloping surface.

Soils and Hydrologic Processes

Soil is the very heart of a watershed, and the focus of both natural and man-directed influences.

Soil can be thought of as consisting of mineral particles, organic material, moisture, and air. Soil is distinguished from undecomposed organic material above and parent material or rock below in that it supports the roots of vegetation. The mineral particles are derived through the physical and chemical forces of weathering. The organic material coating the mineral elements is the product of plant and animal life which has become intermixed by various processes including the downward percolation of water. Moisture, which is an indispensable element of soil, is supplied by the infiltration and downward percolation of precipitation.

Soil is an exceedingly complex and variable material. It varies vertically in its characteristics from the surface downward, it also varies

horizontally so that at even a few feet distance, there is variation. Soil also varies in time, particularly with respect to its moisture content. Among the many properties by which a particular soil can be characterized, certain of these area of particular importance to the hydrology of watershed management. In the following paragraphs, the most important of these will be defined and related to hydrologic processes.

Overall depth of soil is of critical importance as it limits the volume available for storage of water. Soils which are thin, less than 12 inches, present very limited opportunities for effective watershed management.

A fully developed soil, such as is found in a mature and undisturbed forest, is covered by a layer of several inches or more of leaves and other undecomposed plant material. Below this is a layer of decomposed organic material or humus and mineral material. This material is very light and highly permeable to the passage of water. This zone teems with insect and bacterial life which decomposes minerals and vegetal remains into soil materials.

Below the mantle of organic material is the soil proper, which consists of distinguishable layers call horizons. These are referred to by alphabetic letters, and if minor variations exist, by number subscripts starting at the top, such as A_1, A_2, B_1, B_2, C_1, and C_2. The A horizon or top soil is normally the most fertile, loose, and permeable to the passage of water. In a downward direction successive horizons ordinarily become less fertile, contain less organic material, are most compact, and increasingly impermeable to the downward passage of water. Between the lowest soil material and the underlying rock may be parent material which consists of mineral particles devoid of organic materials. Soil difference important in watershed management are discussed in detail in Chapter V.

In non-forested areas, the surface layer of undecomposed organic material is ordinarily not present, but if the soil developed under rich grasslands there may be a deep layer of soil of high organic content. If erosion has been active, the top soil may have been partially lost and some of the B horizon exposed at the surface.

The size of soil particles is referred to as texture. Such particles fall into three broad and widely recognized classes, with clay being the finest, silt being intermediate, and sand being the coarsest. Soils with predominantly fine particles have the greatest total pore space and total water-holding capacity although much of this moisture is tightly held and not readily available. Such soils are heavy and tight, and do not readily permit the passage of water. Sandy soils at the other extreme permit the rapid passage of free water, but have less total pore space and smaller water-holding capacity.

Typical values of the moisture-holding capacity of soils varying in texture, expressed in inches depth of water per foot of soil depth is as follows:

Fine sand	0.5 inch
Silt	2.5 inch
Clay	4.5 inch

The shape and arrangement of the soil particles is called soil structure. Whether particles are flat or round greatly affects characteristics of moisture passage and storage. Another feature of soil structure pertains to whether the individual soil particles are grouped together in aggregates. Such aggregation takes place in the presence of organic material which binds individual particles together. Aggregation is desirable from an agronomic point of view in that even heavy clay soils can have good

tilth and be resistant to erosion. It is also important hydrologically since the aggregated particles can overcome the effects of fine texture and function like a sandy loam permitting rapid passage of free water. Clay soils behave differently depending upon whether they are wet or dry and when dry their rate of shrinkage. Clays with a slight shrinkage rate do not crack and are rendered less permeable by drying. Clays that are rendered impermeable by drought sometimes yield the worst floods in storms that come at the end of drought periods.

The percentage by volume of the soil mass which is not occupied by solid particles is referred to as the porosity. This is the space available for the passage and storage of water and air and obviously a property of great importance to the hydrology of a watershed. Total porosity of a soil is typically about 50 percent of the total volume. This consists in part of capillary porosity which is moisture held tightly by soil particles against the force of gravity. Non-capillary porosity exists in the larger openings between soil particles and is readily available for the passage of free water under the force of gravity.

The downward rate of water movement is referred to as the percolation rate. This term is equivalent to the rate of moisture penetration rate at the surface which is known as the infiltration rate. The percolation rate is a function of the texture and structural characteristics, as previously described, as well as the moisture content at the moment. Moisture content is a particularly significant factor in clsy soils which swell and thus deter moisture movement when wet, and develop cracks for the ready passage of water when dry.

The availability of water for plants is related to the force with which moisture is held by soil particles. The force required by the plant root to separate this moisture can be expressed in pounds per square inch or in atmospheres of tension. The moisture level at which plants can no longer withdraw moisture is called the wilting point and occurs at about 15 atmospheres or 225 pounds per square inch. Although the required energy at wilting point is the same for soils of all textures, fine soils contain greater residual moisture which is thus unavailable to plants. Typical soil moisture in percent by volume at the wilting point is from 2 to 5 percent for sandy soils and about 20 percent for clay soils.

The maximum capillary storage which can be held against the pull of gravity is termed field capacity. At this level, moisture is held by soil particles with a force of 1/3 atmosphere or about five pounds per square inch. A sandy soil at field capacity may contain about 10 percent moisture by volume, and a clay soil approximately 40 percent. Thus, it can be seen that clay or fine-textured soils hold greater moisture, and also contain more available moisture between field capacity and the wilting point.

When all pore space in the soil is completely filled with water, the soil is said to be saturated. The portion of such water, which is beyond that held against the pull of gravity at field capacity, is available for stream flow. Depending upon the hydraulic head and the porosity of the soil, such excess water drains away after being held in temporary storage and becomes a portion of either sub-surface or ground-water runoff.

During and following a period of rainfall or snow melt, water enters the soil by the process referred to as infiltration. Such water continues its downward percolation behind a wetting front or wave of moisture which

is in excess of the field capacity. Downward movement continues so long as moisture continues to be supplied from above or until the water table or an impervious soil or rock layer is reached. However, this downward movement should not be thought of as entirely regular. In addition to the previously mentioned variability of soil, there are channels such as cracks, worm and rodent holes, and channels left by decayed roots. When the percolation rate at some layer is less than the infiltration rate, or the percolation rate from above, water tends to accumulate in excess of field capacity. Such accumulations move laterally and downslope to become sub-surface discharge.

Underlying Geology

A final important feature of the watershed, and one which should be investigated as a part of watershed planning, is the geology. The underlying bedrock usually forms the bottom of the watershed so far as management interest is concerned. The geology affects the watershed hydrology in two highly important ways. First, the form of the underlying rocks determine whether the underground watershed coincides with the waterhsed boundaries as determined by the surface configuration. Such coincidence may be excellent for all practical purposes or the underground bedrock surface may be quite unrelated to the surface in form. Agreement is generally best where soils are thin and residual from the local rocks. If surface topography largely reflects geologic or recent erosion and the soil is deep, agreement is problematic. The second important consideration is wheter the bedrock is impervious to the downward passage of water. In instances where rock is fractured or contains many solution channels it may not confine water. The consequence is the absence of a groundwater zone and

ground water flow from the watershed.

A frequent objective of watershed management is to increase the infiltration of precipitation to reduce erosion and flash floods while increasing soil moisture and stabilizing stream flow. In such instances, particularly, the geology assumes great importance. If the bedrock dips away from the watershed outlet, or if this rock is pervious, waterhsed runoff will be seriously reduced and low flows will not be improved. This follows from the fact that reduced surface runoff results in greater deep percolation as well as soil moisture. If such deep percolation does not become a part of watershed runoff, the desired objectives will not be reached.

Stream Channels and Runoff

Overland flow as described in the section on topography, may continue for just a few feet or as much as a hundred feet or more before it concentrates in a channel. These upstream channels are likely to be intermittent streams which flow only during storms and for short periods following rainfall or snowmelt. Such small channels carry primarily surface runoff which is the product of overland flow. As such, these streams are highly variable in flow and sensitive to rainfall intensities, vegetal cover, and soil conditions.

Such intermittently flowing headwater streams can be put to use if the flow is stored behind a dam. The farm pond, which is used to accumulate water for stock watering and irrigation, is a typical example of such application.

In a downstream direction, the small, intermittent streams join to form rivers, draining larger drainage areas. As the contributing area becomes larger, the streams are more likely to have continuous flow for a number of reasons. One reason is the greater time of travel involved in drainage of the surface runoff. Whereas an intermittent stream in the headwaters may flow for only a few minutes, or perhaps an hour after a rain the period required to pass surface runoff from an area of 1000 square miles might be a few days or a week. Larger basin streams extend this period to many weeks. Another reason for the persistence of flow in larger streams, and particularly in humid regions, is that contributions of subsurface and groundwater flow may be present. Such underground flows take place along and above rock strata or zones of relatively impervious soil material. Such flows also underlie the smallest watersheds, but generally do not flow in surface channels. As streams develop larger channels in a downstream direction they tend to intercept such underground flow which then escapes into the surface stream in the form of seeps or springs. Since underground flow takes place at low velocities, it may continue to contribute to stream flow from one to three months following a rainfall event. This extended drainage bridges the gap between rainy periods and tends to create continuous although variable rates of flow.

In arid regions, there frequently are no underlying groundwater zones, and such contributions do not take place. We thus have the phenomena of drainage besins with perhaps thousands of square miles of area which become dry if supporting rains are infrequent. Beyond this, if the bed of the stream consists of pervious sands and gravels, the stream may leak into its bed and banks, and the flow will actually diminish in a downstream direction.

Runoff is a product of precipitation, but it is also a residual remaining after demands of vegetation and soil are met. Hence, all these factors influence the amount of runoff which takes place. Ordinarily, runoff exhibits a seasonal pattern but with distinct irregularities associated with periods of rainfall or snowmelt. Annually, runoff varies from more than 40 inches in humid areas of high precipitation to less than one inch in arid regions. Between these extreme values, a typical area with 30 inches of precipitation might have a runoff of 8 to 10 waterhsed inches per year.

Stream flow, or watershed runoff, is most commonly represented by the hydrograph. The hydrograph consists of a continuous graph of rate of stream flow versus time. A hydrograph may be used to represent the total flow in a stream, or by analysis it can represent one portion of the flow, such as surface runoff, sub-surface runoff, or groundwater runoff. A hydrograph is roughly triangular in shape, but with a steep rising limb and a falling or recession limb of flatter slope. Each stream has its own unique hydrograph characteristics which reflects the drainage basin variables which influence and modify runoff. It is difficult to generalize a mathematical expression for the rising limb of the hydrograph, but the falling portion subsequent to the crest represents the drainage of water from storage in the stream channel and the groundwater reservoir. The recession limb does have a characteristic form which follows the general equation:

$$Q = Q_o K^{-t}$$

in which Q is the discharge at any instant; Q_o is the discharge at some initial time; t is the time interval between Q_o and Q; K is a constant. The above equation is extremely useful for predicting future stream flows during

recession periods as well as for cumputing the storage characteristics of a river basin.

Stream flow is the only phase of the hydrologic cycle in which water is so confined as to make possible reasonably accurate measurements of the volumes involved. All other measurements in the hydrologic cycle are, at best, only samples of the whole. Measurements of stream flow involves two steps: First, the measurement of river stage which is the height of water above some arbitrary but fixed reference level; and second, the correlation of this river stage with discharge, or flow of the stream. Measurements of river discharge make use of the simple expression:

$$Q = A\ V$$

in which Q is discharge in cubic feet per second, A is cross section area of the flowing stream in square feet, and V is mean velocity of the stream in feet per second. Spot determinations of discharge are mady by measuring the velocity with a current meter as well as the cross-sectional area of the flowing streams. The product of these is the river discharge, which value is plotted versus the concurrent river stage. The plotted points from such measurements throughout the range of stage and discharge define a parabolic relationship which is the rating curve at the station. With this rating curve and a periodic or continuous record of river stage, it is possible to develop a continuous record of rate of river discharge. The river discharge over periods of time represents volume of runoff.

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

Handout No. 2

INSTITUTE OF TROPICAL FORESTRY

U.S. FOREST SERVICE

RIO PIEDRAS, PUERTO RICO

JANUARY 1983

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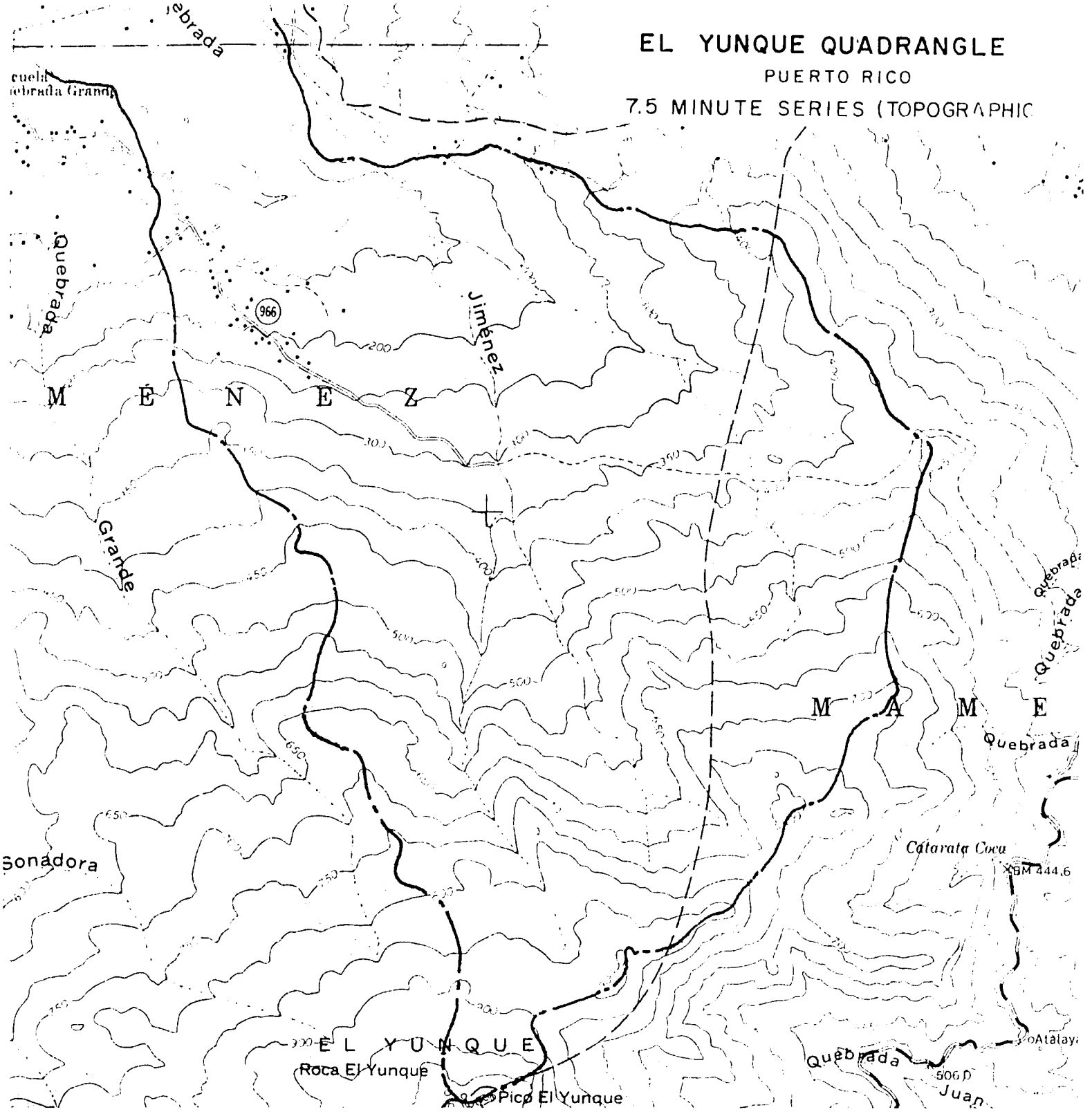

MAP I-I

JIMENEZ WATERSHED CARIBBEAN NATIONAL FOREST

LEGEND

ROAD CLASSIFICATION

HEAVY-DUTY ——— LIGHT-DUTY ═══

MEDIUM-DUTY ——— UNIMPROVED DIRT =======

○ INSULAR ROUTE

KEY BEST AVAILABLE COPY

WATERSHED BOUNDRY [---]

PREPARED BY: J. BAUER
JANUARY, 1983

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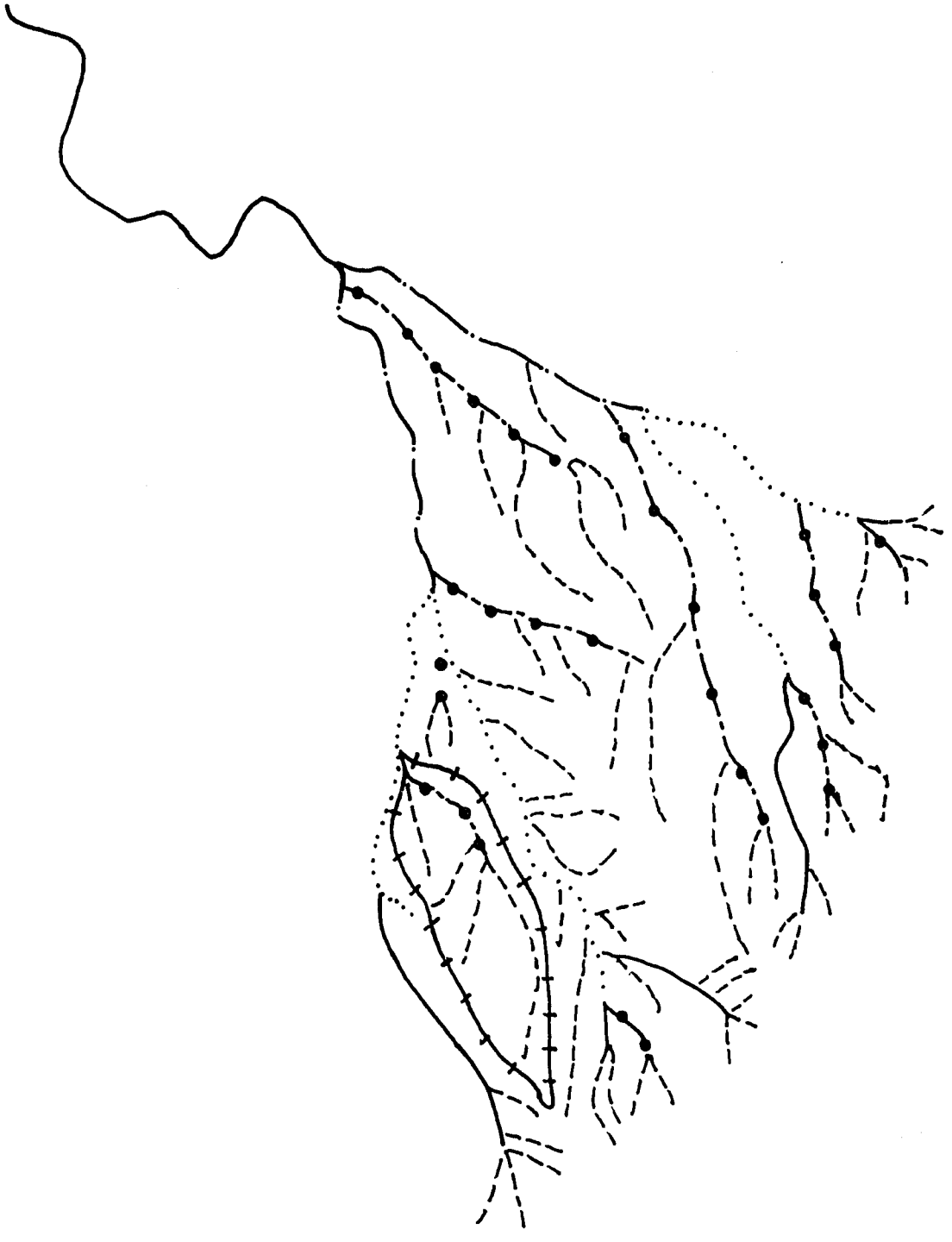

MAP 1-1 OVERLAY 1

SUB-WATERSHED BOUNDRY

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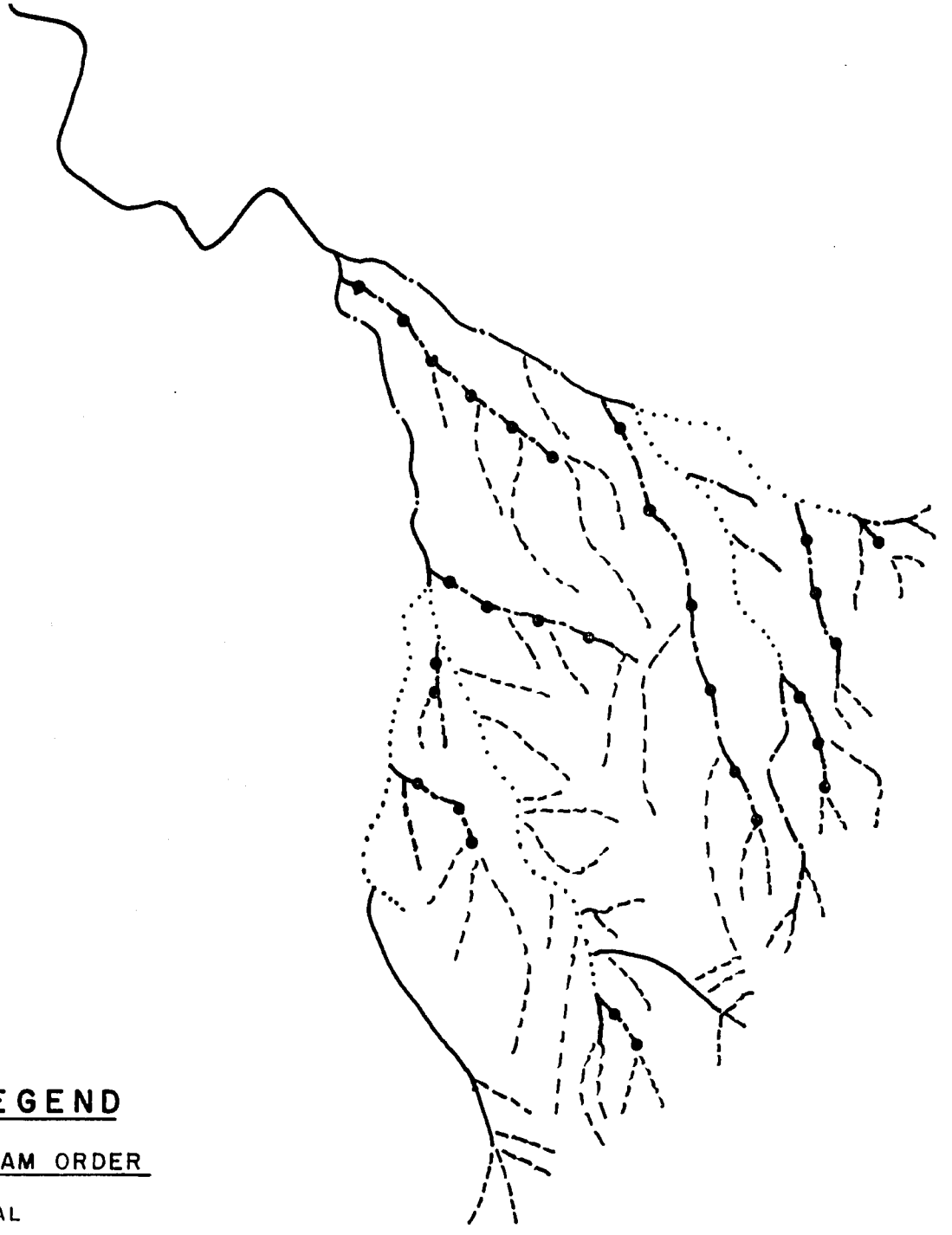

LEGEND

STREAM ORDER

1 PERENNIAL
1 NON-PERENNIAL
2 PERENNIAL
2 NON-PERENNIAL
3 PERENNIAL
4 PERENNIAL
5 PERENNIAL

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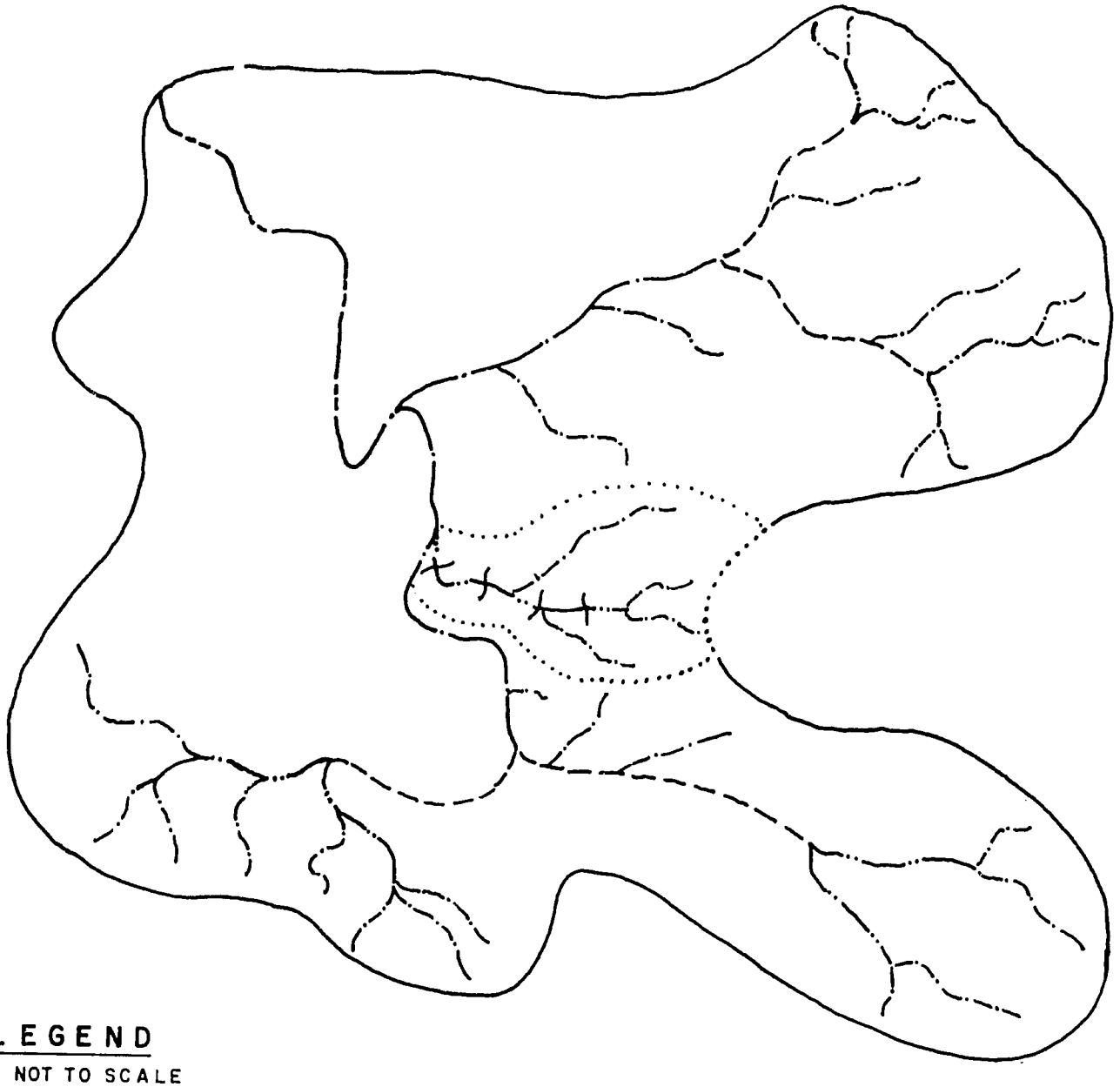
MAP 1-1 OVERLAY -2

MAP 1-2

EXAMPLE WATERSHED



LEGEND

MAP NOT TO SCALE

WATERSHED BOUNDARY

SUB-WATERSHED BOUNDARY

STREAM ORDER

1 NON-PERENNIAL

1 PERENNIAL

2 NON-PERENNIAL

2 PERENNIAL

3 PERENNIAL

4 PERENNIAL

5 PERENNIAL

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PREPARED BY: J. BAUER
JANUARY, 1983

TABLE 1-1

Estimated Quantities of Water on the Earth*

Item	Millions of Acre-feet+	Per cent of total fresh water
Oceans	1,060,000,000	- - -
All fresh water, ice, and vapor	33,016,084	100.00
Polar ice and glaciers	24,668,000	74.72
Ground water, shallow (to 2,500 ft.)	3,648,000	11.05
Ground water, deep (2,500-12,500 ft.)	4,565,000	13.83
Lakes	101,000	0.31
Soil moisture	20,400	0.062
Atmosphere (vapor, clouds)	11,500	0.035
Rivers	933	0.003
Plants and animals	915	0.003
Hydrated earth minerals	336	0.001

*Source: Ackerman and Lof (1959).

+An acre-foot is one acre covered to a depth of one foot, or 43,560 cubic ft. or 325,851 gallons of water.

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WATERSHED MANAGEMENT

Handout No. 3

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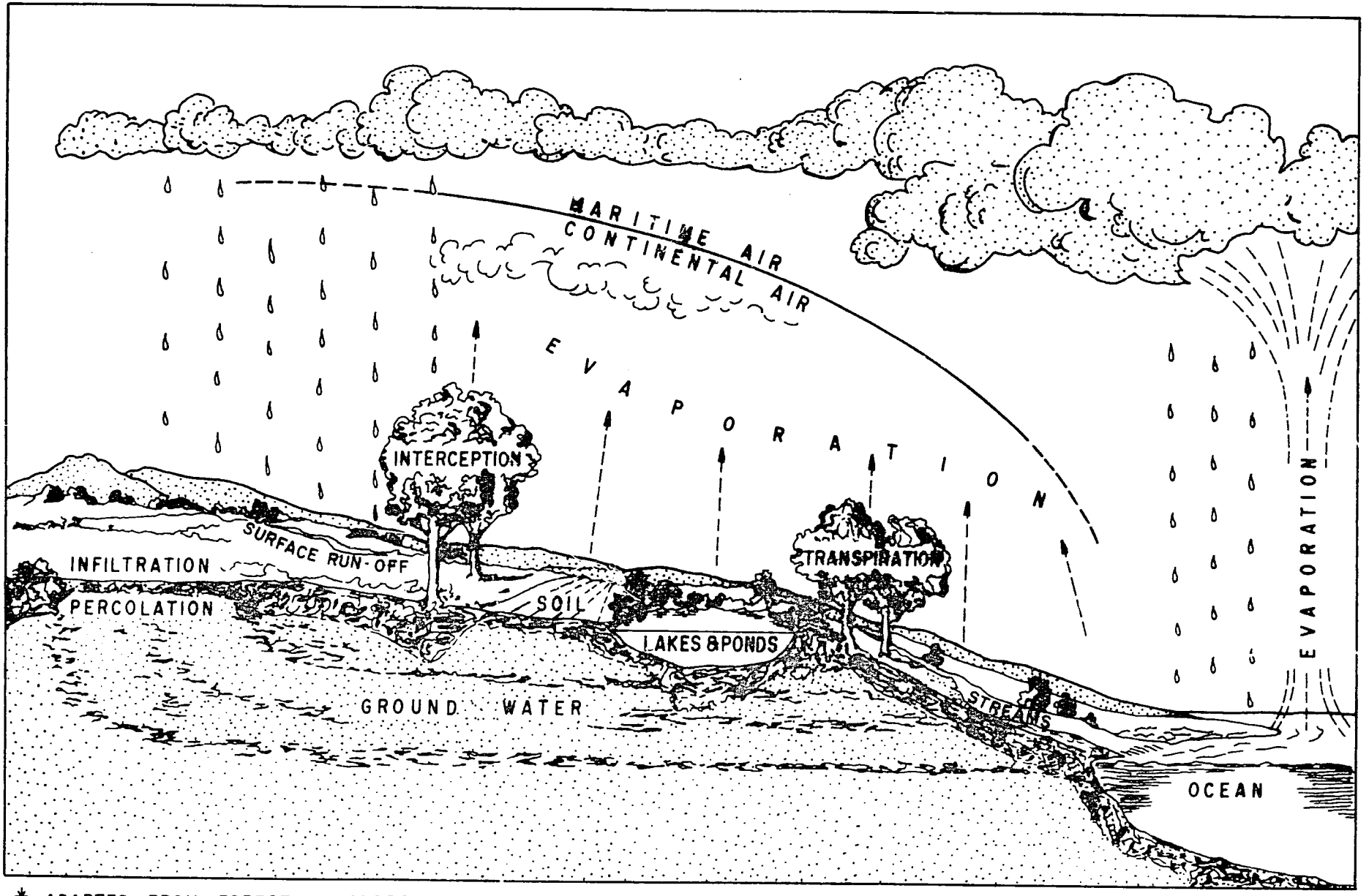
TROPICAL FORESTRY AND ENVIROMENTAL QUALITY SHORT COURSE
WATERSHED MANAGEMENT
HYDROLOGIC CYCLE *



* ADAPTED FROM FORESTRY HANDBOOK, THE RONALD PRESS COMPANY, NEW YORK, 1961.

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WATERSHED MANAGEMENT

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

TABLE 1-2 A

Four Major Size Classes of Inorganic Particles and Their General Properties[a]

Size Fraction	Common Name	Visible Using	Dominant Composition
1. Very Coarse	Stone, gravel	Naked eye	Rock fragments
2. Coarse	Sands	Naked eye	Primary minerals
3. Fine	Silt	Microscope	Primary and secondary minerals
4. Very fine	Clay	Electron microscope	Mostly secondary minerals

[a]From The Nature and Properties of Soils, The Macmillian Company, 1969, pg. 11.

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WATERSHED MANAGEMENT

TABLE 1-2 B

The Classification of Soil Particles According to Two Systems[a] (US and International)

	United States Department of Agriculture System	International System
Soil Separate	Diameter Limits (mm)	Diameter Limits (mm)
Very coarse sand	2.00-1.00	
Coarse sand	1.00-0.50	2.00-0.20
Medium sand	0.50-0.25	
Fine sand	0.25-0.10	0.20-0.02
Very fine sand	0.10-0.05	
Silt	0.05-0.002	0.02-0.002
Clay	below 0.002	below 0.002

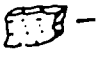
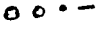
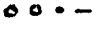
[a]From Soil Survey Manual (US Dept. of Agriculture Handbook No. 18, 1951), p. 207.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

TABLE 1-3

Diagramatic representation of the various structural types found in mineral.[a]

		Location in Profile
Plate like	PLATY (Leafy & flaky also found)	May occur in any part of profile. At times inherited from the soil material
Prism like	PRISMATIC (Tops level) COLUMNAR (Tops rounded)	Both usually subsoil manifestations. Common in soils of Arid & Semi-arid Region.
Block like	 BLOCKY (Cube-like) BLOCKY (Subangular)	These forms common in Heavy subsoils particularly those of humid regions.
Spheroidal	 GRANULAR (Porous)  CRUMB (Very Porous)	Characteristic of the furrow-slice. Subject to wide & rapid changes.

[a]From the Nature and Properties of Soils The Macmillian Company, 1969, Pg. 58.

[b]Their location in the profile is suggested. In arable soils, granulation usually receives the most attention.

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WATERSHED MANAGEMENT

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WATERSHED INVENTORY [1]

Name of watershed:
Location:
Tributary to:
Area:

I. Human elements

A. Land ownership, use and development

1. Ownership - maps
2. Ownership - statistical and descriptive

a. Public

(1) Area by agency
(2) Use; demands, including special use

b. Private

(1) Areas by class of owner

a. Corporate & large pvt
b. Medium
c. Small

3. Cultural features - maps and descriptive: roads, railroads, communication and transportation

a. Dams, reservoirs, canals
b. Cities and towns

B. Population - statistical, descriptive

1. Numbers

a. In watershed
b. Out of watershed but using goods or services

2. Sources of livelihood and use of watershed resources

a. Wood
(1) Number, kind of activity, value, problems

b. Forage
(1) Number, kind of activity, value, problems

c. Wildlife
(1) Number, kind of activity, value, problems

d. Recreation
(1) Number. kind of activity, value, problems

e. Minerals
(1) Number, kind of activity, value, problems

f. Water
(1) Law: Kind, ownership of rights
(2) Uses: Domestic and municipal - who, how much, where, value

a. Agriculture - who, how much, where, value
b. Industry - who, how much, where, value
c. Recreation & Wildlife - who, how much, where, value

---

[1]From Satterund, Donald R. 1972. Wildland Watershed Management. The Ronald Press Company, New York. PP340-343.

Problems: Quantity - who, how much, where, value
Regimen - who, how much, where, value
Quality - who, how much, where, value

3. Social conditions

   a. History and traditions
   b. Organizations - social, political, fraternal, etc.
   c. Technical and educational status
   d. Leaders : their characteristics and outlook
   e. Planned developments

II. The Watershed

A. The physical setting - maps, statistic, and description

   1. Topography and drainage system
   2. Land forms and geology
   3. Soils

      a. Hydrologic depth (storage characteristics)
      b. Permeability and internal drainage
      c. Surface characteristics (infiltration and erodibility)
      d. Mass stability
      e. Soil mechanics and other engineering characteristics

B. Climate-local-may require interpolation on basis of general relationships (maps, statistics and descriptive)

   1. Precipitation
      a. Rainfall
         (1) Amount, seasonal distribution, intensity-duration, frequency, drought.

      b. Snowfall
         (1) Amount, areal distribution and accumulation, temporal accumulation and melt patterns.

      c. Other factors
         (1) Cloud-drip, prevailing storm path and wind direction, rain-shadows, etc.

   2. Energy sources and partitioning
      a. Irradiation distribution - areal and temporal
      b. Advected heat (air mass movement pattern) latent and sensible, temporal characteristics.
      c. Temperature - temporal and areal distribution, including means, extremes, length of "growing season," etc.
      d. Potential water losses

         (1) Evaporation data (empirical)
         (2) Water balance models (theoretical)

C. Runoff

   1. Quantity - total, seasonal, measured or estimated
   2. Regimen

      a. High flow-peaks, volumes, frequencies, time of concentration by location and cause

b. Low flow-amount, duration, frequency, by location

3. Quality

a. Turbidity and sediment
b. Contaminants other than sediments
c. Temperature
d. Other physical, chemical, and biotic characteristics that may be important (dissolved O_2, nutrients, algae, fish, pH, etc.)

D. Channel characteristics (including flood plain)

1. Density
2. Shape of drainage net
3. Gradient
4. Orders
5. Capacities - channel and flood plain
6. Nature of bed-shape, materials
7. Condition (erosion classes)
8. Areas of effluence and influence, springs

E. Vegetation

1. Forest or woodland (include unstocked, but capable of supporting forest or woodland)

a. Overstory
(1) Type
(2) Stocking (density)
(3) Age or size class
(4) Site quality
(5) Hazards (insects, disease, fire)
(6) Successional status
(7) Special features (wildlife, recreations)

b. Understory and litter
(1) Type of understory
(2) Density
(3) Age or size class
(4) Browse or grazing value
(5) Ground cover

(a) Type (litter, grass, rock, bare soil, etc.)
(b) Depth (litter)

2. Rangeland

a. Types
b. Density (by species or range types)
c. Productivity (by species or range types)
d. browse or grazing values
e. Condition
f. Ground cover (as above)
g. Season of use
h. special features

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WATERSHED MANAGEMENT

Handout No. 6

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F. Wildlife (by species

1. Kinds and amounts, location
2. Habitat conditions

a. Food
(1) Kind
(2) Amount
(3) Availability in time and space

b. Cover
(1) Kind
(2) Amount
(3) Dispersion

c. Waters

d. Other

G. Other factors-amenities, unique values: historical sites, rare plants, geological formations, etc.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

Handout No. 7

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WATERSHED RESOURCES IMPROVEMENT PRESCRIPTION

A. Purpose and objective of the watershed improvement project

B. Description of the area

1. General location
2. Major drainages and tributories
3. Topography, including slope and aspert
4. Vegetation and liter, including percent ground cover and type of vegetation
5. Soils data, including depth and texture, percent material, erosiveness, and productivity potential
6. Climate
7. Down stream improvements and uses

C. Description of problem

1. Cause of watershed deterioration
2. Type of problem

D. Project design

1. Layout how problem will resolved (may include photographs and drawings)

E. Equipment and personnel needs

F. Monitoring needs both during and following improvements activities

G. Photographs

1. Illustrative photos protraying present conditions on areas
2. Establish and describe permanent photo points to show before and after comparisons.

H. Maps

1. Small map showing general location
2. Large scale map of project areas, showing location of specific land treatments, fences, and other activities.

UNITS AND MEASUREMENTS USEFUL FOR WATERSHED MANAGEMENT[1]

A. Linear

1 mile	=	63,360	inches
	=	5,280	feet
	=	1,760	yards
	=	320	rods
	=	80	chains (Gunters)

B. Area

1 acre	=	208.715	feet each side if a square
	=	43,560	square feet
	=	4,840	square yards
	=	160	square rods
	=	10	square chains (Gunters)
1 square mile	=	27,878,400	square feet
	=	3,097,600	square yards
	=	102,400	square rods
	=	6,400	square chains (Gunters)

C. Volume

1 gallon	=	231	cubic inches
	=	0.1337	cubic foot
1 cubic foot	=	7.48	U.S. Gallons
1 cubic yard	=	27	cubic feet
1 acre-foot	=	325,851	gallons
	=	43,560	cubic feet
	=	1,613.3	cubic yards
1,000,000 gallons	=	3.0689	acre-feet
1,000,000 cubic feet	=	22.957	acre-feet
1 acre,	=	3,630	cubic feet
1 inch deep	=	0.0833	acre-foot
1 square mile,	=	2,323,000	cubic feet
1 inch deep	=	53.333	acre-feet

D. Weight

1 gallon pure water	=	8.33	pounds

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[1] Adapted from Watershed Structural Measures Handbook. FSH 2509.12. U. S. Forest Service. July 1969.

1 cubic foot pure water	=	62.4	pounds
1 acre-foot pure water	=	2,718,144	pounds
	=	1,359	tons
1 cubic foot sediment	=	70	pounds(variable)
1 acre-foot sediment	=	1,525	tons (variable)

E. Rate of Flow-Quantity-Volume

1 second-foot	=	1	cubic foot per second (c.f.s.)
	=	7.48	gallons per second
	=	448.83	gallons per minute
	=	646,315	gallons per 24 hours
	=	0.992	acre-inch per hour
	=	1.984	acre-feet per 24 hours
	=	59.52	acre-feet per 30 days
	=	724	acre-feet per 365 days
1 second-foot for 1 day	=	0.03719	inch on 1 square mile
30 days	=	1.116	inches on 1 square mile
1 year	=	1.131	feet on 1 square mile
1 inch per hour per acre	=	1.008	cubic feet per second
1 gallon per second	=	0.00223	cubic foot per second
1 gallon per minute	=	1,440	gallons per day
1,000,000 gallons per day	=	1.547	cubic feet per second
	=	695	gallons per minute
1,000,000 gallons per minute for 24 hours	=	2.23	cubic feet per second
	=		acre-feet
1 inch deep on 1 square mile	=	0.0737	cubic foot per second for 1 year
1 miner's inch	=	1/40 to 1/50	cubic foot per second definition varies by law in different states

F. Power and Pressure

1 horsepower	=	500	foot-pounds per second

(CONTINUATION)

1 horsepower	=	33,000	foot-pounds per minute
	=	746	Watts
	=	1	second-foot water falling 8.81 feet
1,341 horsepower	=	1	kilowatt
1 atmosphere at sea level	=	14.697	pounds per square inch
	=	33.9	feet of water

WATERSHED MANAGEMENT SHORT COURSE
March 31 - April 8, 1983

DAILY SCHEDULE

Thursday, March 31

7:30 - 11:30 AM	Part I - General Information on Watershed Management and Hydrology - Jerry Bauer
12:00 - 4:00 PM	Part II - Soil Erosion - Sierra and Acevedo

Friday, April 1

7:30 - 4:00 PM	Part II - Soil Erosion and Control - Sierra and Acevedo

Monday, April 4

7:30 - 4:00 PM	Part III - Watershed Planning and Application - Bauer
	Practice Exercise - Bauer
	Field Preparation - Bauer

Tuesday, April 5

7:30 - 4:00 PM	Field Exercise - Bauer, Sierra, Acevedo and McKinley
	1. Visit area with erosion problem in Caribbean National Forest.
	2. Watershed prescription preparation.

Wednesday, April 6

7:30 - 4:00 PM	Field Exercise - Bauer, Sierra, Acevedo and McKinley
	1. Check Damn construction.

Thursday, April 7

7 :30 - 4:00 PM	Hydrology - McKinley, Bauer

Friday, April 8

7:30 - 4:00 PM	Hydrology Field Exercises - McKinley, Bauer

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

Handout No. 8

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

FIELD ASSIGNMENT #1

Problem: Severe erosion, still active, sedimentation being deposited in stream.

Objective: To control erosion and protect water quality downstream of problem area.

Activities:

1. In a team of 4 persons evaluate the problem and develop a "Watershed Improvement Prescription".
   a. Investigate site - field
   b. Record observations - field
   c. Develop prescription - office
2. Each team build a wooden check down at designated location.

Equipment Needs:

- Poles (pre-cut)
- Wire
- Pliers
- Nails
- Suunto Clinometer
- Flagging tape
- Shovel
- Pick
- Machete
- Axe
- Paper
- Pencils and pens
- Topographic maps

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

INSTRUCTOR NOTES

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TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

PART I (Instructor Notes)

I. Introduction

A. Definition:

1. Watershed management - is the management of all the natural resources of a drainage basin to protect, maintain, or improve its water yields.

2. Wildland watershed management - is watershed management applied on non-urban, non-cultivated lands that are chiefly covered by forest and range. This is the primary source of fresh water for man throughout the world.

B. Purpose of watershed management

1. Watershed management is always aimed at specific objectives and a program is designed to meet these objectives.

2. The objective may be to:

a. stabilize the soil

b. improve crop production

c. improve water quality

d. maintain or increase water yield

3. The above four objectives can be influenced by:

a. Vegetation

1. Type: forest vs. pasture vs. crops

2. Management practices: clear-cut vs. selection cut

b. Rotation length

1. Of forest crop

2. Of time span between cultivated crop

c. Conservation practices

1. Buffer strips along water channels

2. Terrace, contour practices

d. Forces and circumstances of nature - this is the most important of which man has little or no control over.

1. Weather or climate

2. Topography

3. Soils

II. Natural Waters Supplies

A. Worldwide - (Table 1-1)

1. Water is one of the most abundant compounds on earth.

2. 97% of the world's water is salty.

3. Of the remaining 3% most consist of polar ice and glaciers. This 3% is sufficient to cover all the land surface to a depth of several hundred feet.

4. In rivers alone there is enough water at any one time to supply each person on earth with 7,000 gallons.

III. Description of a Watershed

A. Definition

1. Watershed - is all the land area which drains into a stream system upstream from its mouth or other designated point of interest or measurement.

B. Characteristics of a watershed (Handout No. 2)

1. Area

2. Length

3. Width

4. Depth - extends from top of vegetation to confining geologic strata beneath.

C. Define and explain:

1. Surface divide - the circumscribing boundary which surrounds a watershed. This line defines the limts of the area which contributes surface runoff.

2. Underground divide - delineates the area contributing to groundwater runoff, may coincide with the surface divide.

3. Sub-watershed - is a portion of a watershed which in itself is a watershed.

4. Stream order - is a system used to classify stream size and location in relation to other streams in a watershed.

D. General facts:

1. All land is part of a watershed.

2. A watershed may be as small as a footprint or as large as a subcontinent (i.e. Amazon).

3. Most watershed is concerned with watersheds which range in size from an acre to several hundred acres.

4. The larger the watershed, the more complex it becomes.

5. All watersheds are unique, no two are exactly the same.

IV. The Hydrologic Cycle (Handout No. 3)

A. Definition

1. The hydrologic cycle is the large-scale circulation of water between atmosphere and earth.

B. The hydrologic cycles has no beginning and no ending.

C. Components of <u>precipitation</u>

1. rain
2. snow
3. hail
4. fog
5. dew
6. sleet

These 6 forms of precipitation are the principle sources of water on the earths surface. All are derived from the atmosphere where moisture exists as:

a. an invisible gas - water vapor
b. a liquid - rain
c. a solid - snow, hail

D. <u>Infiltration</u>

1. Is the movement of water from the surface of the ground into the soil.
2. Normally begins at a high rate, slows as soil becomes saturated.

E. <u>Surface run-off</u>

1. Is the amount of water which is not absorbed by the earth's surface.
2. This occurs when the rate of precipitation exceeds the rate at which water can infiltrate into the soil.

F. <u>Evaporation</u>

1. Is the process by which water in liquid state is change to vapor or the gaseous state.
2. This occurs when water in the liquid state is heated by solar energy.

3. This happens over land and water surfaces.

G. Transpiration

1. Is the process whereby free water in a plant structure is released as vapor to the atmosphere the pores in the leaves or bark.

H. Interception

1. Is the process by which precipitation is caught and held by foliage, twigs, branches of trees and lesser vegetation, or by surface debris, and evaporated from these exposed surfaces.
2. This results in a reduction of the precipitation reaching the ground.

I. Ground water

1. Is the portion of precipitation which infiltrates the ground surface which is not absorbed by the soil, porous rocks or other material; free sub-surface water.
2. This water eventually reaches a "zone of saturation" called the ground water table.
3. This may penetrate to a stream lake or ocean, thus be returned to a body of surface water.

V. Environmental Factors and their Relationship to a Watershed

A. Weather

1. Is a broad and inclusive term which refers to the state of the atmosphere at a given time and place, described by temperature, moisture, wind velocity and pressure.
2. Moisture or precipitation is the most important weather element to the land manager.

a. Rainfall - most common form of precipitation in the tropics.

b. Factors pertaining to rainfall which are important to the land manager:

1. Amounts - expressed in inches or milimeters.

2. Duration - expressed in minutes, hours, or days.

3. Intensity - expressed in amount per hour.

c. Why are these factors important?

1. They influence soil stability, vegetation type and growth.

d. Precipitation converts to runoff, percolation, and evapotranspiration.

e. Effects of precipitation (other factors being equal).

Higher precipitation <u>amounts</u>	- greater runoff greater evapotranspiration greater percolation
Higher precipitation intensities	- greater runoff lower evapotranspiration lower percolation
Longer precipitation duration	- lower runoff greater evapotranspiration greater percolation
Greater <u>areal extent</u> of precipitation	- greater runoff greater evapotranspiration greater percolation
Greater precipitation in <u>cold season</u> (above freezing temperatures)	- greater runoff greater percolation lower evapotranspiration
Greater precipitation in <u>warm season</u>	- lower runoff greater evapotranspiration greater percolation

3. Temperature is also an important weather element to the land manager. Influences germination, rate of growth and type of vegetation form of precipitation infiltration and runoff.

B. Vegetation

1. This is an essential part of watershed management in any climate where there is sufficient moisture and heat for plant growth.

2. Is essential because:

   a. It increases productivity of the land.

   b. It is the only practical way in which the land can be protected from erosion.

   c. It can be manipulated by man relatively easily.

3. It influences the watershed by:

   a. Interception

      1. This increases as cover density increases.

      2. Can "delay precipitation", thus increasing infiltration rate.

   b. Protecting ans shading the ground surface

      1. Lessen the impact of rainfall, thus protecting soil structure.

      2. Shades the ground surface from direct sunlight which reduces evaporation.

   c. Provides organic material to the soil

      1. Can increase soil fertility.

      2. Provide proper habitat for micro-organisms which break down organic material.

C. Topography

1. Topography influences the watershed by:

   a. affecting velocity of surface run-off

   b. affecting infiltration rate

2. Example - compare slopes.

D. Soil (Handout No.4)

1. Soil is the heart of a watershed and the focus of both natural and man directed influences.

2. Soil is a natural body which covers the earth in a thin layer and which supplies mechanical support and nutrients for plant growth and development.

3. Soil is composed of:

   a. mineral particles

   b. organic matters

   c. moisture

   d. air

4. Soil is a very complex and variable material. It may vary vertically and horizontally.

5. Soil properties of particular importance to the hydrology of watershed management are:

   a. Depth:

      1. This can limit t : volume available for storage of water.

      2. Soils less than 12 inches in depth are considered "shallow". These project very limited opportunities for effective watershed management.

b. Texture:

1. Is the size of the soil particles.

2. Discuss tables 1-2A and 1-2B.

c. Structure:

1. Is the shape and arrangement of the soil particles.

2. Discuss table 1-3.

d. Porosity:

1. Is the percentage by volume of the soil mass which is not occupied by solid particles.

2. This is the space available for passage and storage of water and air.

3. Discuss porosity of different textured soil.

E. Underlying Geology

1. This is the underlying bedrock which forms the bottom of a watershed.

2. Geology affects the watershed hydrology in two ways.

a. Form of the underlying rock determines whether the underground watershed coincides with the watershed boundary as determined by the surface configuration.

b. Determines whether the bedrock can be penetrated by water.

PART III (Instructor Notes)

I. Watershed Management Planning and Application

A. What is watershed management planning?

1. Formulation of management objectives and policy pertaining to the use, protection and conservation of the water resource.

B. Objectives must be defined, they may vary depending on your situation

1. Could include: integration of water management with other resources; coordination with other agencies, etc.

C. Watershed Management

1. To manage a watershed and the water resource must know information on water.

a. Quantity

b. Quality

c. Timing (frequency duration)

d. Form

e. Source

f. Needs of population

D. Information needed to manage watersheds (data collection).

1. Watershed resource inventory (Handout No. 5)

a. A collection of all information available which is related to and may have affect on the water resources. This includes the human and natural environment.

b. Explain watershed inventory outline.

c. Can identify problem areas, data needs, management concerns, etc.

d. Amount of detail depends on your needs and the specific situation you face.

2. Watershed improvement prescriptions (Handout No. 6)

   a. This is an action plan for application of an approved treatment program to attain the predetermined water resource goals.

   b. Lays out on paper how, when and why a problem area will be treated.

   c. It gives detail on work standards, cost, time frame, and

   d. It identifies a "problem area" and lays out on paper how, when and why the problem area will be treated. It gives detail on work standard, cost and time frame.

3. Water monitoring

   a. Monitoring provides the means for assessing, on continuing basis, the degree to which planning management, operation and improvement of the water resource are meeting goals and objectives.

   b. May monitor for quality, effects of other management practices, etc.

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT SHORT COURSE
March 31 - April 8, 1983

DAILY SCHEDULE

Thursday, March 31

7:30 - 4:00 PM	Part II Soil Erosion and Control - Sierra and Acevedo

Friday, April 1

7:30 - 4:00 PM	Part I General Information on Watershed Management and Hydrology - Bauer
	Part III Watershed Planning and Application - Bauer
	Practice Exercise - Bauer
	Field Preparation - Bauer

Monday, April 4

7:30 - 11:30 AM	Soil Erosion and Control - Sierra and Acevedo
12:30 - 4:00 PM	Part III continued - Bauer

Tuesday, April 5

7:30 - 4:00 PM	Field Exercise - Bauer, Sierra, Acevedo and McKinley
	1. Visit area with erosion problem in Caribbean National Forest.
	2. Watershed rescription preparation.

Wednesday, April 6

7:30 - 4:00 PM	Field Exercise - Bauer, Sierra, Acevedo and McKinley
	1. Check Damn construction.

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WATERSHED MANAGEMENT SHORT COURSE

Thursday, April 7

7:30 - 4:00 PM	Hydrology - McKinley, Bauer

Friday, April 8

7:30 - 4:00 PM	Hydrology Field Exercises - McKinley, Bauer

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

Part I - General Information on Watershed Management and Hydrology

I - Introduction

A - Definition

- Watershed Management

- Wildland Watershed Management

B - Purpose of Watershed Management

II - Natural Water Supplies

A - Worldwide

B - Tropical Regions

III - Description of a Watershed

A - Definition (of key terms)

B - Characteristics

1. area

2. length

3. width

4. depth

IV - The Hydrologic Cycle

A - Definition

B - Components of

1. Precipitation

2. Infiltration

3. Surface run-off

4. Evaporation

5. Transportation

6. Interception

7. Ground water

V - Environmental Factors and their Relationship to a Watershed

A - Weather

- Moisture and Precipitation

- Temperature

B - Vegetation

C - Topography

D - Soils

E - Underlying Geology

Part II - Soil Erosion and Erosion Control

I - Soils, Characteristics, Processes and Factors Influencing Soil Erosion

A - What is soil?

1. The soil profile

2. The four major components of soil

3. The mineral (inorganic) constituents in soils

4. The soil organic matter

- Soil Water

- The soil air

B - Soils Form Processes

1. Meteorization

- Primary

- Secondary

2. Chemical Meteorization

- Hydrolisis
- Solution
- Hidration
- Carbonation
- Oxidation
- Reduction

C - Soil Forming Factors (pedologic factors)

1. Climate
2. Plants and animals
3. Topography
4. Parent material
5. Time

D - Soil Classification

1. Classification by slope
2. Classification by capability classes

II - Soil Erosion

A - What is soil erosion?

B - Forms of soil erosion

1. Laminar erosion
2. Rill erosion
3. Gully erosion

- V shaped gullies
- U shaped gullies

C - Degrees of Soil Erosion

1. Slight

2. Moderate

3. Severe

D - Erosion Factors

1. Formula

- A = RKLSCP

III - Introduction to Soil Conservation Planning

A - Inventory

B - Assessing

C - Evaluating treatment alternatives

D - Selecting alternatives

E - Recording alternatives

F - Application of conservation practices and measures

IV - Land Treatment Systems

A - Resource Management Systems

1. Woodland

2. Forest

3. Wildlife

4. Recreation

B - Common Woodland Management Practices

1. Tree planting

2. Woodland site preparation

3. Woodland thinning

4. Woodland pruning

5. Woodland improvement

V - Soil and Water Conservation Practices

A - Access roads

B - Diversions

C - Hillside ditches

D - Contour farming

E - Critical area planting

F - Crop residue use

G - Grassed waterway or outlet

H - Stubble mulching

VI - Soil and Water Conservation in Critical Areas

VII - The Use of Plant Materials in Conservation

A - Plant Material Establishment Techniques

Part III - Planning and Application

I - Watershed Management Planning and Application

A - What is watershed management planning?

B - Objectives

C - Information need to know for watershed planning

D - Data requirements

1. Watershed resource inventory

2. Watershed improvement prescriptions

3. Water monitoring

Part IV - Hydrology and Water Monitoring

I - Water Quanity (discharge)

A - Current Meter Measurement *

1. AA Price

2. Pygmy

3. Types of measurements

- Wading

- Cable way

- Bridge

Questions

B - Other Methods (procedures will be introduced only)

1. Weirs

2. Plume

3. Slope areas

4. Volumetric

C - Water-stage Recorders

1. Continuous *

2. Non-recording

- Staff

- CSI

- Wire weight

Questions

II - Water Quality

A - Field Parameters

1. pH

2. Conductance

3. Dissolved oxygen

4. Alkalinity

5. Temperature

6. Coliform (total, fecal, fecal strep)

Questions

B - Sediment *

1. Sampling equipment

2. Brief introduction to analysis

3. Suspended

4. Bottom

5. Brief introduction to calculations

Questions

C - Chemical

1. Common ions

2. Nutrients

3. Trace metals

Questions

* Emphasis they should know how to measure discharge (with and without recording gear).

TROPICAL FORESTRY AND ENVIRONMENTAL QUALITY SHORT COURSE

WATERSHED MANAGEMENT

Part I - General Information on Watershed Management and Hydrology

I - Introduction

A - Definition

- Watershed Management

- Wildland Watershed Management

B - Purpose of Watershed Management

II - Natural Water Supplies

A - Worldwide (Table 1-1)

B - Tropical Regions

III - Description of a Watershed

A - Definition (of key terms)

B - Characteristics (Handout No. 2)

1. area

2. length

3. width

4. depth

IV - The Hydrologic Cycle (Handout No. 3)

A - Definition

B - Components of

1. Precipitation

2. Infiltration

3. Surface run-off

4. Evaporation

5. Transportation

6. Interception

7. Ground water

V - Environmental Factors and their Relationship to a Watershed

A - Weather

- Moisture and Precipitation

- Temperature

B - Vegetation

C - Topography

D - Soils (Handout No. 4)

E - Underlying Geology

Part II - Soil Erosion and Erosion Control

I - Soils, Characteristics, Processes and Factors Influencing Soil Erosion

A - What is soil?

1. The soil profile

2. The four major components of soil

3. The mineral (inorganic) constituents in soils

4. The soil organic matter

- Soil Water

- The soil air

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- Secondary

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- Oxidation
- Reduction

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1. Climate
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4. Parent material
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1. Classification by slope
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VII - The Use of Plant Materials in Conservation

A - Plant Material Establishment Techniques

Part III - Planning and Application

I - Watershed Management Planning and Application

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B - Objectives

C - Information need to know for watershed planning

D - Data requirements

1. Watershed resource inventory (Handout No. 5)
2. Watershed improvement prescriptions (Handout No. 6)
3. Water monitoring

Part IV - Hydrology and Water Monitoring

I - Water Quanity (discharge)

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3. Types of measurements

- Wading

- Cable way

- Bridge

Questions

B - Other Methods (procedures will be introduced only)

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4. Volumetric

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Questions

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A - Field Parameters

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3. Dissolved oxygen

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6. Coliform (total, fecal, fecal strep)

Questions

B - Sediment *

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4. Bottom

5. Brief introduction to calculations

Questions

C - Chemical

1. Common ions

2. Nutrients

3. Trace metals

Questions

* Emphasis they should know how to measure discharge (with and without recording gear).

Start Audio Tape #4 and Slide Tray #4
At This Point

UNIT #4. Road Construction and Its Potential for Erosion

When top soil is removed during road construction the natural filtering action of the soil is destroyed. Trucks and equipment then compact the underlying soil.

When it rains or the snow melts, surface water is not absorbed because of this soil compaction. Instead the surface water begins to flow onto and over the roads. As the volume and velocity of the runoff increases, the roads become man-made stream channels which allow even greater amounts of water to move over the surface, all the while eroding away more soil and damaging the roads. If roads are not laid out correctly, if ditches, crossdrains, culverts and other drainage devices are not used on a road that cuts across a slope then these problems may occur.

Management of water control goes a long ways towards preventing accelerated erosion. Water control can be achieved by laying the roads out correctly and by finding ways to get the water off the roads quickly before erosion begins.

The principle is simple: poorly planned and constructed roads lead to rebuilding, lost time, higher costs, and increased pollution in our streams, rivers and lakes.

Potential problems associated with road construction are considered in Unit 4.

Unit Objectives

At the end of Unit 4, Y U will.....

1. ....understand how each one of the following activities in road construction is related to water quality management and pollution control:

   a). Road layout through Planning and Pioneering,
   b). Construction Design Constraints,
   c). Maintenance and Inspection,
   d). Retirement or "pu ing the road to bed".

RESTART the Tape

ROAD LAYOUT CONSIDERATIONS for MAXIMUM EROSION CONTROL

General Principles	How Erosion Is Reduced
1. Reduce the total number of miles of road length:	
a). Avoid long, steep grades.	**Reduces the total area of compacted soil.
b). Avoid sharp curves.	**Reduces the volume and velocity of runoff.
	**Reduces the potential for slope overloading and failure of the fill and cut areas.
2. Minimize changes in the natural stability of the land.	
a). Place roads on high ground with gentle grades.	**Reduces volume and velocity of runoff.
b). Keep roads out of wet areas.	**Reduces risk of disturbing stored sediment. Prevents further sediment delivery into nearby streams
c). Keep roads off the tops of toes of banks and slopes.	**Reduces risk of soil overloading which can cause failure of fill and cut areas.
3. Maximize drainage potential of the road area.	
a). Move surface water quickly off road surfaces, out of ditches and onto undisturbed forest floor.	**Reduces potential for runoff buildup and increases time for absorption and infiltration.
b). Relieve subsurface runoff quickly and away from unstable soil areas.	**Reduces risk of cutbank and fill area failures. Reduces risk of sidecast and end-haul area failures.

RESTART the Tape

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Locating Haul Roads in the Forest

STEP 1. Establish "control" points before setting off. These points might be where the road:

1. begins,
2. ends,
3. crosses a stream,
4. follows a stream,
5. follows a ridge, etc.

These points should be places you can identify on a map and on the ground.

STEP 2. Walk the rough road location using the control points to guide you.

1. Flag this route as you walk in and make a mental note for possible landing sites and borrow pit areas.
2. Check skidding distances on both sides of your proposed route.

STEP 3. Walk back out following your flagged route.

1. Adjust your flagging to take advantage of natural features that will make road construction and drainage easier.
2. As you go, check the grades of the flagged route to make sure they are reasonable (within recommended guidelines).
3. Mark areas suitable for landings and borrow pits.
4. Make sure the route provides the best access to present and future harvest areas.

RESTART the Tape

PROBLEM: Selecting the Best Road Layout

Plans A, B, and C show three ways to place truck roads on a forest site. The plan calls for a regeneration cut. The harvest area boundaries are marked.

Circle the plan which you feel will minimize the potential for increased erosion.

Discuss with the group why you selected your plan.

Haul Road:

Harvest Boundaries:

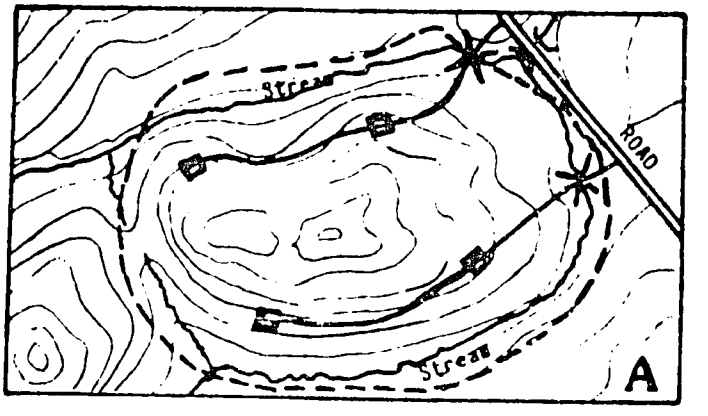
Bridge:

Landing:

Plan "A" Layout

2 Bridges
3 Miles of Haul Road

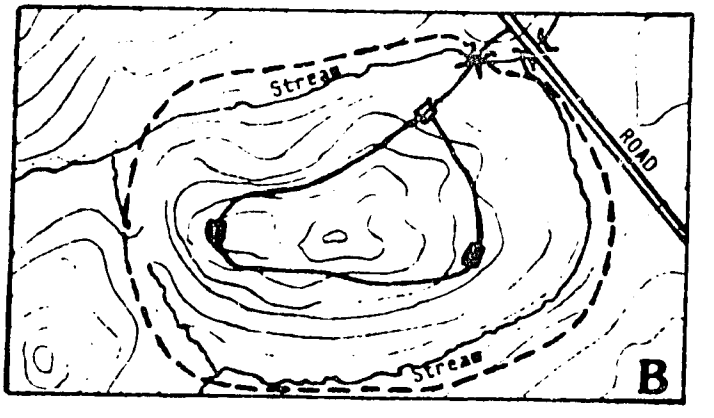
(Comment: Road and Bridge construction costs are high.)



Plan "B" Layout

1 Bridge
3½ Miles of Haul Road

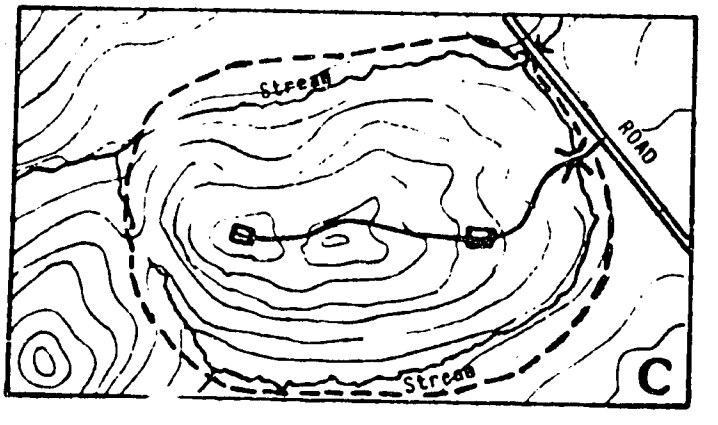
(Comment: Is the Loop Road necessary?)



Plan "C" Layout

1 Bridge
2 Miles of Haul Road

(Comment: Haul Road follows high ground. Minimal Road construction.)



(Adapted After: "Erosion Control On Logging Jobs". The Land Use Handbook, Section 6. Maine Department of Conservation, page 7. November, 1978.)

When Finished, Read page 25

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PROBLEM: **Systematic -vs- Random Road Designs**

Systematic road designs go a long ways towards reducing the potential for erosion while random road designs may increase erosion and sediments downstream.

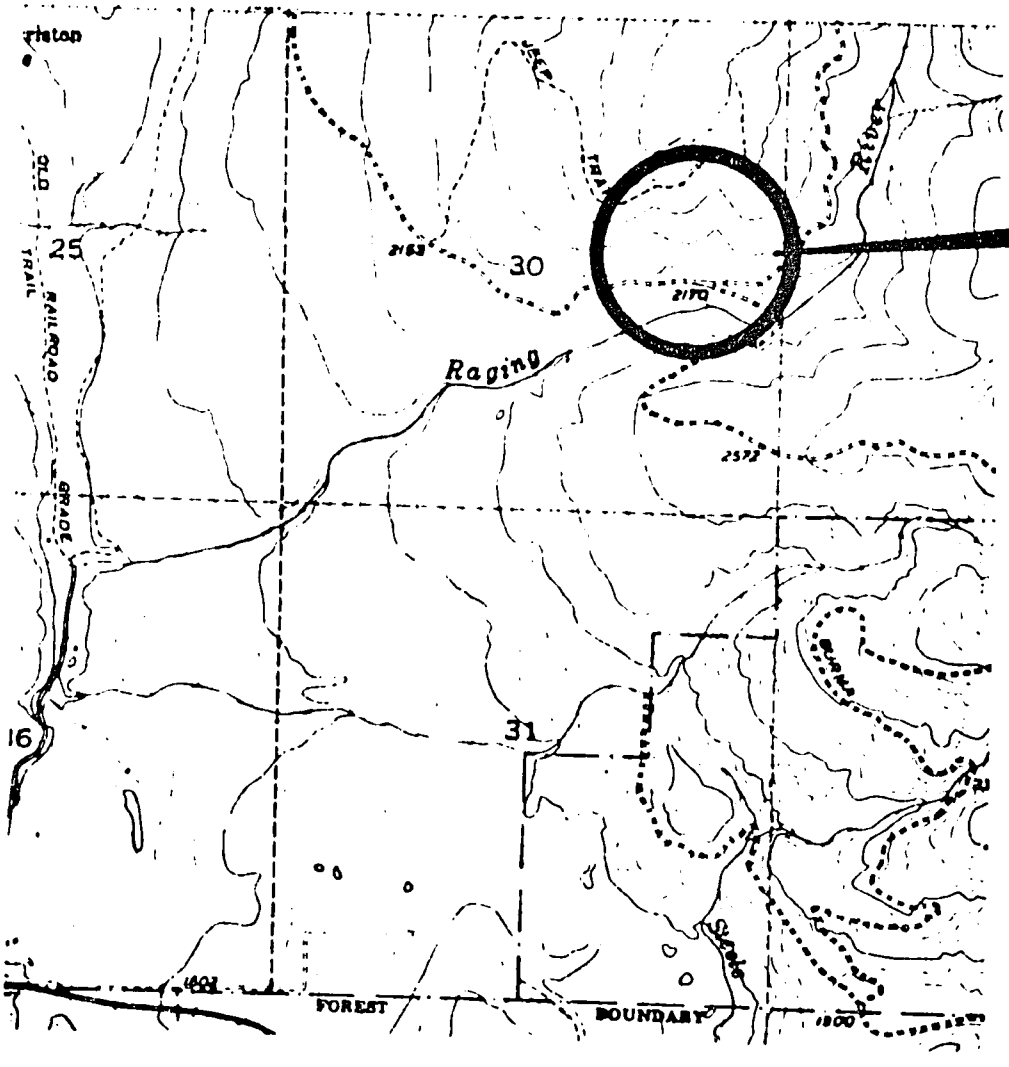
Directions:

1st. Study the general topography in the map below, and especially the area within the dark circle.

2nd. Then study both road layout designs shown on page 27.

3rd. Circle the layout on page 27 you prefer and state the reasons for your choice.

(NOTE: The instructor will provide both Contour feet_____ and the Lineal Scale_____.)



Area of Diagrams on page 27.

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Road Construction Activities Which Affect Erosion

1. Timing of construction and operations.

2. Design Constraints:

a). Road Grade
b) Road Width

c). Road Angle
d). Road Alignment

e). Road Surfacing
f). Sidecasting and End-Hauling

g). Method of Drainage:

-insloping -vs- outsloping
-culverts, waterbars, bridges, broad base dips

h). Stream Crossings

3. Equipment:

(Matching equipment size to the job. For example, not using a D-9 tractor to build skid trails.)

4. Stabilization:

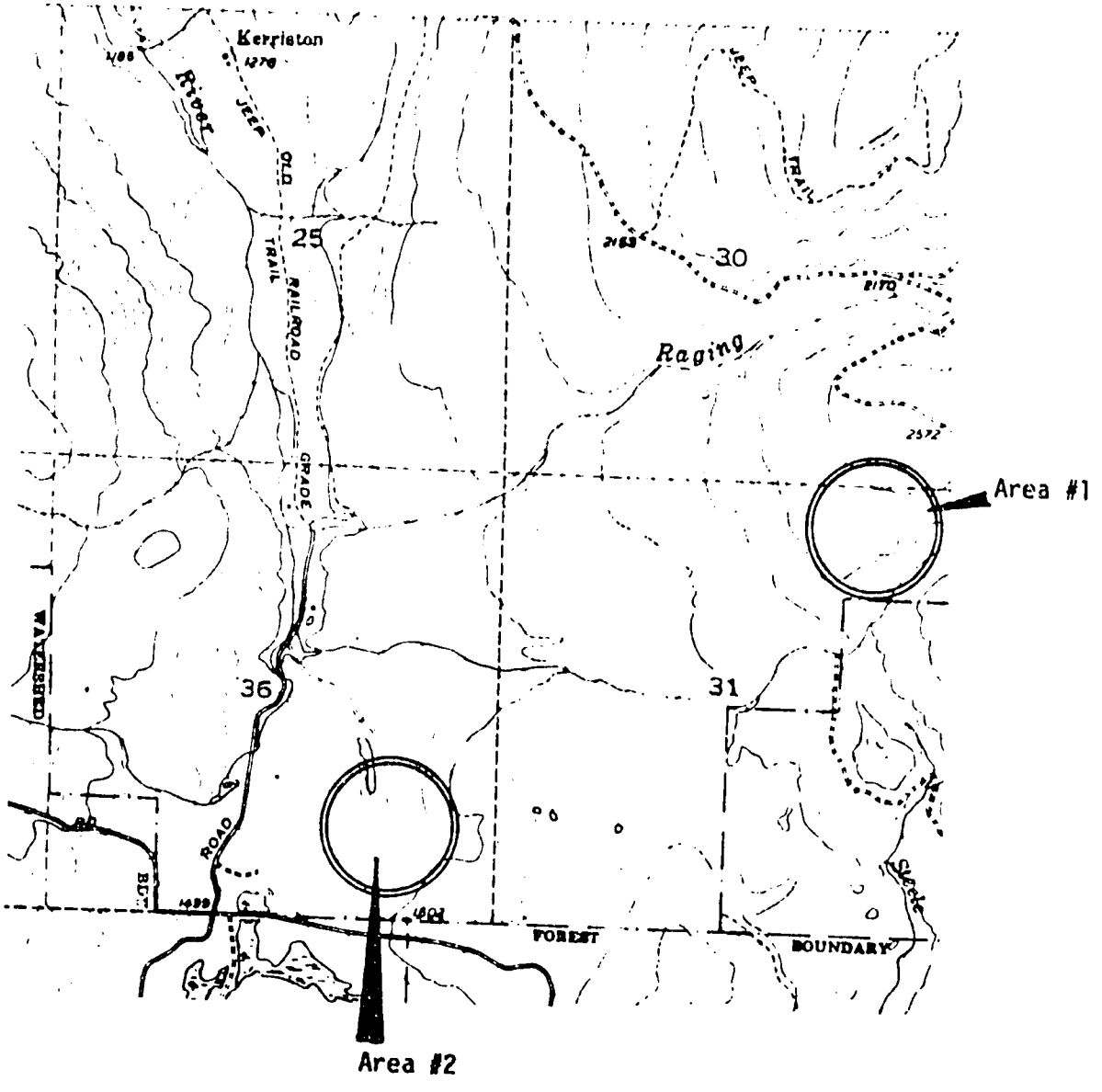
Revegetation of disturbed soil (rip-rap, culverts and stream crossings, tach-tar or hydroseed slopes and fills.)

RESTART the Tape

PROBLEM: **Using Design Constraints in Road Layout**

Directions: Study the two areas circled on the topographic map below. For each area, discuss how (1) road grade, (2) road width, (3) road angle, (4) road alignment, (5) road surfacing, and (6) sidecasting and end-hauling might be different for the two areas.

(NOTE: The instructor will provide both Contour feet_____ and the Lineal Scale_____.)



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PROBLEM: Controlling Erosion Through Drainage Design

Directions: Study each of the drainage control practices on page 31 and see where each one was used in the top diagram.

Then state why the particular practice was used at that specific spot on the road.

Some of the practices may not be all that sound. If so, state WHY?

Figure 1. Insloped roadbed:

Figure 2. Waterbar:

Figure 3. Culvert:

Figure 4. Dip:

Figure 5. Settling Basin:

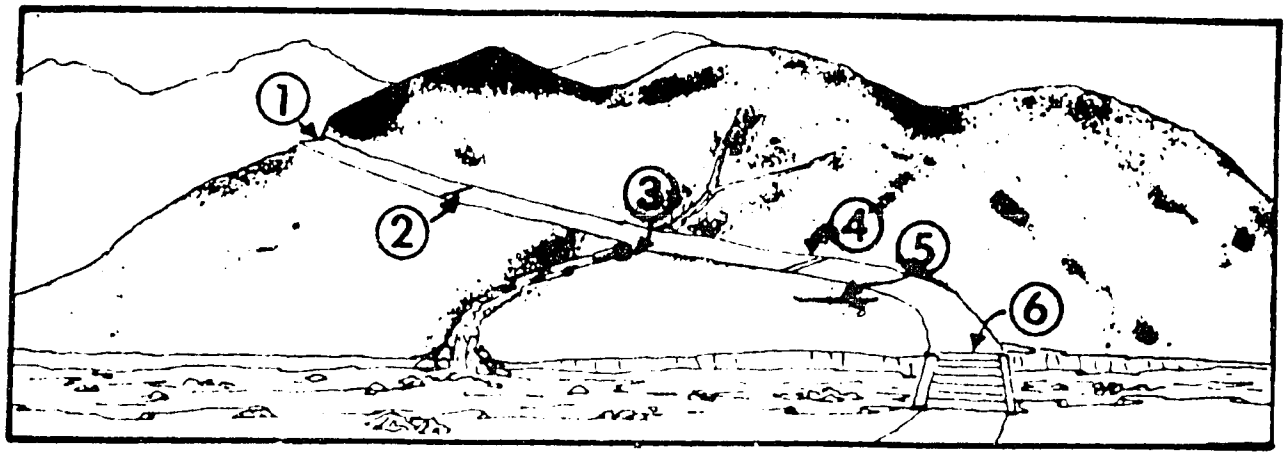
Figure 6. Bridge:

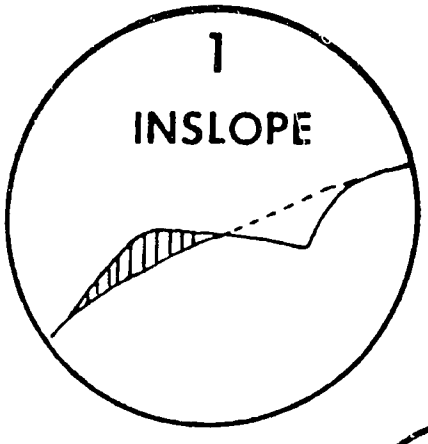
Discuss the following questions:

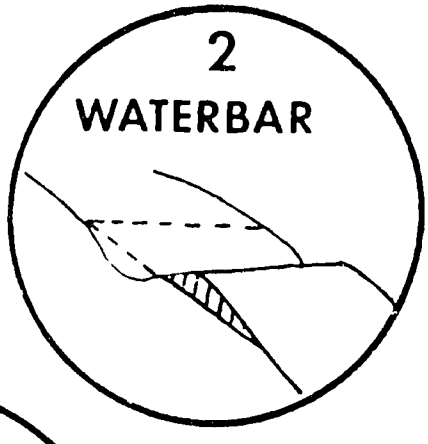
1st. Why is each of the drainage types used? When and where should they be used?

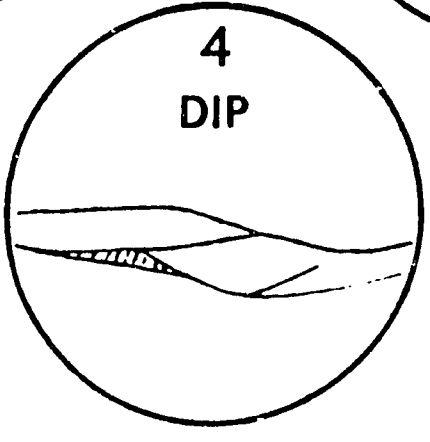
2nd. What drainage practice(s) are recommended for heavy use roads?

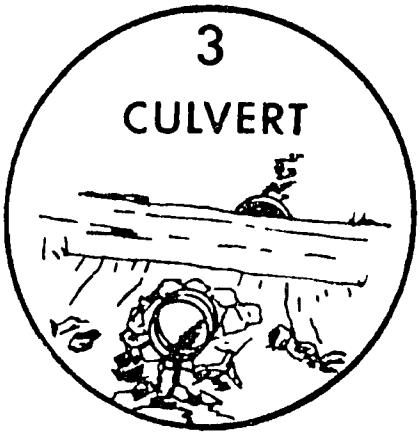
For light use roads?

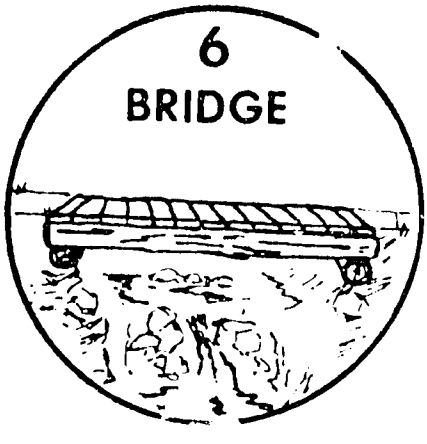












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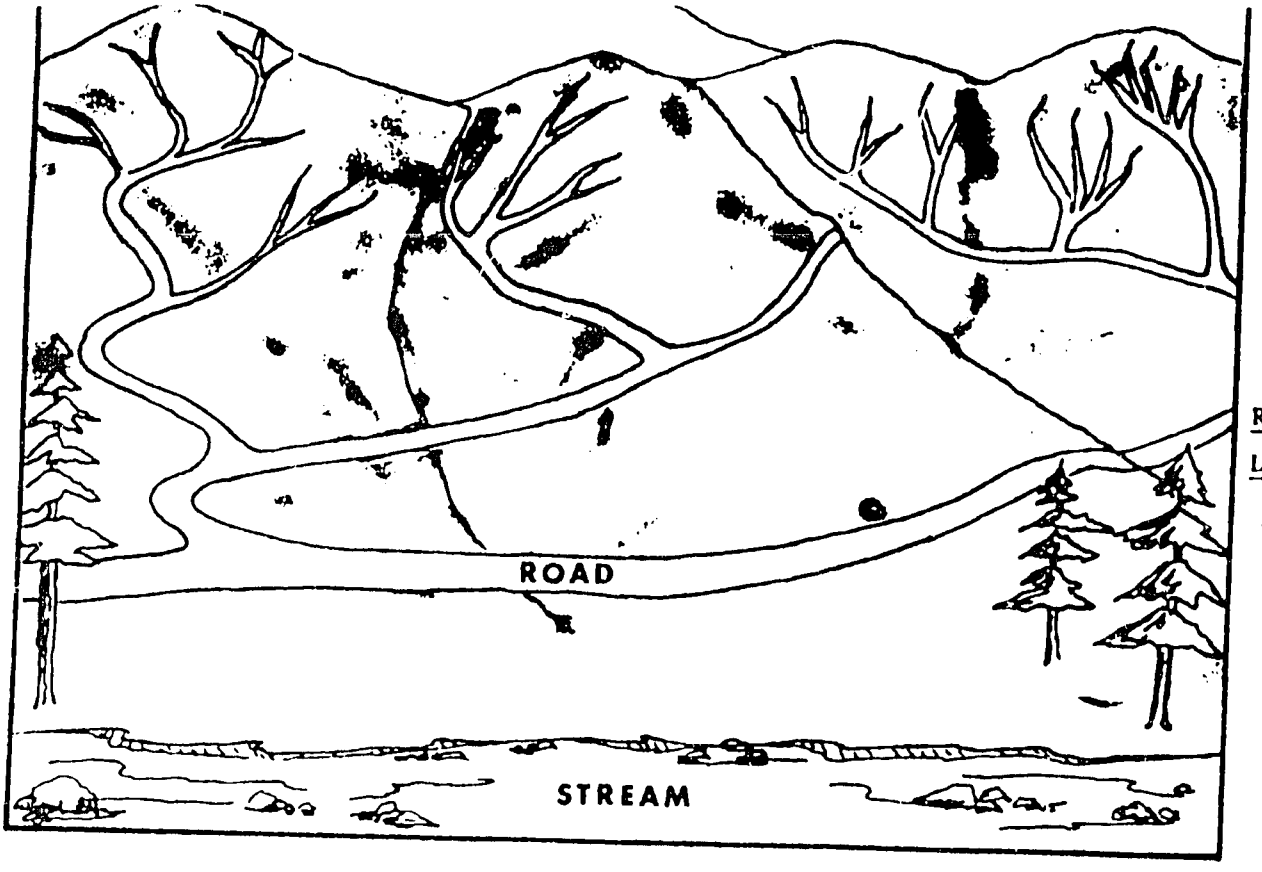
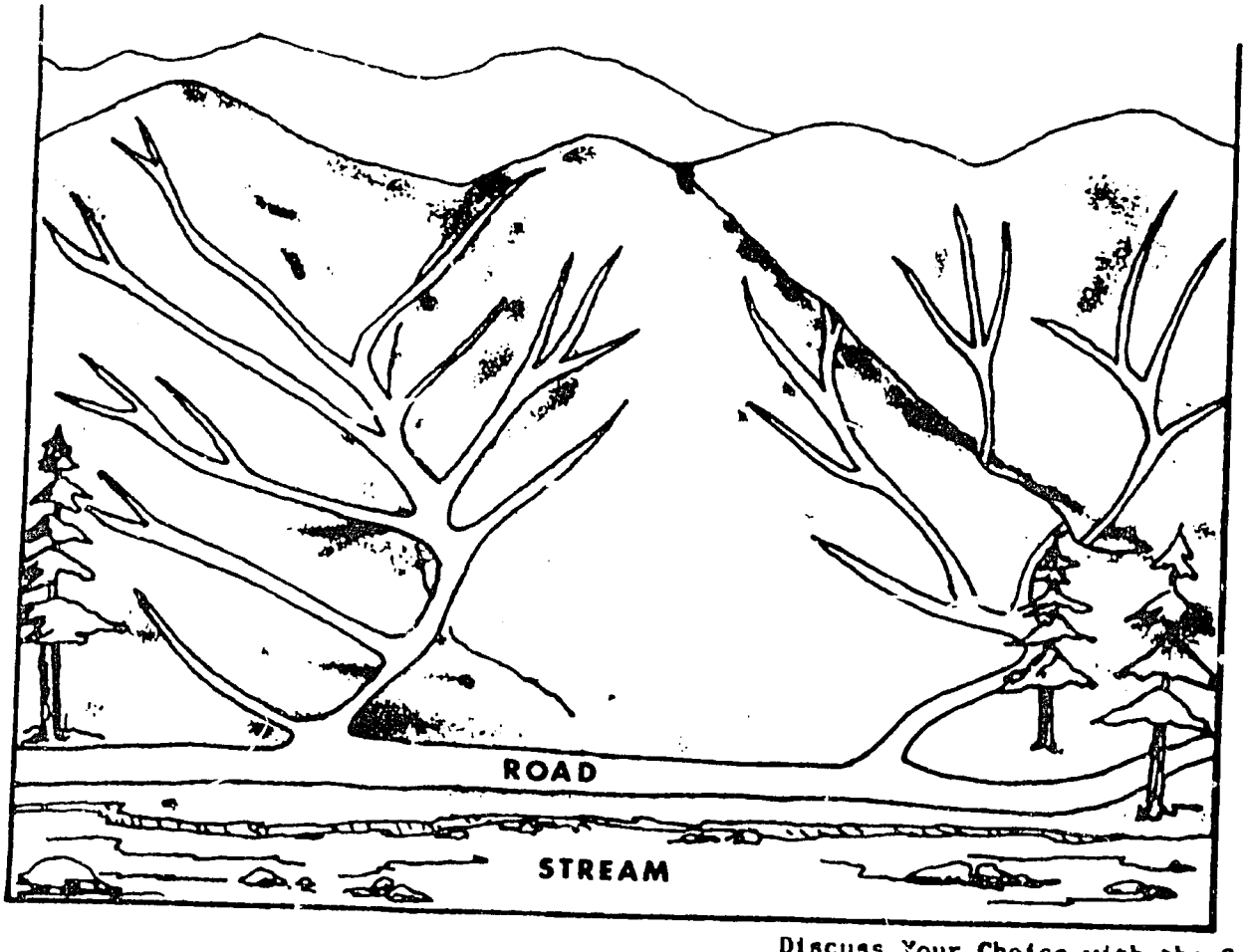


Road Layout #1.



Road Layout #2.

Discuss Your Choice with the Group then read page 28.

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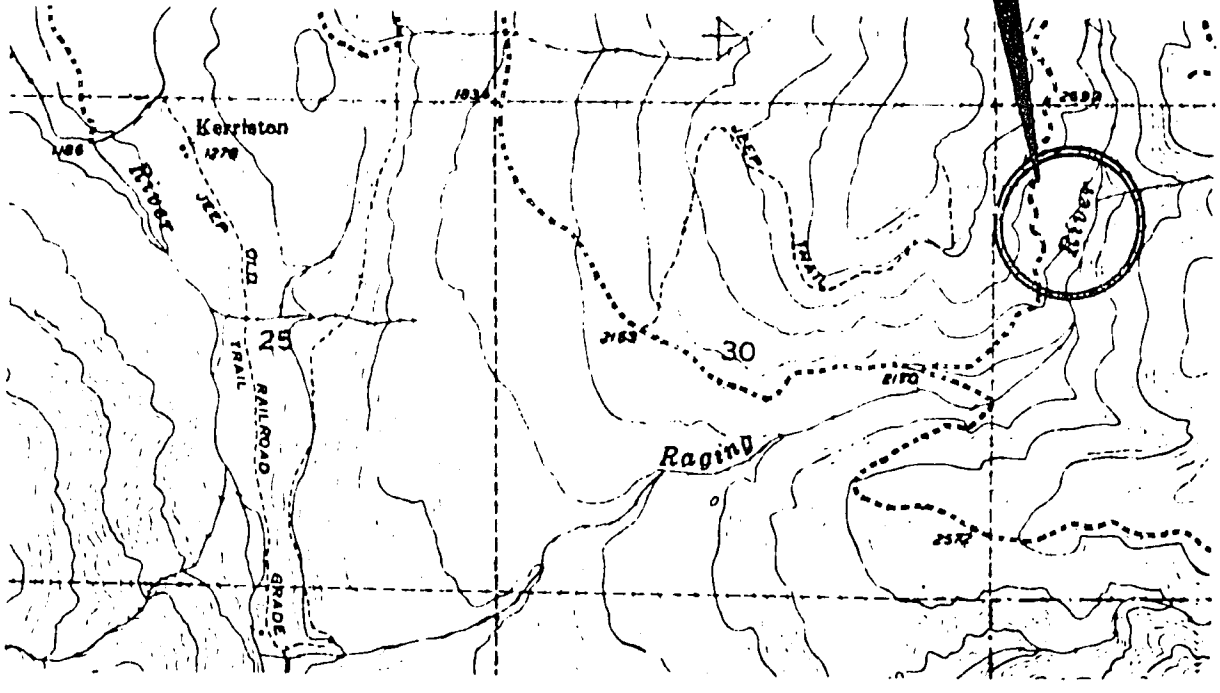
PROBLEM: Maintaining and Inspecting Your Road System

Directions: Study the area circled on the topographic map below and the diagram of the area shown on page 33.

Then discuss with the group the question at the bottom of this page.

(NOTE: The instructor will provide both Contour feet_____ and the Lineal Scale_____.)

Area of Diagram shown on page 33



Discussion Question: How could an active Maintenance and Inspection Program change this situation?

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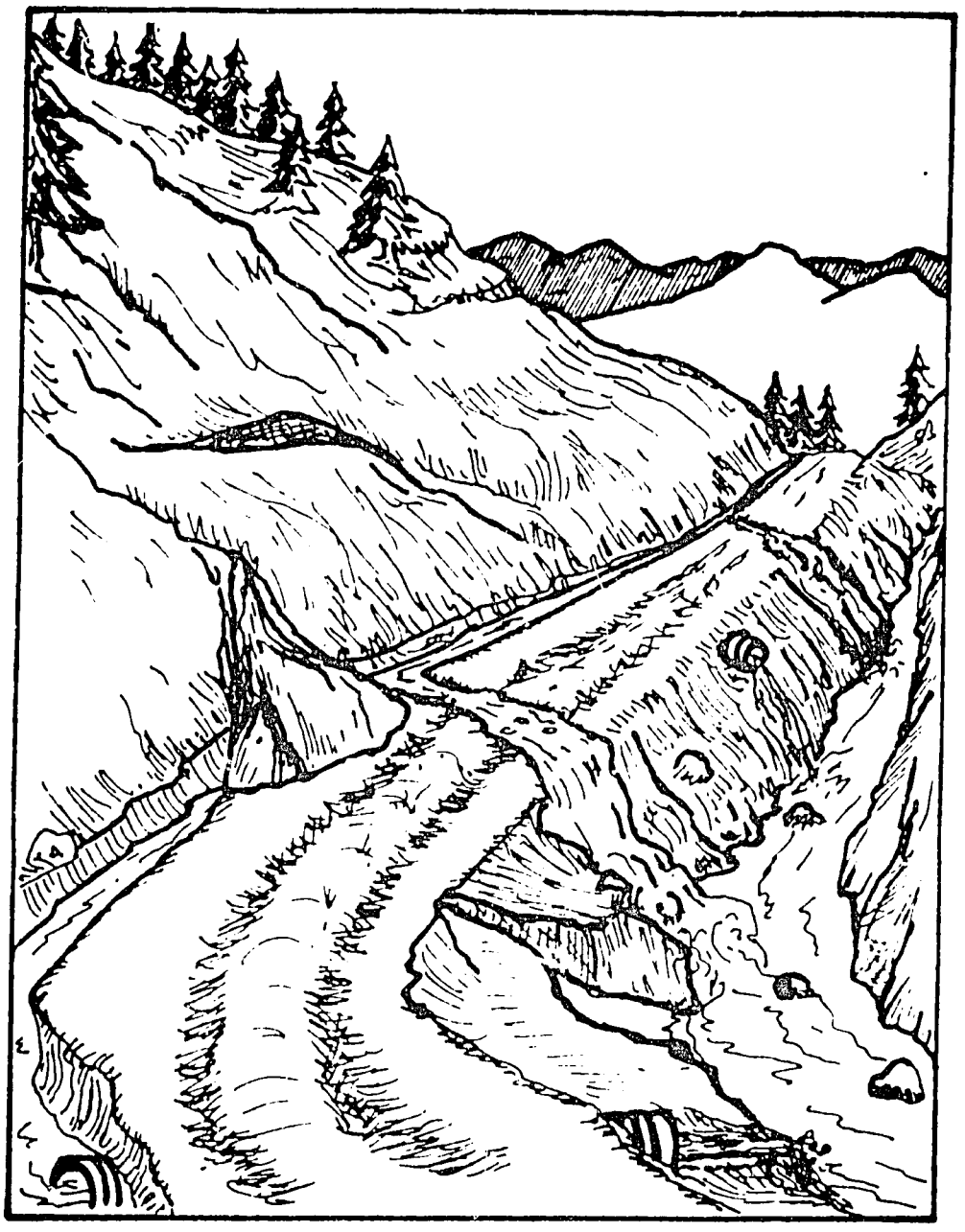

PROBLEM: Maintaining and Inspecting Your Road System.

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After Discussing Your Answer with others move on to pages 34 and 35 and complete the problem.

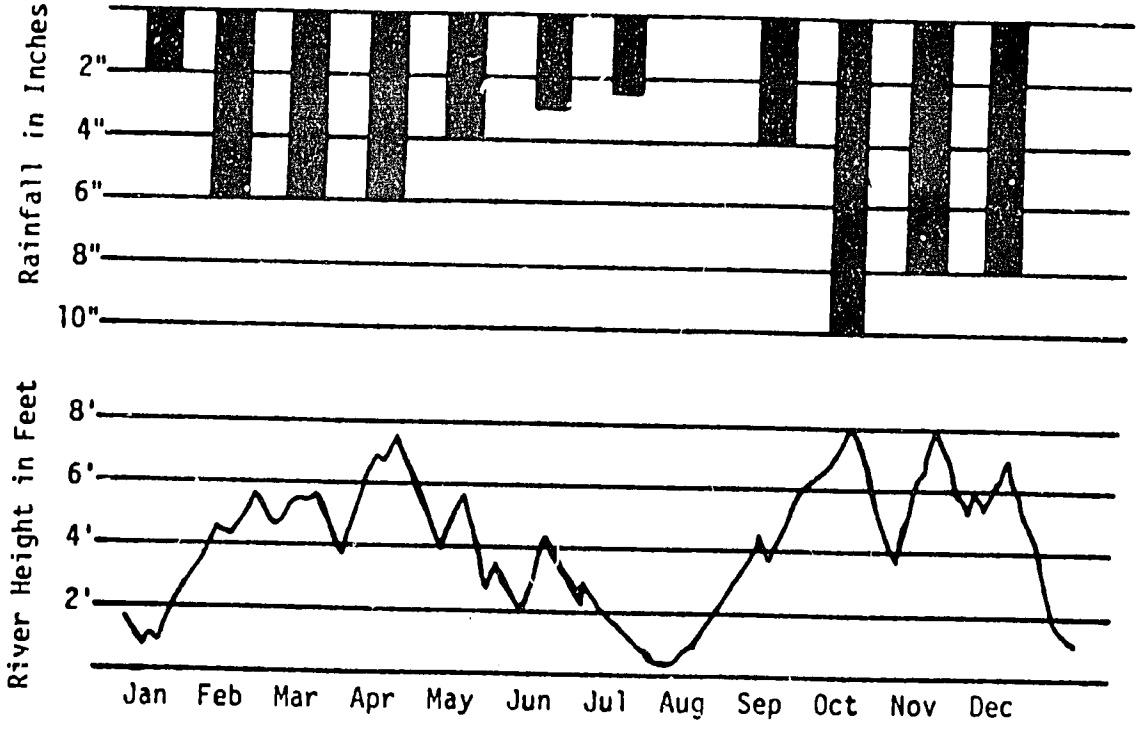
PROBLEM: How's Your Maintenance?

You are supervising road construction in an area of moderately sloping terrain. The soils are generally well drained with the exception of a small flat area of poorly drained clays which is crossed by a secondary road leading to a far corner of the property.

Directions: 1st. Look at the average annual precipitation for the area in the graph below.

2nd. Look at the hydrograph for a nearby river which is fed by streams in your construction area.

3rd. Continue on to page 35.



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PROBLEM: **How's Your Maintenance?**

Directions: 4th. Using the information on page 34, set-up a maintenance schedule for the road and drainage systems.

List below the recommended actions for each month.

5th. Then discuss the question at the bottom of the page.

January:

February:

March:

April:

May:

June:

July:

August:

September:

November:

December:

Question: What are the key factors influencing your decisions on maintenance for this site?

RESTART the Tape

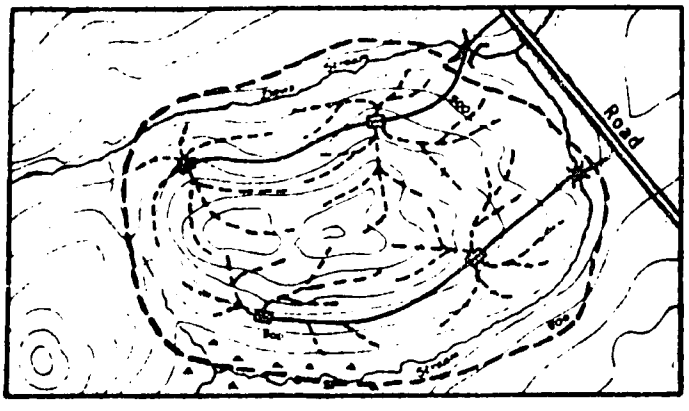
PROBLEM: **Retiring a Road System**

Look at the segment of a watershed in the topograp! map below.

A regeneration cut has been made within the marked harvest area.

Directions: Given this situation what kinds of act would you take to retire the road?

List your actions below and discuss yc ideas with others around you.



(Adapted After: "Erosion Control On Logging Jobs". The Land Use Handbook, Section 6. Maine Department of Conservation, page 7. November, 1978.)

RESTART the Tape

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1. Discuss how the planning, road layout and pioneering stages are essential in reducing the potential for accelerated erosion.

2. Discuss how specific design constraints (grade, width, angle, alignment, surfacing, sidecasting, end-hauling, method of drainage and crossing streams can control accelerated erosion.

3. Discuss how maintenance and inspection are critical features of the road construction process in controlling accelerated erosion.

4. Discuss the importance of "putting a road to bed" when considering the control of accelerated erosion.

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FORESTAL REGULATION FOR SPECIAL PERMITS NO. I

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ADMINISTRATIVE RULES

I. Legal Basis

The Secretary of the Department of Natural Resources, under the authority conferred by Article 6 of Law No. 133 of July 1st, 1975, adopts the present Administrative Rules to regulate the granting and management of Special Permits in the State Forests of Puerto Rico that are under the Secretary's jurisdiction.

II. Purpose

In compliance with forestry policies, those land uses that are compatible with the optimum development of products, services, and forestry utilities shall be permitted under conditions that protect public interest as well as with due regard to the natural resources.

III. Special Permits

A written authorization from the Secretary of the Department of Natural Resources or his authorized representative is required for any use, leasing, location, construction, improvement, or any other utilization of the State Forests of Puerto Rico.

The right to grant these permits is delegated expressly to the Chief of the Forest Service.

Special permits shall not exceed a fifteen year term and must indicate the conditions and limitations regarding the use or development which they authorize. They may not be ceded or conveyed without the Secretary's approval and may be revised and amended annually. They will not be in force if they are not used within the first year of their operation.

The Secretary may compel any applicant or concessionary of a permit to show ledgers, papers, and documents that to his judgment are necessary for the administration of these rules.

A. Special Permits for Electronic Use

1. Definitions

a. Compatibility-the capacity of two or more electronic equipments to operate contiguously without interference between them.

b. Concessionary-a person who receives authorization for a special use permit for those uses contemplated in these rules.

c. Emplacement-the place in the State Forest designated by the Secretary; when it referes to an Electronic Emplacement, it will be understood as the place designated for the operation of equipment that transmits and receives radio signals, excluding posts and television antennas designated for the reception of local programs and passive reflectors.

d. Electronic Equipment-it includes, but is not limited to, systems, equipment and/or facilities associated with: AM/FM radio stations, television transmissions, microwave installations for all kinds of services, radio communication and radiotelephone, radio navigation and trace by radar and telemetry.

e. Installation-electronic equipment or structure associated with such equipment located in the State Forests. The term is also used to describe the emplacement of such equipment in forestry lands.

f. License-certification that is in force for the operation of a transmitter issued by the Federal Communications Commission (F.C.C.) in the event of nationals or juridical federal people, or of the Office of Telecommunications Policy (O.T.P.) in the case of Federal Agencies.

g. Special Permit-written authorization from the Secretary for any use, lease, location, construction, improvement or any other utility in the State Forests.

h. Special Permit for Electronic Emplacement-written authorization for the operation of equipments that transmit and receive radio s nals within the State Forests.

i. Exclusive Permit-written authorization granted to only one concessionary in the State Forests.

j. Secretary-the Secretary of Natural Resources, the Secretary's authorized representative, or the Chief of Forest Service.

2. Management Policy for t Electronic Permits

The Department of Natural Resources adopts, as a policy, not to grant exclusive permits for emplacements or electronic instal-

lations. Such exclusive permits shall be granted only for security reason of the Commonwealth of Puerto Rico, the Government of the United States of America, and in other situations in which the nature of the use and the installation justifies it fully.

For any special permit, with the exception of the exclusive permits, the Secretary reserves the right to authorize the use by a third person of the emplacement, buildings, towers or the concessionary's structures which support antennas, provided that such uses do not interfere with the concessionary's operations. This concessionary will have the right to receive from third persons a reasonable compensation for such uses.

The Secretary will have access at all times to the areas of emplacement and electronic installations, in order to fulfill his administrative duties in the State Forests.

Every concessionary who wishes to install and operate electronic equipment must obtain an additional special electronic permit.

The only electronic emplacement applications that will be considered are those from the holders of licenses issued by the F.C.C. and O.T.P. A State Forest must appear as the location of the authorized station in such licenses.

Permits may be issued to:

a) proprietors of structures designed to accomodate electronic equipment.

b) proprietor-users of electronic equipment located in the emplacements.

c) users of electronic equipment located in the emplacement who lease the electronic equipment without receiving installation services and maintenance from the proprietor.

d) contractors who supply electronic services to equip-

ment they own or that has been leased to holders of licenses in the emplacements.

Proprietors of electronic equipment who rent it to concessionaries or service contractors are not required to have permits if such proprietors do not provide installation or maintenance services.

The concessionary is authorized only to occupy the grounds and structures, and conduct those activities which are expressly specified in his permit. He may sublease the use of the authorized facilities with previous written consent of the Secretary; nevertheless, he will be responsible for the thorough fulfillment of the terms and conditions of his permit.

When a concessionary hires a third person to provide installation and maintenance services to the radio equipment of his exclusive use, it will not be necessary for the third person to obtain a permit.

A new permit must be obtained when electronic installations are added to those already in existence. The proprietor of the equipment to be added will also have to obtain a permit unless he already has one for the equipment installed in that building. In the latter case, the existing permit will be amended in order to add the new equipment and make clear in the permit the owner of the license for whom it operates.

If there is space in a radio structure of the Forest Service, a concessionary may be authorized to locate his equipment in that structure, provided that both equipments are compatible and are contained in a metal box or cabinet that provides reasonable protection againts direct radiation of energy transmitted. An

additional fee will be charged for using the building.

Special permits for electronic emplacement will not be authorized in the observation towers of the State Forests.

The appropriate distance between one antenna and another is determined, in general terms, by the frequency involved, the transmission power, and the probable direct influence of interaction between adjacent antennas.

When frequencies are close, a greater distance must be kept if space allows for it.

The fact that under certain conditions the emanations or radiation from radar and microwave apparatus are harmful to health is acknowledged. Nevertheless, safe levels of radiation and exposition have not been defined.

It is established as policy that these installations will have labeled dangerous. In those situations where people have easy access to the area, and public security is involved, the concessionaries must install a cyclone fence in addition to the signs.

3. Responsibilities of the Forest Service

The Secretary may issue a special electronic emplacement permit once the applicant has submitted a project of location and development which has been duly approved, and the procedures established for the F.C.C. or O.T.P. licenses have been fulfilled. Short term special permits to cover operations of an extraordinary nature may be granted.

To determine the duration of special permits, the following criteria, among others will be used: land management plans, derived public benefits, useful life span of the authorized and associated facilities,

financial investments and operation of licenses and other permits.

Use permits for a fifteen (15) years term will be granted only in exceptional cases.

The agency that granted the license of authorization for transmission is responsible for the fulfillment of the conditions of these licenses. Problems regarding the interference of communications or other analogous ones must be solved between the concerned parties through the F.C.C. and O.T.P.

The concessionaries will be responsible for any damage or loss in the State Forests. They must acquire a public responsibility policy in behalf of the Commonwealth of Puerto Rico and the Department of Natural Resources which covers any damages or injuries caused by their operations in the State Forests. The limits of the policy will be determined in each case taking into consideration the nature of the operations and their size and cost. The policy will not be less than $200,000 in any case.

4. Location of the Emplacement

The Forest Service will prepare a plan for the Development of the Electronic Emplacements for each area classified as available for the establishment of electronic facilities in the future. The general policy of that plan will be to group the concessionaries in common facilities so that structures in the State Forests will be reduced as much as possible.

The Plan for the Development of the Electronic Emplacements will contemplate the eventual development of these facilities. It will include access paths and roads, water lines, telephone and electric lines, parking areas, construction of structures, and areas for improvements. In the preparation of the plan, the following criteria will be pursued:

a) to maximize the number of installations per building.

b) to put electric lines and cables under ground within the developed areas.

c) to reserve the areas of hiest elevation for those omnidirectional or great range transmitters, and the lower elevations for those transmitters that require less range in distance and direction.

d) to utilize the whole area acknowledging that one adequate installation will normally attract others.

5. Procedures to be followed in the applications for emplacements

Applications for a special permit for electronic emplacements will be made in the application forms provided by the Forest Service. A minimum charge of fifty ($50.00) dollars will be paid for such applications. The following information must be given in detail:

a) ground to be occupied or used.

b) description of the project including schematic maps and plans.

c) benefits of the project.

d) environmental impact.

e) terms and conditions proposed to the Secretary and any other information required by the Secretary.

If it becomes necessary, the petitioner must pay the expenses of his project's evaluation incurred by the Department of Natural Resources, which will have a minimum fee of two hundred and fifty ($250.00) dollars.

Once the application for electronic emplacement is approved, the petitioner must survey the approved area if this has not been done.

When the petitioner selects an emplacement that has not been classified for electronic use, he will be informed that such an emplacement will be evaluated, and its availability will be judged on the basis of land management criteria. The availability of the emplacement cannot be notified until the evaluation mentioned above has been made. If availability is determined, a Plan of Emplacements must be prepared, and it must be approved before any occupation or construction is begun.

Procedure for different situations:

a) Emplacement is not available --if the emplacement applied for is not available, the petitioner will be immediately notified.

b) Emplacement is available --if the emplacement is available and the respective plan is duly approved, the application will be processed immediately.

(1) If there are not any concessionaries, the Secretary will issue the corresponding permit.

(2) If there are concessionaries in adjacent areas, copies of the applications will be sent to each one by regular mail, and they will have ten (10) work days to comment on the applications.

At the time when his application is accepted, the petitioner must facilitate and supply the necessary data and information so that the Secretary may complete the applications required by the Puerto Rico Planning Board and any other governmental agency.

6. Types of Permits

Different types of Permits for Electronic uses are identified in the following:

(1) Class A

a. Conditions:

The concessionary who owns the building and the electronic equipment leases the latter without receiving installation or maintenance services from the lessee and operates them for his exclusive use.

(2) Class B

a. Conditions:

The concessionary who owns the building, suble-

ases space to third persons, and does not use space for his own electronic equipment.

(3) Class C

a. Conditions:

1. The concessionary owns the building
2. He may sublease space to third persons
3. He owns the electronic equipment or leases it without receiving installation or maintenance service from the lessee
4. He leases electronic equipment to third persons
5. He does not operate electronic equipment for his own use

(4) Class D

a. Conditions:

1. The concessionary owns the building
2. He may sublease space to third persons
3. He owns electronic equipment or leases it without receiving installation or maintenance service from the lessee
4. He leases electronic equipment to third persons
5. He operates electronic equipment for his own use

(5) Class E

a. Conditions:

1. The concessionary does not own the building
2. He owns electronic equipment or leases it without receiving installation or maintenance service from the lessee
3. He leases electronic equipment to third persons
4. He does not operate electronic equipment for his own use

(6) Class F

a. Conditions:

1. The concessionary does not own the building
2. He owns electronic equipment or leases it without receiving installation or maintenance services from the lessee
3. He leases electronic equipment to third persons
4. He operates electronic equipment for his own use

(7) Class G

a. Conditions:

1. The concessionary holds a license
2. He does not own the building or the electronic equipment
3. He operates electronic equipment

7. Charges

There are four types of charges:

A. Concessionaries who own the building and have equipment or lease it for their own use and/or the use of third persons.

Annual Charge: - One hundred ($100.00) dollars or 0.2% of the sum of the building's total value, the antenna and its structures, and the electronic equipment located in the emplacement which belongs to the concessionary (whichever is greater); plus five (5%) per cent of the total fee on account of subleasing o space; plus five (5%) per cent of each fee on account of services and equipment leasing charges or twenty five ($25.00) dollar (whichever is greater).

B. Concessionaries who own electronic equipment, not the buildings, for their own use and/or the use of third persons.

Annual Charge: -Fifty ($50.00) dollar or 0.2% per cent of the total value of the electronic equipment located on the authorized area and which belongs to the concessionary, plus five (5%) per cent of the service charges and the charges of equipment leased, but not less than twenty five ($25.00) dollars per licens

C. Concessionaries who do not own buildings, structures or equipment, but whose license specify a location within forestry grounds.

Annual Charges:-Direct charges will not be made sin these are included in number A and B.

D. The operations of radio amateurs will have an annual minimum charge of ten ($10.00) dollars.

The value of structures such as buildings, antennas supports and other structures will be determined on the basis of the total costs of the materials and the construction in the area. The value of the equipment will be determined on the basis of its market price in Puerto Rico without including installation costs. Changes in charges may be made annually if increases or reductions in value occur. Depreciation will not be taken into account. The additional value to be used in the revision of charges due to the addition of new equipment will be its price of acquisition. Replacement of equipment will require a determination of the change in value so that the concessionary will pay only for the replacement investment. The value of the equipment replaced will be subtracted and the value of the new equipment will be added consistent with what is indicated above.

To determine the charges, the concessionaries must submit annually a statement of account duly certified by a Certified Public Accountant, and any other document the Secretary judges necessary.

Annual charges will be paid in advance, before the start of the

corresponding Fiscal Year, and an extra charge will be imposed for late payments.

The Secretary has the right to review the charges periodically when circumstances justify it; the concessionaries will receive pertinent notice opportunely.

8. Revocation

The Secretary may revoke, store, or consider closed any special permit of use or electronic emplacement for the following reasons:

a) violation of the ordinances, regulations, terms, or conditions of the permit

b) when the permit granted has not been used

c) agreement between the parties

d) expiration of the permit

e) when public interest thus determines it

This action will be notified in writing 30 days in advance; the concessionary will be given the reasons for this determination.

If the deficiencies in the permit which has been granted may be corrected, a reasonable length of time will be allowed to correct them.

B.- Special Permits for Telephone and Telegraph Lines

The concession of permits that grant the right of way for telephone and telegraph lines is authorized. These permits will be issued by the Secretary.

The concession of right ways under this authority may be for underground lines or cables. The width of the right of way must be limited to the necessary minimum determined by the Forest Service.

The laying of telephone cables under right of ways is feasible and desirable, and should be encouraged, in that with the exception of asphalt roads, the impact of the surface turns out to be minimum and temporary. Lines must not be laid within the surface of asphalt roads. Cables

can be laid through roads, provided that they are in ducts under the pavement so that the maintenance of lines and roads is not di-ficult. In this manner, the impact on the esthetic values along the road will be reduced.

1. Charges

Charges for telephone and telegraph right of ways

An annual charge of $.50 per "cuerda" or $1.00 per mile or fraction of a mile (whichever is greater) is established for each post line or double circuit line which serves only few users or operators.

The minimum annual charges for regular commercial use will be $200.00 per "cuerda" or $10.00 per mile or fraction of a mile, whichever is greater

When the value of the right of way of the land can be appraised, six per cent (6%) of that value will be used. The charges indicated above will applied in all cases.

The rents collected on account of the charges previously stated must go into the "Special Fund of the Forest Development" in accordance with the Forest Law of Puerto Rico (Number 133 of 1975).

IV. Operation

These Forest Regulations for Special Permits No. 1 will become operationals starting July 1st, 1982.

APPROVED ON 18 May, 1982 in San Juan, Puerto Rico.

Hilda Díaz Soltero

HILDA DIAZ SOLTERO
SECRETARY