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COMPARATIVE STUDIES ON TROPICAL MOUNTAIN ECOSYSTEMS

Planning for research

Edited by

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COMPARATIVE STUDIES ON TROPICAL MOUNTAIN ECOSYSTEMS:

PLANNING FOR RESEARCH

Report of the meeting of the IUBS Working Group on
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PREFACE

This report outlines an International Program of Research on Tropical Mountain Ecology. It was outlined at a meeting held June 2-7, 1985, in Merida, Venezuela, hosted by the Faculty of Sciences of the Universidad de los Andes, and cosponsored by the International Union of Biological Sciences and the Man and the Biosphere Program of UNESCO.

The report outlines the objectives and the philosophy of the program, and presents the reports of three working groups appointed at Merida for that purpose. Various individuals were requested to prepare different parts of the manuscripts, as follows: Prof. Bruno Messerli (Introduction); Profs. Maximina Monasterio and Guillermo Sarmiento (Central Theme); Profs. Dieter Muller-Dambois and Thomas van der Hammen (Transect Studies); Profs. Aura Azocar, Guillermo Goldstein, Maxime Lamotte, Fermin Rada, Dr. Irene Garay and Mr. Jaime Cavallier (Ecosystem Studies), and Prof. Guillermo Sarmiento (Land Use Patterns). However all partakers in the meeting (for a list of names see the back pages of this issue) participated in the preparation of one or more of the reports, which were then discussed by the entire group.

The meeting was preceeded by a series of presentations on the geology, biology, and archeology of the area, supplemented by a field trip. The organizers of the meeting wish to thank all the participants for their contributions, but very especially Drs. Maria-Lea Salgado-Labouriau, Erica Wagner, Carlos Schubert, and Dimas Malagon. Finally we wish to thank all the local organizers who worked so hard to organize this meeting.

COMPARATIVE STUDIES ON TROPICAL MOUNTAIN ECOSYSTEMS.

Proposal For a Program of Research

This document represents a proposal for a program of collaborative research on tropical mountain ecosystems. Our concern stems from the present trends of degradation of tropical mountain ecosystems, involving changes in productivity that are severely affecting the stability of the ecosystem and of the human societies that live there. In order to provide better guidelines and management options we need to improve our understanding of the working of the natural and human components of Tropical Mountain Ecosystems, and of prevailing and projected patterns of land use. Consequently, the objectives of a collaborative research program on tropical mountain ecosystems are as follows:

1. To gain an understanding of the functioning and productivity of natural ecosystems at different altitudes and levels of slope.

2. To analyze the interrelationships between natural ecosystems and prevailing patterns of land use, especially between the natural system potential and the impact of man's activities (technological input) in order to determine the carrying capacity.

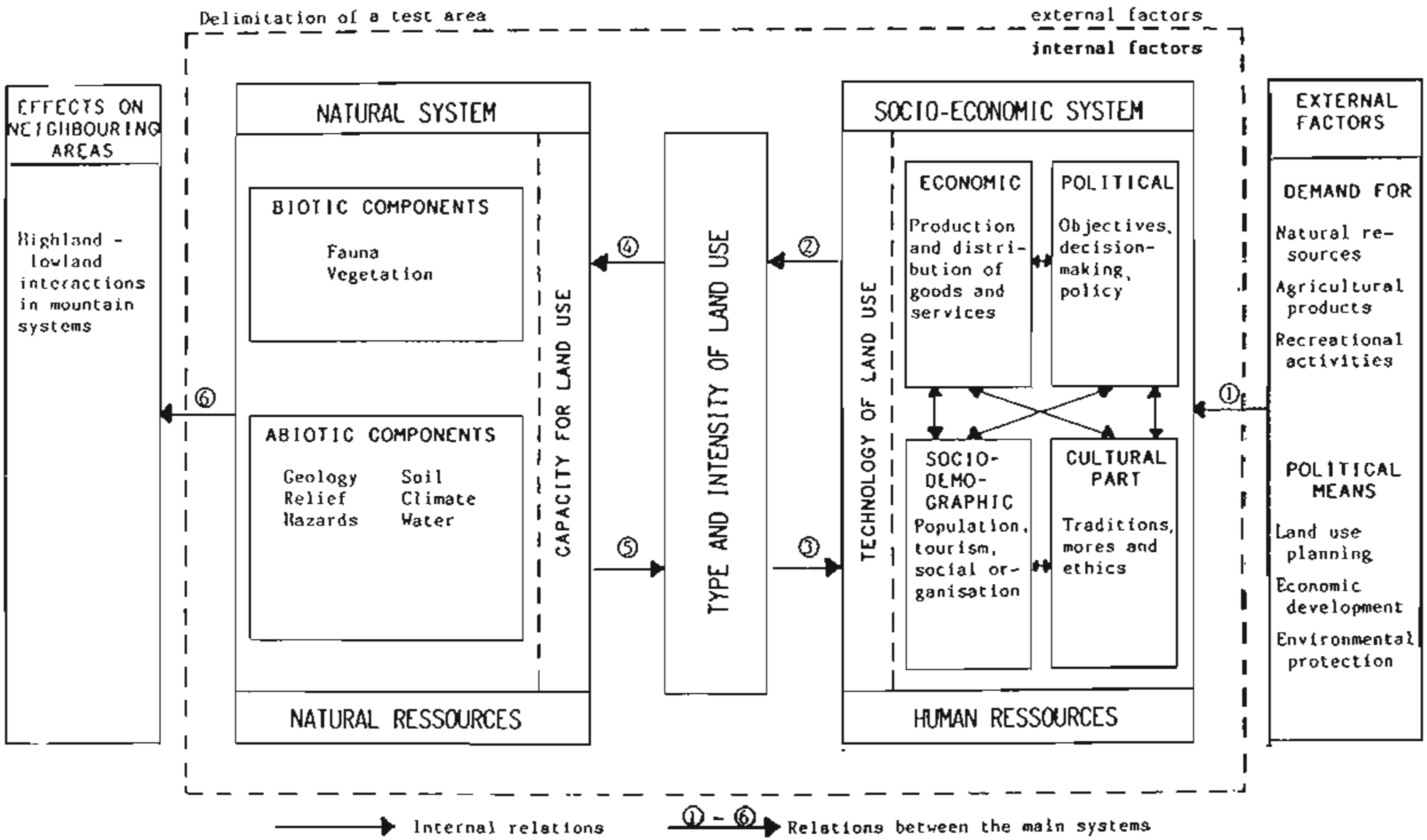
3. To identify and validate general principles of integrated development programs and resource management, and future management strategies in order to preserve the fragile and highly diversified mountain ecosystems of the tropics.

SECTION I: INTRODUCTION AND OBJECTIVES.

Natural and human systems: an integrated approach.

Any research program has to be based on an integrated approach, taking into account the interrelationships between the natural and human systems. In fig. 1 we represent the fundamental structures and processes that occur in any potential study area. Relation one shows the influence of external factors on the system, especially on the socio-economic component. The latter can be divided into several subsystems depending on the local conditions (e.g. economic, political, demographic, cultural, etc.). All the activities originating

Figure 1: Structures and processes in a schematic regional Ecological - Economic System (Modified from MESSERLI, B. and P., 1978)



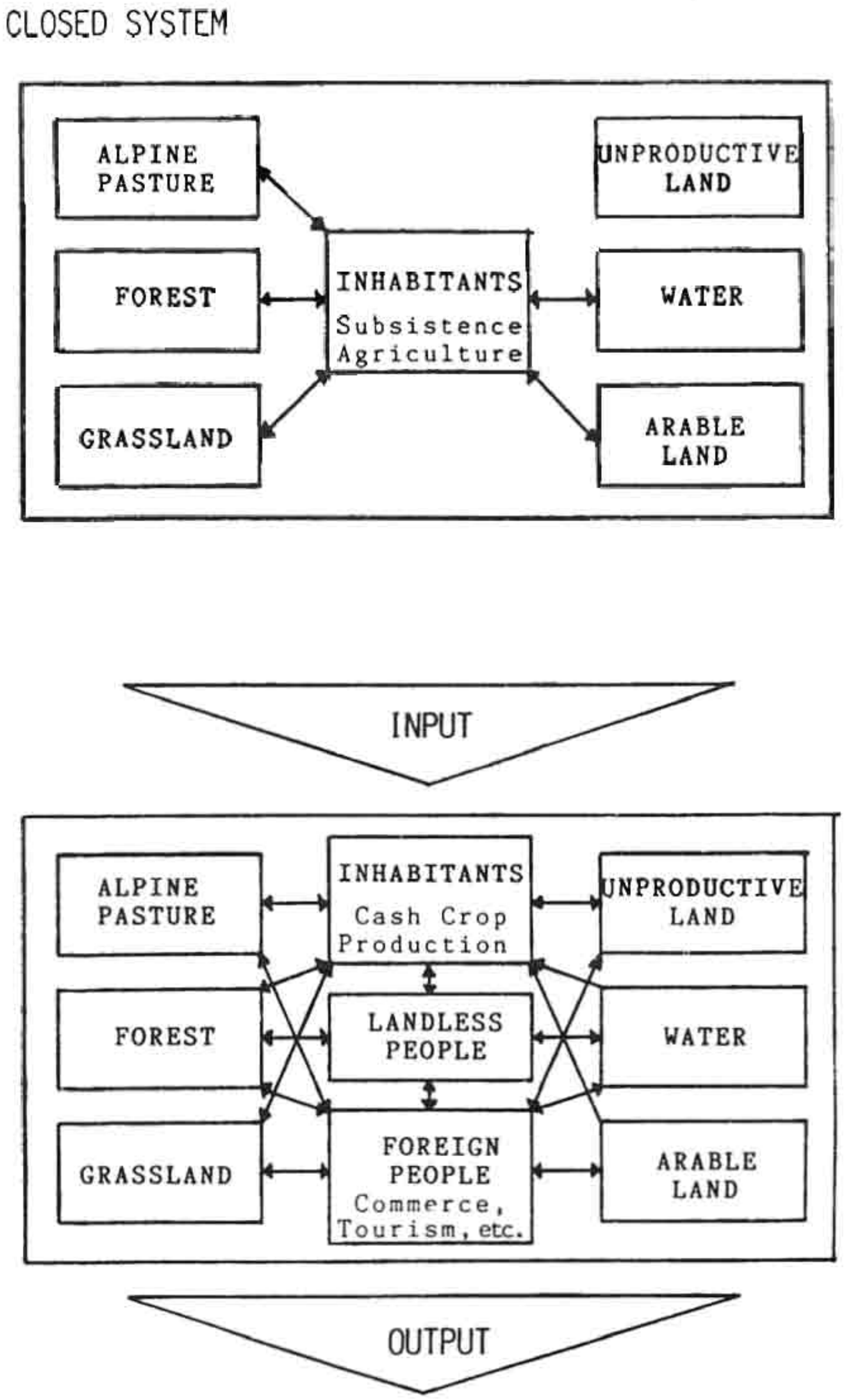
from this socio-economic system determine through the kind of technological input the type and the intensity of land use (relation two). If these activities are in equilibrium with natural conditions, there will be positive feedback from the land to the economic system in the form of yields or productivity of the land (relation three). But if this interaction leads to damage or destruction in the natural system negative feedbacks affecting land and its usefulness, and eventually also the economic system will take place (relations four and five). This general model must be adapted to every local condition. Even though it does not provide quantitative answers it is helpful in trying to understand the functioning of a very complex system and aids in recognizing destabilizing processes and to coordinate remedial action. Finally, such a model can help as an instrument of communication for an interdisciplinary group of scientists, encouraging every participant to adopt methods and findings of other disciplines.

Mountain ecosystems in a rapid and continuous change

All over the world we can observe rapid changes taking place in mountain ecosystems. With a growing world population and increasing migration into mountain areas, with the construction of roads and other systems of communication, with the influence of new economic, cultural and technological elements on the traditionally self-sufficient agricultural societies, rapid and often uncontrolled changes with damaging effects on the natural environment and its stability are taking place. Until now, mountain societies were more or less closed systems. After centuries of experimentation these societies often had acquired an equilibrium with the natural environment, an equilibrium that can be determined qualitatively and quantitatively in terms of plant and animal production, calories and grams of protein. It is fascinating to see how societies of very different cultural backgrounds, from the Andes, to the Himalayas, and Africa, tried to regulate the number of inhabitants in order to preserve the sensitive and fragile environment in which they lived and to optimize production. A similar behavior could be observed until the end of the last century in the European Alps (fig. 2).

With the opening of mountain systems to outside intervention, the natural and human mountain systems became more complex, more difficult to understand, more uncontrolled in its development, and less stable. In general more resources are exploited than are produced, unexperienced persons are involved in the decision making process regarding land use, all in order

Figure 2: **The ongoing qualitative and quantitative change from more or less closed to open systems in mountain villages and valleys** (Modified from MOSER, W., 1975).



INPUT and OUTPUT of: People (permanent and seasonal migration), capital, energy, technology, information, goods and services in different forms.

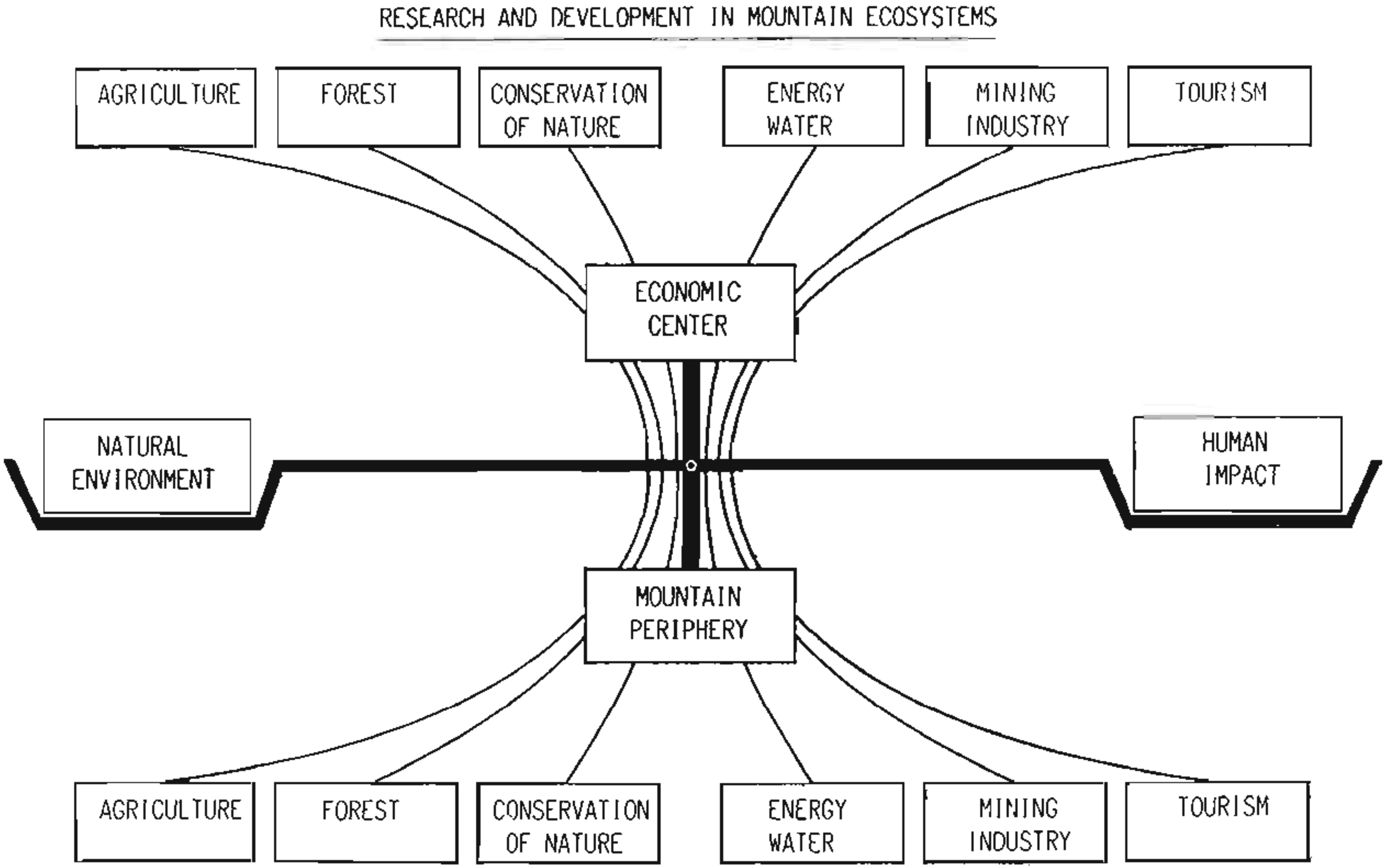
to satisfy the economic needs of surrounding lowland areas. An uncontrolled growing population creates new problems. So, for example, denied the opportunity to emigrate, landless inhabitants as a last resource cut down forests that have protected slopes for centuries. Deforestation is occurring in all tropical mountains, but especially in Africa and the Himalayas.

These changes will probably intensify in tropical mountain areas in the near future. By the end of the century all closed mountain systems will have disappeared. There is therefore an urgent need to implement programs such as the mountain program of the Decade of the Tropics, in order to find ecologically-sound solutions to the problems of tropical mountains in order to avoid irreversible damage and to encourage ecologically oriented development programs based on reliable scientific data.

The mountain periphery and the power of the economic center

Tropical mountains can be favored zones for cash crops such as coffee, tea, fruits, and vegetables. However the consumption of these and other mountain products is outside the mountain area in urban centers, or tourist centers. Market prices for these commodities conform to national and world economic policies. This means that a remote political center makes decisions that affect land use patterns in the mountains and the income of their population. So, for example, a higher coffee price, fixed and guaranteed by the government, can change immediately the land area devoted to coffee in the mountain areas. Not only a national authority, but the world economic conditions can have similar effects. Falling international coffee prices may result in the substitution of coffee by wheat, maize, livestock, etc., and this, in turn can create a need for more land which can lead to deforestation and/or erosion. Land use in tropical mountains is a delicate balance between people's needs and activities and the requirements for stability of the mountain ecosystem. This balance can easily be disturbed by wrong decisions made in a remote political center (fig.3). These decisions concern not only mountain agriculture, but also forestry, tourism, and use of resources such as water, and minerals. Even the establishment of national parks is decided by the central authority, often without consultation and thereby risking a loss of understanding and motivation of the local population required for the protection of the plants and animals in the park. Other political and legal factors can also influence land use patterns. For instance, if a farmer has to pay more than 50% of

Figure 3: The mountain periphery and the power of the economic centre



his yield in fees to an absentee landowner in an urban center he may not have the capital to improve his farming methods.

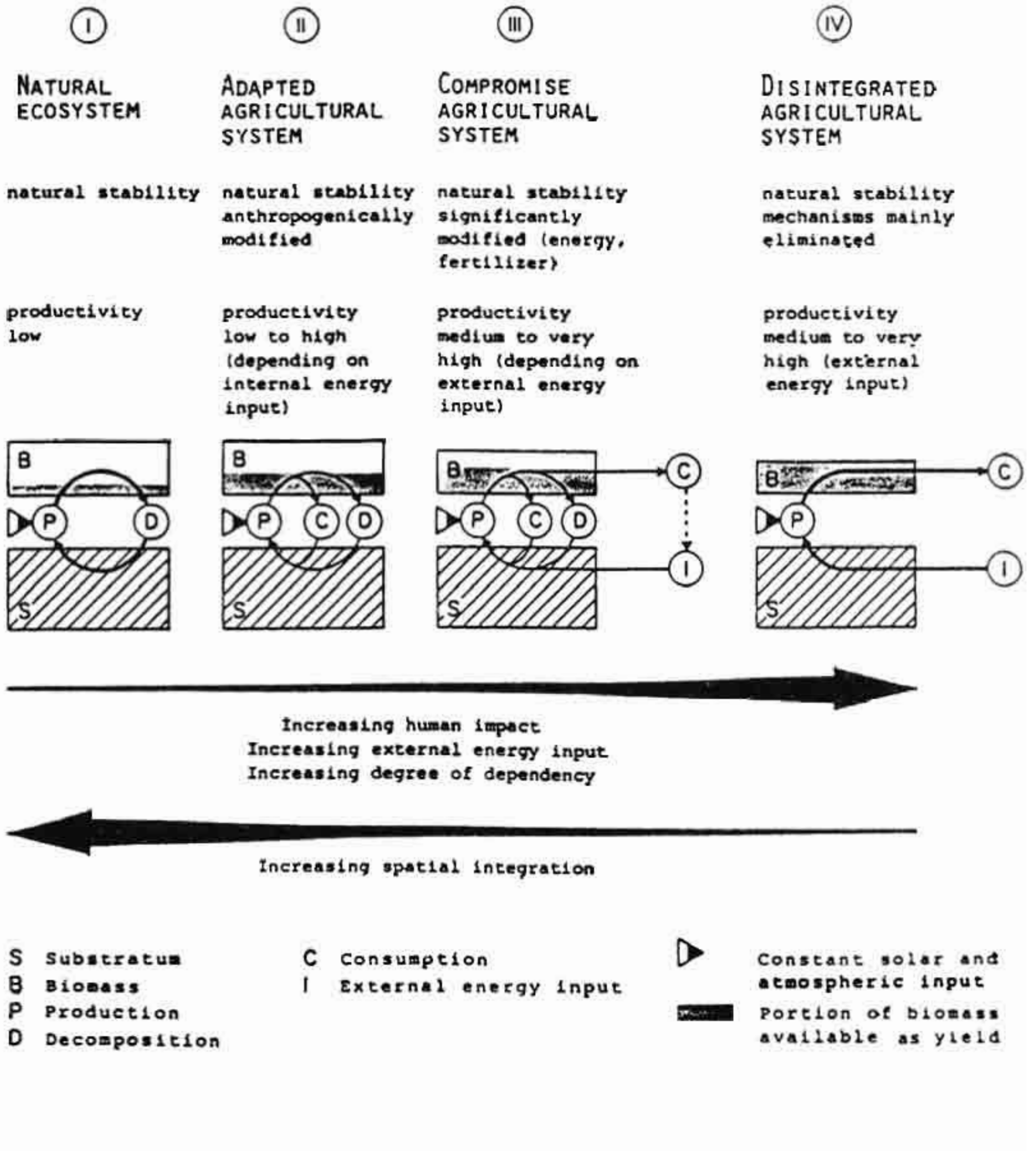
Any study of tropical mountain ecosystems has to take into consideration the physical and social location of the responsabilities for land use. The result of scientific field work, especially that dealing with the limits of productivity and stability, has to be disseminated nation-wide, so that the centers of political and economic power and decision-making understand how their decisions can affect the fragile mountain ecosystem.

The production system in relation to the natural system - a political and economic decision

According to Winiger (1984) agricultural ecosystems must consider the production strategy in terms of the input and output of energy. This is determined by the environmental conditions and the production goals (whether subsistence or commercial) set by the society concerned. This concept is expressed graphically in fig. 4 in four different scenarios: (1) the natural ecosystem within which energy is recycled and the total standing biomass is relatively large; (2) what we call the adapted agricultural system in which some portion of the biomass is available for human consumption but a stable system is maintained through the compensatory input of energy from within the human component of the system. Such a system is typified by a subsistence farming economy that remains unchanged over two to three generations. (3) The compromise agricultural system shows significant human impact and involves export of farm products balanced by the introduction of energy such as artificial fertilizers. A much higher level of production is attained but at the cost of a reduction in total standing biomass, such as is seen in parts of the Andes of Venezuela. (4) The degraded agricultural system, where there is a still further reduction in standing biomass, yields can be very high, but there is complete spatial dislocation and stability is maintained only by considerable inputs of external energy.

An understanding of these four scenarios, combined with scientific data from a study of natural mountain ecosystems, and of their continuously changing human societies, may provide the data necessary for an understanding of Tropical Mountain Ecosystems. Data should provide the necessary inputs for the development of policies that provide equilibrium between nature and human needs and avoid irreversible damage to mountain

Figure 4: Different levels of production and their related flows of substances and energy, from natural ecosystems (without man) to disintegrated agricultural systems (totally acculturated landscapes). (Modified from WINIGER, M., 1983)



ecosystems. This is the objective of the Program on Tropical Mountain Ecosystems of the Decade of the Tropics.

SECTION II. STABILITY: THE CENTRAL THEME OF THE PROGRAM

The program on Tropical Mountain Ecosystems, in spite of the fascination of the many interesting problems that it presents, must have a central, concrete and unifying set of priorities of both practical and theoretical importance, that will be of interest to both the scientific community and to tropical countries that have concrete and pressing food problems, environmental impacts, and/or demographic pressures, in their mountains.

The following suggestions take into consideration the recomendations made during the last session of the Merida meeting that this program demonstrate that the basic knowledge of ecology, physiology, genetics, biogeography, anthropology, etc., can make fundamental and tangible contributions to the management and development of tropical mountains. This, then, is our principal challenge.

The original objective such as was determined in Barcelona is: "to gain an understanding of tropical mountain ecosystems and the interrelationships of the natural ecosystems with prevailing patterns of land use... To identify and validate general principles particularly those that might be useful in gaining scientific support to developmental programs and associated technologies." We propose that within these objectives a central theme be chosen and that other themes be considered as programs of support and extension of this central theme. The theme must be one that focuses on basic concepts and that the approach be to answer practical questions related to the conditions and possibilities of use of tropical mountains. At the same time these themes will permit the integration of the results of all the proposed studies into a global vision, capable of producing quantitative, descriptive, and predictive models.

Of the four topics that were proposed and discussed in the Merida meeting, i.e. (1) transects; (2) productive processes; (3) mechanisms of regulation; and (4) stability, we think that it is this last that provides the unifying base to become the central theme, while at the same time incorporating the elements most directly related with this theme from the other topics. Consequently, we suggest that stability be the basis of the definitive program and we now would like to present a few suggestions on how to do it and indicate the type of problem that should be explored.

Core Methodological Principles

In order to delimit the field of research as well as the methodology we will start from the following premises:

1. A common experimental design at the different sites.

The focus of the program would be the establishment of a number of experimental sites where the evolution of a series of parameters relating to the functioning and structure of primary, secondary and agricultural ecosystems could be studied. A common design would ensure the comparability of the results and could include as well unique experiments at each site. This would be in accordance with the philosophy adopted by other Decade of the Tropics programs, such as the Tropical Soil Biology and Fertility and the Program of Responses of Savannas to Stress and Disturbance.

2. Verticality as the principal characteristics of mountain ecosystems.

The principal characteristics of tropical mountain ecosystems is of course the altitudinal gradient, which serves as a first integrating component of a variety of environmental factors. The experimental design will start from the consideration of verticality, separating the principal altitudinal levels necessary for an understanding of the diversity of the ecosystems and types of land use along such a gradient. Horizontal variation, as well as geological, geomorphological, and topological factors will be introduced into the experimental design as a function of their local importance and our ability to multiply the experimental sites.

3. The mountain slope as a unique characteristic of mountains.

From a strictly geomorphological point of view, as well as in terms of the habitats offered and the possibilities of use, mountains can be divided into two principal systems: valleys and slopes. The majority of the human population is usually concentrated in the valleys due to the better ecological conditions offered: better soils, more favorable grades, possibilities for irrigation, better communications, etc. The slopes instead, even though they can represent up to 95% of the available land surface in a mountain system offer less favorable conditions for human settlement, and are also more susceptible to human modification. Even though slopes and valleys form an interrelated system - the watershed - the ecological and socioeconomic problems of these two types of environment are so different that by necessity they must be considered separately. Until now most research efforts have been concentrated in the valleys, primarily on account of the possibilities they offer for intensified activities with lower ecological risks. Nevertheless we propose that our program consider as first priority, if not exclusively, the slopes, since they are the most difficult to study, the most problematic, the most extreme and the most crucial for the stability of the system.

4. The peasant as fundamental agent in the mountain society.

If we wish to understand the history as well as the present situation of the natural and social environment of tropical mountains we must consider the role of the peasant. We identify the peasant as the principal agent that creates and manages the natural and biological environment according to his culture, his traditions, and his technology. Especially the peasant that works his own or rented productive unit with the almost exclusive work of the family unit forms the basis of the social system. Other social agents exist and will be considered by us, but the peasantry will be the focus and object of our study.

5. How to work with the peasant.

We propose that most of the experimental and observational work on ecosystems and natural processes be performed in the interior of the small peasant farms. Studies at experimental stations and in natural reserves can complement this work, but the most important aspect is to follow the ecosystems under the type of use that the peasant has traditionally employed, including his working methods, motivations and objectives. That is, the work will be performed in the farms following the alternative uses of the producers, or at most, when convenient, suggesting the introduction of soft technologies.

6. Interdisciplinary Program.

The problems that will be addressed in relation to tropical mountain ecosystems and their interrelationships with present and potential use are by their very nature multidisciplinary and their understanding requires a systematic interdisciplinary approach. Even though this program is sponsored by IUBS, and is centered on an ecological and biological approach, it will be essential that other experts not included, especially agronomists, geographers, and specialists in human and environmental sciences. We therefore identify the need to establish immediate contacts with national institutions of applied research in agronomy, forestry, planing and use of natural resources, etc. in order to involve these institutions directly in the development of the program. We also suggest the convenience of involving international scientific organizations such as The International Geographical Union (IGU), through its commission on mountain geography; the International Center for Tropical Agronomic Research and Teaching (CATIE) in Turrialba, Costa Rica; the International Mountain Society (IMS), and others.

7. Altitudinal zones.

In spite of an apparent great diversity in the peasant economies of the slopes of tropical mountains, they can be grouped into a few basic systems that repeat themselves in all the tropical zones where similar conditions are found. We believe that a simple altitudinal zonation should be established compatible with prevailing biological diversity, and that these zones should be considered as the basic types or zones of production and resource use. An initial working classification could be the following:

(a) Lower montane (warm) zone. Ignoring for the moment the ecotone piedmont zone, the first typically mountainous zone is characterized by its ecological and biological affinities with the megathermic tropical environment, characterized by its high biological diversity, structural complexity, and high productive potential. This is the only zone where there are perennial crops such as sugar cane, bananas and other fruit crops, coffee, tea, cocoa, etc. Among annual crops there is also a dominance of tropical or subtropical species such as maize, present in all continents, other cereals or tubers, according to continent (rice in Asia, sorghum in Africa). The upper limit of this ecological and agroecological zone oscillates according to local conditions by a few hundred meters around the 2000 m line. We propose that in this zone two agroecosystems be studied: maize, as an example of a seasonal crop, and coffee or tea, as the more typical case of a permanent crop.

(b) Middle montane (cool) zone. This is the zone where montane forests, pastures, and annual crops of temperate zones predominate. In general cereals such as wheat, barley, as well as grain legumes and cold-region tubers such as potatoes, dominate in the dry slopes. In humid slopes relics of montane forests are found together with deforested areas used primarily for livestock production, especially dairy cattle. We suggest that three systems be studied at this level: seasonal crops; permanent pastures; and natural or semi-natural forests. Elevations of this zone range between 2000 and 3200 m.

(c) Upper montane (cold) zone This is the zone found above the normal limit of agriculture, even though some agriculture may take place under special conditions. It corresponds with the South American paramo and puna, and the alpine zones of Africa and Asia. Its lower limit can be placed around 3200-3600 m; the upper limit is that of the vegetation. Land use is limited to extensive livestock grazing, very often of a seasonal kind. We propose to study the natural vegetation under different intensities of grazing.

Once a more detailed zonation is available, result of the work of the transect group, this simple scheme can be refined, but the important point we wish to make is that we immediately start with the experimental work, based on this preliminary, but reasonable subdivision of the tropical mountain system.

SECTION III. ECOLOGICAL COORDINATES OF TROPICAL MOUNTAIN ECOSYSTEMS

As a fast methodology that can help to characterize the ecological space occupied by tropical mountain ecosystems, as well as the distribution and geographical limits of different growth forms, morpho-structural units of vegetation, cultivated species, bioclimatic phenomena, soil processes, etc., we propose a biological and environmental analysis based on existing geographical, environmental and ecological information.

The proposal is to take the most significant axis of the environmental variability at a continental scale, and within this space to take the largest number of stations located within tropical mountains. With the data from these stations the limits separating the larger units of vegetation, biomass, agricultural systems, species, etc. can then be drawn.

The three most important environmental axes at this large scale probably are latitude (which correlates with daylength, annual temperature amplitude, precipitation seasonality, and minimum temperature), height (that determines the temperature regime, insolation, orographic precipitations) and total annual rainfall (principal determinant of the rainfall regime and indirectly of the temperature seasonality).

Within this tridimensional space or in a multidimensional ecological space if additional variables are included, all the tropical-mountain stations for which there is precipitation data for a certain minimum period (10 years?) will be plotted. We estimate that some 500 stations may be included worldwide. The second phase of the work would consist in the compilation of the information available in the literature (from monographs, general articles, maps, reports, etc.) on native plant formations, present dominant vegetation, dominant species, dominant life forms, dominant species, seasonality, principal crops with and without irrigation, presence of some characteristic species and life forms, presence and frequency of frosts, type of soils, etc.

On the basis of this information, that can be supplemented by qualified local reports, ecological boundaries within the n-dimensional space of coordinates selected can be delimited. This procedure would allow the production of a global synthesis of the existing environmental and biological variability and a number of associations between biological and environmental variability. It might also help to produce predictions for sites with incomplete information or about land use in areas yet unexplored.

A work such as this is justified also from the point of view of costs, since it implies only a small working group that would compile and elaborate the information with a relatively small budget. In Merida there is interest in participating in this type of investigation. We need to incorporate a person who has direct access to good libraries and would be interested in this type of work.

SECTION IV: BASIC HYPOTHESIS AND RELATED QUESTIONS.

The underlying objective of this program is the need to increase stability of mountain ecosystems by providing management guidelines based on sound research data that will lead to an increase in productivity. We now present some of the key questions and hypothesis that need to be addressed. The list is clearly incomplete; some important aspects may not have been included because our knowledge of mountain ecology is still incomplete; others may have been included reflecting our own biases. These hypotheses are intended to focus our research. Their refinement is to be the subject of yearly symposia and workshops.

1. The types of land use that predominate in each altitudinal zone represent viable economic systems that insure the sustenance of the peasant family and minimize short term risks. As long as there are no outside pressures nor internal population pressures, the peasantry will tend to maintain its present system of production, which not only stabilizes the social system, but also maintains a certain natural equilibrium and reduces environmental and ecosystem degradation. In other words, there appears to be a trade-off between security in subsistence and environmental impact. We therefore must learn how the principal actor, the peasant, rationalizes his activities.

The basic questions relating to this hypothesis are: (1) How does the peasant obtain his sustenance? or in more concrete terms, what is his technology, his know-how to produce the different items he consumes and needs? (2) Why does he use these means, and not others, especially those that may appear to be more efficient or productive? In order to answer these questions it is necessary to know in detail how, when, and where, he cultivates, how he chooses the species or variety that he grows, what his calendar of activities is, and what factors determine them; what land he cultivates and which he leaves in fallow, and why; how he integrates in time and space his activities; which crops he fertilizes and which he does not; what changes he would make if he had more land, or labor, or capital, or technical knowledge, a more predictable market, etc.

Specific questions that need to be answered are: what is the yield and the productivity of each of the crops being cultivated; what is the yield by unit surface, by farm; by working hour; by unit of inversion, etc. What factors limit productivity in each case; how much water is available, what is the rainfall distribution, the soil quality, seeds, characteristics of the varieties being used, pests, etc. What means are available to overcome existing limitations without destroying the stability of the system.

2. Transformed natural ecosystems represent today significant areas of low productive potential and with low vegetation cover. An analysis of how these areas may be recovered may

result in a significant improvement for the environment and the people of the region. The questions that must be answered in this respect are: which were the original ecosystems and which were the factors responsible for their present status? What factors are responsible for their present stability? Are they evolving toward more stable or less stable situations? How do secondary ecosystems behave under different types of disturbance? What role do these ecosystems play as sources of fuel, forage, food, soil protection, etc.? Are there simple forms of management that will improve them? What are the labor, energy, and other costs of reverting them to a more favorable condition? Why are these marginal lands not used more intensively?

3. The demographic pressure, that has been on the increase in all tropical mountain systems during the last decades, leads in the first instance, to an extension of agricultural production, with an advance of the agricultural frontier into forest lands or high mountain areas, with poor soils, and steep slopes. This extension brings forth questions such as, at what point does the use of new land produce unfavorable ecological consequences? What short and long term consequences will the reduction and in places total elimination of montane forests have? What will the consequences of the cultivation of very steep slopes be? What are the consequences of the intense grazing of high mountain lands? We also wish to know the role that different natural communities such as forests, alpine meadows, and grasslands, have in controlling erosion, and on the water balance.

4. The conversion of the traditional productive system into more productive forms, as an alternative to the extension of agriculture, implies in first instance a change in the kinds of crops that are being grown, or in the varieties used. In some cases these technological changes have had rather disastrous consequences. In order to avoid these catastrophes we must have answers to questions such as these: What has led to the use of local varieties that are usually less productive? What are the physiological characteristics of these varieties that allow them to stand greater stresses than the highly productive ones? What are the consequences for the peasantry of the introduction of new varieties or crops? How will the agricultural schedule be affected? How will the rotation of crops, and fallow, and consequently the nutrient status of soils be affected?

5. Hypothesis regarding convergence in tropical mountains.

The fundamental question addressed by this group is whether there is convergence along vertical gradients in tropical mountains in different continents. To answer this question the use of transects is proposed in sites that are as similar as possible in terms of their physical and climatic parameters.

In tropical mountains a convergence in the vertical zonation can be detected. This convergence is expressed at different scales of analysis and degrees of resolution. This is especially so under equatorial conditions and in oceanic islands in the tropical belt. This zonation is correlated to altitudinal gradients of basic climatic variables of first order: precipitation and temperature, followed by the radiation-cloudiness duality and the seasonality of precipitation versus its uniform distribution in time.

As one ascends a vertical gradient one encounters barriers that break the climatic continuum, and thereby give rise to important discontinuities related to qualitative changes associated to the basic climatic variables. So, for example, with altitude the frequency and intensity of frost increases, which in term puts a limit to the agricultural activities.

In considering convergence at the ecosystem level we include convergence in both structural and functional characteristics.: life forms, phenological rhythms, processes of production and decomposition, biogeochemical cycles, ecophysiological mechanism of plants and animals, etc. In case these aspects were convergent, a second question to consider, is convergence in the use of these resources by humans before and after the period of contact with Europeans.

The hypothesis of convergence in ecosystem characteristics in tropical mountains was enunciated in the 19th and early 20th -although perhaps not as explicitly- by naturalists and biogeographers: Humboldt (1849), Grisebach (1845) and Schimper (1903). But it was Troll who in his many works clarified the environmental vegetation, and land use relations and similarities, of the mountain regions of the Earth (Troll, 1968). Starting from simple climatic variables such as altitude and latitude, structural characteristics of the vegetation and plant life forms, these naturalists and biogeographers formulated the hypothesis of convergence along vertical gradients in tropical mountains. To improve on the global vision of these pioneers will not be an easy task, since specialization in science has led to the compartmentalization of knowledge and the capacity to synthesize on a global scale has declined to a great extent.

These are but some of the many examples, hypothesis, and fundamental questions that must be answered in order to fulfill the objectives of the program. In the reports of the working groups these questions are elaborated further.

SECTION V: PROPOSED PROGRAMME

This document has been developed over a period of two years involving two workshops (Barcelona, Spain and Merida, Venezuela). The preceding review, hypothesis and questions provide the framework for research. The link between management practices and the desired effect of stability - at the productive, ecological, and social level - may be well known for some, or even most, local situations at an empirical level, but not necessarily at a functional level. Moreover, there are often conflicts between sustaining or increasing productivity, preserving ecological integrity, and improving human well-being. An important aspect of the Tropical Mountain Program is to provide management options that will explicitly state what these tradeoffs are.

It is therefore proposed that an international program of research on Tropical Mountain Ecosystems be initiated to investigate how ecology, phytogeography, geography, biology, physiology. anthropology and other sciences can contribute to a better understanding of tropical mountain ecosystems with the express objective to provide management options for the local peasant population and policy options for the decision makers in tropical countries.

The Program of Research on Tropical Mountain Ecosystems will have four specific goals, as follows:

(1) To improve communication among researchers interested in problems of tropical mountains and tropical mountain human populations.

(2) To promote collaborative, disciplinary and interdisciplinary, research aimed at solving specific scientific questions.

(3) To organize and carry out an intercontinental comparison of tropical mountains, their physical characteristics, and their ecosystems.

(4) To translate the research results into management options.

Procedure

1. Improving communication between researchers interested in tropical mountains. Even though there are several institutions dedicated to tropical mountain research, more communication between tropical mountain researchers is still needed. Better lines of communication are needed between researchers in different countries, especially direct links between researchers resident in tropical countries from different continents, as well as better communication between researchers from different disciplines. We propose the following two steps to try to solve this problem:

(a) Organizing regular symposia and workshops. These will be held on a rotating basis at different research sites, and will provide an opportunity for specialists in tropical mountains to discuss common problems and present the results of ongoing research, and formulate new hypotheses and reserach questions. It will also provide an opportunity to learn first hand the problems and methods for study of different mountain systems.

(b) Through the publication of reports, news of interest to tropical mountain researchers, and a register of workers interested in problems of tropical mountains. The pages of two journals have generously been offered by their editors for this purpose: Mountain Research and Development, and Biology International.

2. Promotion of collaborative projects. In this report several issues have been identified that require further research, including aspects of transect studies, studies on ecosystem structure and function, and on the interrelationship of land use patterns and ecosystem stability. The promotion of studies aimed at solving these issues constitutes one of the principal goals of this program. Such studies may be carried out by local researchers, or they may require the participation of experts from other areas or other fields.

3. Intercontinental comparisons. In order to develop a general theory about tropical mountain ecosystem stability, the information obtained from present and past research at the local level needs to be synthesized and compared with information from mountain systems in other continents. The basis of the comparison will be the various transect studies supplemented with information obtained from the literature. The underlying assumption is that the basic ecosystem processes in different mountain systems and the operation of cultural and social forces, are similar, and that general rules can be obtained. Determining this rigorously (or disproving the assumption) will be an important contribution to ecological theory and tropical mountain management.

4. Translating the results into management. We have repeatedly mentioned that the final objective of the program is to provide better local mangement options, and the scientific justification for them and for present and past practices. At the outset, scientists have to be made aware of the problems faced by the inhabitants of tropical mountains. We therefore have suggested working closely with the peasant, and making his farm our basic research unit. But, if the results of this study are to have a lasting impact they must also be incorporated into national policy, which as has been mentioned is often made at remote centers. Consequently we also hope to incorporate policy makers into the program. Their participation is essential from the very beginning.

Finally, because of the substantial influence that the world economic system has on the fate of tropical mountains through the operation of world commodity markets, we hope also to incorporate sociologists and economists into the program to use their knowledge on the constraints imposed by international conditions when devising realistic management strategies.

Organization.

The program will be organized and coordinated by a Coordinating Committe with the assistance of a Scientific Advisory Committee. The following persons have agreed to serve on the Coordinating Committee:

Professor M. Monasterio (Chairman), Venezuela;
Professor F. Di Castri, France;
Professor M. Little, USA;
Professor B. Messerli, Switzerland;
Professor D. Mueller-Dombois, USA;

Professor G. Sarmiento, Venezuela;
Professor T. van der Haamen, Netherlands.

Ex officio:
Professor O. T. Solbrig, IUBS
Dr. G. Glaser, UNESCO/MAB.

The functions of the coordinating committee will be to oversee the planning and execution of the program; to establish contact with potential contributors and invite them to participate in it; to organize workshops and regional meetings; to organize the flow of information between the various reserch groups; to keep contact with the steering committee of the Decade of the Tropics and its component programs and with the UNESCO/Man and the Biosphere Program; to appoint a scientific advisory committee.

Possible Research Sites.

In order not to diffuse valuable human and monetary resources to widely, only five or six principal research sites are envisioned initially, suplemented by a few more restricted studies elsewhere.

On the basis of prior experiences and of research in progress, and the existence of institutions that might be interested in a long term investigation as we here propose, the following sites may be considered:

(1) A site in Central America. Given the human resources and available infrastructure, the best place is Costa Rica, in conection with CATIE, the University of Costa Rica, and the Organization of Tropical Studies (OTS).

(2) A site in the northern Andes, for which the research sites of the ecology group of the Universidad de los Andes, in Merida, Venezuela is proposed, supplemented by sites in Colombia (Universidad Nacional de Colombia and University of Amsterdam).

(3) Studies similar to the ones here outlined have been conducted in Ethiopia by Addis Abeba University, Osmara University, Ethiopian Ministry of Agriculture in cooperation with the Geography Institute of the University of Berne, Switzerland. This last institution is collaborating with the University of Nairobi on studies in neighbouring Mt. Kenya.

(4) Nepal, where several research groups are active in relacion with ICIMOD (International Centre for Integrated Mountain Development), and the Royal Academy of Sciences of Nepal.

(5) The mountains of the Hawaiian islands, where an active program of research centered on the University of Hawaii is in progress. The inclusion of Hawaii offers also the opportunity to contrast the effect on ecosystem stability of the high input management practices of Hawaii with more traditional systems used elsewhere.

SECTION VI: REPORT OF THE WORKING GROUPS OF MERIDA WORKSHOP

We now analyze the results of each of the three working groups, their interrelationships and the feasibility of the proposed projects at an intercontinental, continental and local level. We also explore whether there are more efficient research alternatives to answer the questions and hypothesis presented by each group.

1. TRANSECT STUDIES.

In the Merida workshop the transect group made two proposals: (1) the production of a manual of procedures for the proposed transects, and (2) the undertaking of so called "fast" transects. The variables to be sampled in both cases are primarily structural. An important step was the proposal that these variables be quantified. The degree of proposed detail in both cases is very high and will require a great inversion of time and effort, even if only the minimum "fast" transects are performed. In order to make a truly original contribution to the hypothesis of convergence we need not only a greater level of detail and quantification of the descriptive and structural variables of the system, but we must relate the transect analysis to the functioning of the ecosystem and the processes that control the diversity of species. For this purpose the proper choice of sites is essential, and both structural and functional aspects must be well integrated.

Minimum program transect studies.

Selection of transects will be realized after a reconnaissance survey, that may lead to the recognition of broad montane zones. The selection of transects and the selection of releves within the transects will be described in the manual. Releves will be made with a vertical (altitudinal) distance of approximately 200m. Points 1, 2, and 3 of the minimum program refer each to the releves, points 4 and 5 mainly to the entire transect.

1. Vegetation releve.

a. List of all species in strata and synusia, and contour cover percentage of all primary producers.
b. Identification of species by life-forms.
c. Drawing of vegetation profile
d. Determination of basal area of trees by prism method.
e. All other data as mentioned on vegetation releve form.

2. Soil.

a. Description of one freshly dug profile according to the FAO guidelines for soil description (variability can be checked with an auger)
b. One sample of at least 1 Kg to be taken from every recognized soil horizon. A soil monolith should be taken from the entire profile.
c. Description of humus profile. Sampling of layers of humus profile (in the highest mountain systems, with incomplete vegetation cover, sampling should be done on at least three different "subsystems").
d. Measurement of soil temperature every 10 cm down to stabilized temperatures (and at least a 50 cm depth)(to be measured in soil pit, as soon as dug).
e. Laboratory analysis: (1) Physical analysis (particle size, bulk density, real density, aggregate stability, soil moisture parameters); (2) Chemical analysis (pH, cation exchange capacity, organic carbon, base saturation, total N, P, and Al); (3) Mineralogical analysis (determination of clay minerals [fraction <2 micra], general analysis of sand fraction [50-250 micra]); (4) general micromorphologic analysis (samples from soil monolith); (5) samples from all layers of humus profile (L,F,H,Al), dry weight of total sample (dried at 85°C), Carbon and Nitrogen,pH, Calcium, Magnesium, sodium, and Potassium concentration).

3. Soil Biology.

a. Root distribution (drawing)
b. Volume, weight, and number of earthworms (and other separatedly) per surface unit (gr/m^2 etc.). Use soil pit (if possible 3 pits of 100 x 100 cm may be sampled).
c. It is highly recommended to establish numbers of

individuals for each group of micro-arthropods (especially Acari and Colembola) per surface unit (expressed as numbers/m^3). This should in general be based on 5 core subsamples of 5 cm diameter, separating L+F and H+A1 (total depth in A1 5 cm).

d. It is highly recommended to measure soil-respiration/microbial activity with a field respirometer method.

4. Climatology.

a. Examples of daily course of temperature and relative humidity.

b. Measure stabilized soil temperature, as a good estimate of average annual temperature.

c. Mean monthly rainfall for at least one year, with altitudinal intervals of 500 m (or preferably 200 or 250 m).

d. Monthly maximum and minimum temperatures (same intervals).

e. Measurement of potential evaporation by Pichi-evaporometer during daytime (one day).

5. Zoology.

A general inventory along the transect of existing faunal elements in relation to altitude.

2. ECOSYSTEM STUDIES.

The transects allow the description of the principal features of the vegetation and the soil, and of the fauna, in a number of places and along altitudinal gradients. They allow the characterization of the mountain ecosystems but this approach does not tell us how the systems function. As a first step in the analysis of the functional aspects of mountain ecosystems it is necessary to define their temporal and spatial structure (horizontal and vertical), as well as their species and trophic structure. A study such as this involves a great deal of work, but is a necessary basis for an understanding of the functional aspects of the ecosystem. Because of the great deal of work involved it is recommended that the studies be confined to a few highly representative sites. The choice of sites will be based on the results of the transect studies.

Given that one of the priorities of the Decade of the Tropics is the development of guidelines for the rational utilization of ecosystems. the study of the function of natural ecosystems must be supplemented with that of transformed systems (crops, pastures, managed forests). In this respect, we like to mention that even though the high altitude environments are the most original and attractive to the biologist, that it is the medium altitude ones that are the ones most used by humans, and consequently their study may have the greatest practical importance. Such is the case with cloud forest ecosystems in the Andes that are used intensively for cattle grazing. However, given some original characteristics of cloud forests, management guidelines cannot be simple transported from other forested systems.

Consequently and given the diversity of mountain systems, only two areas have been selected for study:
(a) The High Mountain Plant formations (Paramos, Afroalpine, and High Mountains of Hawaii), as well as the _Polylepis_ forests, and (b) The cloud forest formations in different altitude mountains.

Subsequently it was decided that within these two systems, priority should be given to high altitude zones. Given the high degree of human intervention to which these systems are subjected, high altitude grasslands, crops, and forest plantations should be included. The following discussion refers therefore primarily to High Altitude Tropical systems.

Ecosystem Processes.

(a) General considerations.

The complete study of an ecosystem is practically without end given the great number of species and interactions between them, the great heterogeneity that exists at the spatial, temporal, climatic, and soil level, as well as in trophic structure. The ability of the ecologist consists in recognizing those features that are essential for developing a synthetic understanding.

The following scheme is only a general guideline of the desirable steps to be taken. The inherent difficulties of working in mountain systems will automatically reduce this list of desiderata. Ideally we would like to obtain information on (a) the specific structure; (b) the spatial structure; (c) the seasonal variation; (d) the trophic chains; (e) primary production; (f) consumption; and (g) decomposition. We recognize that this information can be obtained for only a few sites.

The specific structure of a biocenosis is not defined solely by the list of species present, but requires also an estimation of their abundance, at least of the dominant ones. For poorly known groups such estimation may be done at the level of genus or family, but for the better known groups such as Phanerogams and Vertebrates it should be done at the specific level.

The transect studies will give a first approximation of the spatial structure of the ecosystems. Subsequently such information should be refined and enlarged to include animals groups as well as the vegetation, especially soil organisms that are less mobile, since their distribution will present information regarding the trophic structure of the ecosystem.

The seasonal variation of the vegetation and the fauna represents another element of the diversity of the ecosystem, and plays and important role in the function of the system. In tropical mountains this temporal variation does not depend on temperature since temperature variations are diurnal and not seasonal, but they can be influenced by uneven distribution of precipitation. Consequently our studies cannot be restricted to one site and one season, but have to span the rainy and dry seasons.

The functioning of the ecosystem is directly connected to its characteristic trophic chain. Understanding the function of such trophic chain is based on knowledge of the specific structure, the spatial structure, and the seasonal structure of the biocenosis. It also implies the study of the feeding regimes of the principal species, or at least the dominant ones of the principal ecological groups, based on field observations, stomach contents, and analysis of feces, supplemented when needed with data from the literature. The study should also include the role of decomposers, especially bacteria and fungi.

As in any other ecosystem the production of organic matter by autotrophic organisms and their consumption and eventual decomposition by heterotrophs is the driving force of the functioning of tropical mountain ecosystems. The principal characteristic of the environment of tropical mountains is their low temperature at high elevations and the lack of temperature seasonality. Mean monthly temperatures are very often correlated with rainfall or snowfall, precipitation patterns that often correspond to very well marked seasons.

However the daily variations in temperature are very marked, especially during the dry season due to the low cloud cover. Another characteristic related to altitude is the increase in insolation, and, in the absence of clouds, of ultraviolet radiation.

(b) Outline of proposed studies of production and decompositionand trophic chains.

We now present a brief outline of the projected studies on ecosystem function. This part of the project is centered principally in the high mountain environments, mostly above 4000 m. These are fragile ecosystems and for the most part are the headwaters of watersheds. Nevertheless they are often used for high altitude animal raising. Below 4000 m we find peasant agricultural systems based on a shifting type of cultivation that allow the recuperation of the vegetation over relatively short rotations and with low environmental impact. A more modern and intensive agriculture when practiced in the area almost inevitably leads to a total replacement of the native vegetation. Unfortunately we lack information regarding the processes of succession-regeneration of the native vegetation.

The objectives of the study of production and decomposition is the quantification of the various compartments and fluxes of biomass and energy in the system. The kind of information needed is as follows:

(1) Producers and production: dry weight and caloric content of producers; primary production; biogenic elements.
(2) Consumers and consumption: description of consumers and living biomass; quantification of consumption.
(3) Decomposers and decomposition: consumption of dead biomass; chemical decomposition.
(4) Determination of the abiotic factors affecting the productive processes.

The basic hypothesis to be tested is that In similar High Tropical Mountain environments, primary production should be similar." However, if the levels of primary production are not similar the differences must be due to (a) differences in the phylogeny of the plants and or (b) differences in geological, geomorphological, or edaphic factors. Other factors that may explain the differences in productivity are: (a) differences in the ages of the mountains; (b) different evolutionary ages of the biota; or (c) a different history of human settlement and exploitation.

Primary production.

Based on prior physiological studies on the effect of temperature on photosynthesis and respiration we now know that there can be an appreciable primary production in high mountain areas. This production depends in great part on the morphological, anatomical, and enzimatic adaptations of the plant species. Since these adaptations may be related to the length of time that species have been occupying the high mountain environment, an interesting research question is to compare the degree of adaptation of species from different regions and different occupation histories. Another question of interest is to see whether tropical plant lineages behave differently from temperate plant lineages.

Consumption.

Animals are less controlled by light than they are by temperature. Consumers play a relatively small role in mountain systems, especially in high mountain systems, compared with low altitude systems. Nevertheless it would be of interest to quantify their role in the ecosystem, and the relative role of plant defenses, such as the resins of Espeletia in the Andean paramos.

Decomposition of organic matter.

The low rate of consumption of plant material can have two consequences:

(1) To increase the role of decomposers, especially microorganisms.

(2) The accumulation of carbon in the form of only partially decomposed organic matter brought about by the blocking of the processes of decomposition by anoxia and cold. This is what happens in the many peat deposits characteristic of cold regions.

We wish to emphasize the importance of the studies of decomposition since they determine the circulation of nutrients and determine within a given geochemical cycle the productivity of an ecosystem.

Problems of stability and evolution of natural and artificial ecosystems.

Another group of problems to be studied at the ecosystem scale refer to their stability, evolution and degradation, problems that are closely related to human use of the ecosystems. We propose to undertake a close comparison of the natural and artificial ecosystems at any one locality, to see if an answer to these questions can be found , especially if the transformed systems have been there for a long period. Studies may involve assessing erosion, changes in productivity, changes in the flora and associated fauna, role of fertilizers, overgrazing, degradation linked with tourism, or construction or roads and housing. Another set of investigations may deal with possible climatic changes, especially if there has been much deforestation.

Conclusions

Knowledge of the primary production of green plants is the basis of any appreciation of ecosystem function, and must be measured with great precision. These studies must be complemented with measurements of the quantity of vegetable matter consumed by animals and the precise role played by man in this process. Of the living matter that is not consumed it is important to know how it is disposed off, and how much is consumed by detrivores and how much decomposed by bacteria and fungi.

The comparison of production. consumption and decomposition processes at different sites and in the same site in different seasons, together with a careful characterization of the abiotic factors, will allow the identification of the laws that regulate these processes. In this way it will be possible to identify the limiting factors that affect the system and consequently the possibilities of improvement.

Precise estimation of primary production in several sites, such as the Andes, Mt. Kenya, the Himalayas, and Hawaii, may allow us to asses the evolutionary processes that have operated to increase the adaptive characteristics of the species. An interesting question for which we have at present no exact answer, is whether floras that have been under a high mountain regime for longer periods show better adaptation and higher production levels than those that have invaded such environments only recently.

Other questions relate to the insularity of Hawaii and the presumably poorer genetic stock; and the differences - if any -between organisms derived from primarily temperate lineages, and organisms derived from tropical lineages.

3. INTERRELATIONSHIPS BETWEEN LAND USE PATTERNS AND THE STABILITY OR INSTABILITY OF TROPICAL MOUNTAIN ECOSYSTEMS.

The subject matter of this section has been discussed in the report of the Barcelona meeting (Monasterio et al. 1984) under the heading "Ecological and Economic Rationality of Land Use Patterns and Cultural Adaptations." The conceptual framework interrelating the natural and the socioeconomic systems through land use patterns and their consequences on the stability or instability of mountain ecosystems was also discussed in the Introduction of this Report.

Here we suggest a few research proposals concerning these borderline problems, introducing some applied aspects that complement the basic environmental and biological research projects outlined in the previous two sections.

Watersheds as representative areas.

In order to analyze the consequences of human occupation and land use patterns in tropical mountain ecosystems, we have to first define and select representative areas where the ecological and socioeconomic conditions characterizing each of the research sites can be compared. In this sense, the analysis of altitudinal gradients through transects represents a starting point. Transects are useful to give a rough picture of verticality in land use patterns and a first approximation to the physical, biological, and cultural processes involved. This work must be followed by an analysis of the concrete geographical areas where human influences on ecosystems have modified the landscape.

Watersheds traditionally have provided appropriate units for different research and practical purposes, not only in relation to hydrology, but also in relation to management, protection, or administration of natural resources. This is the case because a watershed represents an area of human settlement with common historical and geographical traits.

We propose to take, at each research site, small watersheds as basic units of study. A few of them will stretcht across most of the ecozones of the mountain system, and constitute representative samples of the various land use types conditioned by the vertical zonation of climatic, hydrological, and biological factors. Thus, the whole range of environmental resources in each site may be analyzed in the watersheds and represented on maps at scales in the order of 1:100 000 to 1:200 000. Topographic maps at these scales have already been produced and are easily available.

An example of this type of research in two small watersheds in the Venezuelan Andes has been discussed by Monasterio & Ataroff (1985). In this particular case, fourteen ecological units occur in two watersheds that cover a total surface of about 50 000 Ha. An altitudinal zonation from the highest zone, above 4700 m, to the submontane rainforest, below 800 m, was represented. Furthermore, the choice of a catchment basin draining toward an interior cordilleran valley and another basin draining toward the outer mountain flank allowed them to include in a small area most of the climatic variability of the Venezuelan Andes. We suggest, then, that similar procedures be adopted in other research sites, selecting representative watersheds as units for more detailed research. In the case of isolated mountains, the whole mountain area above the surrounding plains may be considered as the appropriate sample area to be studied. The soil map of Mount Kenya (Speck, 1983) is a good example of sectorial analysis of an isolated, volcanic mountain, where the centrifuge drainage network does not lead to the separate treatment of different watersheds.

Statistical data needed to assess and quantify population distribution, land uses, agricultural production, and other socioeconomic variables are generally available by administrative units such as municipalities, or local districts. Therefore the most convenient situation for the purposes of this study is met when the boundaries of the watershed coincide with one or more census districts. Otherwise, two levels of analysis have to be made compatible, and some spatial lack of precision may arise with the interpretation of the statistical information.

Methodological Principles

The various impacts of human action on natural ecosystems have to be assessed at different levels of analysis. Some questions may refer to the distribution or density of populations over the entire area, needing a small scale treatment; other questions may require more precise localization possible only at greater scales of analysis. It is suggested that the research be undertaken at different scales of successive approximations, ranging from preliminary reconnaissance surveys to detailed treatment of specific questions at the level of the individual farm. Each scale has to be fitted into the preceding one, thus allowing the successive choices of representative samples for the more detailed analysis.

Small scale or general surveys. The goal of this preliminary phase is to provide watershed studies with an appropriate geographical, ecological, and socioeconomic framework making possible both a general evaluation of the existing problems at each mountain site and an adequate choice of the particular watersheds where further research will be undertaken.

In most regions, the needed information already exists, and this phase will be mostly one of recompilation of existing knowledge to support the choice of transects and watersheds. In these cases, emphasis should be given to an elaboration of previous knowledge in order to produce small scale maps, that is about 1:1 000 000, where relevant data concerning the natural environment, human geography, and biogeographic factors, could be adequately displayed to serve the forthcoming research phases.

Whenever this general knowledge is missing, the use of remote imagery, Landsat or other, is recommended, together with rapid surveys, to establish the spatial distribution of the relevant features. This type of work may be accomplished in a rather short time by small local teams with some external advice, if necessary.

Watershed studies (medium scales). The objective of this second level of analysis is to gain an understanding of the interrelationships between the different modalities of land use and resource utilization, on the one hand, and the characteristics, dynamics, and equilibria of ecosystems, on the other. All this, placed within the context of the existing diversity of ecological belts with their peculiar patterns of land use and their various interconnecting processes.

Several objectives are to be attained during this phase:

(a) To obtain a view of the types, characteristics, and distribution of the ecosystems actually occurring in the pilot watersheds. This inventory will be based on the result of the transect studies, complemented in what concerns secondary or human-derived ecosystems by further analysis of their structure and major ecological features.

(b) To obtain, on the basis of the knowledge of existing ecosystems, together with historical and paleoecological data, a general view of the characteristics and distribution of the original ecosystems, that is, those that existed prior to the intensive utilization of the resources, as well as the modifications that took place during the various stages of human settlement.

(c) To define at each altitudinal belt, the major environmental and biological factors limiting agricultural use and curtailing its productivity.

(d) To establish a network of ecological, socioeconomic, and cultural connections relating the various mountain ecozones, pointing out the occurrences of disturbing or destabilizing processes capable of inducing permanent misfunctions of the entire watershed.

Methodologically, these goals may be reached by a combination of remote image interpretation, ecosystem analysis, historical research, and population and socioeconomic inquiries. Conclusions may be expressed on maps at scales in the order of 1: 100 000 to 1:200 000.

The history of human occupation must encompass at least those periods that produced major impacts on natural resources, going as far into the past as seems justifiable at each site. That means, in some cases, going back a few thousand years, while in areas of recent occupation 50 to 100 years will suffice. Whenever more than one aerial picture of the area is available, separated by one or more decades, they may provide valuable documentation for tracing landscape modifications to complement the purely historical records.

It seems quite possible that at many or perhaps even at most research sites, different aspects of the natural environment and of human geography and ecology are already known. This may be the case with geologic, climatic, soil, vegetation, and agricultural studies. By using this information, several steps can be leapfrogged, making it possible to directly attack the central core of our subject: the comparative analysis of the consequences of land use on ecosystems and the response of tropical mountain ecosystems to various human-generated pressures.

Landscape analysis: natural land units, their use and potentialities (large scale studies)

To know how and why each type of terrain is devoted to a particular form of human utilization with the purpose of evaluating the consequences of land use on the equilibrium and dynamics of ecosystems, it is necessary to continue the study a further step, now at a larger scale of analysis. At this level, the different land units occurring in the pilot watersheds have to be defined and characterized taking into account their natural features: geology, geomorphology, soils, and vegetation.

Several methodologies of land classification and evaluation have been used in different countries with different aims. The CSIRO system, widely used in Australia (Stewart, 1968) and to a lesser extent in South America (Sarmiento et al., 1971) has been more successful in small scale studies. Land forms and their recurrent patterns constitute the basis of this system of land classification. Other methodologies of landscape analysis based on the concept of geosystem have also been applied to the Andes (Bertrand et al., 1980). In Nepal (Kienholz et al. 1983, 1984) and Ethiopia (Hurni, 1975, 1982; Soil Conservation Research Project, 1984), geomorphology and land use have been the main criteria to evaluate erosion, mountain hazards, and other man-induced instabilities.

It is not our intention here to evaluate or summarize these different approaches to land classification. But their existence and application to different situations suggests that there is not a unique, universally accepted, multi-purpose methodology. A pragmatic position is therefore recommended, delimiting land units recognizable on aerial photographs, characterizing their different elements through a rapid field study, and mapping their distribution on maps at about the same scale of the aerophotographs, that is, between 1:20 000 and 1:60 000.

As it is not possible with limited resources available to undertake a detailed analysis in the entire area of the pilot watersheds, the medium scale maps previously produced will serve to select representative zones to be analyzed at this larger scale. A couple of pilot zones in each altitudinal belt, each one equivalent to a few aerial steropairs, that is, with surfaces between a few hundred and a few thousand hectares, have to be chosen, and their respective landscape analyzed, to define and characterize their land units. By these means, the whole picture of land units and their uses in the watersheds and in the mountain region could be obtained.

The characterization of each land units in terms of its elements and processes has to be carried on as far as to permit the evaluation of its capability or long term potentiality. Thus, the emphasis should be on finding out degradative processes: form and intensity of soil erosion, slope instability, sedimentation of river beds, contraction of vegetation cover and soil protection, and decreased biological productivity. This large scale study will also permit us to know if unutilized land still occurs in the area, that is, if an interior agricultural frontier exists allowing the expansion of production without intensification.

<u>Agricultural systems (studies at the individual farm level)</u>

The preceding view, obtained through the large scale analysis of small representative zones in each altitudinal belt of the pilot watersheds, may provide an image of the actual situation of land use and ecosystems, particularly from a spatial viewpoint, answering questions about their degree of utilization and the visible consequences imprinted on the landscape by past and present use. To complete this picture, the temporal dimension in the use of resources has to be taken into account considering the international and seasonal variations derived from ecological or technological constraints, as well as the major changes and trends that may have occurred along the last two or three decades or at least during the peasants last generation.

In other words, there is a need to know more precisely what the producers have been doing in each land type, what they want to do, how they manage their land, and why they are doing things this way and not in other alternative manners. The answers to these questions require a study of the functioning of individual farms or productive units. Similarly, as small representative zones were selected for the large scale study, it is necessary now to select within these representative zones, a certain number of farms in order to analyze the characteristics of their systems of agricultural production. A system approach is required where a whole set of external and internal factors that determine the modalities and possibilities of farm exploitation such as land tenure, extension of farm, intensity of production, technology and level of inputs, are considered.

The sampling design and intensity, the type of inquiry, the nature of questions to be posed to the farmers and their families, may vary greatly according to the available resources and manpower and to the degree and depth desired in this phase of the research, but the data must permit answers, at least at a qualitative level, to the main questions regarding land use and their consequences that we are posing. The choice of sample unit (production unit) must be done not only on the basis of an adequate representation of major ecozones and the most widespread types of agricultural use, but also by considering the inclusion of farms representing extremes of impact. The sample of farms should include those apparently exhibiting good management practices reflected in a harmonious and stable landscape, to those that have induced obvious instability.

With this sociocultural, economic, and agronomic information, it is possible to delineate the management scheme implicit in the annual calendar of each agricultural system and to represent this scheme in the form of maps at very large scales, in the order of 1:1000 to 1:5000. In this way, the process of connecting data, from the smallest to the largest scale, is closed.

Experimental studies on processes affecting the stability of tropical mountain ecosystems.

The preceding program will permit the evaluation of consequences that the successive forms of utilization of natural resources in general and of soils in particular have induced on the stability or instability of tropical mountain ecosystems. Major conclusions will address possibilities of more conservative land uses that tend to produce only slight modifications in natural ecosystems. These should be considered alternatives to forms of land utilization that create instability and handicap the future of both humans and the mountain. Furthermore, the socioeconomic determinants leading to land uses, contrary to ecological conditions and natural constraints, may also be identified.

In addition to the research topics so far discussed, we propose that, whenever possible and as an integral part of the Tropical Mountain Program, experimental studies should be undertaken as a major baseline for intercontinental comparisons. The aim would be to obtain a quantitative appreciation of natural and human-induced processes, allowing prediction of the future behavior of ecosystems. Based on these studies it will be possible to suggest to local, regional, or national powers, management policies for the long-term preservation of the entire mountain system and the lowland areas under its influence.

Three critical aspects are suggested as priorities for a quantitative evaluation of natural processes broken down by human action: erosion, restoration of degraded ecosystems, and productivity and stability of agroecosystems.

(a) Erosion. Erosion is a natural process, active and significant in the dynamics of any mountain region whatever the environmental conditions, vegetation cover, and human occupation. It is also evident that agricultural and pastoral uses, as well as forestry, acting upon unstable lands and fragile ecosystems, accelerate erosive processes up to a point that in almost every mountain area erosion becomes the crucial element responsible for the rupture of natural equilibria.

The concept of erosion has been loosely applied to different phenomena where physical, chemical, biological, and geomorphogenetic processes interact in complex ways. It seems convenient, therefore, to set apart the various components that participate in erosion in its widest sense, distinguishing among well-defined processes such as physical weathering, chemical alteration of minerals and rocks, transport of surface materials by different agents, mass movement and slope wasting, development of soil profiles with its various losses and translocations, stream dynamics and valley development.

On the other hand, the study of erosion could be focussed from a pragmatic viewpoint stressing soil losses and elimination of arable land, by measuring in some way the loss of materials from different types of terrain, under different vegetation cover, and submitted to various management practices. This approach, already in progress in the Ethiopian highlands (Messerli & Aerni, 1978; Soil Conservation Project, 1984), provides data of enormous practical value on which recommendations for management and land policies may adequately be sustained.

The integrated research of all aspects of the erosion processes leads to a deeper understanding of the entire external morphodynamics of mountain systems, but requires a much more sophisticated, extended, and expensive, multidisciplinary research program. An example of such a study in small watersheds under various management conditions is the Hubbard Brook study in the United States (Likens et al., 1977; Borman & Likens, 1979). Apparently, very few projects of this magnitude, if any, are in progress in tropical mountains, in spite of the fact that their urgency is widely recognized in scientific and land management media (Hamilton & King, 1983).

We suggest both approaches: the second approach, cheaper and quicker is recommended for most mountain sites to be compared, whereas the biochemical and hydroecological studies may be restricted to at least a couple of sites affording the most suitable logistic and infrastructural conditions.

(b) Restoration of degraded ecosystems. Almost everywhere in tropical mountains, the exploitation of forests, either for logging or for extruction of firewood, together with recurrent vegetation fires and overgrazing by domestic herbivores, produces a degradation of their original conditions or even the total replacement of original ecosystems by secondary formations often maintained as disclimax by human pressure. In extreme cases of very fragile or abused ecosystems, all their components become unstable, rendering them not only unproductive but also a source of materials that would handicap the potentialities of downvalley lands.

As a general rule, these degraded forests, shrublands, and secondary savanas are biologically and economically far less productive than the original ecosystems they have replaced. They are also much less efficient in soil protection and in maintaining a favorable water balance on mountain slopes.

Very little is known on secondary succession in tropical mountains. Whether or not the vegetation recovers rapidly might well represent the critical element in the long term stability of the whole natural and socioeconomic system.

We suggest starting a research program on modalities and time of recovery of key secondary ecosystems under different management alternatives. These will range from total protection up to some simple procedures of agro-sylvo-pastoral management. The experimental design must permit a quantitative evaluation of temporal changes during periods extending from five to ten years or more. Obviously, the secondary ecosystems to be analyzed will depend on regional priorities and would be different from one country to another. Apparently, almost everywhere the two most critical situations have to do with either clearing or total replacement of cloud forests on the uppermost slopes, or the degradation of arid ecosystems where climate increases the fragility of the natural environment and the dangers to the entire watershed.

Among the most important points to be considered in studies of recovery of these degraded ecosystems, we propose: (1) structural changes in vegetation and their impact on soil protection, rain interception, and microclimates; (2) recovery of faunistic and floristic diversity; (3) changes at the soil surface level such as amount and distribution of litter, structure of the uppermost soil horizons, rain infiltration rates, and amount and characteristics of runoff; (4) modifications in the soil profile, such as type and amount of humus and organic matter, soil acidity and base saturation, porosity and water retention capacity; (5) changes in the productive processes such as primary production, consumption, and decomposition; and (6) relative importance of the various categories of plant producers, such as trees, shrubs, perennial and annual grasses, forbs, and epiphytes.

By following the development of these parameters along the recovery process, it will be possible to assess the intrinsic recovery capacity of each ecosystem under the experimental conditions. Moreover it will be possible to assess the consequences of this development on water and element budgets, erosion, the offer of natural resources, and the stability of slopes and the entire tropical mountain system.

(c) Productivity and stability of agroecosystems. The stability of any peasant society fundamentally depends on the functioning of the agroecosystem from which it derives its sustenance. How an agroecosystem functions, and, especially, what production levels it attains, depends in turn on environmental conditions favorable to the development of the ecosystem along its life cycle, on the characteristics of plant varieties and animal populations, and on the suitability of the agricultural practices employed.

Peasantry in tropical mountain areas relies largely on traditional technologies and local varieties of domestic plants. Both are derived from their ancestral experience and culture. But it is also evident that each day this traditional peasantry is subjected to strong and constant pressure to adopt new "modern" technologies, intended in principle, to increase productivity. However, productivity, whether measured in products or money, is not the only factor to be considered when we refer to peasant life in its widest social and cultural context. Consequently, it is extremely important to acquire a sound knowledge of traditional systems, their adaptations, limitations, and drawbacks, before encouraging changes that could lead to deep modifications of a whole system of life and land management.

Agroecosystems vary greatly from one tropical country to another, and even within each country from one mountain range to another, according to environmental conditions and to economic and cultural factors. Notwithstanding this diversity, it seems possible to distinguish three main types of traditional agroecosystems in tropical mountains:

(1) Extensive rangelands, with natural or derived vegetation. We may include here the pastoral systems of the drier mountains (sheep and camelids in the Puna of the high central Andes) as well as the limited livestock maintained in wetter areas as a complement to harvesting (humid Andes, Nepal).

(2) At high altitudes, when cold and frosts become limiting, or in relatively dry areas, annual crops like cereals, legumes, and tubers constitute the main harvesting products. The nature of the crop varies - wheat, corn, or potatoes in the Andes; wheat, barley, and beans in Ethiopia; wheat and rice in the southeastern Asian mountains - but the agroecosystems maintain some basic similarities.

(3) Perennial crops, generally on the best soils. They are mainly considered as cash crops produced for nearby urban markets or for export. Tea and coffee appear to be the most widespread and economically important market crops in tropical mountains.

We suggest that representative agroecosystems from each of these three types be selected and that they be analyzed as follows:

(1) Biological productivity of each agroecosystem, either in terms of primary (crops) or secondary production (pastures). As in the case of annual crops, normally two or more species are grown in association, productivity has to consider all cultures in a parcel of land along the year.

(2) Production in economic terms, measured either as products obtained or as income derived from its realization.

(3) Seasonality of production and crop calendar throughout the agricultural year. Consequences of the crop calendar on food supply and money income.

(4) Suitability of local populations and varieties with

regard to plagues, diseases, and zoonosis; resistance to climatic constraints and hazards; demand for fertilizers and other external energy inputs.

(5) Stability of the agroecosystem from the viewpoint of long term maintenance of biological productivity.

(6) Stability of the agroecosystem in terms of soil exhaustion, erosion, and other unfavorable effects on soils and slopes.

These points should permit a comparison of traditional agriculture and pastoral systems with systems using modern technology and improved varieties.

Integration of the different research proposals.

The proposals described above have as a common objective to understand and evaluate human effects on ecosystems and the feedback of resource modification on the stability of the local population. They must be considered, together with the other topics of the Tropical Mountain Program, as constituting a wide multidisciplinary research program. By linking biological, environmental, and human factors and processes into a single systematic approach, we can develop a the scientific foundation to provide answers to the serious questions arising from the present situation of population and natural resources in tropical mountains.

Finally, as the analysis of the processes resulting from human actions proceeds, subjects to be researched become more basic, turning increasingly to questions of functioning and productivity of ecosystems and on the ecophysiological behavior of their component species. Consequently all the approaches of the Tropical Mountain Program converge toward the common aim of understanding and predicting the dynamics of the unique system formed by the tropical mountains and their inhabitants.

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