PC-AAA-023
ISN 32115

ASSESSING TROPICAL FOREST LANDS: *Their Suitability For Sustainable Uses*

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EAST-WEST ENVIRONMENT AND POLICY INSTITUTE

PCAAA 023
ISN: 32115

ASSESSING TROPICAL FOREST LANDS: THEIR SUITABILITY FOR SUSTAINABLE USES

—A Report of the Conference on Forest Land Assessment and Management for Sustainable Uses, June 19-28, 1979, Honolulu, Hawaii—

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January 1980

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PREFACE

The East-West Environment and Policy Institute (EAPI) is conducting a continuing program of multi-national, interdisciplinary activities concerning the tropical forests and forest lands. The future of these natural systems is of consequence to the United States and the nations of Asia and the Pacific that comprise the East-West Center region. From June 19 to 28, 1979, about thirty foresters, ecologists, and land use planners convened in Honolulu under the auspices of the East-West Environment and Policy Institute to discuss "Forest Land Assessment and Management for Sustainable Uses." Co-chairmen of the conference were Lawrence S. Hamilton and Ata H. Qureshi. Papers were invited from proponents of land capability classification methods and from experienced planners and forest managers in developing countries. A compilation of the pertinent literature was prepared and provided to each conference participant. Before and after the meeting a group of Environment and Policy Institute staff and visiting professionals worked toward the product represented in this publication.

This report, "Assessing Tropical Forest Lands: Their Suitability for Sustainable Uses," is based on the conference discussions. The section on capability classification was written by Dieter Mueller-Dombois, and that on suitability assessment by Lawrence S. Hamilton. Other contributors were Ata H. Qureshi, W.R.H. Perera, and Richard Carpenter. A draft of the report was circulated to all participants and also to several reviewers who are well qualified in this field. The findings and conclusions are the responsibility solely of the Environment and Policy Institute, although every attempt was made to record accurately both consensus and diverse views from the conference attendees.

Papers presented at the conference are listed in Appendix A. A limited number of copies of each paper are available for readers who wish to request a particular title.

We believe this document is a useful critical review of the state of the art in forest land assessment and also a synthesis, especially adapted to the tropics, of methods to determine the suitability for various uses of tropical forest lands. Readers are encouraged to correspond with the Environment and Policy Institute as to their experiences in suitability assessment and their reactions to this report.

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It is a pleasure to acknowledge the competence and diligence of the staff and participants, all of whom contributed greatly in the spirit of international collaboration that characterizes the work of the East-West Center.

— Richard A. Carpenter
Project Coordinator
Environment and Policy Institute

EXECUTIVE SUMMARY

This report is a practical approach to *capability classification* and *suitability assessment* of tropical forest lands. Its objective is to help land use planners avoid misuse of land and allocate landscape units to uses that will be sustainable with available technology and management. Appropriate and sustainable use requires *knowledge* about the ecological (biophysical) characteristics of land, an *ability* to predict the response of land to human and natural perturbations, and *display* of the information in map form.

The report also contains some special considerations necessary to the proper management of tropical forest lands. Finally, some recommendations for future multinational collaborative research are listed.

Classification procedures are presented at two levels of scale. *Overview level* refers to a land capability classification on a reconnaissance scale (1:50,000 to 1:1,000,000), which shows a whole state, province, or government district on a single map sheet. *Detailed level* refers to a large map scale (1:1,000 to 1:50,000).

LAND CAPABILITY CLASSIFICATION AT AN OVERVIEW LEVEL

In the planning phase of a land capability classification project, the land researcher should discuss scope of work and final products with the land administrators who want the job done. He should then obtain a suitable base map (e.g., road map, topographic map) and aerial photographs and/or satellite imagery, depending on the chosen map scale and availability. Existing thematic maps (i.e., maps of climate, soils, topography, geological substrate, geomorphology, and vegetation) at overview scales are the most important. Data will be available from the weather bureau or meteorological department in the project area (state or province) for rainfall and temperature recording stations. A soil overview map may be obtained from a survey department, agriculture department, or university in the area (or elsewhere). Vegetation information may be found in maps, air photos, publications or unpublished reports, or by contact with local experts. Information gathering is completed with searches for land-use and other geological and hydrological maps and with

a review of literature on all of these ecosystem components in the project area.

Data reduction and synthesis begin by drawing a tentative land-surface pattern map on aerial photographs or satellite imagery. This map of landscape units is compared with all of the thematic maps, i.e., with at least five landscape components: climate, topography, geological substrate including land forms, soils, and vegetation. The tentative land-surface pattern map is converted into a land-capability map through interpreting and classifying surface patterns with the aid of the thematic maps. Boundary adjustment of the landscape units now indicated is accomplished by further subdividing some of the tentative surface patterns or by grouping others. Finally, the mapping process is completed with a field reconnaissance to check the field-physiognomy of land surface patterns with the tentative classification.

Next, the air-photo map boundaries are transferred to an undistorted base map at final map scale, preferably using a topographic base map with few place names and roads. A short but significant biophysical characterization for each landscape unit is given in the legend (climate, topography, geological substrate, land form, soils, vegetation, and current land-uses). For map interpretation, a few profile diagrams are prepared which cut (in the form of transects) through most of the map units. Where unit characterization requires more space than is available on map-sheet and profile diagrams, an accompanying manual is written.

Finally, several discussion meetings are held with the land administrators who are confronted with the task of land allocation. Research may be suggested where insufficient data are available for certain anticipated allocations. For example, this may include a need for research into past perturbations, such as flood frequency on an alluvial land form, or the need to prepare checklists of species in areas to be designated for commercial forestry.

LAND CAPABILITY CLASSIFICATION AT THE DETAIL LEVEL

This classification should serve the land manager of a territory which is already proposed for a general use category, such as, in this case, forestry.

A dialogue is established with the forest land manager about his needs for an ecological approach to land management. Some of the needs may be to know the major tree species in his area, to find out something about their growth rates on different land segments and their reproduction rates on different soils and in different plant communities. Some of these information needs require special research projects, but a forest site classification can be offered as a start. The forest area is subdivided into

land segments which exhibit differences in such properties as: (a) productive capacity, (b) natural regeneration chance, (c) appropriate choice of tree species for planting, (d) site-melioration possibilities, and (e) engineering aspects of the land.

The next step is to obtain large-scale aerial photographs of the area and a topographic base map at the standard large scale available (1:24,000 or 1:25,000 probably), which shows roads and trails. A search is made for all available information of relevance, such as any existing ecological zonation or landscape overview map, climatic map, soils map at overview and detail levels, checklists of species, reports and publications. A timber survey may be available, if the area is considered for forest exploitation. The set of aerial photographs is studied in some detail to obtain an idea of ground-surface patterning. A preliminary surface pattern map is prepared by drawing boundaries directly on air photos or on overlying tracing paper. Field reconnaissance is begun with aerial photographic patterns in mind. Each of the preliminary landscape units should be sampled with a minimum of five plots analyzed for: geographic information, habitat (slope, aspect, elevation), soil profile (and soil samples where necessary), and vegetation.

Sample-plot information is synthesized by using any of the multivariate analysis techniques for classification. Vegetation and soil data are examined separately to see how the data clusters compare to the preliminary aerial photo units. At this point it is possible to prepare a separate vegetation and soil map or a combined vegetation-soil map. The surface pattern map is modified into a site capability map with the aid of the synthesized sample plot data.

A narrative report should emphasize two aspects: characteristics of forest habitats and/or site differences in the management area, and identification of forest sites. Tools for site identification include: field key and/or aerial photo pattern key for site mapping, generalized profile diagrams showing changes along environmental gradients, and forest site map (depending on time available). A ground oblique photograph of the unit is useful. The work is presented in discussion meetings to the forest land manager and his staff. A useful data extension in the forest site evaluation process relates to laboratory analysis of soils for soil physical parameters (such as soil textural variation, soil-moisture constants) and soil chemical parameters (pH, organic carbon, cation exchange capacity, exchangeable cations, and others).

SUITABILITY ASSESSMENT

Each landscape unit is rated as suitable or unsuitable for a variety of plausible uses. Suitability assessment occurs most usually at the detail level (sub-regional or local).

First, criteria for sustainable use are chosen so that a proposed use activity does not result in decreased productive capacity: i.e., loss of fertility, soil erosion, waterlogging, salinization, extirpation of endemic species, etc. A rating scale from suitable to nonsuitable (such as that suggested by the UN Food and Agriculture Organization) is modified by special notations for local conditions as appropriate. The array of possible uses of the tropical forest land comprises these main categories: retention in essentially natural conditions, modification in composition or structure, creation of new forest, and conversion to other uses.

The rating team is assembled comprising skills and experience related to the specific area and the proposed use-activities, including knowledge of present human use and likely levels of technology and management. A consensus is reached on suitability of each landscape unit for each plausible use, based on the ecological land capability classification and professional judgment. The ratings are displayed in a table keyed to the landscape unit map, or by direct indication of the suitability symbols on one or a series of maps.

Suitability assessment does not infer a best or preferred use, but gives the land use planners an array of suitable and nonsuitable uses. The final decision on allocation depends on economic and engineering feasibility and political judgments.

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I. INTRODUCTION

THE EAST-WEST ENVIRONMENT AND POLICY INSTITUTE CONTEXT

This report was prepared as one activity of a long-term project called "Natural Systems Assessment for Development" in the Environment and Policy Institute of the East-West Center. The Institute, in its work, studies the environmental aspects of various government and private sector policies that are of concern and mutual consequence to the United States, Asia, and the Pacific nations. Multinational, inter-disciplinary groups collaborate in exchanging technical information and producing scholarly research, educational materials, and aids to decision making.

The EAPI project on "Natural Systems Assessment for Development" was established in October 1977 to deal with the interdependencies of financial and technical assistance for economic development. Donor agencies and developing countries have recently recognized the value of early comprehensive assessments of the implications of development for natural resources and environmental quality. By requiring such surveys and analyses, opportunities for the wise use of resources may be examined and anticipated, and the unwanted consequences may be avoided. The project includes activities to probe the institutional and organizational setting for environmental administration, to adapt assessment methodologies to developing country situations, to integrate more resource and environment information into economic benefit/cost analyses, and to prepare curricula and training materials for environmental management. Two major development sectors have been chosen for in-depth study: (1) energy resources and conversion processes, and (2) tropical forests.

Natural systems assessment subsumes environmental impact assessment, resource inventories, environmental management, and related topics; a holistic, interconnected system of animals, plants, soils, water, energy, human beings, and technology is viewed as fundamental to economic development. Tropical forestry is a specific development sector of great importance to countries in the East-West Center region. Proper forest management is dependent on adequate scientific information, transformed from research reports and transferred to policy and decision makers for application. Thus the tropical forests present an opportunity to focus interdisciplinary research and policy analysis at the EAPI on a practical problem where new ideas and improved techniques can find immediate application.

BACKGROUND OF THE TROPICAL FOREST LAND PROBLEM

In recent years, many well-documented articles and reports have established the importance and urgency of improved knowledge and management practice for tropical forest lands (see FAO, 1976a; Gomez-Pampa *et al.*, 1972; Hamilton, 1976; Mathur, 1976; Qureshi, 1978a; U.S. State Department, 1978; Webb, *et al.*, 1977; World Bank, 1978). The recurring themes in this literature are:

(1) The natural tropical forests are being modified and transformed at a rapid rate.
(2) Many new uses for tropical forest lands may not be sustainable due to soil erosion, nutrient depletion, altered water resources, and vulnerability of monocultures.
(3) Technology developed in temperate zones may not be appropriate or applicable in the tropics, and relatively little data and information are available for tropical forest lands.
(4) Although these lands are not now empty or unused, in general, future alternatives have not yet been closed off and the potential for rational planning and management is at hand.
(5) Developing countries must exploit the goods and services of their forests and forest lands for economic growth, but they must also protect the essential productivity of these ecosystems for the benefit of future generations.
(6) These forests are important to all nations for their watershed value, genetic richness, wildlife habitat, continuous supply of lumber and other products, esthetic and recreation values, and possibly for their role in global climate patterns.

Policy formation and decision making about tropical forest lands involve a complex of development financing agencies, multinational corporations, and national and local governments in the controlling countries. The basis for policies and decisions should be accurate ecological information about forest lands, as complete and timely as is possible. It is clear that any landscape unit has "something to say" to the planner about how it should or should not be used, i.e., its suitability for sustained production of benefits to society. The need then is for a method of delineating these landscape units and assessing their suitability for one or more uses without unacceptable degradation under a given level of inputs of technology and management.

THE SCOPE OF THE CONFERENCE

In December 1978, foresters and ecologists from eight Asian countries, Canada, and the United States met at the East-West Center (following a conference on the role of fire in ecosystems management). The advice of this group to the EAPI was to proceed to convene a working conference to produce authoritative analyses and technical judgments that could help reduce uncertainties and resolve controversies related to the future use of tropical forest lands.

A forest lands planning group of EAPI staff and visiting professionals conducted an extensive reconnaissance of the forest land classification literature and corresponded or met with many practitioners to ascertain the state of the art.

The Eighth World Forestry Congress in Jakarta in October 1978, attended by EAPI staff, had established a high priority for land suitability assessment. The U.S. Strategy Conference on Tropical Deforestation (June 1978, Washington, D.C.) of the U.S. State Department (1978) had recommended an acceleration of land use planning as a prerequisite for enlightened development decision making. The Forestry Sector Policy Paper of the World Bank (1978) urged forest inventories and land use and soil surveys as essential in tropical regions. Similarly, the Canadian International Development Research Center Monograph on Land Management in the Tropics (IDRC, 1977) emphasized the need for adequate knowledge of the extent and nature of forest resources.

A number of systems for land classification are in use. Some are single factor; others are multiple factor and hierarchical in scale. Some have been adapted to specific developing country situations in the tropics. However, very few critical reviews or comparisons of these methods have been performed. Existing systems were not developed with the particular current needs of tropical forest land planners in mind. There has been, to date, no synthesis of the best features of current land classification techniques. Thus a conference was organized on "Forest Land Assessment and Management for Sustainable Uses" at the East-West Center in Honolulu from June 19-28, 1979 (see Appendices B and C for agenda and participants list).

The conference planners assembled and distributed to participants a reference book of background papers and data from the literature on tropical forest lands and schemes for the assessment of their suitability for various uses (see "References" at end of this report for selected literature). This report is based on the discussions at the conference and the papers submitted or delivered by the participants. A list of papers presented during the conference appears in Appendix A.

DEFINITIONS

Forest Lands

Forest lands include (a) all lands with tree and shrub vegetation, (b) all degraded or denuded lands which potentially can support tree and shrub vegetation, and (c) all water bodies within the boundaries of such lands. However, we recognize that in certain countries there are lands legally defined as forests or forest lands which may not fall within the scope of the above definition. "Tropical" forest lands are those lying in the geographical zone between latitudes 23 1/2° N and 23 1/2° S.

Denuded Land

Denuded land refers to a formerly forested land, the tree cover of which has been removed by man or by natural causes.

Inventory

Gathering of knowledge about the nature and extent of all the forest land resources — by landscape units — so as to permit a rational and pragmatic classification.

Land Capability and Land Suitability

There are varying interpretations of land capability and suitability in the literature. Some consider capability as the inherent capacity of land to perform at a given level for a general use, and suitability as the adaptability or fitness of a given area for a specific land use. Others see capability as a classification of land primarily in relation to its susceptibility to degradation hazards. Some consider the terms interchangeable and this was often the case in the conference discussions.

However, in this report we offer a distinction because of the practical importance of separating the functions of classification and assessment.

Capability classification is the description of a landscape unit in terms of its inherent capacity to produce a combination of plants and animals.

Suitability assessment is the subsequent rating of the response of a landscape unit under a certain use, specifically, whether that use on that unit will cause unacceptable degradation of productivity and therefore not be sustainable.

Landscape Unit

A mappable area, roughly homogeneous as to soil, topography, climate, and biological potential, whose margins are determined by change in one or more characteristics. A landscape unit is characterized as an ecosystem, i.e., the physical structure and relationships of soil, water, nutrients, energy, plants, and animals. Delineation of a geographical area as a landscape unit requires *differentiation* from adjacent units and recognition of *similarity* to the same type of unit recurring elsewhere.

Sustainable Use

Continuing rational use of land without severe or permanent deterioration in the quality and quantity of one or more components of the integrated ecosystem or landscape unit.

OBJECTIVES OF IMPROVED ASSESSMENT METHODS

Human beings and their environment are inseparably linked; their welfare is directly dependent on the stability and the proper functioning of their surroundings. Human beings and the environment are both subject to the natural laws governing matter and energy, and recognition of this fact must be a central feature in all development planning.

Therefore it is necessary to devise improved rational methods to classify and evaluate forest land by its intrinsic features, examining its carrying capacity carefully before changing the landscape patterns in response to pressures of the moment, no matter how profitable such uses may be in the short term.

The prime objective of improved suitability assessment methods is to provide to decision makers more useful knowledge about tropical forest ecosystem resources in terms of inventory and dynamic response under various human uses and natural perturbations. The methods should help planners and managers avoid misuse of the tropical forest land resource for purposes which may appear attractive in a short term socio-economic-political context, but would not be sustainable. They should aim at preventing uses which not only cause on-site damage, but also off-site damage in far off cities, settlements, or agricultural valleys whose water resources originate in a distant forest landscape unit.

They should be pragmatic and flexible, varying according to the needs and state of development in each country. For example, in some countries or regions population pressure coupled with economic considerations might

make it impractical to allocate a landscape unit for the best sustainable use. Under the circumstances the objective would be to advise on trade-offs of certain amounts of ecological degradation in parts of the unit, and aim at a more ideal classification for the more strategically placed and vulnerable parts of the landscape (e.g., in Java and parts of India and Sri Lanka).

In other countries forest land allocation may be dominated by specific national priorities, (e.g., tin mining in Malaysia). The methods adopted should not only predict what the response would be to such practices, especially in environmentally vulnerable areas, but also indicate how a landscape unit degraded as a consequence of these national priorities could be best rehabilitated. This objective should also apply to other degraded and denuded forest lands considered essential for rehabilitation.

Improved methods should enable predictions and advisory forecasts to be made, based on sound and well-proven scientific facts, of what would occur on a landscape unit as a result of natural perturbations or human intervention. These should be presented in documented form, including what can be verified on the ground and the results of past interventions. There should also be a periodic reappraisal of the landscape unit and a continuous collection of data for improved advice on suitability as time goes on.

Improved methods should be efficient, providing advice that is comprehensible to decision makers, with a minimum of time, money and manpower but without sacrifice of professional quality standards. Assessment methods should provide immediate help with urgent problems and critical areas — a quick but sound approach requiring a minimum of information gathering. However, they should also allow for a continued expansion of the data base and sophisticated processing and display techniques where warranted and when time and money are available.

An essential objective during the process of evaluation is the preparation of a forest lands inventory using a multiplicity of methods. This inventory is an input for the subsequent assessment and classification.

In summary, improved assessment methods should facilitate answers to these questions:

(1) Of the remaining natural forests of the tropics and subtropics, how much and which locations should be retained or carefully modified to yield sustainable benefits both in the local and national interest?

(2) Of the previously forested land that is now degraded or denuded (and therefore economically and ecologically inefficient) how much and which locations should and can be restored?

II. THE LAND USE PLANNING PROCESS

NEED FOR A HIERARCHICAL APPROACH

Land classification arises out of a need to allocate and manage land wisely. Land use requirements are the result of socio-economic demands. These demands originate in a human population from various pressures and aspirations and are reflected in political decisions, in administrative regulations, and in the field management of particular parcels of land.

Land use decisions are therefore intimately tied to the governmental structure of a country which can be generalized as hierarchical: national, state or provincial, and county or local. Land use decisions are made within such a hierarchical framework, and the land classification itself must be hierarchical and flexible in order to incorporate new socio-economic demands and new knowledge about the capability of the land.

THE ROLE OF LAND CAPABILITY CLASSIFICATION IN THE PLANNING PROCESS

The role of an ecologically based land capability classification should be to match resource uses and capabilities in such a way that the classification can help the decision maker at all levels of the governmental hierarchy (as defined above).

The help provided should enable decisions which are sensitive to the needs of the people, which aim at sustainable uses of the renewable resources, and which avoid disruptive degradations. To accomplish this goal, the essential content of the land capability classification must be translated into simplified, yet realistic models which are informative, understandable, and acceptable to the decision maker. In addition, the land researchers must make recommendations about necessary use-modifications and suggest resource-use alternatives. This process is understood as suitability assessment. Both land capability classification and suitability assessment are processes which require continued alteration and refinement in relation to new land-use requirements and newly emerging land-resources knowledge. The two processes should be regarded as working according to the principle of "successive approximation" (Poore 1962).

Figure (1) shows the sequence and information flow in the land use planning process. All societies have demands that may be met through use of their landscapes and, conversely, knowledge about the capabilities (step

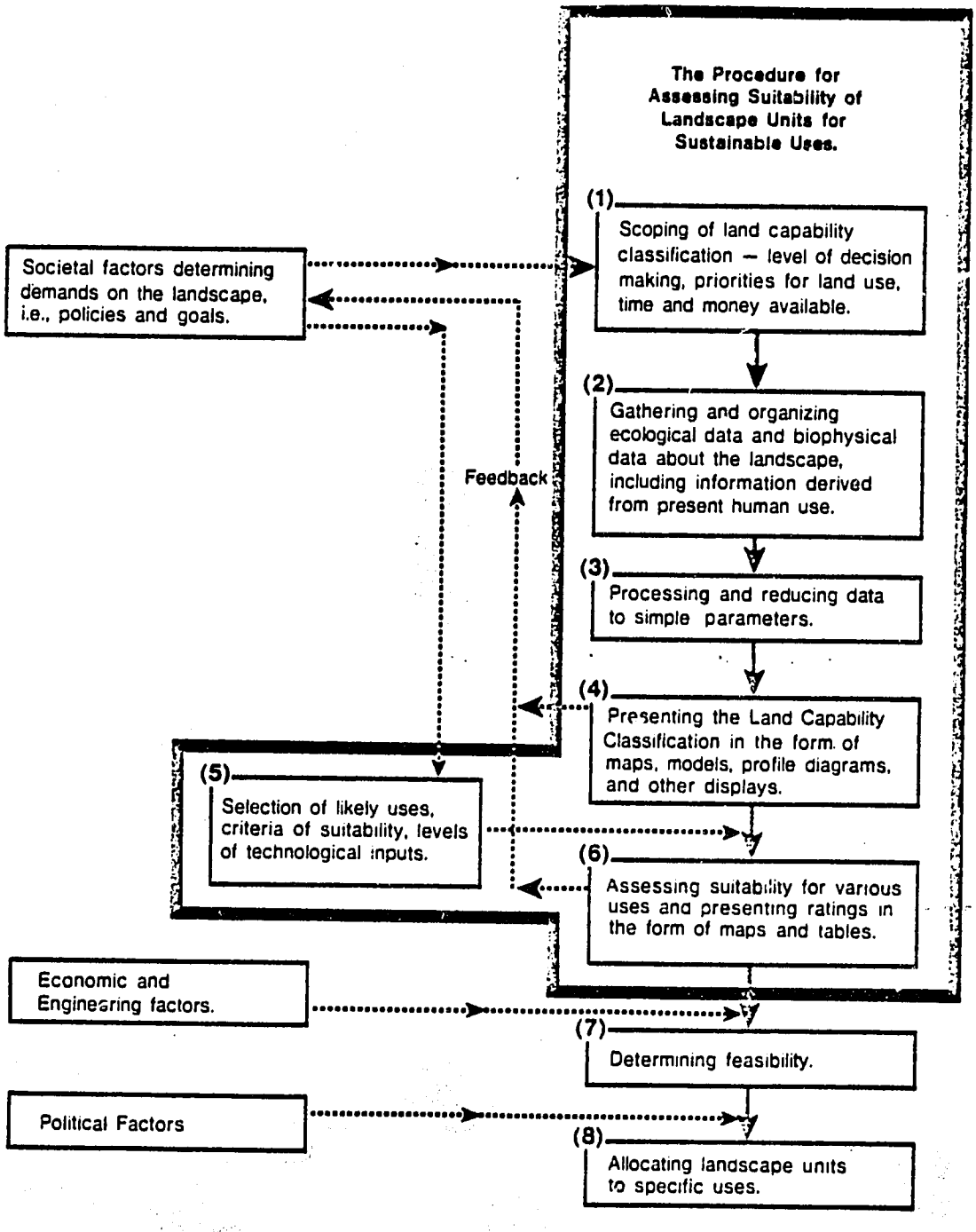

Figure 1 The Land Use Planning Process

4) and suitabilities (step 6) of landscapes suggests opportunities for benefits to society. The six steps of land capability classification and suitability assessment (shown within the heavy border) are parts of a total sequence that includes feasibility determination and allocation. These latter two steps are *not* included in this report because they involve the addition of economic, engineering, and political factors that were not addressed by the conference. Allocation decisions are ultimately a product of economic development policies of a particular country. Societal factors, including present human use, do set the scope, detail, and timetable of the classification procedure (steps 1–4). Societal factors also affect the suitability assessment task (steps 5–6).

HIERARCHY OF PLANNING UNITS

This land capability classification procedure initially restricts consideration of land-use planning units to biophysical parameters, since we are attempting to work out an ecological basis for land planning and management. This means that we may translate planning units into landscape units as a first approximation. In the follow-up procedure, suitability assessment (discussed in Chapter IV), we can join or recombine certain landscape units for particular uses, and the combined units may then become the actual planning units for use categories.

Landscape units (the geographic equivalent to the term ecosystem) are segments of the landscape with their own particular climate and geographically unique dynamic processes and can be recognized at all levels of geographic scale. The term landscape unit, therefore, is without any hierarchical rank. It is convenient, however, to specify a certain ranking order of landscape units as suggested in Table 1.

The three levels should be looked at only as a guide. Landscape diversity is an important factor. Large countries may be better subdivided into four or even five levels; small countries may get along with the lower two levels. A small country with topographically pronounced terrain and a great variation of climate may be usefully analyzed in three levels.

Table 1

Hierarchy of Landscape Units in Relation to Map Scale

Explanation	Suggested Unit Names	Approx. map-scale range*
I. Large size landscape units (approx. 10,000 ha or higher)	Bioclimatic region or zone, Biogeo-climatic zone, Life zone, Vegetation zone, Ecoregion, Biome, Ecological zone	National (small map scale) 1:1 million and smaller in map scale
II. Intermediate size landscape units (approx. 500 to 10,000 ha)	Land system, Land form, Forest cover type, Plant formation, Forest land type, Forest ecosystem type.	Regional - overview (medium map scale) 1:1 million to 1:100,000 (or occasion-ally up to 1:50,000)
III. Small-sized landscape units (approx. 1 to 500 ha)	Forest site type, Forest habitat type, Land type	Sub regional or Local - detailed (large map scale) 1:100,000 (or 1:50,000 up to 1:1,000)

Definitions Relating to Unit Names Given in Table 1:

Bioclimatic region or zone: The data ranges and threshold values are originally adjusted to certain spatial changes in the biota. The biotic characteristics (aspects of vegetation physiognomy) reflect macroclimatic differences.

Biogeoclimatic zone: Refinement to include topography, geological substrate, land form, and soil as additional descriptors.

Life zone: See page 15 .

Vegetation zone: A broad area with a certain macroclimate, which contains a mosaic of more narrowly defined vegetation types.

Biome: Broad area of landscape, such as desert, tundra, or coniferous forest, in which climate, animal communities, and vegetation physiognomy are the main criteria for identification.

Ecological zone: A broader area landscape unit defined through vegetation, climate, soil, and topography.

Ecoregion: An abbreviation of the term ecological region.

Land system: A unit of physiographically related habitats as often contained in a watershed.

Land form: A topographic-geological unit, such as a beach deposit, dune area, lava flow, alluvial flat, talus slope, etc.

Forest cover type: A vegetation unit distinguished usually by dominant species which cover mid-sized areas such as land forms or land systems.

Plant formation: A mid-sized vegetation unit distinguished by vegetation structure or architecture, such as closed forest vs. open forest, low-stature forest, etc.

Forest land type: A specific habitat or site identified in relation to its current or potential forest cover; for large-scale and intermediate scale.

Forest ecosystem type: Mid-sized unit in relation to a certain land system, such as a watershed, for example.

Forest site type: Small-area unit distinguished by a unique forest vegetation, soil-moisture regime, and habitat combination; e.g., alluvial bottomland, periodically flooded.

Forest habitat type: Definable physiographic segment of land, with all its particular environmental factors.

III. LAND CAPABILITY CLASSIFICATION: A PROCEDURE

THE PLANNING PHASE

The most important aspect of the planning phase is the development of a dialogue with the potential users on what they hope to get out of the land classification. In this context, the land researcher should come prepared with suggestions and samples of maps of different scales that preferably refer to the area to be assessed and classified.

For purposes of forest land assessment, we will be concerned mostly with regional (overview or reconnaissance) map scales, which we defined as ranging from about 1:100,000 to 1:1,000,000, and with subregional (local or detailed) scales, up to 1:1,000. The two map scale ranges coincide with the two major sources of remotely sensed land surface imagery: the regional scale with that of satellite imagery, the subregional scale with that of aircraft imagery.

Depending on the user's objectives, the preferred map scales may be different from the two ranges given here. However, one thing is clear: The land administrator will be interested primarily in map scales that show his area in overview - a map that presents the entire area on one sheet which may cover approximately the size of his desk. To name concrete examples: For Sri Lanka, a tropical island country of approximately 420 km length and 220 km width (at its widest points), a scale near 1:500,000 is most commonly used. At this scale, Sri Lanka, fits onto a map sheet of 90 cm by 60 cm. On the other hand, the island of Oahu in Hawaii is only 48 km long and 38 km wide. The island fits in good overview on a map sheet of 90 cm by 100 cm at the scale of 1:62,500. Thus, the optimal map scale for land administrators varies with the size of their district.

An overview scale answers many land administration objectives, but a detailed scale is necessary for on-the-ground management of particular land segments. For example, once areas have been allocated to commercial forestry, the land manager then needs enlarged maps of these areas.

Such enlarged maps may be at the scale of 1:25,000 (or they may vary in range from 1:1,000 to 1:100,000). For forestry purposes, such maps should identify forest site types, habitat types, or land types with differing capabilities in such areas as productive capacity, natural regeneration chance, choice of tree species for planting, site-melioration, and site-engineering aspects.

Thus, forest land assessment should ideally be done at two levels of scale, at the overview scale and at the detail scale. At the overview scale, the land administrator should be provided with the tools to make land

allocations on an ecological basis. At the detail scale, the forest land manager should be provided with a site capability map that allows him to practice forestry on an ecological basis.

THE INFORMATION-GATHERING PHASE

This step differs very much between overview and the detailed scales and information gathering at the two levels will be discussed separately.

Information Gathering for an Overview Landscape Map

We want to identify, describe, and evaluate the inherent capability of landscape units, the geographic equivalent of ecosystems. We need to gather biological as well as physical information to produce the minimum end-product, a landscape map.

The best tools for mapping are remotely sensed images from a satellite for map preparation in the intermediate scale range (from 1:100,000 to 1:1,000,000), from aerial photographs for large-scale mapping (from 1:1,000 to 1:100,000). Photography from high-flying aircraft is particularly useful for map scales from 1:50,000 to 1:100,000, while standard aerial photographs, which may come at the scale of 1:6,000, :12,000 or 1:16,000, are useful for maps ranging from 1:10,000 to 1:50,000. The aerial photo scale does not have to be the same as the final map scale. In fact it is customary to choose an aerial photo scale about twice as large as the final map scale (Kuechler 1967).

Since our chosen map scale is in the intermediate range we may explore both satellite imagery and photography from high-flying aircraft as a starting base. Such imagery usually has the added advantage of insignificant distortion, so that the first map can be made by tracing the most obvious surface patterns directly on the image or on a transparency. The essential information needed to establish landscape units from the tentative tracing relates to the following five ecosystem components: (a) topography, (b) climate, (c) soil, (d) vegetation, and (e) land form and geological substrate.

Topography

There is usually a topographic map available from a survey or planning department at the intermediate (air photo) mapping scale, but if not, such a map can be prepared from a topographic map at somewhat larger or smaller scales, e.g. by omitting every other contour line. The preliminary

surface patterns can now be identified as to their altitudinal variations within units and between units. A surface pattern which may look like a closed forest on the air photo or satellite image can now be identified as either a lowland, montane, or subalpine forest. Moreover, we can describe the units by actual elevational similarities and differences, a work process which is difficult or nearly impossible to do from the remotely sensed image itself. On a topographic contour map there are usually no area units identified but the continuance of data points in the form of contour lines serves ideally to characterize the preliminary surface units identified on the remotely sensed image.

Climate

Climatic information is usually available in form of rainfall and temperature data. This may require a personal trip to the weather bureau or meteorological division. In addition to rainfall data, a few stations may have records of air temperatures for a certain number of years. However, with the help of the topographic map it is usually possible to extrapolate mean monthly temperature data with reasonable accuracy from sea level stations to different altitudes by using the normal lapse rate (i.e., 3.5° F or 1.9° C decrease with every 1,000 feet or 305 meters rise in elevation) or by interpolating air temperature values between neighboring recording stations. Rainfall and temperature data are the most ecologically essential climatic parameters, particularly their month-to-month variation in relation to one another for the determination of seasonality.

Once the temperature and rainfall records are obtained, one can use any of the established bioclimatic zonation schemes to produce a bioclimatic map of the area. The better known schemes are the ones by Koppen (1931, 1936), Thornthwaite (1948, Thornthwaite and Mather 1957), Holdridge (1947, 1967), and Walter (1955, 1957, 1971, Walter and Lieth 1960, Walter et al. 1975). The special characteristics of these schemes have recently been summarized by Mueller-Dombois (1979).

Bioclimatic schemes use climatic data for mapping, while the biota — which here refers to significant spatial changes in vegetation physiognomy — come in only as an initial climatic boundary criterion. This implies that climatic zones are initially adjusted to important zonal changes in vegetation physiognomy, such as tropical-evergreen versus tropical-deciduous forest versus thornscrub, etc. Climatic threshhold values are then defined, such as the number of wet months vs. the number of dry months, etc., and these threshhold values form the criteria for objective differentiation of bioclimatic zones or regions. Holdridge's "Life Zones" are such bioclimatic zones based on particular combinations of mean annual rainfall and temperature (see Figure 2). Such schemes have the advantage

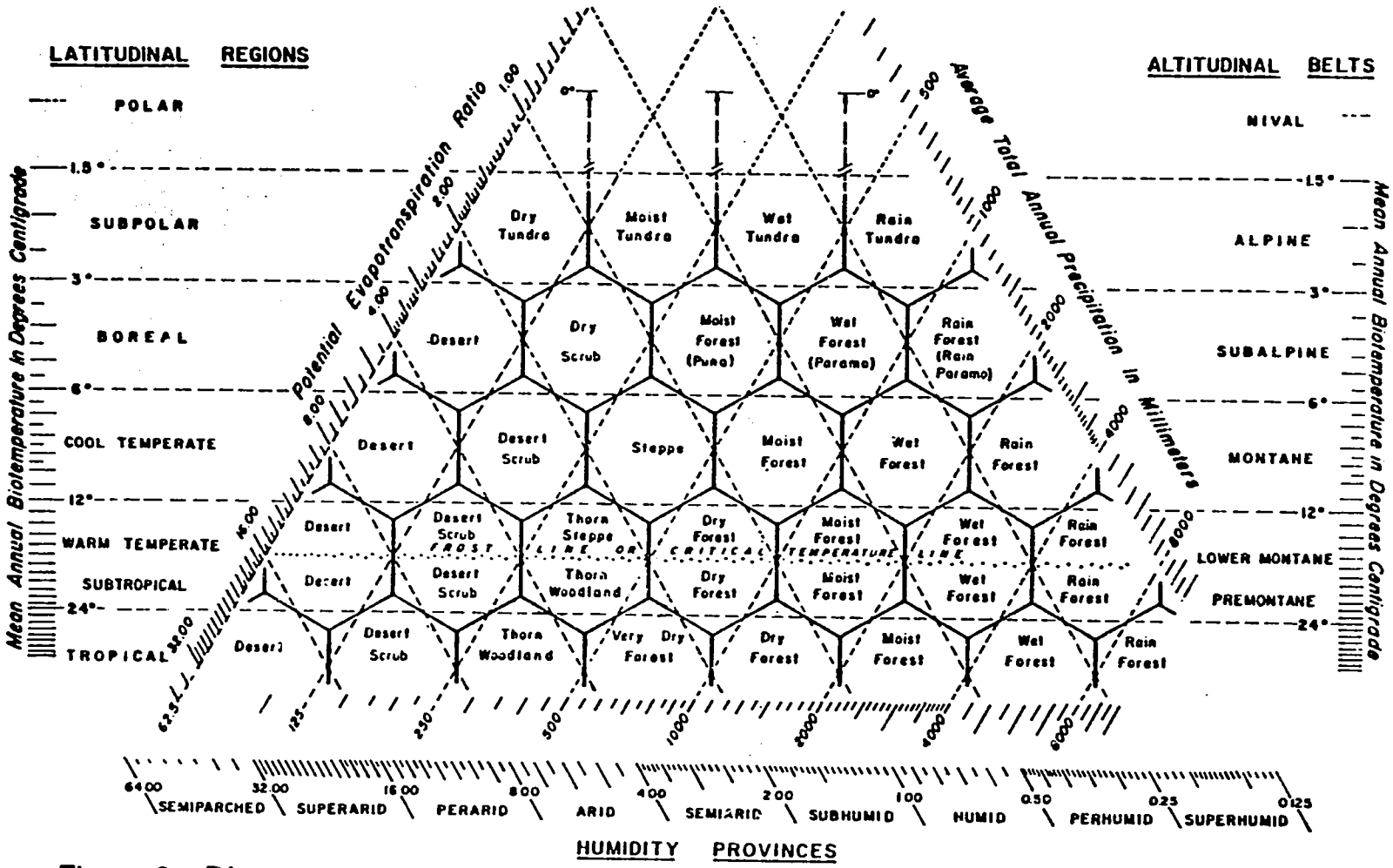

Figure 2 **Diagram for the Classification of World Life Zones or Plant Formations**
by L.R. Holdridge
Tropical Science Center, May 1966

of rapid area mapping of macroclimates which may be assumed to convey a general level of biological homogeneity within each macroclimatic unit.

In terms of our developing landscape map, with the aid of Holdridge's scheme we may obtain broad areas which overlap and include some of the preliminary air-photo units. With the help of such bioclimatic zones, we can get a first climatic characterization of the tentative air-photo patterns.

A better climatic analysis characterizes climatic station points rather than areas on the land surface. Both Thornthwaite and Walter's methods use climate diagrams as a form of data reduction which can be mapped. Walter's method has the advantage over Thornthwaite's method in that it uses mean monthly air temperature directly in each diagram, whereas in Thornthwaite's method air temperature is converted to evapotranspiration by a complicated formula. Otherwise, both use the same diagram-format showing the twelve calendar months in the abscissa and the mean month-to-month rainfall or precipitation curve with reference to the ordinate. Whether mean monthly temperature or mean monthly evapotranspiration is a more useful value for landscape evaluation depends on the objective. Thornthwaite's objective was to estimate mean monthly irrigation needs for agricultural purposes on arable land, while Walter's objective was to characterize climate in areas covered with natural and semi-natural vegetation. (See Figure 3.)

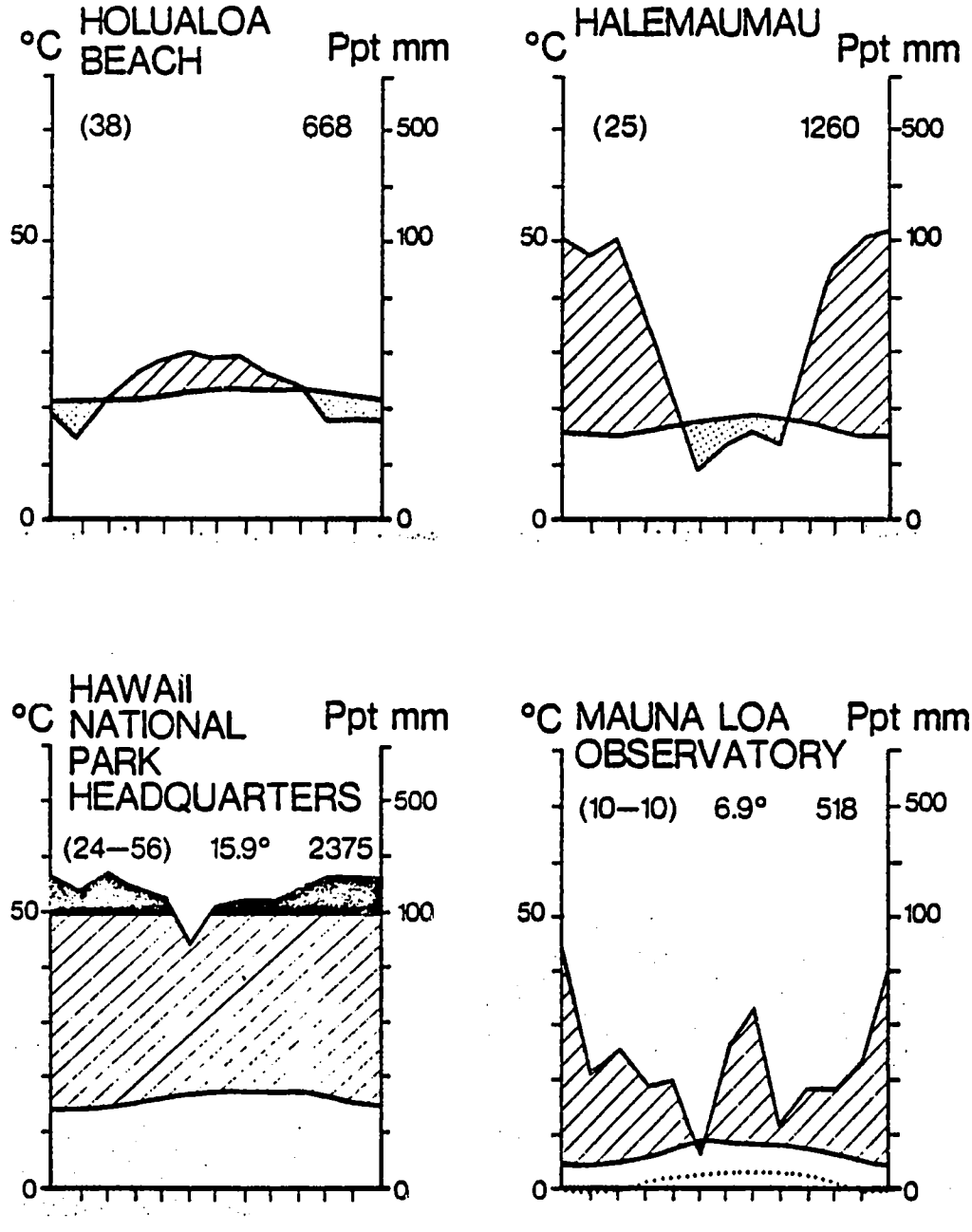

Figure 3 **Examples of Four Climate Diagrams from Hawaii**

Figure 3. Examples of four climate diagrams from the Island of Hawaii (Mueller-Dombois 1966) prepared according to the method of Walter (1955, 1957). The abscissa on each diagram shows the 12 calendar months of the year from January through December with July in the center. The left-hand ordinate gives a temperature scale in 10° C intervals. The right-hand ordinate shows a precipitation (Ppt) scale in 20 mm intervals up to 100 mm. From 100 mm on upwards the intervals have been changed to 200 mm each. Each diagram displays two curves, one for the mean monthly temperature values of a station and the other for the mean monthly precipitation values. The temperature curve is the smooth curve, the precipitation curve is the uneven curve on each diagram. The two curves are plotted at the relationship of 10° C/20 mm precipitation. Wherever the precipitation curve undercuts the temperature curve at this scale relationship, a drought season is implied for that environment. This is indicated by dotted fields on the two upper diagrams, where this applies. Humid seasons with monthly precipitation in excess of 100 mm are indicated in black; see lower left diagram. In addition to station names, the diagrams give mean annual precipitation in mm (upper right side) and mean annual temperature next to annual precipitation value, here shown only on the two lower diagrams. A third value given in parentheses under the station name refers to the number of years of records of precipitation and temperature (where applicable) to which the mean values apply. Several other climatic parameters are added where these are important for an ecological interpretation of the climate. For example, here, for the Mauna Loa Observatory station, a mean monthly minimum temperature curve was added to indicate the period with daily night frost. For a more complete explanation consult Walter (1971, 1973) or Walter *et al.* (1975).

Soil

A well-constructed soil map carries comprehensive data encompassing the physical and chemical properties of soils, which are often of direct and immediate interest to forest planners and managers. Soil maps are in most cases available from the Soil Survey Department or the Agriculture Department. The planning section of the Forestry Department may also have soil maps of forest areas. Over the years several soil survey, mapping, and interpretation systems have been in use in various parts of the world, including the 1938 Great Soil Groups, the FAO system, the Russian system, the French system, and the U.S.D.A. Soil Taxonomy.

Recent developments in Soil Taxonomy (U.S.D.A., 1975), the most commonly adapted system, have improved the utility and universality of soil classification and mapping. This system blends genetic and practical implications into a hierarchical approach with six categories. Beginning with the most inclusive, these categories include the order, the suborder,

the great group, the subgroup, the family, and the series. For mapping, the family-level information would be most useful, as it integrates minerology, soil moisture and temperature regimes, soil fertility, and chemistry of soil. Here soils are classified according to their observable and measureable properties. The properties chosen are primarily those that permit grouping of soils that are genetically similar. This mapping system enables us to understand the pattern of soils, the way they relate to each other, and allows easy transferability of information. With experience, air-photo patterns may be translated with some accuracy into the underlying soil characteristics. The pedologic units are thus similar to landscape units identified by other parameters.

Vegetation

As a further item, the landscape mapper should look for any vegetation information available — e.g., a map of potential natural vegetation. These are site maps which give information on the growth potential for natural vegetation rather than the outlines of actually existing vegetation types (for a detailed discussion see Mueller-Dombois, as listed in Appendix A). A map of existing vegetation types may also be available for the area or for certain parts of the area. To find this out, it is necessary to visit the Forestry Department in the area. Such forest type maps usually are not published, and they may simply show outlines of such units as commercial high-grade, commercial low-grade, non-commercial, and protection forest. Thus they do not convey much ecological information, but with the aid of the already accumulated information on climate, topography, and soil, it may now be possible to translate these already-typed forest units into landscape units. A comparison to the new tentative air-photo map tracing will reveal if such formerly mapped forest cover types are still standing or whether they have been logged or converted to other uses.

Geology

The work process is further continued with geological information, if available. Most useful for forest land assessment purposes are geomorphological maps, which identify landform units. Petrological maps and historic geological maps also are of value in the evaluation of landscape units.

Finally, the landscape mapper may search for a current land-use map (which may already be available), a hydrological map, a historical land-use map, etc. All such existing information, even if not yet mapped and available only in unpublished reports, is valuable background material that should be pulled together in the land capability assessment process.

Information Gathering for a Detailed Landscape Map

A detailed landscape map will usually be larger in scale than 1:50,000. Detailed landscape mapping for land capability classification refers to the enlarging of certain selected areas on the overview landscape map.

Forest managers in the humid tropics must overcome the dearth of knowledge which currently exists and which may seriously hamper the practice of sustained-yield forestry. In fact, it can be said that the background information which may be available at the overview scale for landscape mapping is usually not available for detailed landscape mapping. Rarely is there information on soil types at a sufficiently detailed level so that a satisfactory prediction can be made of forest growth and development. Detailed soil surveys may exist for the land segments allocated to agriculture, but the soil under forest cover has not usually been looked at. Certain extrapolations from agricultural land however, may have been attempted, and there may then be a superficial knowledge of forest soils available. This superficial knowledge is better than no knowledge at all, but it is not good enough for practicing forestry on a sustained-yield basis.

Similarly, there is usually little information on the vegetation at the detail scale for landscape mapping. Although a timber survey is usually the first information that the manager will have to acquire, it is not enough to practice sustained-yield forestry.

For practicing sustained-yield forestry, the manager should be provided with some knowledge about the following for each site type:

(a) Productive capacity
(b) Natural regeneration
(c) Choice of species for planting
(d) Possibilities for site-melioration
(e) Engineering possibilities on the land

Thus, a major work component in the information-gathering phase for a detailed landscape map involves field work. As a preparation for the field work, the site researcher should acquire the following:

— A large-scale base map (1:24,000 topographic) which shows the access routes in terms of roads and trails.

— Large-scale air photographs, preferable as overlapping stereopairs, are useful.

— A landscape overview map, preferable already prepared, is useful, as it gives the ecological reference framework for the detail maps.

— Last but not least, as a preparation for the field work, the forest site surveyor needs to do a literature review about the area to be surveyed. This includes a search for the "gray" literature (i.e., unpublished reports and maps, such as forest inventory maps) which may be available for the area of concern.

The next step is to study the air photos in some detail. They need to be sorted by flight line. Their scale (and approximate scale variations) should be determined. In some cases air photographs may be prepared by an engineering firm with overlays of topographic contour lines and polygons excluding the areas on each photo (away from the central focal point) which show unacceptable distortions. This initial air-photo work may include preparation of a preliminary surface pattern as was suggested for landscape mapping at the broad overview scale.

The preliminary air-photo analysis will guide the field work. The field work location is, of course, primarily determined by the already existing access system (roads and trails) in the area. The task now is to identify the ground-surface patterns that are reflected in the air-photo patterns.

A useful starting point is to locate the environmentally extreme surface patterns, such as mountain tops versus valley bottoms, streams and streambeds versus rock outcrop areas, swamps and bogs, dunes, steep cliffs, and other extreme sites found in an area. These are at the opposite ends of environmental gradients. It is then a useful practice to arrange the reconnaissance in such a way that the surveyor traverses the area from one extreme site to another along the presumed environmental gradients. In this way, the environmental or site diversity is most rapidly encompassed.

This walk-through reconnaissance survey should be supplemented wherever possible with a fly-over reconnaissance by helicopter or small aircraft. The combination of ground and aerial views permit analysis of the surface patterns evident primarily through variations in structure of the vegetation cover and the topography of the land. A preliminary map should result from this reconnaissance survey.

It is possible for a minimum program to stop with this intermediate product. However, such a reconnaissance cannot yet answer adequately the manager's needs for a working knowledge of the five landscape variables (i.e., productivity, regeneration chance, choice of species, melioration, and engineering aspects).

A sampling phase should follow to establish and analyze at least five plots in each type of preliminary map unit. A 100,000 ha area with 30 preliminary map units should thus be sampled with a minimum of 150 sample plots. This is to be taken only as a rough guide. An adequate number of sample plots depends on the within and between variability of the tentative map units. The greater the within-variation of units, the more sample plots are required per unit. The greater the between-variation of

units, the fewer samples are needed to adequately differentiate between them.

The size of a sample plot depends on the questions one wants to answer. If a sample plot should represent the plant species composition of a tentative map unit, one can use the "minimal area concept" for plot size. If one wants to enumerate an adequate number of individuals for the prevalent tree species, the sample plot size will be determined by the spacing of such species-individuals. At least 30 to 50 individuals should be enumerated for the important or more dominant species (Mueller-Dombois and Ellenberg 1974). Both plot-size criteria may cause severe problems in species-rich tropical forests. It is therefore expedient to adopt a plot size which is practical, perhaps 20 m by 20 m.

In addition to sampling all important map units, it is desirable to ensure a fair geographic distribution of the sample plot, if possible along environmental gradients.

The minimum information needed for each sample plot in such a detailed-scale forest site survey is as follows:

(1) A checklist of the plant species with an estimate of their quantity. This may be restricted to tree species above a certain minimum size, depending on the more specific objectives and the time available.
(2) A stratification of the forest community into layers. This can be done by estimating the height of layers (in meters) and their combined cover (in percent) of the plot surface.
(3) A soil pit with profile description according to soil survey standards. In addition, one should make special observations on the rooting pattern, the soil surface characteristics, and subsoil characteristics in terms of whatever restricts rooting in depth, i.e., a hardpan, water table, underlying rock, etc.
(4) Habitat information. Measure slope in degrees or percent, aspect (N, E, etc.) and elevation above sea level.
(5) Geographic location.

If time and resources are available the capability classification may be expanded. In addition to a description of the soil profile, it is recommended to determine soil pH, organic carbon, cation exchange capacity, and easily determined soil physical parameters, such as texture, water holding capacity at the -0.3 bar value (field capacity), -15 bar value (permanent wilting percentage), and the current soil water content. This should be done at least for the surface soil (0-20 cm depth) and the rooting zone (or near 100 cm depth). This requires the collection of at least two soil samples for each soil profile analyzed in the field.

The soil analysis can easily be intensified through taking a larger number of samples (such as five) per profile and through increasing the

number of soil pits to two per plot. The soil laboratory analysis also may be intensified by analyzing the samples for nitrogen, phosphorus exchangeable cations, etc. Such intensified soil analysis, however, should only be done to answer more specific questions that arise during the survey of the minimum parameters. A more thorough analysis then may become a special research project.

Similarly, the vegetation information can be intensified by including as many plant species as possible in the checklisting procedure — e.g., trees, shrubs, forbs, sedges, grasses, bryophytes, and lichens. The quantification of plant species can be intensified by measuring the undergrowth species by frequency in quadrants, or their cover by the point-intercept method. The quantitatively more important tree species should be enumerated by species individuals, and the size limit may be extended to include saplings, seedlings, and germinants. Such a tree tally by size is necessary to answer the question of natural regeneration chance, which is of interest to the manager. The competition of tree seedlings from undergrowth species, including the factor of shading, should also be evaluated.

A further aspect in intensifying the site evaluation study is the selection of permanent plots to be used to monitor the temporal variations in soil-water and nutrient regimes; seedling survival and tree mortality; the measuring of tree growth rates; and other factors. Such monitoring work then would become a separate research project.

DATA REDUCTION AND REPORT-WRITING PHASE

The information components gathered in the preceding phase must now be brought together in form of a synthesis. Here we distinguish again between the data reduction needed for the overview landscape map and that needed for the detail level.

Data Reduction for an Overview Landscape Map

When the five ecosystem components (climate, topography, land form including geological substrate, soils, and vegetation) are on separate maps, there are two technical problems in reducing the data to a single landscape map. First, their scales may not match, but reduction or enlargement is possible. We may use one map — for example, the topographic map — as a base map, and then overlay the others, one after the other, as transparencies. The second problem is that the different zones of climate, soil, landform, and vegetation will probably not match. In fact, their fit may be rather poor.

Opinions vary as to which of the area patterns to use as the basis for the synthetic landscape map. None of these components form strictly self-evident units in nature. Unit recognition, in all cases, requires some abstraction and interpretation so that they become projectable on a map sheet.

For convenience, landscape units may often be recognized by using individual landscape components in the form of a hierarchy. For example, the climate over an area may be relatively uniform, and one may thus conveniently use macroclimate to provide a first level of broad unit recognition. Within this climatically defined area, one may recognize topographic units or land forms as indicating a second level of unit recognition. Within land forms, one may recognize soils as providing a still more exacting and finer level for unit recognition. Vegetation in turn may also be used for landscape-unit recognition at the second and third level, somewhat in parallel with land forms (i.e., broader plant cover types) and soils (i.e., more narrowly defined plant community types), respectively. However, the point made here, and emphasized in the conference, was that these individual ecosystem or landscape components should be considered equally and that they should be recombined in the land classification process. In other words, a landscape classification should not be based on either land form, topography, vegetation, or soil alone, even though these individual components do often reflect some of the effects of the total landscape formation process.

Some of the preliminary units could be grouped as they are described by essentially the same climatic and topographic ranges, by the same major land forms and soil units, and/or by the same major vegetation units. In other cases, what may have appeared to be a uniform surface pattern may need to be subdivided on the basis of climatic difference, topographic variation, major soil, and/or vegetation difference.

The guiding criterion for this adjustment of the preliminary aerial map unit should be our concept of "inherent land capability," the natural capacity of a land segment to support a certain biological potential and to react to degradation hazards.

Degradation hazards relate to both man-induced disturbances and to natural perturbations. The latter may include periodic floods, storms, droughts, ground-frost occurrence, or insect outbreaks, while man-induced disturbances may include such factors as soil erodibility from removal of vegetation, overgrazing by domestic animals, or toxification from industrial waste products. All of these are perturbations whose effects are indicated by the rate and recoverability of the natural vegetation cover. Therefore, the degree of impairment and vegetation recoverability can be taken as a measure of degradation. The relationship of vegetation recoverability and degradation of a land system may be quite complex in detail, but at a broad overview level it does not need to be so complicated. With some experience, vegetation recoverability can be fairly well

estimated from the combination of climate, soil, topography, geological substrate or land form, and current vegetation cover or land-use patterns.

Biological potential, the other measurement of inherent land capability, is also related to vegetation recoverability . But biological potential may be more specifically defined by the kinds of plant and animal communities that a landscape unit can sustain under natural conditions. It can also be defined as the potential capacity for organic production. Biological communities and organic production are variables which can be meaured. However, for the overview landscape map, the best approximation for outlining map units with different biological potentials would appear to be those vegetation formations which are relatively stable under natural conditions.

A pragmatic criterion for unit recognition is to choose a certain optimal number of map units which neither overcrowds nor under utilizes the chosen map scale.

Data Reduction for the Detailed Map

Data reduction for a landscape map in the large-scale range requires a few additional steps because the data base is largely in the form of field samples, along with the preliminary air-photo map, which initially served us as the framework for distributing the sample plots.

It is now necessary to synthesize the sample plot data on the physical habitat (in form of elevation, slope, exposure, micro-topography and soil) and vegetation (a checklist of species quantities, layer structure, and possibly, a size structure analysis of the more important tree populations). It is useful to carry out a multi-variate analysis. For classification purposes one can profitably use any of the dendrogram cluster analysis techniques (Orloci 1978), but the computation task is very great, so that one needs to have access to a computer. A more simple synthesis method is the two-way table technique which can be done by hand or computer (Mueller-Dombois and Ellenberg 1974).

PRESENTATION AND INFORMATION-TRANSFER PHASE

During the planning phase we suggested landscape maps as perhaps the most useful outcome of the land capability classification process. However, such maps can vary considerably in technical detail and information content, and there are other means of bringing the information to the user. Moreover, there are also some differences in the information

transfer of land capability classifications, whether they are done at the overview level or at the detail level.

Users at the overview or regional level include primarily the administrators concerned with land allocation, but also managers of smaller segments allocated to their custodianship. Such land managers may be foresters, range managers, agriculturists, park managers, municipal engineers, and others. Because of the varied backgrounds of these users, technical terms should preferably be avoided, or if necessary, they should be defined on the landscape map.

If possible, the landscape map should be self-explanatory. This means that particular care should be given to the legend. A main consideration is that the map units represent a certain mid-size level of ecological homogeneity reflected in a certain general vegetation cover and soil type, which may be topographically delineated, or in a mosaic of land-use patterns delimited by general soil type and topography. Possibilities for naming and characterizing such units vary among regions.

Since the objective of the regional landscape map is not necessarily to integrate the map unit information with that of other regions, it is useful, wherever possible, to use local names, which are well understood in the area. However, the most important aspect is an appropriate characterization. Once this is done, unit names can be interpreted in local as well as international terminology.

The climate of the area should be stated in the legend. If climatically variable, it may be useful to print a few selected climate diagrams on the map sheet. In that case, however, these diagrams have to be explained briefly in the legend also. In addition, the cover types (natural, semi-natural, crop vegetation, etc.) should be characterized for each map unit. The general soil type or range of soil types also should be stated, together with some of the outstanding soil parameters such as depth of fine soil, stoniness, microtopography, prevailing soil formation process, etc. The topographic variation should be characterized by drawing a few contour lines on the landscape map or by using a topographic map as the base map. Finally, it is practical to show certain roads and places with their names on the overview landscape map for rapid orientation.

It is useful, though not necessary, to color-code the landscape units on the map. A simple but clearly contrasting system of stippling and hatching may be nearly as effective and much less expensive in the preparation of the map. Numbering of the areas is often useful for proper cross referencing to the unit names and descriptions of the legend. Such technical detail is well explained by Kuechler (1967).

Since maps are merely two-dimensional, it is always useful for map interpretation to draw a few profile diagrams to scale in terms of distance and topography. (See Figure 4.) These can serve as a simple means of portraying the third dimension in mapping. The location of such profile diagrams should be indicated in the form of transects on the landscape map, preferably drawn through a maximum of variation of the landscape

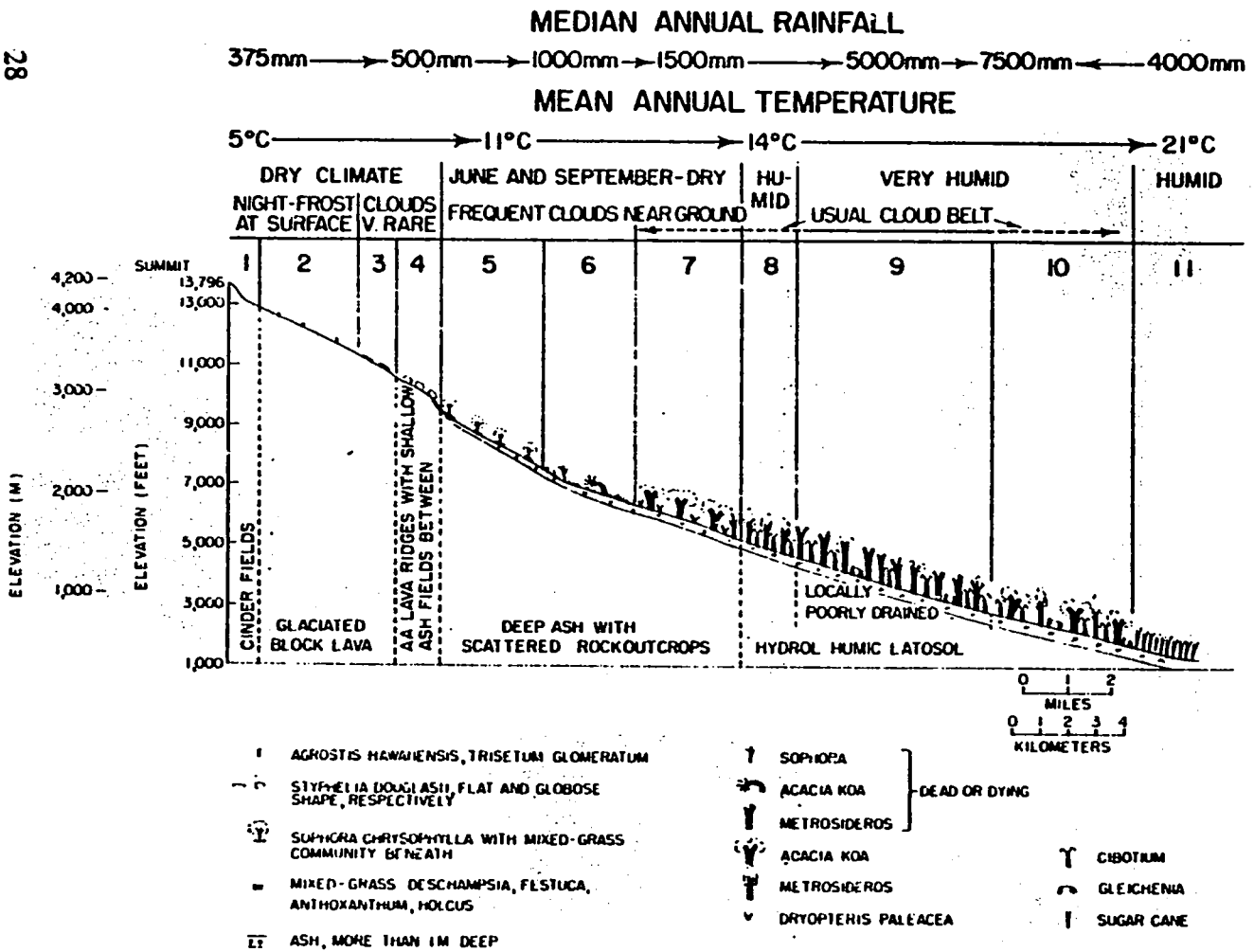

Figure 4 **Example of Profile Diagram**

map so that the third dimension can be optimally characterized with just a few profile diagrams.

Figure 4. Example of a landscape profile diagram. It is representative of a 2 km wide belt-transect on the east slope of Mauna Kea (Island of Hawaii) and extends from the summit down into the sugarcane fields above Hilo Bay. In this case eleven landscape units have been recognized. Their boundaries are based primarily on spatial changes in vegetation physiognomy, but each unit is briefly defined in terms of climate, soil, topography, and vegetation. From Mueller-Dombois and Krajina (1968).

An additional advantage to showing the third dimension is that profile diagrams can serve as excellent tools for synthesizing the essential landscape information. Climatic information such as rainfall and temperature can be indicated over the topographic profile in form of gradients, the vegetation changes can be stylized, and the soil information can be characterized underneath as well as the landform types or geological substrates.

The legend may need to be expanded in form of a separate manual to go with the map and profile diagrams. In such an accompanying manual it is often useful to show a few selected oblique photographs to provide the user with a visual impression of the major landscape units.

At the detail or subregional and local level, the minimum product for transferring the information to the user should be a narrative report. The considerable data accumulated in the field survey from the sample plots should be reduced to summary tables and/or data figures.

The narrative report should accomplish two things: It should explain the names and characteristics of forest habitats in the management area, and it should specify how the different forest sites can be identified. The best tool for site identification is of course a map. However, at the large-scale level, preparation of a landscape map may require considerable time. An alternative is to prepare a field key as well as an air photo key for objective mapping. The latter should be prepared in such a way that a trained photo interpreter can apply the key for completing the map over the whole management district in a follow-up work phase.

The field key should stress easily recognizable characteristics, such as microtopography, indicator plants (where applicable), and soil surface characteristics. The field key can then be used by the manager or his staff to locate specific sites for selected treatments. The key should also prove useful in completing the ground survey for the site map of the entire area.

Also very useful for site identification and explanation are generalized profile diagrams of habitat series which occur along the more important environmental gradients of the area. They synthesize the information of climate, vegetation, soil, land forms, and topography in an easily understandable manner and may also be used to interpret the third dimension of the forest site map, once the latter has been completed.

IV. SUITABILITY ASSESSMENT

The landscape units are now delineated on a map, and for each of them the appropriate biophysical information has been obtained commensurate with scale (local, regional, or national) and with the time and money available. Now comes the task of analyzing the ability of each landscape unit to sustain, without significant degradation, an array of likely uses. Suitability assessment translates ecological information into a form more useful to planners and decision makers so that allocation is better balanced regarding sustainable productivity from the land. The exercise does not attempt to indicate a single best use for the landscape unit. Rather it indicates which of a variety of likely uses are suitable and which are not, under either prevailing land management practices or some assumed higher or lower intensity of management practice. For example, a steep landscape unit with erosive soil would probably be rated as "unsuitable" for annual cultivation under traditional plowing and planting methods, but might be "suitable" if terraced.

SUSTAINABLE USE

The basic constraint underlying suitability assessment is that of "sustainable use." To be considered a suitable use, the activity must not result in site degradation that decreases productive capacity. Loss of soil fertility is one major cause of diminished productive capacity. This is of special concern on forest sites in the humid tropics, where the nutrients of the ecosystem are largely in the vegetation rather than in the soil. In these cases removal of the biomass results in a dramatic decline in fertility. Felling and burning to clear the site for agricultural use is the basis for the system of shifting agriculture which is common in many tropical forest areas. After abandonment following a few years of crop cultivation, if the forest is allowed to come back through a long enough fallow period, the fertility is restored, and the forest may be cleared again at some future date. These stable systems of shifting agriculture under low population densities have been practiced for hundreds of years. However, if the forest is removed for continuous (no long fallow period) agriculture or grazing, and fertility is not maintained artificially, the system rapidly degrades. Such use would be called "unsuitable," because it cannot be sustained. One

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must, therefore, make realistic assumptions about the level of management or technologic inputs in assessing whether fertility will decline.

Another major cause of site degradation is physical loss of soil due to erosion. Certain kinds of land use which expose the soil may not be sustainable on landscape units which have steep slopes and erosive soils. Units which are subject to mass wasting or land slips also present problems when the natural vegetative cover is disturbed to some degree. Again, assumptions must be made as to the likelihood of remedial measures being instituted. Use of terraces on slopes of 45 percent makes a landscape unit suitable for cultivation, whereas without such technological melioration the area would be unsuitable due to site degradation. Similarly, if helicopter or balloon logging is feasible, forest harvesting is a suitable use of even steeper slopes than could be logged by conventional methods. Minimal erosion as a constraint is essential not only because erosion impairs productivity of the site where it occurs, but because the resulting sedimentation may adversely affect other sites or water bodies further down the watershed. Irrigation, hydroelectric power, flood control, water supply, and fisheries values may be impaired, and these are important elements in economic development. It is reasonable to suggest that there is a public economic interest in having sustainable, non-degrading uses in important watersheds.

Some landscape units may have special soil constraints which render them unsuitable for proposed new uses, because those uses cannot be sustained. An area may become more saline or waterlogged after irrigation or have toxic elements in the soil that adversely affect a proposed use (e.g., the experience with salinization in interior Queensland, Australia).

Sustainable use must also be concerned with those unusual natural hazards which may not be manifest at the time the biophysical assessment is made. These too are part of the system, though some of them may occur only infrequently. These include such perturbations as floods, tsunami, lava flows, and strong winds. Where these natural hazards are expected, they should be considered in rating the suitability of a site for a proposed use. Where they are not predictable, some warning should be given in narrative form in the description of the landscape unit, that a certain perturbation is likely but unpredictable as to where and when.

Ecologically based assessment would also suggest that any use which resulted in the loss of endemic species (extirpation) would be unacceptable deterioration. Thus if a landscape unit or series of adjacent units represented the last known habitat for endangered flora or fauna, uses which would cause species extinction would be rated unsuitable. Consideration should also be given to eruptions of pests, malaria vectors, and plant diseases which may affect (or be caused by) the proposed use.

SUITABILITY CLASSES

Suitability ratings are taken from guidelines suggested by FAO (1976b) for international use as follows:

Class S_1 Highly suitable — land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly raise inputs above an acceptable level.

Class S_2 Moderately suitable — land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S_1 land.

Class S_3 Marginally suitable — land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Class N_1 Currently not suitable — land having limitations which may be surmountable in time, but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land type in the given manner.

Class N_2 Permanently not suitable — land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

These ratings assess the capacity of the landscape unit in its present condition to sustain the activity or use which is proposed. Major importance attaches to the two non-suitable classes, for these should give a warning to planners or decision makers that the proposed use being considered cannot be sustained on the site under the available inputs of technology or management of the activity. An ecological penalty is indicated in these cases.

It is suggested that the symbol "NR" be used where the use activity being considered is "not relevant." For example, it is not relevant to assess the suitability of a landscape unit which is currently in intensive grazing use for purposes of biological conservation, since the original flora and fauna have been completely replaced.

THE ARRAY OF USES

The options for forest land in the tropics include retention (essentially unaltered), modification (forest remains but is altered in composition or structure), and conversion (forest is removed to make way for other use). Forest may also be created by reforesting denuded lands. Within these categories, especially for the conversion activities, the array of uses is very large and includes many kinds of highly specialized uses such as roads, airports, etc., — the so-called "built environment."

For regional-local planning purposes at a scale of 1:20,000 to 1:100,000, it is suggested that "uses" be considered as general types of activities and not at the level of specifying crops or plantation species. The more specific uses will be selected by the land manager in more detailed planning, at larger scale and with a much greater amount of information. Thus, suitability would be assessed for "annual crop agriculture" where there is regular cultivation, rather than for "production of maize."

The conference participants suggested an array of uses for which suitability ratings would be made as follows:

A. Retention in essentially natural condition

1. Watershed protection.
2. Biological conservation, scientific reserve.
3. Wildlife management and hunting or fishing.
4. Outdoor extensive recreation.

B. Modification — still forest but altered in composition or structure

5. Intensive forest management — such as frequent return to area, permanent road network, fire and pest control, enrichment planting.
6. Extensive forest management — harvested infrequently with few or no inputs to growing the tree crop.
7. Agroforestry — forest trees remain, harvesting and replanting occurs, plus perennial or annual crops or grazing.

C. Forest Creation

8. Reforestation or afforestation.

D. Conversion to other use

9. Annual crop agriculture — frequent cultivation.
10. Perennial crop agriculture — cultivated rarely (includes rubber, oil palm, food tree crops).
11. Irrigated crop agriculture — without major land leveling.
12. Intensive grazing — usually reseeding, fertilization and often with use of exotic pasture grasses.
13. Extensive grazing — only input may be fire, may be nomadic.
14. Surface mining of sand, gravel, clay.
15. Pond development for aquaculture or waterfowl.

Subsurface mining for metals or fossil fuels and various kinds of urban settlement or infrastructure would involve much more detailed information from geology, hydrology, and engineering and are not considered at this level of forest land assessment and evaluation.

For use in some areas, the suggested groupings may be considered too broad. It may be desirable in those cases to have some homogeneous subsystems. For instance, annual crop agriculture might be subdivided into two or three sub-uses based on homogeneity of practice or crop types. Agroforestry might be subdivided into two or three distinct kinds of cropping practices if such refinements are carried out locally.

THE RATING PROCESS

Requirements

Ideally, the rating of suitability should be carried out by a multidisciplinary team including the person who has previously mapped the landscape units and carried out the land capability classification. The skill and expertise involved should include familiarity with:

(1) The use or activity being rated; e.g., for "modification of forests" (uses 5, 6, 7) a forester familiar with forest harvesting and management practices in the area concerned should be involved.

(2) The processes of erosion, fertility maintenance, and interpretations of soil characteristics for various uses.

(3) Ecology in general, and vegetation ecology in particular.

(4) Land use practices, population trends, socio-economic conditions in the area under consideration.

An up-to-date map of existing land use, or recent air-photo coverage together with knowledge of societal objectives in the region under scrutiny, will suggest which of the array of potential uses are most likely. It may be that each landscape unit should be rated for all uses, if the population in the area is one which adapts to change, or if in the case of public land the mandate is for some optimum mix of sustainable multiple uses. However, existing land use may rule out suitability rating for other uses, at least for short-term planning. For instance, a given landscape unit which has been cleared and put successfully into coffee should not be rated as suitable for intensive or extensive forest management since there are no trees on it nor are there likely to be (thus it would be designated NR for these uses). It is capable of growing forests and being used for intensive forest management, but at present is not suitable. It is suitable (probably highly suitable — S_1) for reforestation, although the chances of it being allocated to the use are probably slight, and it would also be designated NR for that use.

Assumptions must be made, based on present or immediately foreseeable socio-economic conditions, in the area under planning scrutiny as to the kind and level of inputs for each of the activities or uses. Interviews, field visits, and study of local practices are usually the basis for this kind of knowledge. As levels and kinds of financial and technological inputs change, the suitability rating may change. This attention to inputs and management is not a weakness, but a strength, in that it provides more useful information to decision makers, provided that it is updated when these changes occur (e.g., a new technology becomes available, a current technology becomes inoperative, or inputs become prohibitively expensive or unavailable). Inherent capability does not change (though our knowledge about it may change), but suitability does change over time. Moreover, it may change with geographical location. The same landscape unit with the same inherent capability may have a different suitability rating in two different locations, if the prevailing practices are markedly different (e.g., if fire control activities are operative in a steep, shallow-to-bedrock area so that burning is not used as part of the extensive grazing, then grazing might be rated more suitable on the same unit, since there would not be as great a potential for degradation due to erosion).

An Illustration of Suitability Rating

At the conference on "Forest Land Assessment and Management for Sustainable Uses," a small multidisciplinary working group was able to carry out a suitability rating for a landscape unit in a tropical mountain watershed and to have a reasonable degree of confidence in the assessment. The watershed, land uses, prevailing practices, and the landscape unit were known personally to one of the team members. The expertise of the team included: forestry, soil science, geography, biology, and land use planning. (Country backgrounds included: Japan, Malaysia, India, New Zealand, Argentina, and United States.)

A general description of the landscape unit follows: Steep, irregular concave mid-slope; outcrops of sedimentary bedrock; soils acidic, primarily shallow colluvial deposits with some deep colluvium, mostly fine loams, well-drained or excessively drained. Slopes are from 40 to 60 percent. Latitude 8° N; precipitation ranges from 1600 to 2000 mm, with a dry season of about 4 months. Mean annual temperature of 24° C. Elevations are from 800 to 1500 meters. No perennial streams. Present cover is a mixture of grasses and shrubs, with small patches of forest at the higher elevations on the steeper, more inaccessible slopes. Present use is mostly grazing and fuelwood cutting.

Using this biophysical information, the present land use, and the knowledge of the area which enabled the group to make assumptions about the likely levels and kinds of management practices, the ratings were made as follows:

1. Watershed protection...S_1
2. Biological conservation...NR
3. Wildlife management...N_1
4. Outdoor recreation...N_1
5. Intensive forest management...N_{1e}
6. Extensive forest management...S_3
7. Agroforestry...S_2
8. Reforestation...S_2
9. Annual crop agriculture...N_{1e}
10. Perennial crop agriculture...S_3
11. Irrigated agriculture...N_{2sl}
12. Intensive grazing...N_{1e}
13. Extensive grazing...S_2
14. Surface mining...N_2
15. Pond development...N_{2sl}

Further notation can be made either as narrative or in symbol form to explain the major limitation to some of the "not suitable" or "marginally suitable" uses. For example, biological conservation is rated NR because

most of the area, even the forest, has been modified, and the genetic material of the original forest has been altered. Most of the other "not suitable" ratings are because of excessive slope and the erosion hazard. The symbol "e" for erosion hazard has been added (e.g., N_{1e}) by way of explanation. Irrigated agriculture (terraces are not used in this region) and pond development are both rated as permanently not suitable because of slope (N_{2al}). Other information might be included in narrative form. This landscape unit is rated as only moderately suited to reforestation instead of highly suited because of the fire hazard due to the prevailing burning practices on this and adjoining landscape units associated with the grazing land use. Such information can be imparted with symbols or by footnotes.

Through team discussion, and give and take, a consensus as to suitability can be arrived at. This is a qualitative rather than quantitative process, and although based in science, must depend on professional judgment about likely performance.

The next step, of rating the *feasibility* of various uses for each of the landscape units, requires engineering information, economic data, and consideration of markets and infrastructure and policies of subsidy and taxes.

The *allocation* process is basically a political decision, in which it is to be hoped the suitability ratings will play an important part. Population and land tenure or ownership are handled as constraints and opportunities. Present land use can be altered by governmental decisions made on behalf of a larger public interest. In other words, present land use or even ownership may not be overriding concerns when the final decision is made. Therefore, although they are important in allocation, they are not part of the suitability assessment.

DISPLAY

Probably the most useful way in which to present the suitability assessment to the decision maker or land use planner is in tabular form on the map sheet which shows the landscape units and the biophysical data. It would be presented as illustrated by the following hypothetical table:

Table 2

Array of Alternative Uses or Activities

Mapped Landscape Units	5 Intensive Forest Management	7 Agroforestry	8 Reforestation	9 Annual Crop Agriculture	13 Extensive Grazing	15 Ponds and Storage
A	NR	S_1	S_1	S_2	S_1	S_2
B	S_1	S_1	NR	N_{1e}	S_2	N_{1sl}
C	S_3	S_3	S_2	N_{2e}	N_{1sl}	N_{2sl}
etc.						

e=erosion sl=slope NR=not relevant

Some subscripts commonly used are following. Others may be included if limitations for suitability ratings are warranted;

i — irrigation and drainage
m — moisture availability for crop growth
n — nutrient availability for crop growth
w — wetness
s — salinity

A second method is by a series of maps, one map for each alternative use or activity. These can be put on transparent overlays, to assist in the process of visualizing which are the sustainable competitors for the various landscape units. Each suitability class would have a separate shading of color and a symbol (see Figure 5).

Because this requires a series of maps (15 of them if the total suggested possible array is used), there has been a tendency to adopt the process of combining these on one map to make a "maximum intensity of use" map.

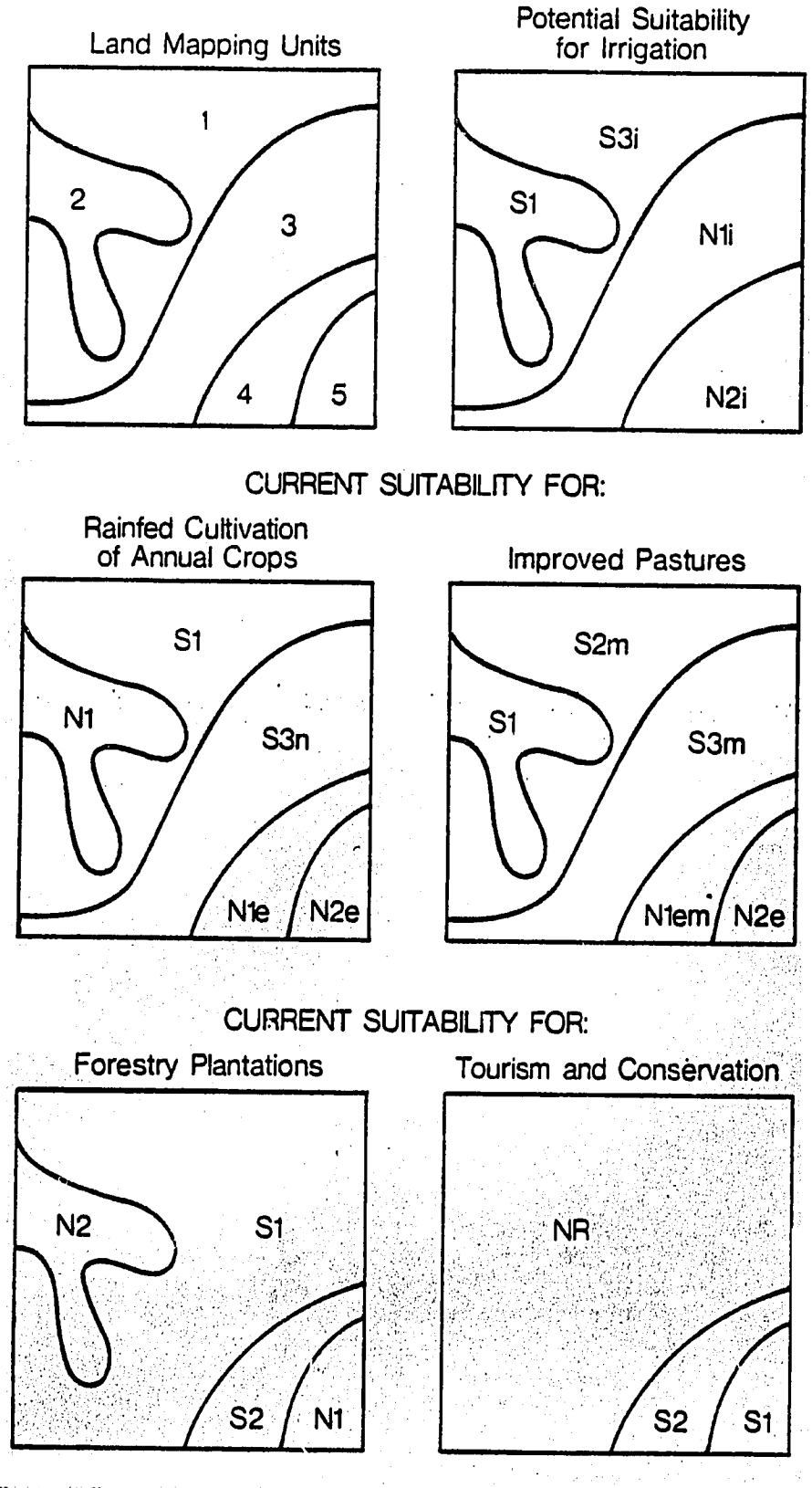

Figure 5 **Examples of Qualitative Land Suitability Maps**

This procedure has been adopted by the U.S. Department of Agriculture Soil Conservation Service in its land capability maps. Such a method seems to have been adopted in Indonesia (see Kartawinata, Appendix A), Malaysia (see Lee, Appendix A), and several other countries. It requires ranking the activities or uses in a hierarchy of use intensity, but the ranking is with respect to one kind of hazard — usually erosion. Then the map unit will contain a symbol indicating the maximum intensity use which is suitable in order to have sustainable use. For example, if the maximum intensity of use is perennial crop agriculture, it would mean that all other uses of lesser intensity — intensive and extensive grazing, intensive and extensive forest management, watershed protection, wildlife, recreation, biological conservation — in fact, all uses involving grass or forest cover, would also be suitable. It is difficult to work in such uses as mining and pond construction, because they do not fit the hierarchy. Moreover, there is the implication that the designation of perennial crop agriculture as "suitable" means that this is the "best" or preferred use. Such an inference is to be avoided at all costs. Suitability assessment should be displayed so as to indicate the array of suitable and not-suitable uses.

As a practical matter, when it comes to sites of unusual value for biological conservation, superb recreation sites, and areas important to wildlife, planners and decision makers usually want specific locations identified for these uses rather than a suitability rating. This will involve much more detailed appraisals, however, which brings one to the feasibility level. Landscape units which are no longer forested will in most cases best be called Not Relevant (NR) for these purposes (biological conservation, recreation and wildlife), rather than rated. If special knowledge exists about the special suitability of some landscape unit to any of these special conservation purposes, the rating of S_1 should be given, with a footnote indicating why this specific site is of unusual suitability for that purpose.

Having at hand a capability classification map with the landscape units identified, and a suitability assessment for an array of uses in tabular (or map) form, the land use planner is in a position to identify and display on one map all sites having high suitability (or moderate and high, or marginal and better) for a given single use. He can simply make an overlay map of all landscape units rated S_1 (or S_2 plus S_1, or S_3 and better) separating these from unsuitable units by a color code. For example, if a policy decision were made to increase beef production as a national or regional goal, the planner would be asked to designate where such grazing could be carried out with ecological safety. However, to see what other uses would be suitable, and therefore be possible competitors, would require reference to the landscape unit-suitability rating table.

V. SPECIAL TROPICAL CONSIDERATIONS, CONSTRAINTS, AND OPPORTUNITIES

A forest land classification and suitability assessment for tropical forest lands would be incomplete without taking into account certain special considerations, constraints, and opportunities which make conditions in tropical regions different than in temperate areas. Temperate lands have received much more land assessment research. Less is known about tropical ecosystems, and transferring principles or methods from temperate situations may not be satisfactory. The research gap is a substantial one, and data are often missing or inadequate. Other constraints result from the unusual relationships in the man-land interaction. The special considerations set forth below should be taken into account when determining suitability of tropical forest lands for an array of uses.

ARBITRARY AND/OR LEGAL DESIGNATIONS

In several countries of the tropics, forest boundaries were designated by law decades ago, even though now in some of these areas forests may have been removed due to agricultural encroachment, illicit cutting for lumber and firewood, etc. Many national forest policies contain clauses designed to keep a certain percentage of the land in forests. These percentages are based on some ecological factors — e.g., elevation, slope, hydrology. Arbitrary numerical objectives may have strong support from public opinion as an expression of national concern over the loss of forests. The Philippines' law, requiring 40 percent of the area to remain under forests (BFD, 1975), is based on slope and elevation. In Pakistan, the national forest policy sets 25 percent of the land to be kept under forest cover, although presently forests are confined only to 4.5 percent (see Qureshi, Appendix A) of the land. There are areas within the high hills which must be brought under protective vegetation cover to protect watersheds. The national forest policy of India mandates 60 percent of land to be under forest cover in the Himalayas, and 33 percent in other parts of the country. This includes not only crown lands, but other lands as well. In some cases, Indian foresters are apprehensive about the loss of even more forest, because there are within the presently forested areas some lands suited to sustainable agriculture (see Pandey, Appendix A). Thus, the

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legally constituted area of forests may be out of date or may not reflect reality. These designations are nevertheless difficult to change and may give a confusing statistical impression of a country's actual extent of forest land.

TROPICAL SPECIES

(1) *Species diversity.* Many tropical forests (especially rainforests) are characterized by a high species diversity per unit of land area. Sustained forest management requires a basic knowledge of the ecological behavior of each species, and information is far from adequate. Moreover, great species diversity (both plant and animal) means few individuals of any one species on any area — and many species occur only rarely. Thus, species are more easily lost from the composition of the original forest in the tropics. Sustainable use is more difficult with the diversity — rarity situation.

(2) *Unknown species.* The great diversity of species and the lower level of floral and faunal inventories in the tropics results in the presence of species which are not yet known to science. New species and even new genera are being continually discovered. This raises the problem that in our forest land conversions, we may be losing species before we are even aware of their existence and possible uses to man.

(3) *Species regeneration problems.* Along with the general problem of lack of knowledge about silvical characteristics of the great diversity of species and how to regenerate them, there are additional problems. Many primary rainforest species have heavy seed which is dependent mainly on animals or gravity for dispersal at any distance from the parent tree (compare with many light, wind-dispersed seeds of temperate trees). Moreover, the seed often has short viability. Thus, many primary species are not aggressive in their reproductive habits, have trouble competing with opportunistic secondary species and weeds, and cannot pioneer in cut-over areas.

(4) *Utilization of tropical species.* Until recently, only a limited number of species were exploited by selective logging, and little was known of the wood properties and utilization potential of the large number of species and large volume per hectare left behind. This practice led to impoverishment of a few valued species, and under-utilization of the productive capability of the site. Selective logging usually results in the loss of an appreciable part of the total stand. This situation still prevails in many parts of the tropics. "Total logging" is now making its appearance in parts of the tropics. This all-tree, any-tree harvesting for wood fiber presents a whole new array of problems with regeneration, both natural and artificial. Total

logging causes a dramatic alteration of habitat for forest fauna and flora, often irreversibly.

(5) *Choice of species for plantation.* The choice can be based on a number of factors — rate of growth, tree form, wood quality, ease of obtaining seeds, germination rate, resistance to insect damage and diseases, rooting capacity, etc. In plantation forestry, there is usually tremendous simplification in species numbers to the point where monocultures are often established. In the tropics, this situation is an even more drastic departure from the natural condition than it is in the temperate zone, where pure stands of one species do occur in natural forests with some frequency. Moreover, because there is so little experience with many native trees and because of the rapid growth of a few well-known plantation species, exotic tree species are often used. Monoculture and exotics may offer high payoff in rapid production of high volume of usable material, but they also present unusual risks in terms of pest outbreaks, disease, or possible lack of adaptation to the site conditions at hand. Rating suitability for reforestation involves much uncertainty because of these factors.

TECHNOLOGY

The level of technology applied in any given situation will vary more in the tropics than in the temperate zone. Peasant farmers will be using simple tools and their own labour in one area, while large tractors and modern implements may be in use in an adjacent area. Moreover, there is a risk of a transfer of technology from developed countries which is inappropriate to a forest operation or a land development program and which can result in unsustainable use. The fact that multi-national corporations with high technological capability may move into a technologically primitive man-land situation is always a possibility today. Thus, a suitability rating which depends on some assumed level of technology has a great deal of uncertainty, and suitability will change as a new technology is introduced into the scheme. More flexibility in suitability ratings may be needed in the tropics than in the temperate areas.

SOILS

An important property of tropical soils is the extent of weathering of their parent rocks. This largely arises from the rapid rate of parent material decomposition due to high temperature and precipitation. Soil structure beneath tropical forests is generally good and maintains a good infiltration rate. It is only when the vegetation is removed that problems arise due to soil exposure to high temperatures and intense rainfall. These soils have low mineral content, with kaolinite predominant within their clay fraction, giving a weak capacity for cation adsorption. Organic matter is generally well decomposed and has a C/N ratio of about 12 in tropical soils (UNESCO, 1978). Where drainage is impeded, peaty conditions may develop, and with high iron contents podsol may form. Tropical soils are low in silica, and most of them are high in iron oxides and equally large quantities of aluminum. High acidity often becomes a problem for the tree growth due to the toxic effect of heavy metals such as aluminum, manganese, titanium, etc. On the other hand, once the forest vegetation cover is removed, leached bases make the soil poor in nutrients. These considerations are important when determining suitability for various uses.

MELIORATION

In the tropics, there is a delicate nutrient relationship between vegetation and soils. Most of these soils are highly leached, but rapid nutrient recycling keeps them productive. However, where vegetation cover is removed and the soils are left bare or on otherwise degraded sites, fertilization may become necessary to produce trees or crops. Tropical soils have very low pH and are often high in aluminum (Qureshi, 1978b); thus, they may require liming and phosphatic application before they can be productive. In other cases, planted crops may become invaded by fast-growing weeds which may put competitive stress on the planted material. Melioration through weed removal may be an important management investment. Similarly, reclamation and terracing of the cut, eroded, and gullied land would make sites suitable for a variety of uses.

NATURAL HAZARDS

Higher intensities and frequencies of rainfall and higher temperatures in the tropics cause rapid changes in soil and vegetation characteristics. Such soils are usually susceptible to rapid erosion, and those located on precipitous slopes are vulnerable to landslides, mass wasting, etc. Where drainage is impeded, waterlogging may occur. Once the structure of soil is destroyed, percolation of salts is restricted and salinization could ensue. Often, in young soils, the rooting depth is shallow and windfalls are common. Other examples of natural hazards in the tropics include pests, diseases, and epidemics. Fires invite grass establishment and therefore make such sites susceptible to more fires. Repeated fires lead to "savannization" and a substantial decrease in site potential.

VI. RECOMMENDATIONS FOR FURTHER MULTINATIONAL COLLABORATION

The Conferees were asked to consider priorities for additional studies that could benefit from multinational participation, whether sponsored by the East-West Environment and Policy Institute or by other organizations. Readers of this report are invited to comment on these suggestions, add to them, and indicate interest in working in one or more of the areas.

CASE EXAMPLES

Site Histories

A premise of the Environment and Policy Institute is that more timely, reliable, accurate, and properly organized information leads to better management, fuller utilization of resources, and maintenance of environmental productivity. Case studies of specific forestry sites should be instructive in improving the acquisition and use of scientific and technical information by forest managers. It is proposed that six to eight tropical forest production sites in Asia and the Pacific region be chosen on which authoritative reports would be written by local experts. A common format would be used, and after site histories were drafted the writers would meet together to draw conclusions and compare findings. In addition to technical and economic descriptions of each forestry project site, the reports would address the following:

(1) The extent to which information about natural resources and the environment was *available*; format, how acquired and prepared (including traditional silviculture data and more comprehensive environmental impact analyses).

(2) The extent to which information was *used* in planning and operating the activity; distribution, outside review, public participation.

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(3) Procedures for incorporating the information into decision making and management practice; e.g., benefit/cost analysis, regulation of concessions.

(4) The consequences of forestry activity at the specific site for:
   a. renewable resource base, soils, genetic stock, etc.
   b. water resources
   c. local population
   d. non-lumber forest products and services
   e. offsite and downstream areas.

(5) Alternative approaches that were or might have been considered to achieve the economic development of the project site.

(6) Additional information that would have been (or would be) most useful for improving the net cumulative benefits of the forestry project.

(7) Additional information that would be *practical* to obtain and the limitations to more complete assessment.

Benefit Studies

The cost of adequate capability classification and suitability assessment may be quite small in comparison to the benefits (or damage avoidance) of preventing misuse and misallocation. It is necessary to demonstrate to planners that land assessment is worthwhile. Well-documented studies of situations where proper suitability assessment has led to sustained economic productivity are needed. Success stories are much more desirable than a recitation of mistakes.

It is proposed that a professional survey be made of forest management practices in the tropics with the expectation of documenting the substantial benefits, in financial terms, that derive from proper land use. These instances could be assembled in a report supporting the development of indigenous capabilities for land use research and the preparation of suitability assessments.

Remedial Activities

A third set of case examples comprises the use of suitability assessment to guide reclamation of degraded and denuded lands. Improper allocations and natural perturbations have often resulted in drastic decreases in productivity, but without (as yet) irreversible damage. In many instances (e.g., for fuel wood plantations), these lands may be prime targets for further economic investment if their potential is properly understood.

Land researchers in the tropics are urged to identify and report on such remedial activities and possibilities.

COMPARISON OF DIFFERENT ASSESSMENT METHODS AT A TEST SITE

There is no single method or set of data which can be recommended over others for universal application. It would be of value to have a rough comparison of the costs (time, money, manpower) and efficiencies of alternative approaches as adapted to a tropical forest site. A workshop is proposed at which proponents of various methods of information gathering, data reduction and presentation would assess the same site. Users of land suitability assessment results would also attend and thus a collective professional judgment could be derived on different approaches.

This exercise was performed at least once previously in the temperate zone and proved to be instructive (Ellenberg, 1967).

CALIBRATING LANDSAT D INFORMATION

Satellite images are already quite useful for forest land assessment. The next vehicle to be launched is Landsat D, which will have improved information-gathering capacity. The key step in using these signals is to relate them to the actual vegetation and surface characteristics from which they are reflected to the satellite. Much of the "calibration" work done by the United States will be on temperate zone agriculture. Some special effort in tropical forestry appears to be warranted.

It is proposed that representative sites in Asia and the Pacific be chosen to be thoroughly characterized by ground observation. These same sites would be overflown by Landsat D sensors, and the data processed to develop "signatures" corresponding to the information needed for land

suitability assessment. These sites could also be used for training in the interpretation of remote sensing information.

This activity should be jointly sponsored by nations that are using satellite images now in their forest lands management programs.

TROPICAL FORESTS RESEARCH PLANNING AND COORDINATION

The resources of money, manpower, and organization available for research on tropical forest problems are inadequate in comparison to the importance and urgency of the work to be done. Communication among these researchers is poor. Therefore, it is proposed that the East-West Environment and Policy Institute help sponsor meetings for research, planning, and coordination, as well as communication and dissemination of results.

Some of the other institutions and organizations which might cosponsor such meetings are the United Nations Food and Agriculture Organization, the World Bank, the International Center for Research on Agro-Forestry (Nairobi), the International Union of Forestry Research Organizations, United Nations Educational, Scientific and Cultural Organization/Man and the Biosphere, and the International Society for Tropical Ecology.

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APPENDIX A

List of Papers Presented at the Conference

(Single copies are available on request to the Institute)

Cameron, D. M., "Review of Forest Land Classification in Tropical and Sub-Tropical Australia," 14 pages.

Davidson, John, "Status and Methods of Forest Land Classification in Papua New Guinea," 30 pages.

Hamilton, Lawrence S., "Some 'Unbiased' Thoughts on Forest Land Use Planning — From an Ecological Point of View," 10 pages.

Hawes, Robert A., "Method of Biophysical Land Classification and Assessment for Regional Planning of Tropical Mountain Watersheds," 24 pages.

Holdridge, L. R., "World Life Zone System," 7 pages.

Kartawinata, Kuswata, "The Classification and Utilization of Forests in Indonesia," 19 pages.

Kawana, Akira, "Classification of Forest Soil in Japan," 15 pages.

Lacate, Douglas S., "Discussion of Biophysical Land Classification in Canada," 11 pages.

Leamy, Michael L., "The Status, Needs and Problems in Forest Land Classifications and Capability Assessments in New Zealand," 14 pages.

Lee, Peng Choong, "Forest Land Classification in Malaysia," 19 pages.

Marten, Gerald G., "A Landscape Approach to Regional Land Use Planning in Tropical Mexico," 28 pages.

Moss, Michael R., "An Evaluation of Some Existing Biophysical Land Classification Schemes in the Context of the Felda Land Developments in Malaysia," 7 pages.

Moss, Michael R., "A Process Approach to Biophysical Land Classification: Some Applications to Peninsular Malaysia," 9 pages.

Mueller-Dombois, Dieter, "The Ecological Series Approach to Forest Land Classification," 75 pages.

Pandey, J. N., "Problems of Forest Land Classification for Sustainable Uses in India," 5 pages.

Perera, W. R. H., "Forest Land Assessment and Management for Sustainable Uses, Sri Lanka — Country Report," 15 pages.

Qureshi, Ata H., "Forest Land Classification and Capability Assessment in Pakistan," 12 pages.

Revilla, A. V. Jr., "Land Assessment and Management for Sustainable Uses in the Philippines, 19 pages.

Sandy, I. Made, "Land Classification System for Land Use Planning," 10 pages.

Umali, Ricardo M., "The Application of Remote Sensing to Forestry in Developing Countries," 6 pages.

Wacharakitti, Sathit, et al., "Nam Pong Environmental Management Research Study — Studies on Land Use and Plant Canopies," 12 pages.

Whitesell, Craig D., "Vegetation Classification of the Trust Territory of the Pacific Islands," 8 pages.

APPENDIX B

Conference Participants

FOREST LAND ASSESSMENT AND MANAGEMENT FOR SUSTAINABLE USES

June 19-28, 1979

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APPENDIX C

Conference Agenda

CO-CHAIRMEN ATA QURESHI, LAWRENCE HAMILTON

All plenary sessions will be held in the Asia Room of Jefferson Hall.

Tuesday, June 19

9:00–12:15	Chairman – Ata Qureshi	
9:00–10:15	Welcome and Introduction to Environment and Policy Institute	
	Scope and Function of EAPI	William Matthews
	Relationship of Conferences to EAPI Project: Natural Systems Assessment for Development	Richard Carpenter
10:15–10:30	Conference Procedure	Ata Qureshi
COFFEE BREAK	(15 minutes)	
10:45–11:00	Post Conference Field Trip	Dieter Mueller-Dombois
11:00–12:00	Theme Presentation	Lawrence Hamilton
	Some Unbiased Thoughts on Land Use Planning–from an Ecological Point of View	
12:00–1:15	LUNCH – Jefferson Hall Cafeteria	
1:15–4:30	Chairman – Lawrence Hamilton	
	Expression of status, needs, problems in forest land classifications and capability assessment. Twenty minutes each plus discussion.	
	1. Sri Lanka	W.R.H. Perera
	2. Malaysia	Lee Peng Choong
COFFEE BREAK		
	3. Australia	David Cameron
	4. India	Jagannath Pandey
4:30–4:45	Procedure for Interviews and Recording with Media Production Services	
	– Paul Lundberg and Lori Noma	
5:30–6:30	Reception on Lanai at Jefferson Hall by Invitation	

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Wednesday, June 20

9:00–12:00	Chairman Ata Qureshi	
9:00–9:15	Summary and Review of Previous Session	
9:15–11:15	Continuation of country reports on status, needs, problems in forest land classification and capability assessment (twenty minutes each plus discussion)	
	7. Philippines	Adolfo Revilla
	8. Indonesia	I. Made Sandy
COFFEE BREAK	(15 minutes)	
	9. Thailand	Sathit Wacharakitti
	10. Japan	Akira Kawana
12:00–1:30	LUNCH – Group Photo	
1:30–4:30	Chairman – Lawrence Hamilton	
	11. New Zealand	Michael Leamy
	12. Pakistan	Ata Qureshi
	An evaluation of some existing biophysical land classification schemes, in the context of the FELDA land developments in Malaysia	Michael Moss
COFFEE BREAK		
	Presentation of current systems and a response to needs, problems as previously expressed. Discussion after each presentation.	
3:15–4:30	1. Douglas Lacate –Canada Biophysical Classification	
4:30	Adjourn Session	
4:30–5:00	Interviews and Recordings with Selected Participants	
	– Paul Lundberg and Lori Noma	

Thursday, June 21

9:00–12:00	Chairman – Richard Carpenter
9:00–9:15	Summary
	Continue Presentation of Systems
9:15–10:30	2. Leslie Holdridge – "Life Zones"
COFFEE BREAK	
10:45–12:00	3. Dieter Mueller-Dombois - Ecological Series Classification

Thursday, June 21 (continued)

12:00–1:15	LUNCH
1:15–4:30	Chairman – Gerald Marten
1:15–1:30	Summary
	Continue Presentation of Systems
1:30–2:45	4. Robert Hawes – Life Zones and Biophysical Land Types
COFFEE BREAK	
3:00–4:15	5. Craig Whitesell – Classification of Trust Territories
4:15	Adjourn Session
4:15–5:00	Interviews and Recording with Selected Participants

Friday, June 22

8:30 -12:00	Chairman – W.R.H. Perera
8:30–8:45	Summary
	Continue Presenting Systems
8:45–9:45	6. Gerry Marten – Landscape System Developed in Mexico
9:45–10:45	Some Thoughts and Observations on Process-Related Data Input Into Biophysical Land Classification Schemes — Michael Moss
COFFEE BREAK	
11:00–1:00	A critical look at the process of *"suitability assessment."* Round table discussion, especially inviting comments from: – A. Terry Rambo, Fellow, EAPI (Anthropologist) – Hiroshi Yamauchi, Department of Agricultural Economics, University of Hawaii (Economist) – Roy Stubbs, Research Associate, EAPI (Public Administration) – Fred Hubbard, Fellow, EAPI (Planning) – All Other Participants Discussion might focus on the following topics:

Friday, June 22 (continued)

A. How much value is there in rating suitability? i.e., is it realistic and worth the effort in view of all the other determinants of use?

B. Should suitability be rated with a constraint of no significant site degradation?

C. How do you narrow down to manageable dimensions the possible array of uses for which interpretations will be made?

D. The difficulty of getting an effective multidisciplinary effort for use interpretations.

AFTERNOON	FREE TIME	

Saturday, June 23

9:00–4:00	Field Trip led by Dieter Mueller-Dombois Box Lunch Provided Depart Jefferson Hall	

Sunday, June 24 FREE DAY

Monday, June 25

9:00–11:15	Chairman – Ata Qureshi Special Invited Papers and Discussion	
9:00–10:00	1. Kuswata Kartawinata	
COFFEE BREAK		
10:15–11:15	2. James Bethel	
11:15–12:00	3. John Davidson – Papua New Guinea country report	
12:00–1:15	LUNCH	
1:15–3:15	Chairman – Paul Lundberg Special Invited Papers and Discussion on Use of Remote Sensing	
1:15–2:15	1. Marion Baumgardner	
2:15–3:15	2. Ricardo Umali	
COFFEE BREAK		
3:30–5:00	Charge to Synthesis Working Groups and First Meeting of Groups	Richard Carpenter

Tuesday, June 26

9:00–12:00	Synthesis Working Group Sessions
12:00–1:15	LUNCH
1:15–3:00	Chairman – Richard Carpenter Plenary Session – Progress Reports
COFFEE BREAK	
3:30–5:30	Individual Creative Writing Period

Wednesday, June 27

9:00–12:00	Synthesis Working Groups
12:00–1:15	LUNCH
1:15–4:00	Chairman – Richard Carpenter Plenary Session Strategy for Generating Conference Report

Thursday, June 28

9:00–4:00	Plenary Session – Chairmen – Richard Carpenter, Ata Qureshi, and Larry Hamilton Consensus on Elements of Enhanced System of Classification and Capability Assessment for Tropical Forest Lands
12:00–1:15	LUNCH
4:00	Adjourn Session

Friday, June 29

Optional Trip to "Big Island" (Hawaii) to Forest Reserve and National Park. Expenses borne by participants.

THE EAST-WEST CENTER—officially known as the Center for Cultural and Technical Interchange Between East and West—is a national educational institution established in Hawaii by the U.S. Congress in 1960 to promote better relations and understanding between the United States and the nations of Asia and the Pacific through cooperative study, training, and research. The Center is administered by a public, nonprofit corporation whose international Board of Governors consists of distinguished scholars, business leaders, and public servants.

Each year more than 1,500 men and women from many nations and cultures participate in Center programs that seek cooperative solutions to problems of mutual consequence to East and West. Working with the Center's multidisciplinary and multicultural staff, participants include visiting scholars and researchers, leaders and professionals from the academic, government, and business communities, and graduate degree students, most of whom are enrolled at the University of Hawaii. For each Center participant from the United States, two participants are sought from the Asian and Pacific area.

Center programs are conducted by institutes addressing problems of communication, culture learning, environment and policy, population, and resource systems. A limited number of "open" grants are available to degree scholars and research fellows whose academic interests are not encompassed by institute programs.

The U.S. Congress provides basic funding for Center programs and a variety of awards to participants. Because of the cooperative nature of Center programs, financial support and cost-sharing are also provided by Asian and Pacific governments, regional agencies, private enterprise, and foundations. The Center is on land adjacent to and provided by the University of Hawaii.

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