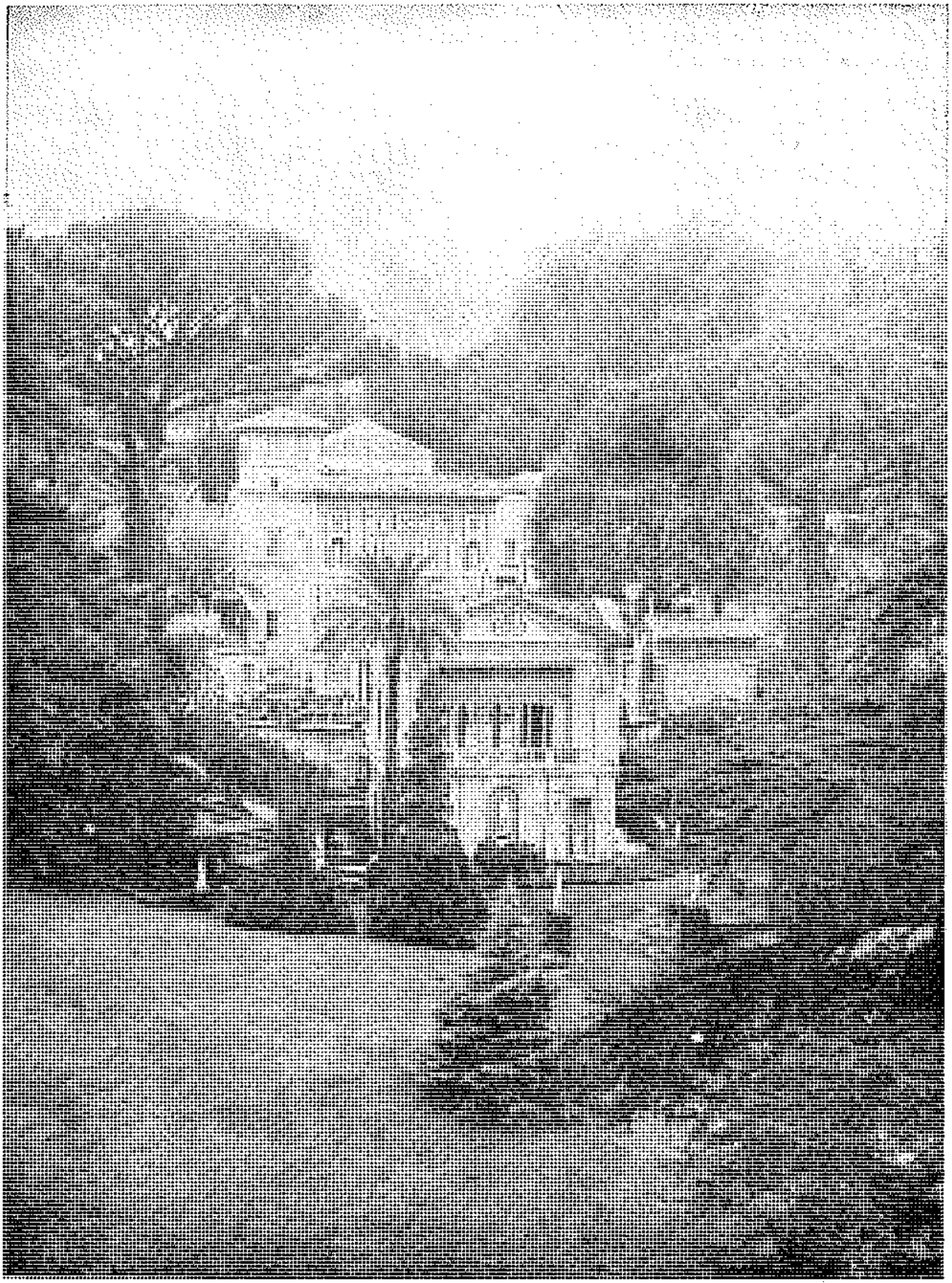

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STUDY WEEK

ON:

A MODERN APPROACH TO THE PROTECTION OF THE ENVIRONMENT

November 2-7, 1987

EDITED BY

G.B. MARINI-BETTÒLO

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INDEX

SCIENTIFIC PAPERS

I.

ETHICS OF THE USE OF NATURAL RESOURCES AND OF THE RESPECT OF THE ENVIRONMENT

II.

STRATEGIES FOR THE PROTECTION OF THE ENVIRONMENT

III.

SYSTEM-WIDE APPROACH TO THE PROBLEMS OF THE PROTECTION OF THE ENVIRONMENT

IV.

INSTRUMENTS

FOREWORD

The protection of the environment represents today a priority in both research and action to avoid the disruption of the ecosystems forming the biosphere, which may lead to an unlivable planet.

Concern about the environment was clearly expressed by Pope John Paul II in his allocution to the Academy on October 28, 1986:

"The harmonious relationship between man and nature is a fundamental element of civilisation, and it is easy to grasp all the contribution that science can bring to this field of ecology, *in the form of defence against violent alterations of the environment and of growth in the quality of life through the humanisation of nature".*

The Pontifical Academy of Sciences, which since 1970 had made a choice of studying the scientific problems concerning ecology, following the suggestion of the Pope, organized immediately a Study Week on A Modern Approach to the Protection of the Environment, *which took place on November 2-7, 1987.*

Among the multifaceted topics and aspects of ecology, it was decided that on the basis of the data so far obtained through research in the last twenty years and the analysis of the state of the biosphere, the object of the meeting should be that of suggesting solutions in order to protect our environment, that is, how to go into action.

I am very grateful to all the participants who accepted to be with us in this task, bringing the contribution of their knowledge and their papers but also of their enthusiasm.

Finally, my warmest thanks and appreciation go to the Società Cartiere BURGO S.p.A. for their generous support which made possible the publication of the present volume, and to ENEA (Comitato Nazionale per la ricerca e per lo sviluppo dell'Energia Nucleare e delle Energie Alternative) for contributing substantially to the organization of the Study Week.

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AUDIENCE OF THE HOLY FATHER

On November 6, 1987, His Holiness John Paul II granted a Solemn Audience in the Apostolic Palace of the Vatican to the participants in the Study Week on "A Modern Approach to the Protection of the Environment".

The group, introduced by the President of the Pontifical Academy of Sciences, His Excellency Prof. Carlos Chagas, and accompanied by the Director of the Chancellery, Ing. Don Renato Dardozzi, was paternally received by His Holiness, who at the end of the Audience wished to greet personally all the participants.

The President of the Academy, Prof. Carlos Chagas, delivered the following address:

Holiness,

Allow me to express, in the name of the Pontifical Academy of Sciences, of the participants in the meeting on "A Modern Approach to the Protection of the Environment", and on my own behalf, our gratitude for the generous and constant attention You give to Your Academy, as well as for Your permanent preoccupation with the impact of science and technology on the world's social development.

During these last weeks, the Academy has held three Study Weeks. The first one treated "The Aspects of the Use of Genetic Engineering". The second one, ending today, dealt with "A Modern Approach to the Protection of the Environment". Next week a third meeting will study the "Large Scale Motions in the Universe". This meeting will be aimed at obtaining new important data for the improvement of our knowledge of the Universe.

Part of the Study Week on "Aspects of the Uses of Genetic Engineering" was devoted to the use of modern biotechnology in the treatment of congenital diseases. We also discussed thoroughly the production of new *vaccines and new drugs to be used in humans and animals. Some of the diseases which haunt the world's population, such as malaria and virotic ones, can and will be eradicated by the new vaccines forged by genetic engineering.*

As all human inventions, the matter requires an extremely profound reflection, a deep awareness, and it needs to be intensely studied in order to avoid any problems which might arise in case they are used without respecting strict criteria established by ethics, morals and religion. In no way can a change in the structure of a normal human genome be accepted, be it in any stage of the human development. Genetic engineering should be used only where it can serve humankind under ethical and moral principles.

The Study Week ending today has dealt with one of the greatest challenges facing all the world.

The abuse of the environment is corroding our world very often in a hidden way and is vigorously impelled by greed, selfishness and egoism, be it of individuals, economic groups or nations.

Man, being the intermediary between God and Nature, must protect Nature in wisdom. The protection of the environment, because it has been abused by activists who, beyond the respect due to Nature, wish to deify it, has been used for political purposes. This has undermined the real aims of those who work with the noble purpose of protecting the future of humankind.

Allow me, Holiness, to ask you, in the name of all the people of the world, to proclaim — in the way you may feel to be most appropriate — the necessity of protecting the human environment. Your appeal will be heard throughout the world in the same way as has resounded Your homily pronounced in Val Visdende in the Dolomites.

I dare say, Holiness, that the anti-nuclear movement and the protection of the environment blend together in the quest for peace, and that your constant concern against the nuclear danger and Your preoccupation with respect to the protection of the environment, fulfill the expectations of the international scientific community and are a blessing for humanity.

The Holy Father replied with the following discourse:

Dear Friends,

1. *It is a distinct pleasure for me to welcome those taking part in the study week arranged by the Pontifical Academy of Sciences on the subject of* A Modern Approach to the Protection of the Environment. *This topic merits most careful attention and is truly one of tremendous importance at the present moment in the history and development of our modern world.*

Science is a human work and must be directed solely to the good of humanity. Technology, as the transfer of science to practical applications, must seek the good of humanity and never work against it. Therefore science and technology must be governed by ethical and moral principles.

Theory aimed only at profit has produced in the last century a technology that has not always respected the environment, that has led to situations causing great concern by reason of the irreversible damage done, both locally and worldwide.

Similarly, inadequate farming systems in many countries and the need for energy have continued to create very serious inroads on forest resources. The adverse effects on the environment can be corrected in the causes that produce them only by teaching people a new and respectful attitude towards the environment, an attitude that ensures the rational use of the natural resources which have to be preserved and passed on for the use of future generations.

2. *Plans for the rational use of resources must include a harmonization between nature and human settlements. This will be done through education and through planning which is gradual but which takes into account the enormous problem of poverty.*

In 1983 the Academy of Sciences carried out a specific study of the damage done to the environment by the increase of carbon dioxide and by the reduction of the ozone layer. In developing countries — which are generally characterized by a hostile climate and adverse weather conditions — there is the acute problem of the destruction of the forests in the wet tropics and of desertification in the dry tropics, problems that threaten the feeding of the population. The findings of science must be put to use in order to ensure a high productivity of land in such a way that the local population can secure food and sustenance without destroying nature.

In the industrialized countries there is the worrying problem of waste products in gaseous, liquid, solid or radioactive form. Imprudent practices have caused very serious damage to nature. Uncontrolled discharges have resulted in acid rain, trace substances in the environment and the contamination of the seas, as for example the Mediterranean.

3. *Many people have contributed to the effort to protect the environment, but the skill and good will of individual experts and scientists are not capable of solving the complex problem. Profound worldwide economic and moral changes must be dealt with at the level of groups of communities and governments, which must include interregional and international exchanges and agreements. Fundamental to this action is educating people about the environment and creating an attitude of understanding, respect, and genuine goodwill.*

4. I wish to thank all those present here who have contributed their scientific knowledge and their enthusiasm. I likewise thank the representatives of the international bodies such as the European Economic Community and the United Nations Environment Programme, whose headquarters in Nairobi I visited in 1985.

I also wish to thank the experts who last week concluded an important working meeting, developing reports and scientific discussions on Aspects of the Uses of Genetic Engineering: *the production of drugs and vaccines, and the improvement of the nutritional situation especially on behalf of the developing countries. The prospects of genetic therapy for treating diseases are likewise hopeful and deserve the commitment of science and the skill of those carrying out research. But in genetic therapy extreme care must be taken to avoid endangering the physical integrity and the life of each individual. Above all, any attempt or danger of altering the inviolable genetic identity of the human person must be stopped.*

Finally, I send in advance my greetings and welcome to the scientits who will next week begin discussions on an important subject of modern astrophysics: Large Scale Motions in the Universe. *Twenty scientists will seek to increase our understanding of the degree of homogeneity in the universe on a broad scale, the distribution and nature of "hidden mass", the question of whether the universe will continue to expand or is destined to fall into another "singularity".*

May your efforts, individually in your particular fields of competence and as a body associated with the activities of the Pontifical Academy of Sciences, be crowned with every success, as you labour for the good of all humanity.

SCIENTIFIC PAPERS

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The Editor wishes to express his appreciation for the valuable assistance provided by Father Bernard PRZEWOZNY, O.F.M. in the preparation of this volume.

A MODERN APPROACH TO THE PROTECTION OF THE ENVIRONMENT

INTRODUCTORY REMARKS

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I thank you for having traveled long distances to come here, to the Casina Pio IV in the Vatican, specifically in this year of 1987, the year that has been dedicated by the United Nations to the environment.

Quite a number of meetings on the subject of the environment have been held in the world these past months. The present one, however, taking place, as it does, on the Vatican Hill — and, if I may add, in the very shadow of St. Peter's dome — has a unique character: the results of our studies and discussions of the contemporary environmental crisis, which affects so profoundly the dynamic equilibrium of man's existence in the biosphere, will be presented to the Holy See for its consideration.

The mismanagement of the environment on the part of humankind has caused, as we all very well know, deep modifications in the biogeochemical equilibria which sustain life on earth. Indeed, these modifications may irreversibly affect the natural, dynamic equilibria which make our present way of life possible. Allow me to cite some of these imbalances: global change of climate, depletion of the ozone layer in the stratosphere with the concomitant danger of increased ultraviolet radiation, desertification and deforestation with consequent changes in the earth's water cycle, pollution of the seas, and so on. Furthermore, the continuous exploitation of natural resources, both renewable and non-renewable, for the purpose of satisfying not only the needs of an ever-growing world population but also those of wasteful consumerism will render ever more rare the raw materials that are extracted from the earth's crust, such as petroleum and heavy metals, and will destroy, with severe damage to the integrity of "nature", important species of flora and fauna.

These absurd policies — "nature" being the expression of the biogeosphere which constitutes the framework for and the means of humankind's survival — represent a great danger: they are rendering our planet as unlivable as the moon. Not only persons and groups, but even certain governments, are motivated by shortsightedness and selfishness which permit them to exploit and dominate our planet without any concern for the future, without any respect for the future of the generations which will follow us.

The warnings of scientists, issued a few years ago, reached countless people, professionals in mass media and leaders of governments responsible for the management of the earth. As a result, a change in attitudes toward the environment has been noticed. More and more people are aware that we live on a finite planet with limited resources which were accumulated during millions of years and which cannot be destroyed or dispersed at the present, rapid rate without danger to life as we know it. This does not mean that the reversal of tendency is complete, but it does imply that some steps toward improvement have been taken. Still other incentives will have to be found to motivate our efforts to correct the present degradation of natural and humanly modified ecosystems.

Already in 1970, that is, before the United Nations Stockholm declaration on the human environment, and, more recently, in 1983, the Pontifical Academy of Sciences considered the global effects of pollution on the atmosphere. The purpose of the present Study Week is to discuss how and to what specific areas ethical principles may be applied to direct our actions and our use of scientific and technical means in protecting the environment.

A number of analyses of the present state of degradation of the dynamic equilibria which sustain the environment have been made, supplying us with an immense quantity of data which will enable us to formulate a fairly good, even if not complete, picture of the present situation and will permit us to extrapolate various future scenarios. The ascertainment of these data, however, cannot constitute the goal of our work, rather it must become the basis for our future action toward better management of the environment and the biogeosphere.

If a constructive, global, strategy toward the protection of the environment is to be socially compatible and even economically sound, then it must be developed through an interdisciplinary approach which will avoid the impossible and impractical solutions which might be suggested by theoretical or unilateral considerations. Thus, such a strategy must be sustained primarily by the effort to attain the common good and not by exclusive or vested commercial interests. We cannot pretend, on the one hand, that the earth's 5 billion people return to a silvopastoral economy, which ecologically might be sound but insufficient to sustain the population, and, on the other, that the earth's surface be transformed into great factories and vast, industrially run agricultural areas which would modify the equilibria of natural ecosystems wasting and diluting precious raw materials. Furthermore, we must remember that particular problems make up the global view. For example, a new approach is necessary to environmental protection in the South, mainly in the tropics. In the recent past, measures to prevent environmental decay were erroneously considered a limitation to development, whereas, today, they may indeed be one of the main contributors to wealth.

Before the natural equilibrium, which includes atmospheric and climatic phenomena, is disrupted irreversibly, we must propose feasible solutions which will be acceptable to all the peoples of the world and will enable them to face the challenge of the future. Science and the means of technology should offer solutions which are consonant with the continuous growth of the human populations. But science, technology and the economy, unless they are supported by a new way of thinking about the environment based on ethical principles, will not be capable by themselves to save the future of the biosphere. Consequently, an interdisciplinary and systematic approach is necessary in order to overcome reductionism in proposing solutions.

You, the most distinguished scholars in the field, are gathered here to offer your expert analyses, advice, and suggestions. Our task is not easy. At times it will require not only a modification but even the eradication of ideas and forms of behavior that have conditioned humankind from its very beginnings. Ecological, economic, social and cultural research must be accompanied by the development of a new mentality, one that will respect "nature" and the environment and will inculcate a reasonable and moderate use of natural resources. Such an attitude toward "nature" should be the object of education at every level, not only in schools but in temples, mosques and churches of every religion.

We should recall here the example and the teachings of Saint Francis of Assisi, the patron of all those who are concerned for the ecological health of the biosphere. Already in the thirteenth century, he anticipated the attitude which should motivate every human being today. Convinced that, by reason of their origin and destiny, all living and inanimate creatures are dependent upon each other, he recognized a form of cooperative partnership among them and called them his brothers and sisters — *brother sun, sister moon, brother air, sister water*, and *sister earth, our mother*. If only some of the Saint's enthusiasm were to motivate our attitudes, it would enable us to solve our immense environmental problems, and, finally, to face the future with serenity and hope.

I.

ETHICS OF THE USE OF NATURAL RESOURCES AND OF THE RESPECT OF THE ENVIRONMENT

GLOBAL CRISES AND THE ENVIRONMENT

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1) *Introduction*

The title of this introductory presentation, as suggested by the organizers of the Study Week on "A Modern Approach to the Protection of the Environment", was based on two antitheses: Economy and Environment — Man and Biosphere. In this context, it could have been even more consistent to propose the terms of three — true or false — dialectic oppositions, such as economy and ecology, development and environment, man and the biosphere.

Economy and ecology represent two disciplines, one from the natural and the other from the social realm. They can be viewed also as two ideologies. Nevertheless, granting status of an ideology to economy and ecology could be wrong and dangerous in my perspective, for the credibility of these disciplines themselves [23].

Development and environment can be envisaged, from an anthropocentric viewpoint, as two much-needed dimensions of planning. Taking an evolutionary approach, they integrate two groups of selective forces; *natural disturbances* acting on the evolution of organic diversity coalesce as the environmental component; *man-made disturbances* inherent in development are also selective forces, while more deterministically oriented; the impact of the latter on living beings is of growing relevance. The word "disturbance" does not have a negative meaning, but is understood here as a dynamic force acting on "unities of selection" such as species, populations and ecosystems [66].

Finally, man and the biosphere represent two biological entities. But they can materialize two philosophical attitudes, when presented as antagonistic (man and/against the biosphere) or synergistic (man in/part of the biosphere) elements.

I later decided to change the title, first of all because it largely overlaps that of Dr. Maler's presentation. In addition, I am not convinced that the terms mentioned above represent acceptable antitheses. Furthermore, it is my view that most of the environmental problems that we are facing now and, even more, those that we are likely to face in the near future are originated by what I call "globalization crises". These crises lead to economic and also ecological interdependence, and — at last — to close economic-ecological linkages [56].

By globalization crisis, it is not meant that all problems, either environmental or socio-economic, are identical everywhere, but that they emerge because of complex relationships that take place on a very large scale. They reach a global dimension, and they cascade at national, regional and local levels, acquiring their specificities as regards patterns and solutions.

After all, this is the most appropriate place to touch upon ecumenical problems, etymologically speaking.

2) *The Emerging Counterpoints (and Cacophonies) of the 70s*

Perceiving as opposed the terms mentioned in the introduction, as well as feeling that development is incompatible with the environment, that man plays the wicked role as regards nature, and that the economic imperative is intrinsically bad, progressively took shape at the end of the 60s and beginning of the 70s. Even science and technology were considered guilty of the crime of environmental degradation. It is true that the effects of the accumulation of pesticides and other pollutants impacted as "surprise" [8, 15] the dwellers of the industrialized and mostly urbanized world.

The still ongoing discussion on the coalition or opposition between development and environment appeared to be the key issue at that time, and eventually gave rise to the United Nations Stockholm Conference on the Human Environment.

Retrospectively and from a personal viewpoint, when I was in Chile in the early 60s, involved at the same time in research on ecology and in regional planning for arid lands development [19], I was very far from predicting that in a few years' time, as an ecologist, I would have taken the risk of being considered an "antidevelopment man". As a matter of fact, ecology and genetics are the two fundamental pillars for agricultural, livestock and forestry production. Furthermore, I have always believed that science and technology, if backed by public awareness and political will, are the only tools to face environmental degradation successfully.

The Stockholm Conference, held in June 1972, was the first of a series of very large United Nations conferences (on population, water, desertification, science and technology, etc.) that have revealed how sharp the North-South division is in a search for a new economic order [78].

The Stockholm Conference exemplified a kind of "war and peace" between industrialized and developing countries. Many developing countries were considering this Conference as a maneuver to stop their development. Several industrialized countries were focussing too much on the pollution control aspects of industrialization. Too often, a romantic, naively paternalistic and "western" view was prevailing while considering Third World development, and discussing realistic solutions to acute problems of soil erosion and tropical deforestation.

These strong but challenging controversies between industrialized and developing countries, between natural and social scientists, that took place during the preparation of the Stockholm Conference as an immense brainstorming, had in themselves many positive outcomes.

First of all, they led to the recognition that environmental problems do exist also in the less developed countries [20, 21], although they are often of a different nature compared with those of the industrialized world.

Secondly, it was highlighted that many environmental problems are not a consequence of development, but of lack of development, poverty and economic dependence [43, 37, 3]. These are problems such as lack of sanitation in rural environments, of appropriate infrastructures for urbanization, desertification, soil degradation, and erosion of biological diversity through species extinction.

Thirdly, it was further recognized that, if science and "careless" technology had been sometimes at the origin of environmental degradation, it could not be possible to solve and reverse such degradation in the absence of usable scientific knowledge and technological tools.

Fourthly, the global nature of environmental issues [51, 76] was put in greater evidence, including their geopolitical implications and the potential of cooperation on environmental actions for improving peace.

All these controversies seemed to have acted as a kind of "decompression valve". The Stockholm Conference took place in a most pleasant and peaceful atmosphere, and many fruitful contacts between scientists and economists from both industrialized and developing countries were initiated at that time. Most likely, it has been the most successful of all the series of United Nations Conferences. A conspicuous result was also the launching of a new United Nations agency, the United Nations Environment Programme (UNEP), whose headquarters are now in Nairobi (Kenya). The Stockholm forum has had therefore a continuation, thanks to the various conferences and actions organized by, or within the framework of, UNEP. It is also after Stockholm, and largely due to UNEP, that national institutions dealing with the environment (e.g., Ministries of the Environment, Environmental Protection Agencies, etc.) have been set up in more than sixty countries.

Nevertheless, comparing the state of the environment in 1972 with the present situation may lead to rather pessimistic or paradoxical conclusions.

The first paradox is that, in spite of the increased awareness of environmental problems, of the institutional — national and international — framework, and of the proliferation of international environmental programmes [25], interacting, competing and overlapping among them, the *global* environment has not ceased to increasingly deteriorate.

Secondly, environmental problems are likely to become more acute and stringent precisely in underdeveloped countries. This is the great paradox of the post-Stockholm situation, and it is due to different causes: (a) the indebtedness of most of these countries urges them to exert an increased impact on their resources; (b) conversely, the agricultural policy in most Western countries leads to a decreased impact on their marginal fragile lands, and also on some of their most productive agricultural fields; (c) the current harsh international competition often stimulates and facilitates establishing factories in countries where manpower is cheaper and pollution control is less stringent (or environmental laws are more loosely applied); (d) the explosive urbanization of developing countries, partly because of uncontrolled rural exodus, partly due to an intentional policy to concentrate people and manpower where control is easier and health and education facilities are less expensive leads to pollution level that comparatively increase more in developing countries than in the industrialized ones.

A third paradox is that, in spite of people's growing concern and awareness as regards environmental problems, public investment in environmental protection, management and research does not follow accordingly. Even more, the "backbone" scientific discipline for environmental studies (ecology) is losing credibility and status within the scientific "establishment" of several countries [23, 24, 31, 32].

3) *The Hybrids Between "Zero Growth" and "Wild Development"*

As a reaction to what was perceived as the consequence of an uncontrolled "wild" development devoid of any environmental consideration as feedback mechanism, and also because of the rather obvious statement that resources may not be unlimited, the idea of a "zero growth" was presented as an alternative to the "euphoric" development of the post-second-war period [52]. Both extremes being unacceptable or unrealistic in the long term, a series of intermediate types of development have been successively proposed.

The word "hybrids" of the subtitle has, by no means, a disparaging connotation, if one takes into account the "hybrids' vigour". Nevertheless, a number of these propositions have failed to become a reality, to a large extent because they have experienced a kind of escalation from the initial purposes, and mostly because they did not take into account the progressive interconnectedness of market economies [9].

For instance, "ecodevelopment" is an unquestionable concept insofar as it means a development that gives due recognition to ecological implications. Conversely, this concept has no real viability if it refers to a very small scale, autarchical development, or if it is exclusively based on the so-called "peasant science". Peasant science has been an adaptive response to a given resource base and to a given social context, but also to specific economic and trade conditions (and also to a given relation between population size and resources). Adapting to new market situations necessarily implies a good blending of the new and the old, and certainly a huge use of the emerging technological and communication tools.

The concept of "endogenous development" is indispensable insofar as it implies a real commitment of local and national actors (people, entrepreneurs, etc.), and a preservation of cultural values [78]. However, if the interpretation goes up to the concept of a national-restricted development, disregarding the progressive interdependence of trade and markets, this development will unavoidably lead to economic marginalization and alienation.

The expression "integrated development" refers to the perceived need for better coordination of the different economic sectors, in order to avoid or to limit side-effects of unbalanced development. However, research dealing with integrated development may lead to such a loose and wide interdisciplinarity that there is no common language among research workers, and quality control of results is absent. Furthermore, integrated Research and Development (R&D) activities too often ignore the existence of the so-called "administrative trap" [2], so that results are not applicable or not applied.

Something similar could be said regarding "appropriate technology". The criterion of appropriateness is an obvious requirement, but too often this term refers to a kind of second-class technology and dependent development. There is no reason for developing countries to adopt either a second-class technology or a second-class science.

As regards technology and environment, attention should be drawn to a special issue of *Ambio* [72], where five different scenarios were lucidly discussed, with particular emphasis on policies in developing countries [80].

Finally, the motto "conservation for development" underlines the important target that development should be based on long-term conservation of natural resources, but it should not be loosely used as a simple slogan.

In conclusion, all these types of intermediate development have an important heuristic value for exploring alternative ways, in view of keeping options open in a period of high unpredictability. Unfortunately, realities are often mixed, in a most inextricable way, with myths or wishful thinking. In addition, given the fact that most of these concepts have been proposed by students from the industrialized world, or by scientists rather inexperienced in the real life of development operations, they are sometimes defined by students of the Third World as "veterinarian types of development", thus implying that they have been conceived irrespectively of the opinion of the "patients" directly concerned.

More recently, the concept of "sustainability" and of "sustainable development of the biosphere" has gained ground [11, 12, 41]. It takes into account the complexity of biological, economic and political interactions and, above all, recognizes the progressive change of scale towards the globalization of problems.

This concept cannot be easily defined briefly, but it has been extensively explained from different angles in a recent publication by Clark and Munn [15]. Roughly presented, Figure 1 exemplifies three

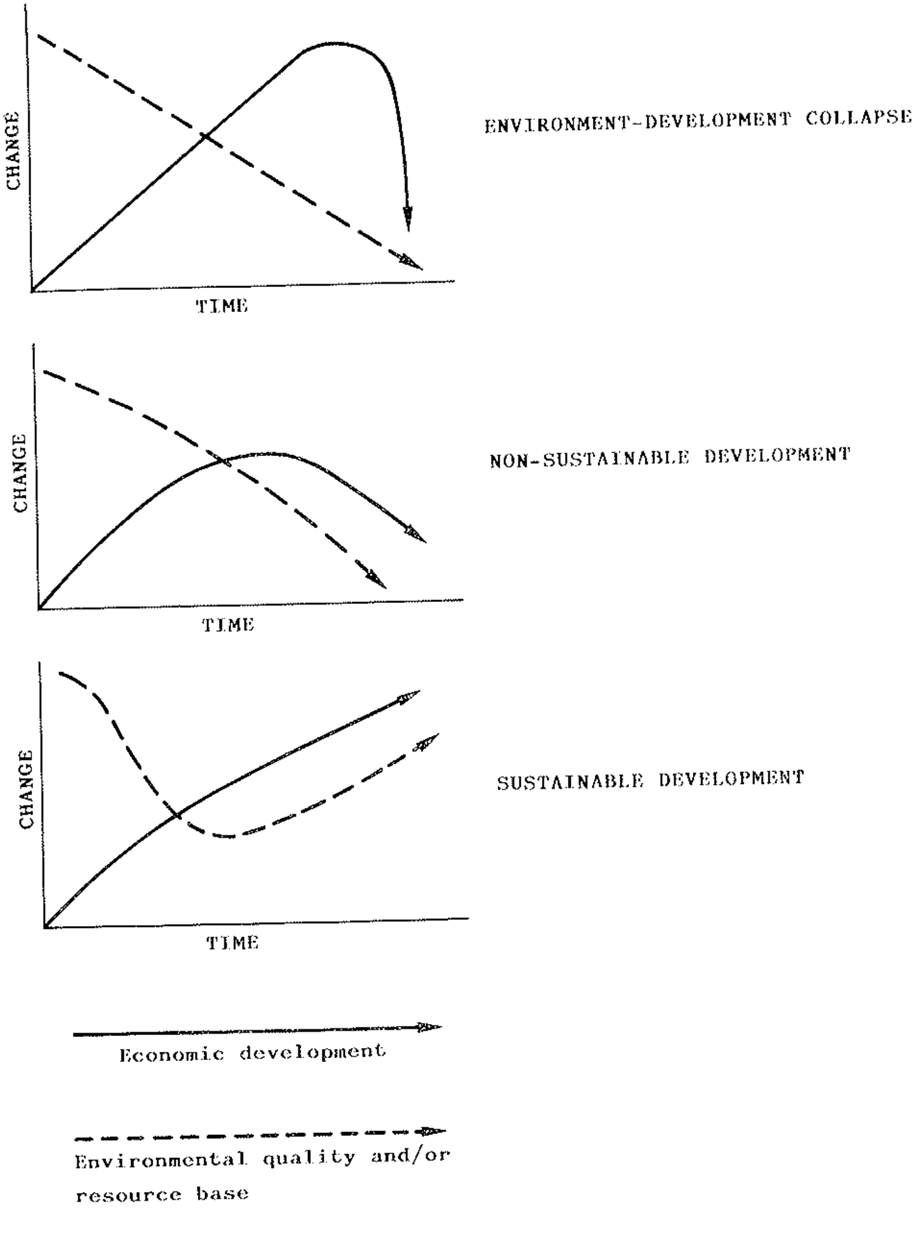

FIG. 1. Sketchy types of relationships between development and environment, from irreversibility to sustainability. In the model *above*, after a period of almost exponential growth, a threshold of resource availability is overcome, and development collapses. In the *intermediate* model, environmental resources cannot sustain development; at last, both development and environmental quality progressively decrease. In the model *below*, interactions between development and environment are such, that development continues to moderately increase, while environmental quality is being restored. (After an idea of Dr. William C. Clark, Anniversary-Conference "The Earth as Transformed by Human Action", Clark University, Worcester, USA, October 1987).

different trends of development, as related to environmental quality and resource availability. In the upper part of the figure, development suddenly collapses when the resource base has reached a critical threshold. In the middle part, development decreases progressively, having lost sustainability because of decreasing resources. The last graph of Fig. 1 illustrates the idea behind a sustainable development: after an initial decrease of environmental quality, adaptive interactive patterns are established between development, resources and environment.

4) *True or False Oppositions?*

The discussion of the first three points of this presentation was intended to point out that these "antitheses" do not represent real oppositions, but rather the terms of a kind of dialectic synthesis.

Nevertheless, it is unquestionable that several manicheistic attitudes still persist in opposing man to nature, development to environment, and economy to ecology. Accordingly, it is not unusual to hear it stated that "everything produced by nature is perfect and untouchable", or "everything done by man is intrinsically bad".

In order to avoid, or at least limit this kind of manicheism, it seems worthwhile to highlight some aspects as follows:

(a) Nature is not always optimizing resources at the best of environmental potential. Evolution and adaptation of species, as well as development of ecosystems, are just a blend of environmental necessity and historical chance. In other words, adaptation and evolution are just "optimizations of the possible"; the allocation of resources is optimized as far as it is permissible, taking into account species and genotypes available at a given moment and in a given place.

(b) There is no such balance of nature, but a "metastability" fluctuating in accordance with different disturbance regimes (climatic changes, extreme events, etc.), or by simple stochastic processes. Even the term of biogeochemical cycles is improperly used, and one should rather refer to "flows" where recycling and recuperation are never complete nor perfect.

(c) Man is not necessarily guilty of whatever has happened or is happening in relation to ecosystems and species. Man has increased both evolutionary constraints and opportunities. Some of the man-modified ecosystems and landscapes are more stable and more productive, and therefore are making better use of resources, than the preexisting ones. In addition, current human activities are impacting an already man-modified environment.

(d) The emergence of the human condition has established new series of negative or positive feedbacks with natural processes (clearing, fire, etc.). Some "co-evolutionary" patterns now exist between man and several species, not only domesticated species but also biological invaders, whose role has not been intrinsically harmful in any event [29].

(e) Therefore, an articulation (or "relay") takes place between natural and man-made disturbances. Since species and ecosystems could not evolve without some degree of disturbance, for most of the man-modified ecosystems the persistence of human disturbance is a necessary requisite for conservation.

(f) In conclusion, man has become a geological factor and an evolutionary agent. Besides environmental necessity and historical chance, man has introduced a sense of "will" (or a determinism) that makes it even more important for him to fully assume all consequences of his *evolutionary responsibility*. From a practical viewpoint, this implies that some degree of human intervention is much needed at present for protecting the environment, and even for keeping biological diversity and genetic variability. There is no long-term protection without environmental management and economic measures, including in natural reserves.

(g) Furthermore, the natural variability of climates, natural erosion and siltation pulses, natural species extinction (including mass extinction), and even natural oscillations of marine fish stocks, represent a kind of natural "noise" that obscures and increases difficulties to quantify differences between natural and man-made changes. There is mostly a problem of degree of intensity, and of spatial and temporal scales.

(h) What is really an unprecedented phenomenon in the biosphere is the present harsh disruption by man of the scales of change. The spatial scale is rapidly increasing up to the globalization of most phenomena. The temporal scale is shortening and experiencing such a "contraction" that impacts and reactions approach a level of simultaneity at a planetary level. As a consequence, the unbearable acceleration of the pace of changes is no longer compatible with evolutionary processes of speciation and ecological processes of ecosystem recovery [28].

5) *The Globalization Crises: Prevention and/or Adaptation?*

The end result of increasing spatial scales is the globalization of driving forces and impacts. This means that local ecological processes and responses are increasingly determined by complex global interactions and not necessarily, or not exclusively, by local environmental events, or locally-based decisions on resource management.

Globalization is not an unprecedented pattern within the geological history of the planet. As shown in Figure 2, terrestrial and astronomical factors have been at the origin of global climatic change during all the history of the earth, and are still acting now with cycles of different duration [17, 26]. The biological consequence of such changes includes periods of increased rate of speciation and periods of mass extinctions.

Globalizations are not unprecedented either in the history of mankind. The first conspicuous globalization took place around 1500 A.D., at the time of the Great Discoveries [29]. At that time, many plants, animals, and microbes were intentionally or inadvertently introduced from one continent to another, thus disrupting the biogeographical realms. After this period, there were frequent pulses of partial globalization and

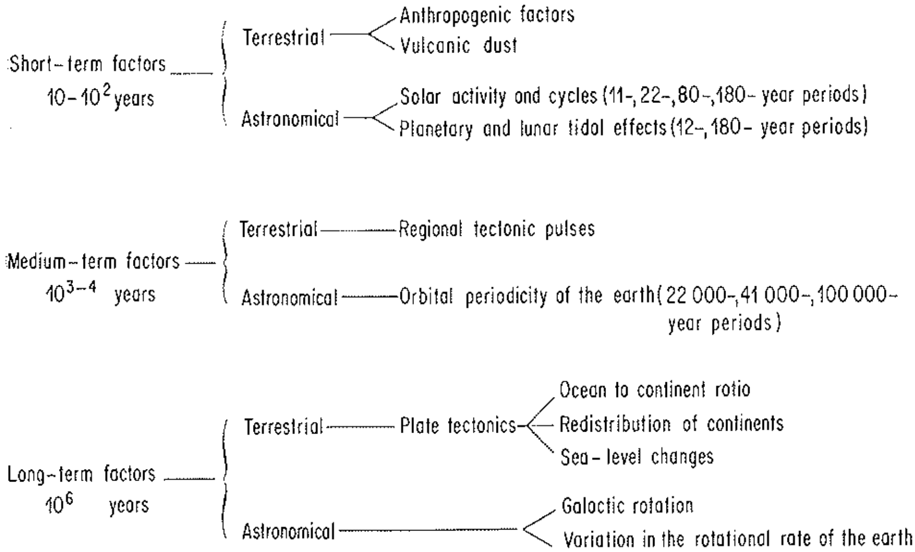

FIG. 2. Time scale of factors leading to global change of climate. (After di Castri 1985b, and di Castri and Hadley 1988, based principally on data from Degens *et al.*, 1981).

partial retreating, following waves of expansion (including through colonialism) and protectionism or autarchical policies of various countries. As shown in Figure 3, the waves of almost complete globalization have increased in frequency during the last few decades. This trend is likely to be even more accentuated in the future, particularly when the first man-made global change of climate will appear, early in the next century [49, 58, 36, 50].

The current trend is rather economically controlled, but on a short-time horizon one should envisage superposition, interaction and linkages of economic and climatic global driving forces.

It has already been pointed out that globalization would have very different effects on land use, according to the geopolitical configuration. Developing countries could be forced to increase their impact on already fragile resources, in an attempt to overcome their huge and growing indebtedness. At the same time, western industrialized countries could decide to abandon for a long time some of their most fertile agricultural fields, to reduce and minimize costs of food surplus and storage.

Another example of the interplays (and the differences) between external economic forces and local ecological and agricultural response is that of slope terracing. Given the fragility of the mountain environment, keeping slopes in activity implies a strong management and a very important manpower investment. Considering countries of three continents, responses to external economic forces (e.g., external to mountains at the national level, or internationally originated) can be radically different. In the Andes, there is a progressive abandonment of terraces, because of people's migration towards the coastal lowlands or the Amazon basin for new colonization; existing terraces show serious degradation up to total collapse. In southern France, a partial abandonment of terraces occurs because of decreasing demand of the local wine production, but some restoration takes place in other parts to cope with tourist requirements. In the Kathmandu valley of Nepal (mostly near the city of Kathmandu), a rearrangement of terracing has already begun in order to shift from a traditional subsistence agriculture (rice) towards a market agriculture (fruit, vegetables), to respond to tourist demands for these products.

Figure 4 exemplifies, for a given developing country, the "cascade" of local, regional, national and global impacts and responses, because of frequent drought periods. Drought not only deteriorates the resource base through desertification, but originates series of agricultural, economic and social changes at the various scales concerned.

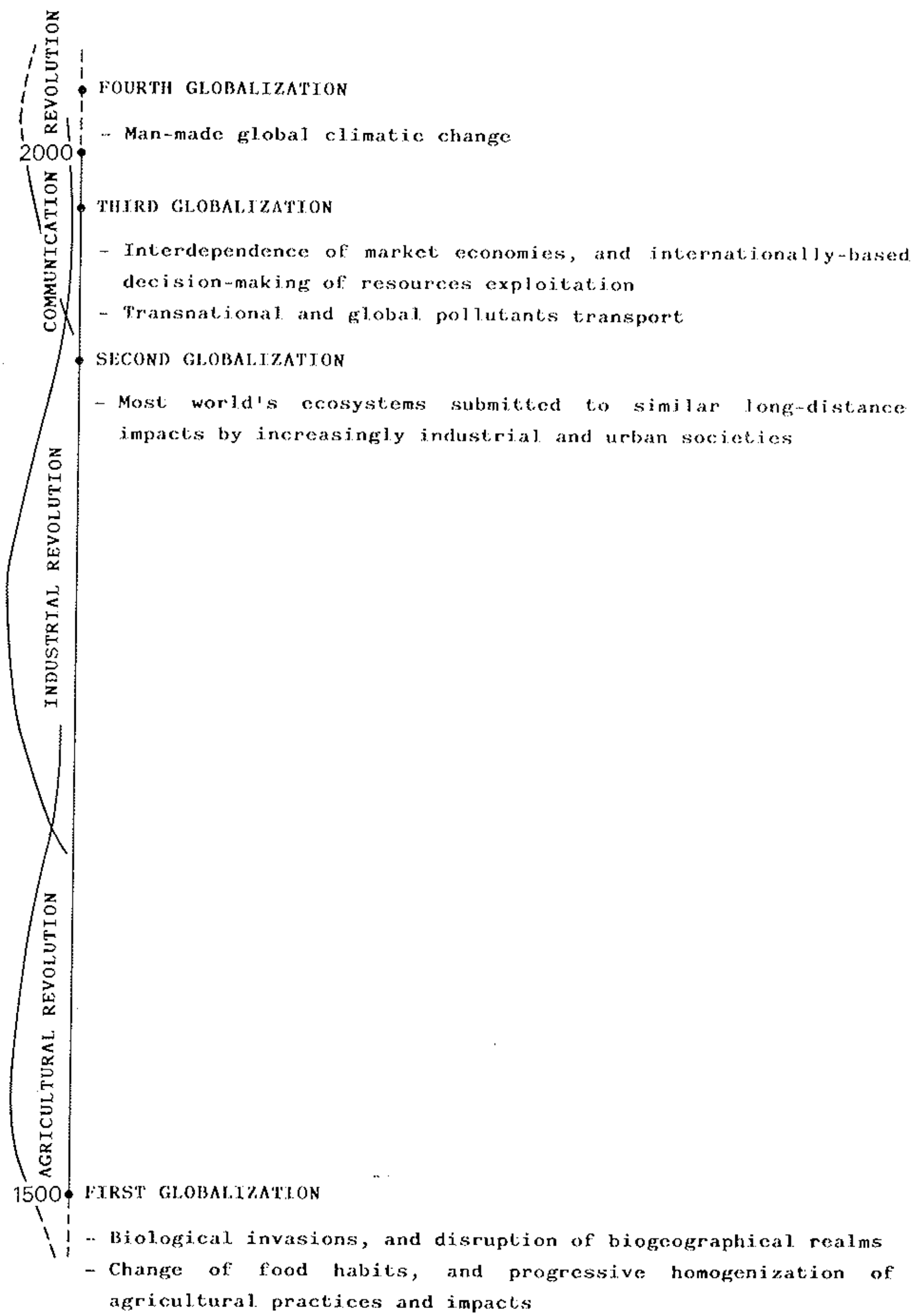

FIG. 3. Man-induced globalizations, from the Great Discoveries (around 1500 A.D.) to global change of climate (soon after 2000 A.D.).

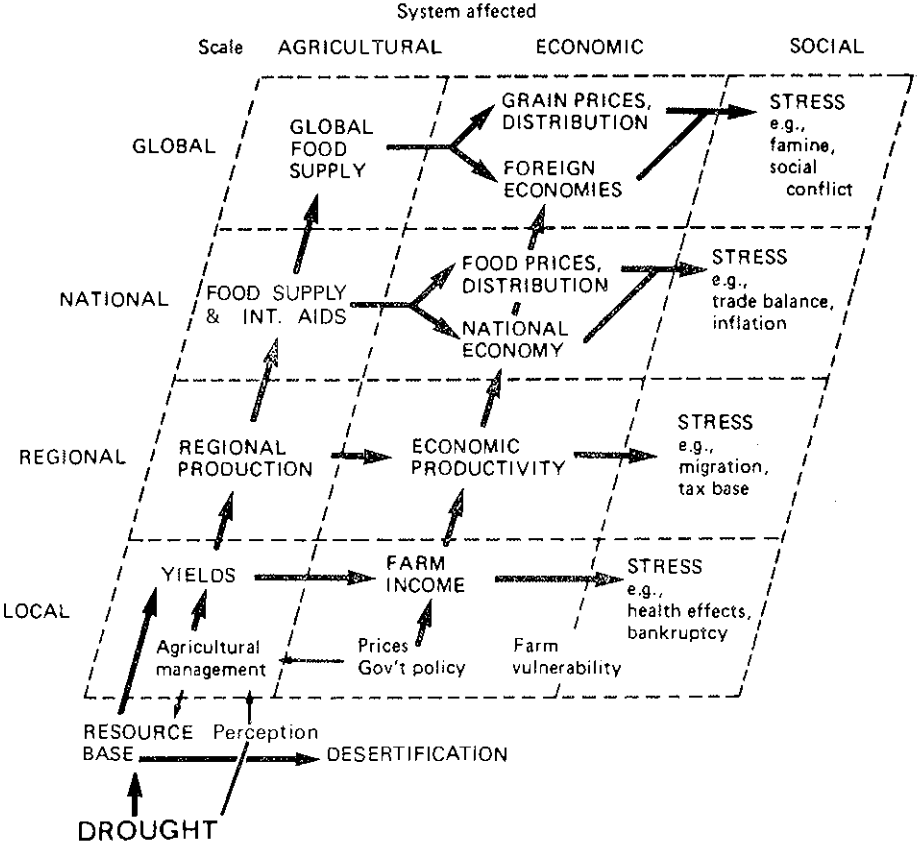

FIG. 4. Tracing the effects of a worldwide climatic event (drought), as they cascade through physical, ecological and socio-economic systems, at local, regional, national and global levels. (Modified, from Warrick and Bowden 1981; Parry *et al.*, 1984; di Castri and Hadley, 1988).

Economic and climatic changes described above do not imply intrinsically negative impacts, but rather new constraints and opportunities, both from an economic and a biological-evolutionary viewpoint. The first signals of trends toward globalization are an increased turbulence and a more frequent occurrence of extreme events. This is being predicted for both economy and ecology [39, 83]. Economic indicators of global interactions can be detected within the current disarray of stock exchanges; biological indicators, by monitoring modifications at the ecotonal boundaries between ecosystems, particularly in the treeline edge of mountains.

Figure 5 indicates that, to face globalization crises, there are two alternative or complementary responses. From the one side, prevention or limitation of the phenomena that are leading to change; from the other side, adaptation to foreseeable changes. Prevention would imply, at the economic level, putting some order in the international market, or establishing feedback mechanisms for decreasing fluctuations of currencies, or maintaining a long-time expectable value to a given resource. Prevention or limitation in environmental terms means, for instance, reducing combustion of fossil fuels, and emission of trace gases that lead to greenhouse effects. All these measures are difficult to envisage, and even more to apply. In addition, ongoing phenomena have already an intrinsic inertia, so that even if immediate measures are taken, unavoidable consequences will still appear in both economic and ecological aspects. In other words, prevention and limitation are indispensable, but it is unquestionable that they will never be timely enough, or efficient enough, to make adaptive response unnecessary.

Some of the adaptive measures to the likely climatic change are exemplified in Figure 6. Many other adaptations would involve natural

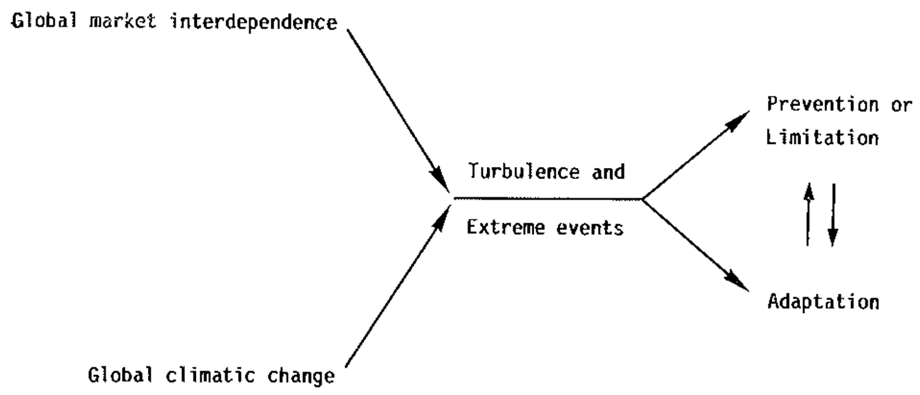

FIG. 5. The emergence of the last two globalizations through turbulence and higher occurrence of extreme events. Man's response should be an interaction of prevention/limitation and adaptation.

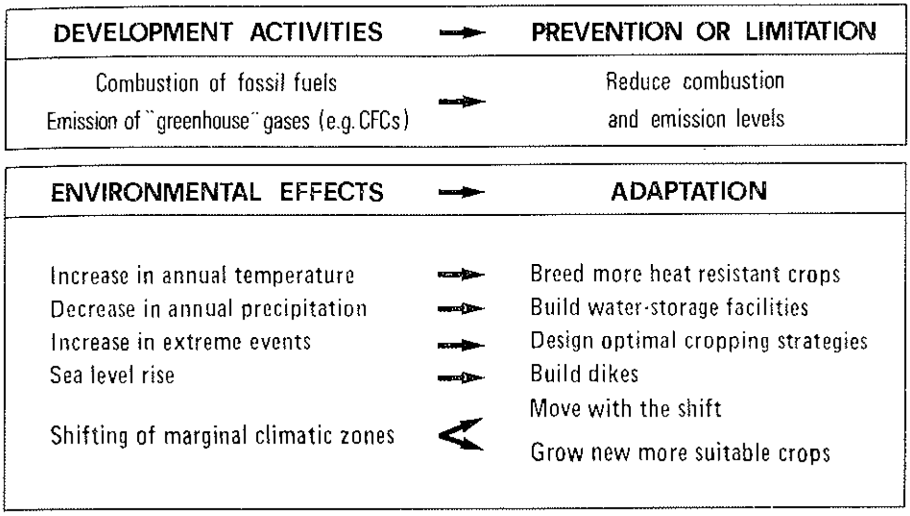

FIG. 6. Man's possible responses to the greenhouse effect due to development activities. Some examples of "adaptation" to new environmental conditions are shown. (After Stigliani 1987, modified).

(genetic, ecological and evolutionary) mechanisms for individuals, species, communities and ecosystems.

As regards effects of climatic change, management and control actions should already be conceived and applied as regards rising sea-level. Figure 7 shows that taking no action (either limitation or adaptation) would imply a prohibitive cost that could lead to economic collapse of some coastal zones. An ideal tackling of this problem would be a combination of both "limitation" and "adaptation" measures, more realistically, some limitation and an increased effort towards adaptation.

As already mentioned, globalizations (both economic and climatic ones) will not have the same consequences everywhere. There will be "winners" and "losers" among the different countries, as well as in relation to the evolutionary adaptive response of wild and domestic species of animals and plants.

In addition to economy and ecology, and the effects on economic resilience and biological diversity, a main problem remains: how to adapt to globalization, while keeping one's own "cultural" diversity? This could be done through establishing semi-permeable membranes (or filters to

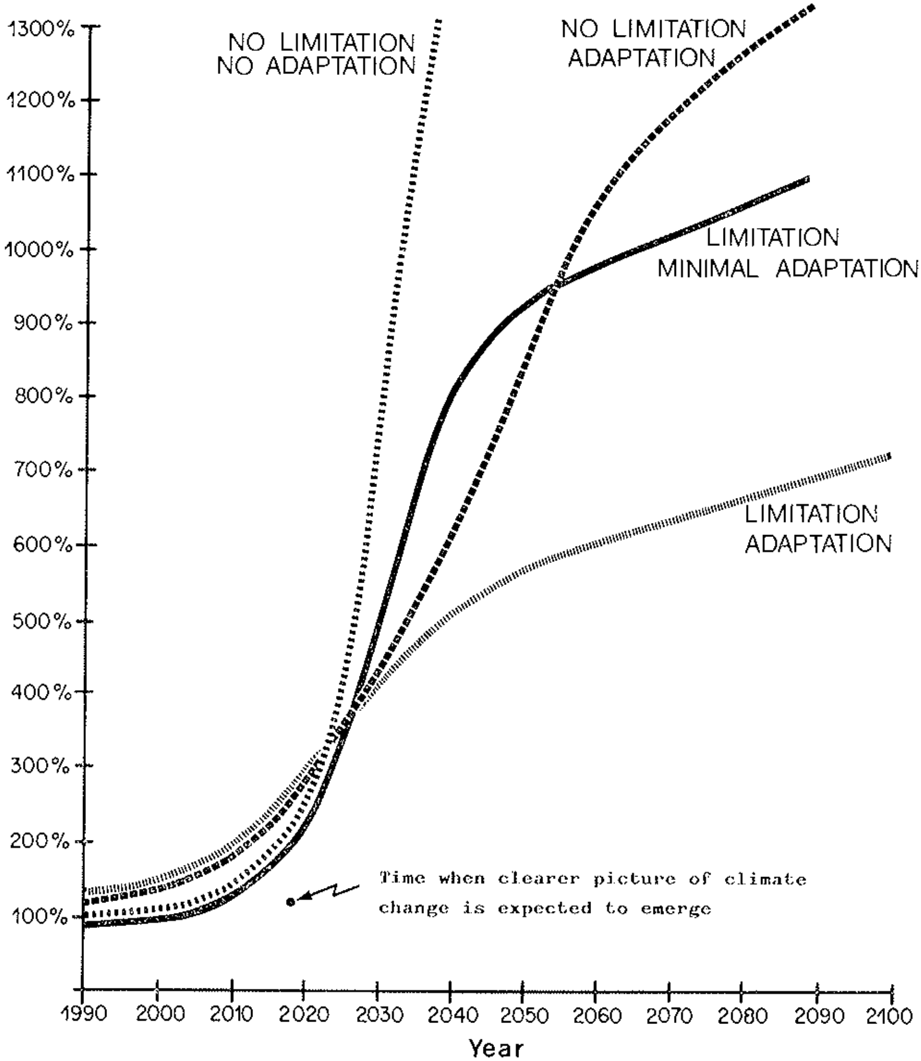

FIG. 7. Approximate relative costs (as percentages) for management of rising sea-level due to greenhouse effect. Limitation would imply reducing emissions by 2% per year. Adaptation results in implementing "in advance" selective coastal engineering measures. Minimal adaptation means taking *ad hoc* measures « after » disasters. (From UNEP-World Climate Impact Assessment Programme, unpublished document, 1987).

information), but more efficiently, and more ethically, through mobilizing internal cultural forces.

The need for a global approach is well perceived also at the United Nations. The two main reports that have been prepared by the United Nations system on the issue of Environment and Development have two evocative "global" mottoes: "Only one earth" by Barbara Ward and René Dubos in 1972, and "Our common future" by the Brundtland report of 1987 [85]. Convergence of words, unfortunately and probably unavoidably, does not always correspond to convergence of, and stimulus to, actions. These are commendable attempts to find a common denominator out of a wide variety of polarized or opposite interests. Their impact lies mostly in increasing awareness and consciousness. Their danger is to be considered as a "valve" or an alibi for inaction and the cost of inaction would be prohibitively high.

6) *"Convergent" Evolution of Ecology and Economy*

In the relations between economy and ecology, objective differences and difficulties should be differentiated from perceived ones.

Objectively, these two disciplines deal with different objects or units of study. The temporal scale of economic events is also shorter than the ecological and evolutionary scales. Furthermore, there is nothing equivalent in economy to the total lack of reversibility represented, for instance, by species extinction, or the non-renewable destruction of some ecosystems (some tropical and temperate rain forests, cloud forests, many relict ecosystems, etc.); it is intrinsically difficult to attach a monetary value to them.

The perceived difficulties are mostly due to semantic problems and, above all, to the fact that ecologists and economists are usually interacting with different decision-makers, that pursue different objectives and have different concerns.

Conversely, there is a danger in considering economy and ecology as being largely overlapping. It would be a Panglossian attitude to deny or obscure all conflicts between ecological and economic issues, and much too easy to simply accept the definition of the Shorter Oxford English Dictionary of ecology as "the science of economy of animals and plants". In addition, one has to be aware of the limitations of analogical reasonings, where identical words may have a quite different meaning. Admittedly, in the relations between economy and ecology, there have been use, misuse and abuse of conclusions based on analogies.

It should also be added that, for unknown reasons, a neo-marxist view of economy has dominated most of the dialogue on ecological issues. Conversely, most ecologists who have approached economic problems have been inspired by a rather static and "equilibrium" view of nature.

The situation is rapidly changing now, within the present "environment" of both economic and ecological disorder. The need to take into account disturbance and change in regulation processes, and the fact that reactions to disturbance are different when placed on a different scale of space and time, are increasingly widely accepted by both ecologists and economists.

Non-linearities, discontinuities, non-equilibrium, accumulations and thresholds, and therefore surprises [8, 15], are becoming the main conceptual and operational basis of both ecology and economy. The ozone depletion over the Antarctica [7], and the sudden "dollar turbulences" during the last few years, have been recent surprises for ecologists and economists.

The increased use of mathematics and modelling in ecology is also facilitating a dialogue with economists [6]. The game theory and chaos theory [65] are becoming familiar to both ecology (and evolution) and economy. It is amazing that even in newspapers such as the *International Herald Tribune*, ecological and economic principles are mixed up to see some order in markets' disarray [39]. Moreover, adopting an increasingly large scale of space in ecology, as well as adopting an increasingly large scale of time in economy, facilitates "meeting interfaces" between these two disciplines.

It should also be stressed that ecology and economy, within the present context, are both "crisis sciences". This expression refers to a science that has the social obligation to give advice based on conventional wisdom, and to release data based on imperfect knowledge. This happens, first of all, because of the intrinsic complexity of problems and the low predictability of solutions, and secondly, because of the urgency of looking at ways and means to tackle such problems. An expression used in environmental impact assessment, where ecological and economic considerations are playing together, is the rather "exotic" acronym of BATNEEC; it simply means "Best Available Technology Not Entailing Excessive Cost". This gives an idea of the relativity of values when approaching this kind of problems, and pinpoints the importance of the "perceptional" component of planning [31].

Admittedly, this scientific behavior is far from being the most accepted one, and is hardly in accordance with the usual and understandable aspiration of a research scientist to release results only when the degree of reliability reaches a probability of, let's say, 95%. The pressure for releasing results in due time for application, on the one hand, and the moral obligation not to release results when scientific evidences are too small, on the other, are a dilemma that stands on a razor edge. Indeed, it is a very small step from a "crisis science", that is a science rapidly responding to social demands, to a "science in crisis", that is a science that is losing its own credibility because of lack of methodological rigour.

With this in mind, enormous advances have been achieved in the alliance between economy and ecology, since the early 70s. At that time, many economists denied the very existence of environmental problems in underdeveloped countries, precisely the very problems that are so pervasive now in these countries. Similarly, too many ecologists were still thinking that only traditional land-use on a local basis would constitute a solution to environmental degradation. They were unable to recognize that practices such as small-scale shifting cultivation or nomadism were applicable within a given demographic context, and a given geopolitical and historical configuration, all conditions that are vanishing now in most of the regions of the world.

Some words of caution are necessary at this point.

First of all, ecosystems are not a suitable "meeting point" for interaction and convergence with economic issues, when appropriate spatial and temporal scales are taken into account. This remark refers to the ecosystem as an ecological unit, and does not undermine the validity of a "system approach" for interacting with economy. Larger units such as landscapes and regions have to be adopted more often by ecologists, as well as socio-economic-oriented units such as "human-use systems" and "resource systems" [34].

Finally, if interdisciplinarity is the only response to complex management problems, one has to be well aware of the difficulties and bottlenecks of the interdisciplinary approach. Sometimes the so-called "committee interdisciplinarity" is just an alibi for not taking any action. Interdisciplinarity often exceeds thresholds for real interaction, as exemplified by some of the large conferences organized by the United Nations. Furthermore, the evaluation or even the possibility of publishing results of large interdisciplinary endeavors present almost unsurmountable obstacles [31, 33]. It should be said, in conclusion, that the interdisciplinary team should be as small and as *ad hoc* as possible, just to address and solve the specific problem to be tackled at a given moment.

7) *Institutional Inadequacies and Administrative Traps*

Two hundred years ago, there were less than 1000 million people on the planet. Since about last year, we are ahead the symbolic figure of 5000 million people, and there may be more than 6000 million by the end of the century. The number of independent states has multiplied by a factor of 4 to 5 during the last century, according to varying notions of the Nation-State.

Still, institutions are largely the same as they were fifty years ago, when policies focussed on isolation rather than interconnectedness. They are unable to follow — or they follow in a very partial and almost reluctant way — the speed of emerging problems, emerging knowledge, emerging aspirations, and increasing scales. With a broad generalization, institutions tend to be too large and "depersonalized" to really understand and solve everyday problems. Conversely, they are powerless to face the kind of complex transnational and global problems to which we have referred earlier in this article.

It is unquestionable that we are facing unprecedented "qualitative" changes, turning points, and crises. These can be considered as positive or negative stimuli, according to the behavior of the response. There will be new constraints and new opportunities, and a change appeals to adaptive strategies. Varying adaptations of people, institutions, states and international organizations will not necessarily conform to the same mode of response, both as regards rates and trends. There will probably be a few early responses and adaptations, together with much inertia and stagnation, but probably not — unfortunately — "institutional extinctions". This would imply an even worse deterioration of institutional efficiency.

It should be realized that institutions have been long adapted to a *steady state*, their main target being that of increased internal securisation, including the filtering of external interferences. The energy crisis, in particular, has pushed to some institutional adaptation vis-à-vis a *non-steady state*. However, very few institutions are preadapted to react to the *surprise-rich state* of our complex future. At present, most institutions, national and international, educational and research-oriented, or responsible for planning and management, show a kind of built-in inefficiency, and lack of adaptiveness (and willingness) to change.

This "non-adaptation syndrome" can be detected through many symptoms:

(a) There is no synchronisation between emergence of problems and adaptive response. There is even no synchronisation among adaptive responses of institutions belonging to the same Nation-State.

(b) Most institutions are not perceptive of changes in scales, including scale of disparities and scale of urgency. Stagnation and alienation, that is to say, lack of capability to represent people's aspirations and values and to perceive early signals of change, are two common patterns of our institutional "environment".

(c) Sectorialization and overspecialization are dominant features, so that results of integrated inderdisciplinary research should be "disintegrated" into different pieces to be perceived and understood by a sector-oriented administration, a sector-oriented research evaluation, and a sector-oriented university training and career. This is the vicious circle of the administrative trap [2]. Sectorialization (and lack of curiosity) can begin as early as in the high school, thus leading the student to select a well-circumscribed university discipline. If he is successful, he will be recruited by a sectorial ministry, will accept only results recognisable as belonging to such a sector, and eventually will later recruit the most specialized out of the new generation of students. The condition of being involved in interdisciplinary training and endeavors implies, therefore, to sail against the stream, and to disregard the facilities of a career within the current scientific and administrative establishment.

(d) In their search for control and self-securisation, bureaucracies tend to discard risks, and to deny the "right to error", thus decreasing even more the possibility of finding new adaptive strategies.

(e) Lack of true evaluation and little concern for quality control further lower the selective pressure on institutional development.

It is not surprising that intergovernmental organizations and programmes are forced even to magnify shortcomings and bottlenecks of national institutions. Evaluation is even more rejected (or applied in a most cautious or intricate fashion), in order not to hurt national susceptibilities. In particular, governing bodies of international programmes tend to provide most unrestricted and unconditional support, instead of exerting their original function of guidance and evaluation. It is sad to say that even non-governmental scientific organizations and programmes are progressively and very largely "contaminated" by the "governmental institutional syndrome".

Accordingly, the degree of institutional plasticity and fitness is further decreasing, thus leading to major dephasing as regards emergent problems. Within this context, I define institutional adaptiveness as the quality that makes societies and institutions more adaptable to coping with discontinuities, surprises and breaking points.

Taking into account this institutional framework, both ecology and economy are facing the most disturbing bottleneck of a national and global "decision-making crisis". The realm of the short term, the decisions-turnover, and the shortening of the period when action is still possible (the early period of a new government settlement?) undermine opportunities for both ecology and economy.

Moreover, for both of them, a number of questions remain to be explored in depth. How are policies determined in a time of crisis? How to catch opportunities and avoid constraints? How to transform a constraint into a societal opportunity?

It is beyond the context of this article to discuss the almost untouchable problem of an institutional change, capable of coping with the waves of global change. More flexibility as regards control measures, an encouragement of "trial and error" behavior, accepting the existence within large institutions of small "commandos" with higher creativity and plasticity, the recognition that the real institutional loyalty is the right to disagree and even disobey under extreme circumstances, favoring some built-in opposition as a feedback mechanism of regulation and evaluation, are partial elements for breaking down some of the walls of our institutional fortresses.

Are these institutional problems more acute within the environmental organizations, and as regards environmental decision-making? In other words, are environmental organizations less efficient than the others? Within the present context, one is tempted to reply yes to both questions.

Environment being a new topic (and, unfortunately, too often a new "sector"), it is not surprising that really professional background and behavior are often missing. In addition, one cannot help being shocked by the multiplicity of environmental programmes, mostly at the international level, by a widespread lack of quality of their research, by the conflicts rather than the coordination existing among them, and by the enormous overlap and dissipation of efforts intrinsic to that proliferation [25].

However, I would say that environmental organizations are "intrinsically" less efficient, because they have to live in an interdisciplinary fashion and with long-term targets, within a very sectorialized world dominated by short-term planning. And probably this kind of "inefficiency" is badly needed, because it acts as a "complexifier" of over-simplistic situations, and as a breaker of current decision-making patterns.

Figure 8 shows some of the forces intervening in the Development-Environment equation. Global market forces, including transnational entrepreneurial activities, are now overtaking even the strength and coverage of national politicians. This is not intrinsically bad, to the extent that it could make the present national institutional setting obsolete, and promote indispensable change. Hopefully, some more solidarity and international understanding may, at last, obscure chauvinistic and parochial attitudes, and modify the current anachronistic conception of the Nation-

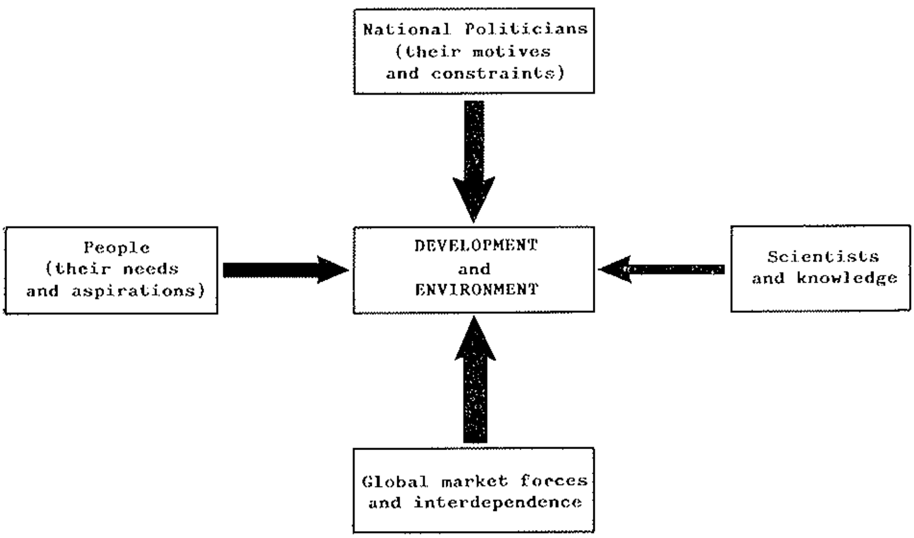

FIG. 8. Driving forces regulating Development/Environment relationships. Their current importance is proportional to the thickness of arrows.

State. The idea of Nation-State is still worthy of great attachment, insofar as the need for interdependence is also perceived.

The main problem is that people's needs and aspirations, at the local level, play a decreased role in decision-making. Admittedly, this happens also because people are "dephased" to perceive challenges and opportunities of the new international situation. Unfortunately, in most cases, the end result is a non-constructive and widening disillusionment, disengagement and alienation of local populations. In spite of all theoretical statements, it is not always easy to perceive both local and global environment [71], and to follow Dubos' motto: think globally and act locally.

As regards scientists, our weight is probably even smaller. This largely depends on our own failure to understand mechanisms and implications of decision-making processes, and of the absence of coherent effort to act together, and not to be almost confined to a series of intra-disciplinary and interdisciplinary competitions and guerrillas.

8) *Rays of Hope for a Coalition Between Environment and Development*

Previous paragraphs have been rather pessimistic in evaluating the present situation. Some of the largest environmental activities (namely, world-wide conferences) have rather hidden, through a convergence on paper, urgent divergencies to be solved in practical terms. Nevertheless, beyond the rhetoric of such conferences, some awareness has been reached, including the environmental "hints" to promote peace and international cooperation. In addition, there are several success stories of environmental actions, as for instance the Law of the Sea, the current reduction of pollution in some of the major cities, many useful results of ongoing international programmes, etc.

Futurologists foresee that a wide reaction to global challenges will occur only after a series of economic and environmental catastrophes.

Being personally more optimistic, I perceive some elements for hope in relation to three different aspects: new emerging theories, new powerful technological tools, and timid but real signs of conviviality among all actors concerned.

Among emerging theories, mention has already been made of the game theory that will be further developed by Dr. Maler's presentation. Present advances in economic-ecological modelling [6] and expert systems, and in adaptive environmental assessment [42, 81], will facilitate interaction between biological and human sciences including in qualitative terms.

As regards theories, I would like, in particular, to draw attention to the hierarchical theory [61, 63, 66, 32] that may combine different scales of space, time, perception, and concerns, in a very interactive way, thus providing a common purpose and a common language to different disciplines. Looking at a higher hierarchical level will facilitate understanding relevance and constraints of the problem under study. Conversely, descending towards lower hierarchical levels will help discover the elementary processes and explanatory mechanisms involved in the problem.

Figure 9 shows, in the central part, how a unitary logic for ecology can be built up out of the fragmented pieces of the ecological subdisciplines. Through a kind of zooming effect among and across hierarchical levels, some coherence is provided along spatial and temporal scales, as well as between an energy-budget (functional) ecology and an evolutionary (population and community) ecology. The former has as a main objective the understanding of the biological productivity of the biosphere; the latter faces the immense problem of the evolution and conservation of biological diversity of the biosphere [27, 32]. Figure 9 further adds seven windows (or interfaces) to this ecological building: at the biospheric level, two windows are open towards atmospheric sciences and macro-economy, so that the two main global driving forces can be taken into account in ecological research. At intermediate levels, windows of regional and landscape ecology provide inputs and outputs to economic and socio-cultural problems. On the opposite side, windows with geology and human history highlight the need to take into account evolutionary selective forces in a changing geological environment, as well as the changing human impact on living beings. Looking downwards from this "diving cask" of ecology, windows to molecular biology and thermodynamics allow enlightening mechanisms at elementary biological and physical levels.

Along with new theories, new tools are appearing in a very rapid progression. Each tool has enormous potentials, but also some pitfalls or risks to be avoided. The main risk is, consistently, that of becoming a slave of the tool, and not of mastering the working hypothesis that is essential for the advancement of science.

Among tools, remote sensing provides new insights as regards continuity of observations, and a change of scale from a region down to a few square meters [1, 74]. It is therefore particularly adequate for research that should combine global driving forces and local responses. Figure 10 shows an experimental device, based on the scaling issues [45] and the hierarchical theory, that is being implemented in order to improve predictability of global change through a better understanding of gas exchanges at the ground level, as well as to test the impact of foreseeable climatic change on terrestrial ecosystems and populations [58, 36, 32].

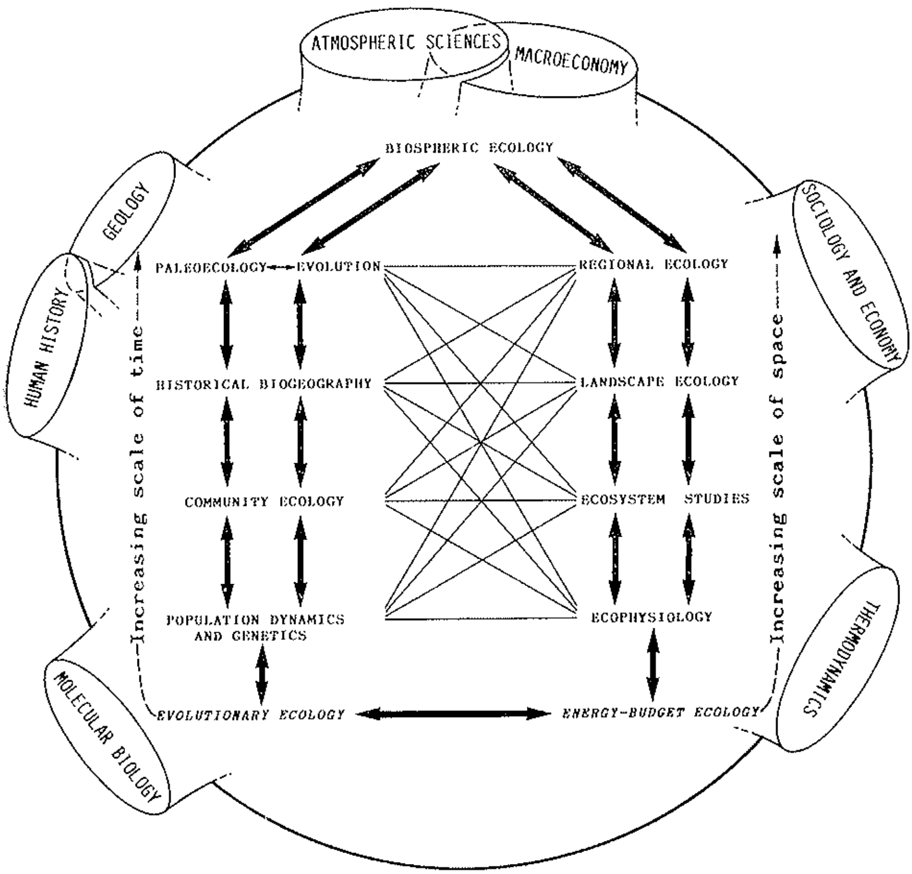

FIG. 9. The universe of ecological subdisciplines linked along and across hierarchical scales. To increase both scientific and societal relevance of ecology, windows (e.g., interfaces) on a large scale should be open towards atmospheric sciences (in relation to global change of climate), macroeconomy (as regards global interdependence of markets), socio-economy (for regional planning), and geological and human factors (for understanding evolutionary and historical constraints acting on ecological systems). To improve the explanation of mechanisms at a lower hierarchical level, windows should be created and/or enlarged towards molecular biology and thermodynamics. (Largely modified and redesigned, after di Castri 1986).

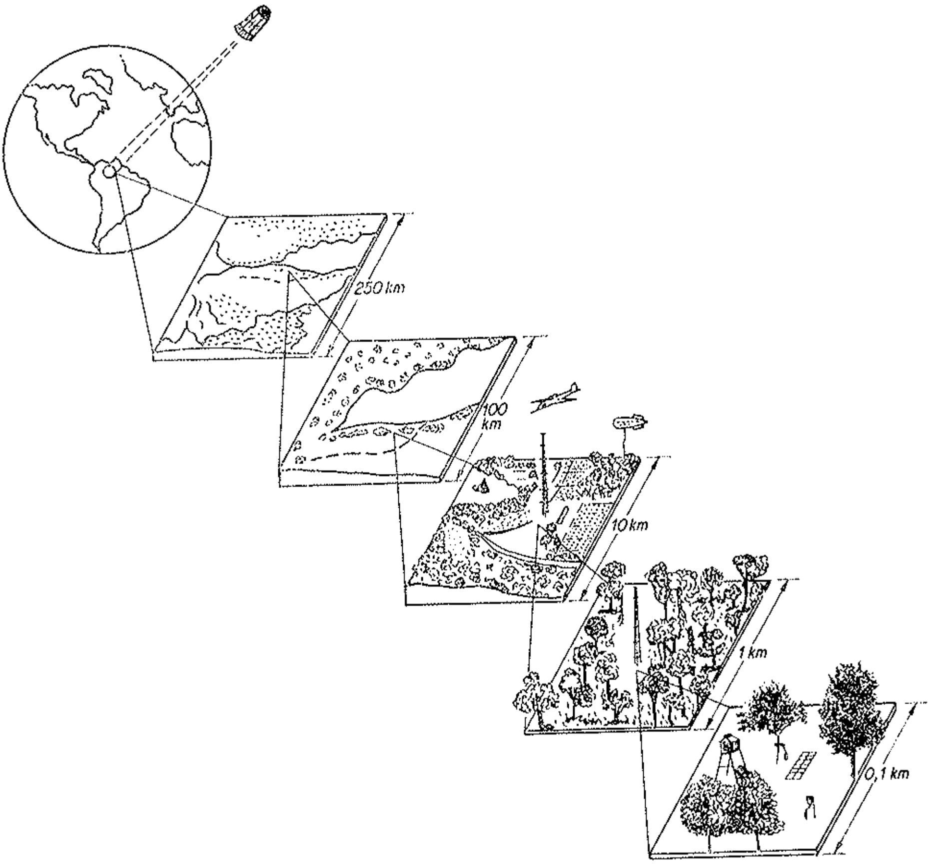

FIG. 10. Use of satellite imagery, aerial survey and ground research for linking observations at different spatial scales, through a "zooming up and down" process. (Redesigned and redrawn, after US National Research Council, 1986).

Computer potential, including that of microcomputers, is also an indispensable tool to cope with the immense amount of data to be collected, handled and stored as a response to globalization. The problem in this respect is how to keep quality control of observations, in spite of a "congestion of information". A 1968-like motto that may counteract an over-enthusiastic approach to data collection is "less data and more imagination", that is to say, an original and rigorous experimental design. Computers can also provide an almost simultaneous way of communicating research results from one center to another, all around the world.

Using both remote sensing and computer facilities provides ways and means for a "digitalized cartography" (including cartography for land-use management and resource utilisation). The static aspect of cartography is over, since new data can be incorporated as soon as they become available. In addition, the changing of scales is easily achieved.

Similarly, highly-performing recording systems for chemical analysis and monitoring meteorological data help tackling complex research problems that were untouchable only a few years ago, but contribute, again to inflate data base requirements.

Finally, from a more biological aspect, the manipulation of genetic material by bioengineering techniques allows creating new highly productive, or highly resistant, varieties of crops, nitrogen-fixing bacteria, etc. Nevertheless releasing genetically designed organisms in the field represents a serious risk, since their behavior and invasion potential cannot be easily detected in the laboratory.

My third element for hope is the fact that we see renewed attempts of conviviality involving the different actors of natural resource management. The essential requisite in this case is to respect a threshold as regards the number of participants (scientists from different disciplines, representatives of local populations, entrepreneurs, planners, managers, politicians, and different types of decision-makers). Unless the opportunity for interaction is a real one, the common denominator of the agreements will be too low to have operational repercussions. A kind of meaningless consensus, reached through erasing all normal diversities of approaches and interests, is often the result of overly large non-interactive meetings.

Dialogue is facilitated now by an increased awareness of environmental problems, and this is a goal that international and national organizations did achieve to a certain extent. To improve this awareness, I strongly believe that specific ethics should be adopted: preventing the abuse of rhetorics, and avoiding biased dramatizations not backed up by scientific evidences. Otherwise, the credibility of environmental issues and of ecology in general will be undermined.

Awareness should be achieved on two apparently opposite aspects: one, on the progressive globalization of driving forces, based on economic and climatic grounds; the other, on the fact that no action will be possible without a shared participation and a strong commitment of people involved [30]. Increasing local motivation on environmental issues is not only an ethical condition; it is also an economic necessity.

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DISCUSSION

MALER

I am an economist from the Stockholm School of Economics and I have been interested in environmental and resource economics for fifteen to twenty years. I am going to give a presentation on some specific topics in environmental economics later on and now I would only like to make some comments on Dr. di Castri's presentation.

First of all, unfortunately, I think we're in agreement and so we cannot really start to have a heated discussion on different issues. I would like to take up a few points and discuss them. First of all, the relation between ecology and economics; what are the relations? As Dr. di Castri pointed out, there have been some efforts to integrate ecological theories and economic theories into one theory and my judgement is that those attempts have failed. However, there have been very interesting developments in integrating ecological models and economic models for particular management problems. Let us take the example of management of residuals discharge into the Delaware River in the United States. To consider resources for the future, as resources for the future, a team was set up in early '70s consisting of ecologists, engineers and economists in order to develop a model that, on the one hand, took into account tbe technological possibilities; on the other hand, the economic realities; and, on the third, tbe ecological mechanisms of the Delaware River. They constructed rather a large model of residuals management in the Delaware River which was in a way a breakthrough in that kind of modelling attempts. Afterwards, similar models have been developed all over the world and put into use. That, I think, is a very fruitful way of integrating ecological and economic expertise: to have teams consisting of people with different competence working together for particular environmental problems.

Another example is given by a Swedish study of the ecosystem on and surrounding the island of Gotland in the Baltics. Headed by an ecologist, Professor Anne Marie Joahnson at the Stockholm University, a team was set up consisting of economists and ecologists trying to look at the interactions of the local economy in that island and the ecological systems in the Baltic and on the island. It's a very interesting attempt to integrate these different aspects of reality.

Let me add to this that there are now new journals emerging in which ecologists and economists are cooperating. These is a new journal called « Journal of Environmental Economics and Management » in which ecologists and economists publish scientific articles. A new journal is coming out very soon. I think its name is « Economy and Ecology » and on the editorial staff there will be two economists and two ecologists, and there are other similar journals coming out. This shows that we will probably see much more cooperation between ecologists and economists in the future.

Now let me take up another point made by Dr. di Castri and that is to do with irreversibility, irreversible change in nature, the cause of man's interaction with the invironment. During the Seventies and the Eighties, there have been very interesting developments in decision theory and the theory of social cost/benefit analysis, taking into account that kind of irreversibility. Now irreversibility in itself is not a problem. It's a combination of irreversibility and uncertainty about the future effects of the decision that's really the theoretical problem. How do we make a rational decision today on an irreversible change when we don't know the future effects of that decision? The theoretical development has shown that the common rule of thumb in governments and in business, in making such a decision, gives too many irreversible changes. The common rule of thumb implies that you look at the expected values and compare the expected future revenues with the expected cost, and that decision criterion will give a biased answer.

Now, the theory has been applied to the preservation of biological diversity in the Northern American continent and to some other similar fields, and has shown quite interesting results. There, once again, is a very strong similarity between what Professor di Castri pointed out and what I, as an economist, would like to point out. There is however one basic issue to which I think we all have to give much thought, although I don't foresee a single solution to the problem, and, that is, how, if we are uncertain about the future, do we construct mechanisms to increase flexibility of the economic and ecological systems in such a way that we will be able to manage problems that we cannot foresee today, that is, problems that we don't know about. How can we now prepare ourselves to manage such purely unexpected changes in the future? I think, that is a very, very, important issue that we should give some thought to.

Di Castri

One of the convergencies between ecology and economy can be summarized thus: "How to manage uncertainties and foresee the unexpectable?".

In other words, how to plan in a situation of uncertainties, some of which are due to lack of knowledge and others are intrinsic to the complexity of the system one is dealing with?

However, the level of theory is not very advanced, and a coherent theory has not yet matured in the relations between ecology and economy. Even more difficult is the relation between sociology and ecology. At least as far as I am concerned, the dialogue is much easier with economists, probably because both ecologists and economists can share some mathematical tools. Many new advancements in the field of "expert systems" will certainly facilitate this kind of interaction.

JEFFERS

I am an ecologist by vocation but a statistician by profession, so I am a somewhat mixed up person, I guess. I suspect that some of the difficulties which both ecologists and economists share is that in an attempt to become scientific, both of these disciplines have grasped at some aspects of mathematics. So much of ecosystem theory now, for example, is highly mathematical, but unfortunately, because biologists and, I suspect, most economists and most sociologists are by definition failed mathematicians. If they could have really understood mathematics at the undergraduate level, they would have become physicists or engineers probably. The mathematics upon which much of ecology is based — I can't speak for economics or sociology — is a rather limited kind, mostly based on Newtonian calculus, and I think the dilemma which has been touched upon by both of our previous speakers really derives from this attempt to apply a very limited kind of mathematics to a subject matter which requires something very much more complicated. The danger is that people think that's all the kind of mathematics that exists. Of course, we now have very many more tools available to us, a much wider range of mathematical or families of mathematical models which would, I think, and we are increasingly being able to show this, be able to deal with these surprisingly rich situations. It's customary today to somewhat derive catastrophe theory, but catastrophe theory does show a very interesting way of pointing out precisely the kind of situation which often exists in ecology, in economics, and in sociology, where you get a discontinuity in the situation and have to start to work on a totally different mathematical plane with a different set of variables perhaps. It's perfectly possible to model that kind of situation and, indeed, to predict where the discontinuity arises.

One of the interesting things that has emerged from research on expert systems, which I hope to talk about on the last day of this meeting, is the ability to combine the qualitative information upon which most managers depend with the highly quantitative information with which we, as scientists, expect to provide them. In the past we have been trying to insist with managers that they use our highly quantitative approaches.

So I don't accept what has been said by both speakers or hinted at by both speakers, that we don't have any approaches capable of dealing with these surprise rich situations. I think we now, for the first time, do, but it's going to require a certain re-education of the people coming from our universities. Much more urgently than that, it will require a re-education of the people who are currently making the decisions.

De Giorgi

I am a mathematician and I am pleased to learn that interdisciplinary collaboration exists between ecologists and mathematicians. In my opinion it is not enough that some mathematicians understand ecology. I think that at present there is no direct connection between ecological problems and what we call mathematical culture.

Nevertheless, mathematicians are acquainted with some concepts of other disciplines, that is, cost benefits, energy, conservation, development, etc. This should be possible also with ecology. A dialogue between the two should be possible.

I believe that for mathematicians the problems studied by ecology are very complex, and even more complex is the assessement of their impact on society.

Mathematics could contribute more qualitatively than quantitatively: its contributions should not be limited to calculations but extended to the development of mathematical models, even simple ones, in order to better understand the course of certain phenomena.

I would now ask if in ecology, as it happens in economy, it is possible to calculate with a reasonable approximation the advantages and disadvantages of conservation? Can you in ecology, determine, as in economy, an ecological gain?

I would add that we should explain to the public the need of better information concerning these problems, of which we know so far very little in respect to what we should know by reason of the seriousness of the problems.

Di Castri

As regards the need for a new "culture" integrating different disciplines, and mostly integrating the mathematical languages, the situation is far from being satisfactory. There are, however, many promising beginnings. Undoubtedly, a useful target for us — ecologists — and probably also for mathematicians, is to maintain as close a contact as possible.

As an example, the mathematical theories of dynamical systems and of non-equilibrium thermodynamics have helped bridge some gaps between students in mathematics and physics from the one side, and students in ecology and evolution on the other. I draw your attention to a recent initiative of the International Union of Biological Sciences to organize a series of workshops on "self-organisation processes, emerging properties, and biological complexity", involving a full spectrum of disciplines from mathematics to thermodynamics, molecular biology, behavioural sciences, population biology, ecology and evolution. Nevertheless, I reiterate my full agreement with what has been said by Prof. de Giorgi and Dr. Jeffers, on the fact that ecologists are still not aware of the potential of many mathematical tools. Indeed, mathematics should not simply be conceived as a tool, but as a basis for building-up and understanding ecological theories.

As regards increasing public awareness on environmental issues, I fear that this fundamental issue is being approached in an emotional rather than scientific way. One can read in the newspapers too many untruths, too much dramatization, so that it is difficult to even recognize ecology as a science. Accordingly, scientists and journalists have a great responsibility for the kind of message to be transmitted. I believe in the force of emotions, but they should be backed by facts.

Raven

It seems to me that there are at least three major problems that confront ecology. First, the field is often viewed as one of social action, rather than a science. Many of the leading spokesmen for "ecology" actually have no training whatever in the field, and yet we depend upon the scientific development of the field for our survival.

Secondly, the all-important interface between ecology and economics has received little serious attention up to now from the practitioners of either field. There are very few individuals who have made an effort to relate the two areas, which remain conceptually very distinct, despite the obvious connections between them.

Third and finally, ecology, in the United States at least, has remained too distinct from the rest of biology. This has tended to result in its under-representation in our universities at just the time when ecological knowledge is so badly needed for our survival.

TANDBERG

I am the Foreign Secretary of the Royal Swedish Academy of Sciences and I am an ecologist by belief and a bureaucrat of science by profession. I will be brief and I will confess that I'm a bit worried by di Castri's label of administrative trap and I'd like to have this concept, or his concept of administrative trap, somewhat more elaborated.

MALER

I would like to respond to Dr. Jeffers' comments on the role of mathematics in economics and ecology. Well, I can't speak for ecology but I think I know something about economy and I think he's absolutely right when he says that on the undergraduate level, economists are very seldom using mathematics. Perhaps we use the simplest tools in calculus. But if you go to advanced research, the situation is quite different and in fact some mathematical disciplines have developed because of demands from economists. I would like to remind you that one of the highest esteemed mathematicians of this century, John von Neuman, made some very influential contributions to economics, partly in some general-equilibrium papers from the Thirties, but mainly because of his invention of the theory, in my presentation, of environmental economics. Today, advanced research in economics includes quite a lot of different mathematical tools, stochastic processes, convexity theory, catastrophe theory, chaos theory, various control theories, both stochastic determistic theories, et cetera. I don't really think that the problems is a mathematical problem, when we look at ways of increasing flexibility in society. There are two fundamental problems here, I think. First of all, economists are not interested enough in studying these problems. Very few economists are looking into these issues. Secondly, I think there is an inherent difficulty in trying to design institutions and social relations in order to increase the future possibilities of adapting societies to something that we have no idea will happen. And that is, I think, once again the main issue: How do we design society in order to take care of absolutely unforeseen changes.

SCARASCIA MUGNOZZA

I am an agronomist, a plant geneticist. I think that one of the examples of the relationship between economics and ecology is maybe agriculture, agricultural production. Modern agriculture cannot be considered in principle, by definition, as a dangerous practice. I think the role of agriculture as producing foods and also non-foods, raw materials for industrial utilization, has not been sufficiently quantified, either in a global way, or in a more disintegrated form. The problem is really a problem of correct information in both directions, public opinion, public powers, and farmers.

KECKES

I am from the United Nations Environment Programme and I am what Professor Jeffers would call a failed mathematician who turned to ecology. I never regretted it.

Mr. Chairman, I listened to the vety stimulating presentation of Professor di Castri and I would like to share just a few of my thoughts with you, although they may be personally biased. As a young scientist, I was actually flirting more with biology and physiology than ecology. But then I slowly shifted to ecology because I was becoming more and more aware that scientists have a very serious social responsibility and I felt that ecology is the field of biology which comes closest to that. It was a very rewarding experience to have this feeling, but, at the same time, also very frustrating because, as soon as I became aware that ecology cannot be ecology for the sake of ecology, I was confronted with the dilemma: How to link it up with the rest of social sciences, and economy in particular. It was frustrating, because very frequently I just was more confused than clear in my mind how to act.

Now, when you try to link ecology with economy, with all its political, ideological, and cultural biases, the situation becomes very baffling and complex. In my mind, the problem boiled down to a few basics, which are probably over-simplified if I say them in two sentences. Basically, my feeling was that neither ecology nor economy, at their present stage of development, has a high level of predictive value. They are not predictive sciences in the strict sense of the word. They are explaining events *post factum*, after they have happened. They can really predict events in advance with precision, which is used in physics, chemistry and other basic disciplines of biology, and, even then, only *per analogiam*. I feel that this is one of the reasons why it is still difficult today to link up ecology and economy. You are adding the uncertainties of both disciplines and you compound them with uncertainties which stem from political, ideological and cultural events.

Nevertheless, I feel strongly that ecology and economy have to be linked, and it is not only my feeling. I would like to draw to your attention the recent changes in the World Bank. The World Bank was naturally not an institution that was very much environmentally minded, but it realized that economy without ecology is no good. Mr. Conable, the President of the Bank, in his recent statement made it very clear that "ecology is a sound economy".

Three new concentration areas were selected by the Bank in the field of environment and economy. One is tropical forests, where the Bank felt that some of the past projects of the World Bank have hurt more than helped, not only the ecology but the economy also.

The second concentration area is the fight against the spreading of deserts, in the Sahara region in particular, where it was also realized that some large-scale investments in so-called developmental projects have created more havoc than offer help, not only vis-à-vis the environment but the economy itself.

The third concentration area selected by the Bank, which certainly is very pleasing to me, although I feel it was not justified, is the Mediterranean basin. I feel that the Bank should have selected some more important target because I agree with my friend Professor di Castri that the Mediterranean is not ecologically and economically the most endangered part of our global ecosystem.

Di Castri

I am not sure that I will be able to reply to all the points mentioned during a very rich discussion. I want to start with something that I have not said yet. The first thing to do, in order to increase interaction between ecology and economy, is to save ecology as a science. Ecology as a science is an "endangered species", at least in a number of countries. Only a strong and coherent ecology will be in a position to cooperate in an operational way with economists and sociologists. Ecology is still much too descriptive and with too poor a predictive power. Mathematics, thermodynamics, and molecular biology should really constitute the basis of modern ecology.

As regards relations with agriculture, I believe that ecology should stand as a pillar for agricultural development, and not only for the protection of the environment.

On the next point, the term "administrative trap" was coined by a British geographer, Dr. Randall Baker. It means that the results of integrated research have no place within the sectorialised administration of science, or the sectorialised ministries. If a project does not fall into a simple category, it is never approved or never applied. On the career potential, there is also a trap if a researcher does not follow the usual disciplinary patterns.

As a practical recommendation, in the course or at the end of an interdisciplinary endeavour, it is not always advisable to prepare a very large report with recommendations addressed to nobody. It is pragmatically more convenient to dissociate the different recommendations of integrated research, and to address usable and specific recommendations, let's say to the ministries of health, of agriculture, etc. A solution might be to send the whole report to the ministry of the environment, but — unfortunately — in too many countries, the ministry of the environment is so powerless that it cannot have a real impact on the ministries dealing with different sectors of national development.

I would like to stress again the fact that, in my view, the real problem lies in the question whether or not it is possible to build-up institutions and public services that are not contaminated by the "administrative trap syndrome », and that are able and willing to see the advantages of an integrated approach.

The game theory has also been evoked during the discussion, specifically as regards economic and environmental issues. As a matter of fact, even organic evolution can be seen as a kind of game between environmental necessity and historical chance.

Finally, I am very pleased about the progressive implantation of environmental concerns in the framework of the operations of institutions such as the World Bank. However, in too many countries, environmental impact assessments are devoid of any scientific background, and they may even play a role of alibi to justify any kind of development scheme.

CHAGAS

Dr. di Castri, when you were speaking about difficulties in countries, I was really thinking that you were speaking about Brazil.

IVES

I am a geographer. When my students ask how I became involved in the geography of high mountains, I answer that I was born below high tide mark on the east coast of England and I cannot swim. That perhaps also explains partly how I came to be here, and I would like to express my great appreciation for the invitation.

I would like to take up only one point, which is really and endorsement of an optimistic remark made by Professor di Castri about the linkage between sound development and ecology, or ecologically correct development, which seems to be a growing notion. I am concerned, however, that while this may be the case from a theoretical point of view, is it so from a practical point of view also? We have heard the optimistic remark about changes occurring in the World Bank. One could perhaps make similar comments about changes in the bilateral and multi-lateral aid agencies. No doubt a critical reassessment is underway based perhaps on the realization that foreign aid and "development" has largerly failed over the last 30 or 40 years. Yet I am still very concerned, and I do not necessarily wish to pick on the World Bank; I am sure that one could examine any of those vast agencies. I want to share with you, however, a statement made by a very dedicated and impressive colleague, Sunderlal Bahuguna, one of the great messengers of the Chipko Movement, who has done so much in terms of the environmental problems of the Indian Himalaya. He made the remark that one of the greatest threats to the Himalayan environment is the World Bank. I would like to enlarge upon this briefly because we can meet here for the rest of the week and probably reach general agreement amongst ourselves. What would be more important would be to use our energies to sieze the opportunity presented by the current reassessment in the corridors of the World Bank and the United Nations agencies, and those of the bilateral aid agencies, to push them further toward really active and successful modifications of their policies. As I will be talking later on about mountain problems, and particularly those facing the Himalaya, I will confine myself here to a single example: the apparently fashionable policy of building expensive hydro-electricity projects often dependent on high dams. Such a policy has been justified as tbe best means of providing countries, such as Nepal and Bhutan, with the means of improving their economic situation through the sale of surplus electricity, in this instance, to India. Such projects are often undertaken without due concern for the nature of the mountain environment, and particularly without awareness of the danger associated with the catastrophic drainage of glacier lakes, a phenomenon known to the Icelanders as "jökulhlaup", or "glacier bursts". I have recently completed a careful documentation of one such "jökulhlaup" in the Khumbu Himal of Nepal (Mt Everest) which occurred in August, 1985. It totally destroyed a hydroelectricity project, the entire Austrian aid programme in Nepal. And what, we might ask, has been the official response? — to look for another site for further power plant construction! How can these mad-headed projects continue to go ahead despite the enormous growth in our understanding of the dynamics of the mountain world? What can we do to tone down these kinds of losses which are not only environmental losses, but which are very severe socio-economic losses as well? The group of us who have come together for this Study Week can perhaps be regarded as already "converted" to awareness of the perils of environmental endangerment. How can we project ourselves in the direction of modifying development policy?

PRZEWOZNY

My approach would be somewhat different from what I have been hearing this morning. I don't think we should ignore the applied ecology of environmental groups. They insist on an interdisciplinary approach, and I agree with them, provided the various specialization are methodologically safeguarded. Furthermore, since sciences arise in a certain cultural context, perhaps a response to needs and behavioural patterns is in order. Undeniably, the more a science is specialized the more extensive becomes its field of study. Consequently as far as environmental protection is concerned, all specializations should approach the task in an interdisciplinary manner.

DI CASTRI

I do not disagree as regards what has just been said on the need for interdisciplinarity. During the last 20 years, I have been working on interdisciplinary programmes, mostly within the framework of the Unesco MAB Programme. My main message is that there is no epistemological impossibility to reach the level even of a "transdiscipline" between ecology and economy. The bottleneck is again in the institutional and decision-making processes, that are not adapted to work with transdisciplines. I certainly believe that solving epistemological problems could help — to a certain extent — to approach in a more realisitc way a decision-making that has necessarily to ever face both ecological and economic uncertainties.

CHAGAS

Any other questions? I think I forgot to tell you a very important fact. It's that Father Bernard has just established an Institute for Ecology, in the Faculty of Saint Bonaventure here in Rome, in a theological faculty.

PRZEWOZNY

The Ministers General of the Franciscan Families have established a Commission which will present a concrete project for their approval. This second Commission is developing the plans of a previous group in order to produce a Center of Environmental Studies which will follow an interdisciplinary approach. The Center should involve philosophy, theology, anthropology and the positive sciences such as ecology, biology, botany and so on.

ENVIRONMENTAL ECONOMICS

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1. Economics has been described as the science that explains the management of scarse resources and prescribes how to manage these resources for the benefit of all mankind.

Traditionally, economics has been preoccupied by the analysis of scarcity of labour and capital (in this paper identified as man-made factors of production). Marx, in his analysis, followed the classical economists, Adam Smith and David Ricardo, and analysed the scarcity of consumer goods in terms of the scarcity of labour. Capital was seen as consisting of embodied human labour, hence the labour value theory. In neo-classical economics, the predominant school today, time was recognized as an important feature which gave capital independence from labour. Thus, the neo-classical economists explain the cost of goods in terms of both labour and capital used in the production process. The value is determined by the interplay between this concept of opportunity cost and the marginal value the consumer associates with the goods. Thus the value of produced goods and services is explained in terms of consumer preferences and the labour and capital embodied in the goods.

2. However, environmental and natural resources are not in general included in this model. By environmental resources, I mean such resources that are potentially exhaustible but capable of regeneration if the stock of such resources is not depleted below certain levels, and by other natural resources I mean exhaustible resources, such as petroleum, iron ore, etc. The negligence of these resources contrasts sharply with the works of the early 19th century economists, Malthus and Ricardo. Both regarded land as scarce, but with different meanings. Malthus considered land a bounded resource which ultimately would limit the

production of foodstuff unless the population stopped growing. Ricardo, on the other hand, considered land as an unlimited resource but such that land with lower quality had to be brought into use, thereby continuously increasing the price of foodstuff. Unfortunately, these discussions of natural resources were almost forgotten and, for a long time, economists disregarded environmental and natural resources in the mistaken belief that these resources would not be scarce. Thus almost all economic analysis from Marx onward was on the allocation of labour and man-made capital.

3. However, once it was recognized that environmental and natural resources are not available in unlimited amounts, it was quite easy for economists to incorporate them into existing theory. The established theory, going back to Leon Walras and Wilfred Pareto, explains how resources are allocated between competing ends by the means of prices determined on markets. It also demonstrates that under certain conditions, the outcome of market processes may be a desired outcome, i.e., a "Pareto optimum". When environmental resources are introduced into the theory, the same theory demonstrates that the outcome of market forces will in general be different from a Pareto optimal outcome. In particular, the theory gives a systematic account of the failures of an uncontrolled market mechanism to achieve an efficient allocation of resources when environmental resources are important inputs to production and consumption.

4. In order to understand the approach of economists to the problems of environmental and resource problems, it is necessary to have at least an intuitive understanding of what markets can do and cannot do. Adam Smith's famous dictum about the invisible hand that causes individual self-interests to promote the public interest is the origin of the economist's analysis of the efficiency of markets. The main idea is that under certain and very important assumptions, prices will convey information from the producers to the consumers on the true social cost of production and, in the same way, prices will convey information on the desires of the consumers to the producers. With this assumption of perfect transfer of information, consumers make their decisions on which goods and services to buy on the basis of true social costs of production, and when they try to maximize their self-satisfaction, they will indeed take these social costs into consideration. On the other hand, producers in their striving for maximal profits, will take consumers'

desires into account because these are reflected in the prices. Goods that are highly desired will be higher priced and therefore in general more profitable to produce.

Although Adam Smith did not provide any rigorous support for this view, there now exists deep mathematical analysis of this role of prices to convey prices [1]. The objective of this analysis is not so much to prove the efficiency of a market system but to clarify the conditions necessary for markets to provide efficient allocation of resources and thereby at the same time provide a ground for a discussion on the issue of how to improve the allocation mechanisms in a society.

One can classify the conditions under which markets tend to allocate resources efficiently into three broad categories: continuity, convexity and completeness. The first has to do with assumptions on production technology and consumer preferences which must obey some reasonable rules that limit the reactions economic agents may show in face of changes in the underlying parameters. The second category is about the nature of production technology. For example, convexity means that increasing returns to scale must not predominate technology. With very strong scale economies it is intuitively reasonable to expect monopolies which would be a deterrent to efficient allocation of resources. The third category, finally, contains assumptions that would imply that all goods and services and other effects from production and consumption are priced on markets. There must be a complete set of markets. It is this category of assumptions that is of interest in connection with a discussion of environmental problems.

5. One major reason for the failure of markets to achieve efficient allocation is the existence of external effects or externalities, i.e., effects that affect other people but are not the objectives of decisions that generate them. In a way, they can be considered as unintentional side effects from production or consumption decisions. As they are unintentional and as they are of no consequence to the decision maker, he does not take them into account when he makes the decision. The result will obviously be too much of these external effects if they are considered negative or too little if they are considered positive. Many factors that affect the deterioration of the environment are of this kind — air pollution that damages the neighbouring households, for example.

(1) See, e.g., G. DEBREU, *Theory of Value*, New York 1959.

Note that the problem for efficient allocation of resources comes from the fact that these external effects are not priced on markets.

Another reason for the failure of markets is the existence of public goods, i.e., goods that must be consumed in the same quantity by a group of individuals. It is in general impossible to collect revenues from the sales of public goods in the same way as it is possible to collect revenues from selling automobiles. Most environmental resources are public goods in the sense that they cannot be divided among the different consumers. Instead, each consumer must consume the same quantity as the others of, e. g., air quality, water quality, scenic views, wildlife, etc. Now, for public goods, the private producers have very small or even no incentives to produce such goods. This is why we should expect a market oriented economy to follow a path that leads to deteriorated environments. Once again, the nature of the efficiency problem is that there are no, and cannot be, any markets for these public goods.

A third reason has to do with the difficulties or even impossibilities to enforce property rights. Hardin (2) has in a superb way described the tragedy of the commons which is based on the lack of well defined and enforceable property rights. When a property right cannot be enforced, an over use of that property can be expected. Once again, exchanges on markets require enforceable property rights.

A fourth reason has to do with the valuation of the future. It generally takes a long time before an environmental resource has recovered from excessive consumption. Here the problem can be seen as a lack of markets between future and present generations. Future generations cannot act today in order to "buy" themselves a better environment.

Thus one can see the failure of markets to allocate environmental resources efficiently as a result of the impossibility of pricing these resources on markets in a proper way. As a result, prices of goods and services bought and sold on markets will not reflect the true social costs. Instead, our economic systems will be based on an incentive structure that gives consumers the wrong signals when they are choosing among different consumer goods and services, and the producers the wrong signals when they choose what to produce and how to produce. Perhaps, most importantly, the incentive system to develop new technology better adapted to the demand of the environment will be completely absent.

(2) *The Tragedy of the Common.* « Science », 162 (December 1968).

Thus from the viewpoint of an economist, the basic problem is the failure of the incentive system to take environmental aspects into account (3).

The presentation up to now has been solely concentrated on an economy based on free markets. The arguments are valid, however, even in other economic systems. One should take note, that even in a centrally planned economy, prices have an important role. In such an economy they do not reflect the desires of the consumers but the objectives of the planners and even if the planners are using quantitative regulations, the formation of prices will still affect the resource allocation. The basic problem in planned and market-oriented economies is the same: the failure of the incentive system.

6. It might be of interest to study in more detail how failures of markets will indeed result in excessive abuse of the environment. I will therefore report very briefly on some results from an ongoing research project at the Stockholm School of Economics on acid rains in Europe. I will, for the sake of this presentation, assume that governments indeed have full control of the emissions in their respective countries and that they act rationally with respect to domestic environmental issues. Thus they would control the domestic sulfur emissions in such a way that they minimize the total national cost of emission control and damage cost from acid deposition. In many ways, this seems to be an accurate description of governments' behaviour except that they may not value the environmental damage at their true cost to society but underestimate that cost. According to this scenario, all European countries are thus behaving rationally, each optimizing its own (4) welfare. Such a situation is in game theory literature known as a Nash equilibrium. More precisely, the assumption is that in 1984, the European countries were in a Nash equilibrium with respect to their strategies to control sulfur emissions.

(3) For a deeper and more technical discussion of these issues see K.-G. MÄLER, *Welfare Economics and the Environment*, chapter 1, in: *Handbook of Natural Resource and Energy Economics*, eds., Allen V. Kneese and James L. Sweeney, North Holland 1985.

(4) Game theory was originally formulated as a mathematical model of various parlor games in which the players have strategic interests; chess, bridge, poker are examples of such games. The theory was created by John von Neuman, who also discovered, together with Oskar Morgenstern, that the theory could be used to analyse economic and social interactions in general. During the last ten years, the theory has developed into a very powerful tool in analysing social and economic conflicts. A good, but mathematical introduction to game theory can be found in JAMES FRIEDMAN, *Game Theory with Applications to Economics*, New York 1986.

Now sulfur emitted in the air will be transported from one country to another and cause environmental deterioration, not only in the source country but also in other European countries. Obviously, it is not in the selfish interest of any government to take into account the damage to other countries from its emissions (5). However, cooperation between groups or all countries may very well turn out to be beneficial to all. Simulation has shown that compared with the situation 1984, i.e., with the assumed Nash equilibrium, complete cooperation between the countries would reduce the total emissions by 50 percent and would entail a total benefit to the European community of approximately 10 billion D-mark. The table below illustrates the gains and losses to European countries from a policy based on minimizing the total control and damage cost (the numbers should only be viewed as illustrations of the principal argument partly because the uncertainty is very large and partly because they are based on some arguments which because of space cannot be discussed here).

Apparently, there are some substantial gains to be made by a full cooperative agreement between the various countries. Such an agreement would mean a reduction of about 50 percent of the European emissions in 1984, and the total benefit would be close to 10 billion D-marks.

However, there are several problems connected with such a cooperation. The first problem is that in the case of acid rains in Europe, some countries would actually be losers from complete cooperation because they are located "upwinds". For example, the UK would experience a loss of about 600 million D-mark if they would take part in an international agreement on reducing the total environmental cost as much as possible. Thus, the UK would have very strong incentives to refuse to cooperate.

But, secondly, even if all countries would gain from the cooperation, their gains would be higher if they abstained from cooperation in the hope that the other countries would cooperate. For example, if Italy

(5) It can perhaps be argued that there are social norms that would induce countries to take interest in the welfare of other countries. However, one should then have to explain these norms in terms of mutual interests. This theme has been developed in a most fascinating way by professor ROBERT AXELROD in his book *The Evolution of Cooperation*, New York 1984. Axelrod shows how cooperation may evolve over time because conflicts are repeated, and the behaviour in one time period will affect the behaviour of another agent in a later one. In our project on acid rain in Europe this kind of approach is being tested.

Country	Net benefits million D-mark	Emission 1000 ton SO_2
Austria	380	29
Belgium	234	117
Bulgaria	35	39
Czechoslovakia	1275	1625
Denmark	204	143
Finland	4	25
France	986	100
German Dem. Republic	43	2000
Federal Rep. of Germany	484	1375
Hungary	−113	...825
Italy	35	396
Netherlands	661	112
Norway	388	31
Poland	2465	1057
Spain	−20	194
Sweden	878	5
USSR	1974	330
United Kingdom	−560	1845
TOTAL	9356	10210

refused to participate in a cooperative effort to reduce European emissions, it would gain about 130 million D-marks, while the gain from cooperation would only be 35. Thus Italy would gain 95 million D-marks by refraining from cooperation if the other countries would cooperate. This holds true for every country, and in the absence of enforcable commitments, all countries would have incentives to avoid cooperation, irrespective of what all other countries are doing. In fact if UK would refuse to take part in the cooperation, they would, instead of a loss of 600 million D-marks, experience a gain of almost 100 million D-marks if the others cooperate, i.e., a net loss of 700 million D-marks from cooperating. There is no doubt that it is rational, from the point of view of the British government, to refuse to participate in the present international efforts to promote cooperation. On the other hand, Sweden is required in the cooperation scheme to reduce her emissions by only 5,000 tons SO_2, which would not cost very much. In fact, Sweden could only gain 1 million D-marks from refusing to cooperate if other countries do, while the potential gains are quite high. No wonder that Sweden tries to promote international cooperation. We have here an example of incompatibility between individual rationality and collective rationality. It is really this incompatibility that is behind Hardin's story about the tragedy of the commons. Even if each agent behaves rationally from his own point of view, in the presence of a common property resource such as the European athmosphere, the outcome would not be collectively rational. There are other reasons too for this incompatibility, due to differences in economic systems, imperfect international capital markets, etc. But the main factor is that the European athmosphere is a common property resource.

In order to make any progress in promoting cooperation, it seems therefore necessary to find ways of compensating those countries that would lose from cooperation and means of enforcing international agreements on emission reductions. In view of the problems of collecting reliable information on emissions, costs of emission reductions, environmental damages, etc., it seems necessary to engage in the challenging work of finding new international institutions that could accomplish a more economical and efficient cooperation.

The conclusions from this brief survey of a common property resource problem ([6]) are i) that individual rationality will not in general be compatible with collective rationality, ii) in order to promote collective rationality, it is necessary to find a way of enforcing commitments, iii) it is also necessary to find a way to induce all users of the common property resource to take part in the cooperation, and iv) to design a system of transfers between the users in order to make it profitable for all to participate.

7. If the problem is a failure of the incentive system, how could this system be improved? This question could be divided into two subquestions: what are the proper incentives, and how should these incentives be implemented? The first question could also be formulated as a question about the objectives society should set with regard to environmental quality. The second subquestion concerns the tools in environmental policy.

8. What are the proper objectives in environmental policy? What should be aimed at when formulating goals for environmental reforms?

([6]) For a more detailed discussion of the problem of common property resources see PARTHA DASGUPTA, *Control of Resources*, Oxford, 1983.

Most people would probably look at these either as political issues or questions that could be resolved on scientific grounds. However, basically, the issue is one of subjective valuation. How much do we value reduced acid deposition? How much do we value the survival of a species? How much do we value a decrease in the risk of getting an air pollution-induced disease? Obviously, the answers to such questions will differ between different individuals. To some, an environmental improvement or an elimination of a threat to the environment may mean much more than to others. In fact, very often some individuals may regard a change as an improved environmental quality while others may consider it as a deteriorated environment. The two things common to these individuals are that they have to live with the same environment and that they therefore cannot affect the quality of environment by actions on markets. Instead of a market demand for changed environment, there is a need for quantifying these values into something that can be used for making a trade-off between an improved environment and other economic ends that are desired by the individuals.

What economists do is to try to quantify these values in a way that mimics the demand for ordinary goods and services. The demand for bread, e.g., can be interpreted as a relation giving the amount consumers are willing to pay in order to get the bread, and it is exactly this willingness to pay that is transmitted through the price system to the bakers and induces them to produce the amount of bread that is demanded. In the same spirit, one could imagine the concept of willingness to pay for improved environment. In general, society has to give up something in order to achieve an improved environmental quality. If society is not willing to give up that amount, then it is not in the interest of society to improve the environment; or if society is prepared to give up more, then environment quality should be further enhanced. Thus, in order to quantify the values of environment, economists try to measure how much individuals or households are willing to pay for improvements (7).

(7) I have here introduced the concept of willingness to pay. There are a lot of other similar concepts that are more theoretically satisfying and which are used in actual estimation procedures. However, space does not permit a more thorough discussion. Those interested are referred to MÄLER, *op. cit.*, and K.-G. MÄLER and R. WYZGA, *Economic Measurement of Environmental Damage - A Technical Handbook*, OECD, Paris 1976. This approach also requires a discussion of income distribution aspects, which also, because of limited space, is neglected here. The reader is referred to Mäler's chapter in *Handbook of Natural Resource and Energy Economics.*

However, there are no easy ways of measuring the willingness to pay for environmental changes. To simply go out and ask people about their valuations would hardly work because, in general, they will have all kinds of reasons to distort their answers. Moreover, as psychologists have shown, their answers turn out to be dependent on the ways questions are formulated. Therefore, economists have developed various alternative methods (8) of estimating the "demand for environment".

The methods can be divided roughly into the following categories:

i) Whenever the environmental quality change affects marketable outputs (or inputs), that part can be measured by using market prices;

ii) Contingent valuations;

iii) Measuring changes in demand functions for marketable goods and services;

iv) Measuring capitalization effects.

The first approach has been very much in use, in particular by engineers for simple pollution problems. If corrosion on materials increases because of increases in air pollution, then the cost of this can be measured by estimating the cost of preventing corrosion (better paints or more frequent repainting e.g.). The second approach is a sophisticated way of asking people about their willingness to pay for environmental improvements. I will shortly give an example from a study on the valuation of preservation of a forest in the North of Sweden that among other methods also used contingent valuation. Today, this approach has been so accepted that it has been used in American court cases.

The third approach starts from the assumption that sometimes a change in the environment will change demand for marketable goods and services — a change in water quality in a lake may change the demand

(8) There now exist many good surveys of techniques for measuring the economic value of environmental changes. One of the oldest is MÄLER and WYZGA, *op. cit.* Later books are M. FREEMAN, III. *The Benefits of Environmental Improvement: Theory and Practice*, Johns Hopkins University Press, 1979; HUFSCHMIDT, JAMES, MEISTER, BOWER and DIXON, *Environment, Natural Systems and Development*, Johns Hopkins University Press, 1983. Y. AHMAD, P. DASGUPTA and K.-G. MÄLER present in *Environmental Decision-Making*, vol. II, Hodder and Stoughton, 1984, (sponsored by UNEP) a number of case studies which illustrate the use of different techniques of valuing environmental benefits. V.K. SMITH and W.H. DESVOUSGES, *Measuring Water Quality Benefits*, Boston 1986 contains a summary of research carried out by Smith and Desvousges over a number of years that illustrates in a fascinating way the power of various methods of estimating environmental benefits.

for fishing equipment — and uses economic theory in order to infer the willingness to pay from this observed change. It has mainly been applied to environmental changes that are of consequence for recreation. Finally, environmental changes may quite often be capitalized in property prices. An improvement of air quality in one community will make it more attractive and the property prices will, as a consequence, rise. By studying that rise, it is possible to deduce the willingness to pay for environmental improvements.

Although these techniques have developed very rapidly during the last ten years, it should be pointed out that our methods are still quite incomplete and that many environmental changes cannot be valued today. Often the cause for this is the lack of a good scientific understanding of the underlying problems or the lack of a good data base.

In order to illustrate some of these approaches, I will give a brief summary of a research project carried out at the Stockholm School of Economics (9). Valadalen is a valley in the Northern Mountains of Sweden. It has been quite popular among tourists, both for summer and winter recreation. The land is owned by the national forest service, which planned to use the standing forest for increased timber supply. That would mean clear cutting in large areas and would change the view of the landscape. Would such a development be consistent with an analysis from a social point of view that also contained the values of the tourists visiting the area? In order to answer that question, a questionnaire was developed, in cooperation with psychologists, which could be used to infer the willingness to pay to preserve the forests in the valley. A few samples were drawn (10) and their willingness to pay per day if they stayed in the valley was estimated. The result was that they were on the average willing to pay about 30 Swedish crowns per day for preserving the valley. By multiplying this with the number of person-days per year, one gets a total annual willingness to pay for the preservation alternative of about one million Swedish crowns (11), which strengthened the case against the cutting plans.

(9) JAN BOJÖ, *Kostnadsnyttoanalys av fjällnära skogar - fallet Vålådalen*, EFI, Research Report, ISBN 91-7258-205-7.

(10) Unfortunately, time did not permit random drawing.

(11) A special study of the economics of the cutting plans had revealed that, even if the cutting was profitable from the point of view of the National Forest Service, it was not profitable from a social point of view, mainly because the subsidies to road construction in forestry must be deducted in order to get a social study.

In order to check the result, a travel cost study was also carried out, i.e., we looked into the cost of travelling to the valley for the persons participating in the study to find out whether they would continue to visit the valley if the cuttings took place. That information was enough to enable us to calculate the value the tourists put on the preservation alternative by using different information. The result was of the same order as the previous, which strengthened our trust in the methods used. Partly as a result of this study, the valley has now been put aside as a nature reserve.

9. Let me now return to the incentive system. As already mentioned, this is equivalent to the design of a rational environmental policy. The objective of environmental policy must be to achieve a certain environmental goal in the "best" way. What does the "best" way mean? Obviously there is no unique best design of environmental policy, but it seems that the following criteria are essential when designing an incentive system:

— Static Efficiency. This criterion has to do with the cost of achieving a specified environmental objective by using a certain policy design. Obviously, the lower this cost is, the more attractive is the design.

— Dynamic Efficiency. This criterion has to do with the flexibility of the design in response to future unforeseen changes and also to the incentives to develop new and better technologies which are not available today.

— Information Requirements. This has to do with the amount of information that is needed in order to use a particular policy design.

— Monitoring and Control. The need to monitor the behaviour of agents with regard to their interactions with the environment and to control this behaviour varies with policy designs.

— Political and Ethical Effects. The most obvious such effect is on income distribution.

Most of the economic analysis of different policy designs has concentrated on the first criterion, static efficiency, although all criteria have been studied, in general and in connection with different applications. Because of limit of space, I will also concentrate on static efficiency, although I do believe that, in particular, dynamic efficiency and problems of monitoring and control are as important.

Economists classify environmental policy instruments into pure incentive schemes and quantitative regulations. Quantitative regulations are by far most used in environmental policy the world over in spite of the fact that they have some serious drawbacks, unless they are cleverly designed. The reason is of course that they are not as abstract as economic incentives and it is much easier to understand and believe in their effects than it is to understand the mystical force of economic incentives. However, most empirical studies have shown that economic incentives have much stronger effects on a polluter than a corresponding quantitative regulation [12]. Moreover, a uniform charge or tax on the emissions will induce the polluters to control their emissions up to the point where their marginal cost for continued abatement is equal to the tax. Thus the tax scheme will guarantee static efficiency, i.e., that the reduction in the total emissions has been achieved at least cost.

There are three weaknesses in this argument, however. The first has to do with the difficulty of monitoring the emissions. There are, in general, ways of solving this problem. For example, a group at the Stockholm School of Economics proposed to a government commission on automative exhaust that a tax differential between unleaded and leaded gasoline combined with a tax differential between cars equipped with catalytic cleaning and cars not so equipped would do the same trick as a pure emission tax. The Parliament introduced such tax differentials a couple of years ago and the result has been a complete success.

The second weakness has to do with the fact that often it is not the total emissions that are of interest but their spatial distribution. In such cases a uniform tax will not achieve static efficiency; it will however achieve dynamic efficiency. A more complicated tax structure will solve that problem, but the structure may be too complicated to be used in practice.

The third weakness is based on the impossibility of predicting with full certainty the outcome from an emission tax. If the taxing authority does not know the exact cost functions in all sources for abating the emissions, it cannot calculate the resulting emissions correctly. If it is very important to be sure that the total emissions are reduced to a prescribed level, then the tax system is not an appropriate policy instrument, and quantitative regulations should be used.

(12) See, e.g., the dissertation by H. BRESSERS, *Twente University*, Enschede, The Netherlands.

Quantitative regulations can, however, be designed in many different ways. I will, for simplicity, discuss only regulations that can be formulated as a prescribed maximum of the permitted annual emission. In principle, it is possible, by using such regulations, to reduce the emissions to the desired level (13). In general we do not expect that the regulations will be efficient from a static point of view and they will not be dynamically efficient. Given permission to emit a certain amount, the polluter has no incentives to reduce pollution further if technical opportunities appear, while a tax would provide a continuous incentive to improve technology. There are ways to modify the regulation system in such a way that it will be both statistically and dynamically efficient. The trick is to make permits tradeable.

If a permit to emit 10 tons of sulfur can be transferred from one polluter to another, there will be a market for such permits, and there will be a cost for having a permit — a cost similar to a tax on the emissions. If the markets for permits work efficiently, all polluters will be facing the same price on the permits, and static efficiency will be achieved. As there is a cost of owning a permit, there will be a constant pressure on polluters to develop new technology in order to reduce that cost. Thus the system also tends to be dynamically efficient. Moreover, even in the face of violent changes in the economic environment, the system will provide for a stable total emission.

This system seems to have many attractive properties if one regards it from a theoretical point of view. However, it developed in the US because of very practical needs: how to combine economic development and environmental protection in regions where they are in deep conflict. In the US, there are now markets for such permits in many states, and most information points in the direction that they work efficiently.

At the Stockholm School of Economics we made some game experiments (14) on different strategies for reducing hydro-carbon emissions in Goteborg. We considered only four sources, the Volvo manufacturing plant and three refineries (BP, Shell and Nynäs). Volvo was the dominant source hut had also the highest costs for reducing

(13) In practice, it may not work, because of measuring, monitoring and other reasons. As emissions are random variables, it is not possible to guarantee a certain emission level. Thus regulations must take that into account.

(14) *Överlåtelsebara utsläppsrätter. En studie av kolväteutsläpp i Göteborg*, L. BERGMAN, K.-G. MÄLER and I. STAHL, EFI Research Report 229, ISBN 91.7258.229.4.

the emissions. We looked at the alternative of reducing all emissions by ten percent and compared that with a least cost emission reduction of the same size. The least cost reduction would cost about 10 million SEK less than a uniform reduction [15]. With only four agents and when each of them has incomplete information on the cost functions, one should not expect efficient markets from theory. In our experiments, we almost always were able to achieve the least cost solution, i.e., an efficient market. Thus, it seems that efficiency in markets for tradeable permits is quite robust.

(15) In reality, a uniform reduction is not probable. There are signs that show that the authorities first of all want to reduce the emissions from Volvo. If that is the case, the gains from a least cost reduction would be correspondingly higher.

DISCUSSION

JEFFERS

I am glad Dr. Maler introduced the idea of the repeated gain, because my understanding of gain theory is that it was originally developed with the concept of the repeated gain. Richard Dawkins in a recent book, and in an even more entrancing television programme, showed that if you play that kind of game of the tragedy of the commons, actually the long-term strategy is a forgiving strategy. The best possible strategy that anybody can adopt is actually a forgiving strategy, whereby you cooperate, and as soon as anybody doesn't cooperate, you hit them hard once, but then you go back to cooperating again. So it's very important to think that, in moving from this kind of gain theory, we take into account the difference between a short-term and a long-term strategy, and I mean that. Certainly Dr. Maler mentioned that, but I think it's something that certainly needs to be emphasized strongly because in trying to talk about this kind of concept in relation to economics with my own government departments, the emphasis very often in those government departments has been on what's the best short-term strategy, because elected governments anyway tend to take rather short-term rather than long-term views.

MALER

There are some very big problems of applying the simple idea of tit-for-tat strategy in these connections, because, when playing the present dilemma a number of times, there are some very well-defined starting points. You don't have it when you look at the acid rain gain. There must be some point which can be taken as a natural basis for all European countries, but there is no such natural point and that creates additional difficulty. The reason I didn't go into the repeated gain theory in detail now was that I haven't finished that part of the research yet.

GOLTERMAN

I would like to come back to the problem of pollution crossing national frontiers. As you know, the Dutch population has had a lot of problems with sodium chloride being disposed of in the Rhine. I'll face that problem on Wednesday morning. There is economic damage to our agriculture due to the salt which the French potassium mines have been disposing of in the Rhone; and against the advice of the government, which believed in negotiations, two or three Dutch farmers went into court and have been fighting a legal battle for ten years. But finally, they can claim damages, which seems to be the only way of stopping the French from putting the sodium chloride into the Rhine. Has this been tried in the case of air pollution? Would it be possible for the Swedes, for instance, to claim damages in England? I think this is the only solution for this pollution problem. I don't believe in negotiations.

Maler

I am not an expert in legal matters so I am not able to give a satisfactory answer to the question put by professor Golterman. I don't think that Swedes would be entitled to claim compensation in Britain for acid rain damage in Sweden. There are many difficulties in proving that it is the British emissions that cause damage in Sweden when we know that the deposition of sulfur in Sweden has many sources including our own. We have in Scandinavia, however, some possibilities because of a Nordic treaty that gives us the right to claim damage in other Nordic countries for air pollution damage, but I do think that we would be in difficulty trying to claim damage from countries outside the Nordic community.

I agree that, if one could establish a common framework for claiming damage at court, the problem of transboundry pollution would be greatly resolved, but not completely. Because the European atmosphere is a common property resource, which is used by many countries, the sulfur deposited in Sweden originates from many countries, including Sweden. Which country is the "marginal" emitter? I do see difficulties in settling this kind of common property resource problem in court.

Jeffers

There was a claim by the Scandinavian governments to the World Court that Britain was slowing the growth of forests in Sweden and killing fish in Swedish waters. This caused the birth of the research on acid pollution in Britain. This was some 12 or 13 years ago now; my institute was asked to look into this claim from the Swedish government. We did some research for 3 years and went back to the British government and said, well, we don't think that we are slowing the growth of the Swedish forests, but we are almost certainly providing at least some of the component which is killing fish in Swedish waters; but we are doing the same thing in our own waters.

MALER

It's not a good way; it's the only way.

DI CASTRI

I would like to support the fact that game theory is an extremely valid tool as applied to this of economic-environmental problem, and also to the so-called evolutionary "theater" of species.

However, there are two kinds of difficulties: the problem of the number of players involved, and the problem of their quality (fair play of the different partners). If the number of players is too great, the complexity of the solution may reach a kind of threshold. Furthermore, it is not easy to verify whether or not players, or countries involved, are really applying the rules of the game, or are playing with "pipped cards", that is to say, non-reliable information. In other words, there should be some quality control provided by governments, national institutions, etc.

Moreover, incitation and compensation, that are part of the game, are not always interpreted in the same way by the different players. I would like to know if there is a minimum/maximum threshold in the number of players, and what should be done to increase the quality control and reliability of data used in the game.

This point touches upon my own concern about institutional inadequacies and bottlenecks. I wonder if some really objective evaluation mechanisms can be applied in relation to very large institutions. These institutions tend to have inherent mechanisms to resist evaluation. Also, concerning international scientific programmes, I strongly believe that the only controlling mechanism is some discontinuity after a given lapse of, let's say, 10-15 years.

This "institutional parenthesis" does not undermine at all my conviction on the usefulness of the game theory for the simulation of environmental problems and solutions, as well as for the simulation of evolutionary strategies.

LIKENS

I would like to make two brief points. It is a joy and at the same time a major frustration for an ecologist to consider all problems simultaneously from as many viewpoints as possible, particularly in ecosystem ecology. This is difficult because, even though we may be studying some specific component of an ecological system, we are forcing ourselves to try to put it into the perspective of a larger picture and of all the interacting components. This perspective, I believe, is the hallmark of sociology.

The second point relevant to this discussion is that when we try to do cost-benefit analyses for an environmental problem, we usually focus on one or only a few items, because we don't know the totality of the ecological interactions. We don't know what a bacterium in a lake is worth. We don't have a dollar value for a bacterium in a lake or in the soil. We know that the process of nitrification is important but if the process of nitrification is affected by a pollutant, we have no idea of what monetary value to put on that. I use the bacterium as an example, but I could go on to describe the complexity.

It is indeed frustrating because it would seem to be hopeless to place a monetary value on the totality of the complexity involved in ecological systems. If we are going to have a fair cost-benefit analysis, however, it seems to me that we must apply costs and benefits to the ecological complexity because it is relatively easy to put a cost on what it would take to reduce emissions, say, of sulfur dioxide or some other pollutant, into the environment. That's an engineering cost that we can put a precise value on.

OTTOSON

I am the Secretary General of the International Brain Research Organization and, as such, I am very much interested in cognitive sciences and I try to understand even what I am not supposed to understand. I think my precise question to Dr. Maler will reflect my ignorance here and it's a little bit related to what Dr. Likens recently brought up. You present a lot of figures here, and that's cost-benefit, but, rather than about benefit, you've talked about gain. These figures are very seducing as a matter of fact and they are very interesting, but my question is: How did you arrive at these figures? You gave them in Deutschmarks, that's very interesting; but how do you estimate the destruction of forests or human homes in Deutschmarks? That's my first question. The second question is: I suppose that all your calculations are based on official figures you get from various countries; how reliable are these figures really?

I suppose there must be a difference in reliability for various countries. So these are my questions to Dr. Maler. I would very mucb like to hear his answers.

MALER

They are very interesting questions. Let me start with the question asked by di Castri and Ottoson about the quality of data. The true answer is that the quality of data is quite bad. For instance, such a simple thing as an inventory of emissions of sulfur oxide in the atmosphere is very uncertain. We have something called, the 30% Club, that is a Club of nations that have agreed to reduce their emissions by 30%. Now, it happened that just before they signed that agreement, some countries reported increases in their emissions by 30%. Now, there are very severe credibility problems with the emission figures. There are serious problems with the estimates that I have been using for cost and control measures; no doubt about it. The statistical basis for tbe figures I presented here are very bad. However, I have made some sensitivity analysis which shows that even if I changed the assumed emissions for 1984 quite a lot, and even if I changed the assumptions on the cost of control, the same story, not the same numbers, will show up. Remember that my figures are only for illustrative purposes. They are not saying anything about the actual gains because, then, I would have needed quite a different data base.

Now, let me turn to the other questions. We have di Castri's question about the number of players. I think there is a dramatic difference between two players and three players. There's not that much of a difference between three players and three hundred and thirty-three players, and the reason is that with two players you cannot form any coalitions. You have only two players each one against the other. With three players, two players could join together and play against the third, that is, there is room for coalition formation and you have that to a much larger extent when you increase the number of players. But the main point is that with three or more players you can form a coalition, with only two, no. On the other hand, there is a substantial difference between 333, or in 20 players versus 3 players, because the number of coalitions increases dramatically with the number of players, and if we have 20 European, 28 European countries, that would mean about 100 million, or 200 million perhaps, different coalitions. It's absolutely impossible to do tbe calculation for each of those possible coalitions. And I didn't do that in this research project, from which I have reported some results, simply because it is absolutely impossible. With three players you have only 2 to the power of 3 coalitions, and it's very easy to calculate, but in principle there is no difference between 3 and 333.

Now, Professor di Castri took up the very interesting question about the application of gain theory in a world where you have incomplete information. That's my interpretation of his comment. You don't know the emissions; you don't know the benefits other players, other nations, will get from different emission control strategies, and so on. However, there is a theory of gain under incomplete information. I haven't used it in this research project, but I think I mentioned that in my presentation. Besides the opportunities offered by looking at repeated gains, I am looking at the possibility of building up institutions which in a way give incentives to the contracting parties to reveal the true benefits from different strategies. Now this, in the economic literature, is called the problem of incentives compatibility, and it is a very fast-growing area. It has successfully been applied to the theory of regulation of public utilities in the United States. How should one develop the control and instruments in order to be sure that the information provided by the utilities to the State Commission is correct. I think I mentioned the idea of mutual compensation as developed by Henry Smith at OECD in 1972-73, which, in the incentives compatibility literature, gives a basis of formulating, of designing institutions, that will enable countries not to overstate their emissions with 30%, but to give as good as possible predictions of the emissions, the cost of controlling them and the damage from their deposition.

David Ottoson asked also about the nature of the gains. Now the gains are the reduction in the total cost of controlling sulfur emissions and the damage costs. The cost of controlling emissions is based on studies that were carried out at the International Institute of Applied Systems Analysis at Laxenburg in Austria, and these are the basic input to these simulations. Now, if you look at this game in an abstract theoretical format and you try to correct the so-called Nash equilibrium in such a model, and if you make the simple additional assumption that the model damage cost is constant, then you can calibrate the model by using the G cost figures and by using the A model, so that it will reflect the situation in 1984. And that's the basis for my calculations. The assumption that we bave a linear total damage cost function and that the model can calibrate it for 1984. That is the nature of the gains I have calculated and showed you. These are conservative estimates on the D for the reason I mentioned in my presentation because it implies that the governments really takes all the environmental damage from acid deposition into account. As I said previously, I am quite sure that Hans Lundberg will show that in fact they are not, which means tbat I have underestimated the environmental damage and in spite of that, been able to show that there is a very significant opportunity of gains from cooperation, but at the same time I have shown that no country will have incentives to take part in that cooperation given the other parties' behaviour. That's the basic conclusion I would like to present to you.

Finally, regarding the cost-benefit analysis, I agree with the statement that we need to have a dollar value because it's very easy to put a dollar value on the other side, the cost of control side. If you don't put a dollar value on the other side, that other side will carry very small weight in the discussion.

However, you don't need to get a total dollar weight from adding up dollar weights on specific items. Sometimes it may be easier to put a dollar value on the totality, start up and then go down. That's happening more often than the reverse when we have very complicated situations. In general, the dollar values we come up with will be very, very uncertain, and that gives me reason to come back to the real fundamental problem: What do we do in situations with a very high degree of uncertainty? How should we treat those situations? Fortunately, as I mentioned earlier, there is progress made in the field of decision analysis and in the field of cost-benefit analysis, which enables us to get at least some qualitative indicators on the bias in the more simple approach, but I would like to add to that that perhaps we shouldn't try to end up with one single result, one single number, one single conclusion. Instead, let's show that we can be explicit about our insufficient knowledge and conclude that anything of this can happen. We have some reasons to believe that this is more probable than the others, but we should try to end up with, let's say, an interval estimate then instead of a point estimate.

AYYAD

It's just a general point, not a question. We often look at the relationship between environment and economy or socio-economy as a one-sided relationship. We speak about the effect of environmental degradation on the economy. Its effect on the economy is not what would be its economic cost. We should really consider the other way effect, that's the effect of a change in the economy on the environment, as for example, the effect of changing a society's economy from subsistence economy to cash economy in rural societies, as in Bedouin societies and in the rural urban migrations, and the feedback effect of the affected environment by this changing economy on the environment itself.

ENVIRONMENTAL RISK IN THE PRODUCTION AND CONVERSION OF ENERGY AND THE PROBLEM OF SOCIAL ACCEPTABILITY

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1. *Introduction*

Environment may well prove to be the real limiting factor to development. The capacity of the environment to absorb increasing loads deriving from human activities without undergoing irreversible transformations is limited, and it has certainly been surpassed in many cases.

The quality of the environment is important in many respects. At the limit, it is a prerequisite of survival for humankind. It conditions the physical possibility of carrying out industrial, agricultural and other economic activities. It is an ever increasingly important factor of the quality of life. And, last but not least, it affects cultural and biological richness. The extinction of species, the disappearance of natural habitats leave man poorer. The degradation of environment endangers human accomplishments as well: monuments are at risk as much as forests.

It is not enough to find ways of ensuring survival and economic growth; "artificial" environments cannot always replace the richness of nature and the cultural heritage we receive from past generations, that we must transmit enriched and not depleted to our successors.

Some of the damage to the environment is reversible. We can devise ways to clean the waters of a lake and to restore a biological equilibrium. Some damage may be much more difficult to overcome: the disappearance of tropical forests, desertification, or the depletion of the ozone layer are obvious examples. Some damage is clearly irreversible: the extinction of species or the destruction of a work of art has no return.

Many of the irreversible damages are the consequence of global phenomena. Acid rains know no frontier, the pollution of oceans rapidly spreads everywhere, the cumulated production of carbon dioxide may lead to global climatic changes.

Energy is perhaps the sector whose relationships with environment create most problems. This is true for extreme and apparently opposite cases: from the large power stations or the myriad of motocars of the affluent nations to the cutting of firewood in the poorest areas of the world.

The energy needs of the world are continuously increasing. The growth is slow in industrial countries, where population is becoming stable (Fig. 1), where consumption is often saturated, and where increased efficiency in using energy may soon compensate whatever additional demand should appear. In the longer term, it is conceivable that energy use in the present industrial countries will slowly decrease, as the demand shifts towards less energy- and materials-intensive goods, towards services, towards quality rather than quantity.

However, the present level of energy consumption in these countries is much higher than the world average. With only one-quarter of the

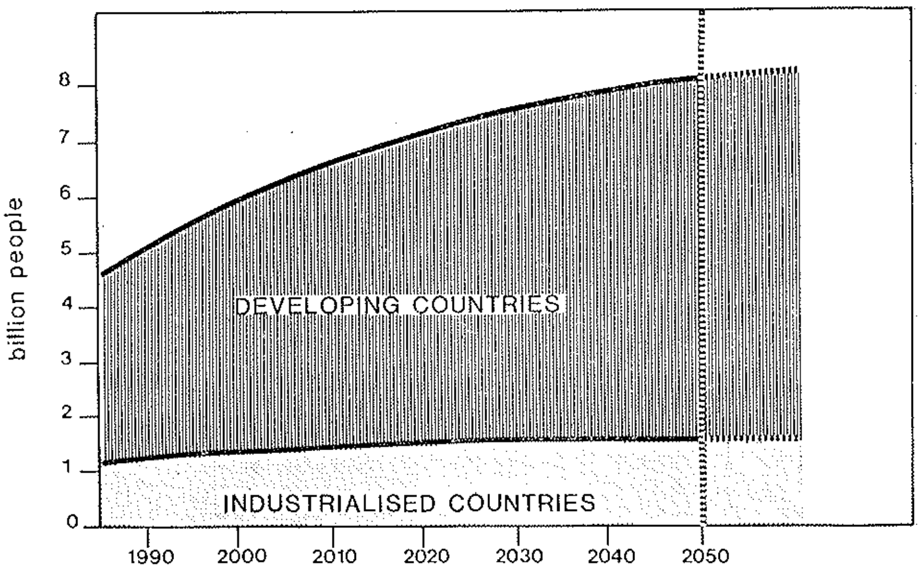


FIG. 1. World population data and forecast (billion people).

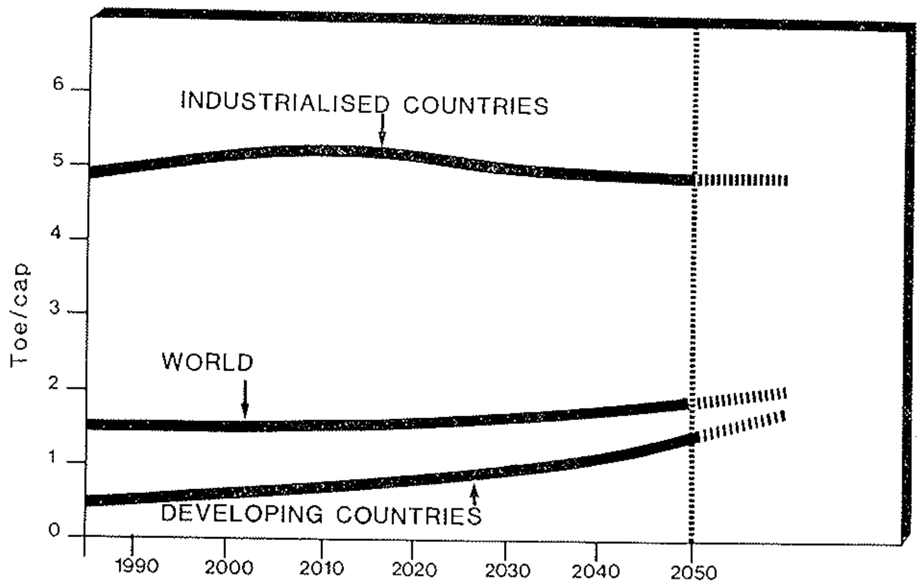


FIG. 2. Per capita energy consumption (Toe/cap).

population of the earth, industrial countries use nearly four-fifths of the (commercial) energy in the world, with a pro-capita energy consumption ten times as high as that of developing countries (Fig. 2).

The situation is going to change. Whatever less energy-intensive route to development will be followed by the less developed countries (and this is a sheer necessity), their pro capita consumption must increase substantially if a minimum acceptable standard of living has to be reached. With a population expected to double in the next 50 or 60 years, and with a pro capita consumption also bound to double, the present developing countries will acquire a determining weight in the way in which energy will be produced and consumed in the world by the middle of the next century (Fig. 3). The world of tomorrow will increasingly be a "Third World"; whatever we do to limit energy and materials consumption in industrial countries, we must face the needs of this new world.

This growing energy need is going to impose greater and greater burdens on the environment. Will it be able to stand such an increased pressure? Will a new and acceptable equilibrium be eventually reached? What shall we do to preserve or restore the essential qualities of environment?

2. *Environmental Effects and Risks*

The assessment and evaluation of the environmental effects of energy (as of other human activities) is complicated by two factors: our limited knowledge of the chain connecting energy production or utilization with its final effects on environment and man; and the probabilistic nature of many of these relationships.

Let us consider first the effects in "normal" conditions, i.e., in the absence of accidents. The first link of the chain may be the release of pollutants or other substances to the environment (Fig. 4). This first link is generally well understood: one knows with good approximation, for instance, how much sulfur dioxide is released in the combustion of a certain coal in a given power plant, or how much of nitrogen oxides can we expect to be emitted from the current mix of automobiles in a crowded street at rush hour (Fig. 5).

The following link of the chain is much less deterministic and much less understood. What is the fate, for instance, of the released pollutants? They may remain in the neighbourhood, creating dangerous local concentrations, or they may be dispersed by a strong wind (which of these will happen depends on random variables). Further, the emitted substances will react with other substances present in the atmosphere (or in the water, or in the soil) forming new substances, which will be transported by diffusion and convection, which may react again and finally be

	Historical data		Projections	
	1973	1986	2000	2035
OECD Countries	3,669	3,771	4,190	4,500
(electricity penetration)	(26%)	(34%)	(41%)	(47%)
Centrally planned countries	1,274	1,997	2,670	3,500
(electricity penetration)	(21%)	(23%)	(29%)	(35%)
Developing countries	970	1,821	2,930	6,000
(electricity penetration)	(14%)	(20%)	(28%)	(31%)
Total world	5,913	7,589	9,790	14,000
(electricity penetration)	(23%)	(28%)	(33%)	(37%)

FIG. 3. Primary energy requirements in main geopolitical areas (million toe).

	Sulfur oxides	Nitrogen oxides	Suspended particles	Carbon monoxide	Volatile organic compounds
Agriculture and fishery	28,600	70,000	26,600	148,000	38,600
Transports	115,000	942,000	203,000	4920,000	629,000
Industry	483,000	125,000	43,300	86,000	6,080
Residential and commercial	242,000	71,100	46,100	246,000	42,200
Power plants	1190,000	295,000	81,400	24,300	6,260
Other minor sources	174,000	30,900	12,100	1,450	1,960

FIG. 4. Italy-estimated major air pollutants emissions by the various sectors in the combustion process in 1984 (in metric tons).

	Sulfur oxides	Nitrogen oxides	Suspended particles	Carbon monoxide	Volatile organic compounds
Biomass fuel	542	8,970	43,000	261,000	34,100
Coal	179,000	109,000	9,050	10,000	1,910
Natural gas	292	107,000	1,440	19,200	7,060
Gasoline	6,400	498,000	21,300	4470,000	379,000
Diesel oil	240,000	497,000	214,000	578,000	253,000
Fuel oil	1740,000	220,000	118,000	17,900	4,030

FIG. 5. Italy-estimated major air pollutants emissions by different fuels in the combustion process in 1984 (in metric tons).

deposited or absorbed in one form or another. The mechanisms are often fairly complex, and our understanding of them is limited. It is generally possible, however, to measure and monitor the presence of polluting substances in the environment, even if the connection with their emission (or the emission of their precursors) is not always easy.

The final link is the most uncertain. How will the presence of a certain pollutant affect the health of humans or of other living beings? Will the increase of greenhouse gases in the atmosphere lead to a global change in climate, at what concentration, and what will this change be like? In the best of cases, we are able to give a probabilistic answer. The effects of radiation and radioactive substances are among those which are best understood in statistical terms. In other cases, we are able to indicate ranges of impact inside which the effects should be expected. In other cases still we can just acknowledge our ignorance, and work to improve our knowledge.

All that we have mentioned so far concerns the normal conditions. When we consider accidental conditions, probability is at home by definition. One would never accept an accident as inevitable, even if statistics of frequent accidents seem to disprove him (it is unfortunately possible to predict with appalling accuracy the number of casualties of traffic accidents on a sunny weekend).

The energy cycle is confronted with a number and a diversity of possible accidents with highly variable probabilities and greatly different consequences on environment and on health. They range from the spill of oil in a river or at sea to the hreakdown of a dam or the melting of the core of a nuclear reactor.

The existence of probabilistic factors and of areas of insufficient knowledge and uncertainties create special problems both as concerns the assessment of various options in energy policies and in the area of public acceptance. These problems will be addressed in another section of this paper.

We shall now consider a number of effects of energy production and utilization on the environment that are of a global nature. Although localized effects can be very important, they may more easily be dealt with in the frame of existing institutions, while global environmental problems need consideration of new approaches and possibly new institutions. Moreover, it is among global problems that irreversible effects on the environment are to be found: and this is certainly the area that requires most attention.

3. *Energy and the Global Climate*

The notion that human activity may change the Earth's climate on a global scale is not new. For instance, a group of experts from various fields chaired by Margaret Mead was appointed by the U.S. Government over ten years ago to study this very problem. It is only more recently, however, that this has become an issue of public debate.

The most important mechanism by which human activities can have an impact on the global climate is the greenhouse effect. Carbon dioxide (CO_2) as well as other "greenhouse gases" are transparent to visible radiation and opaque to infrared radiation; they therefore trap solar energy and tend to increase the average temperature of the atmosphere.

The use of increasing quantities of fossil fuels (coal, oil and natural gas), as well as deforestation, are the main cause of increase of CO_2 concentration in the atmosphere (Fig. 6). The quantity of CO_2 discharged every year in the atmosphere as a consequence of energy production from fossil fuels at the present rate is evaluated at about 20 billion tons. Energy production and utilization contribute to the build-up of other greenhouse gases (such as hydrocarbons and fluoro-chloro-hydrocarbons), which are also generated by other industrial and agricultural activities.

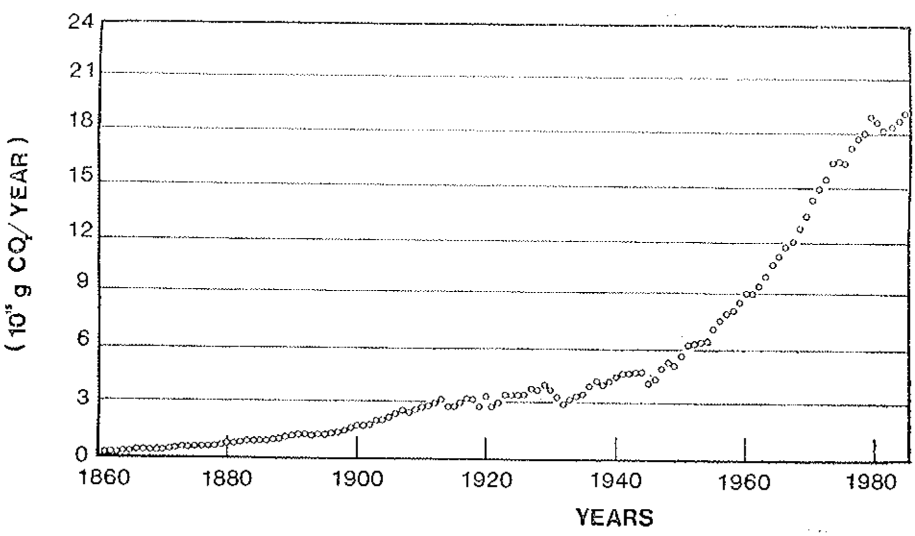


FIG. 6. CO_2 emission by fossil fuels: 1860-1985.

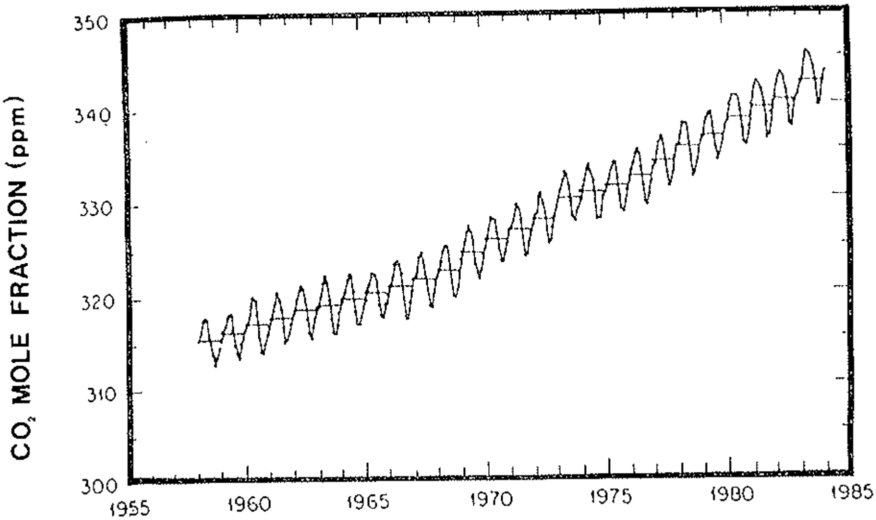


FIG. 7. Atmospheric carbon dioxide concentration.

The steady increase of CO_2 in the atmosphere has been accurately measured, from the 280 part per million (ppm) at the beginning of this century to about 350 ppm today. On present trends, this concentration is expected to reach a value of 560 (double the initial value) sometime before the middle of the next century (Fig. 7).

It is not easy to predict the increase of the average temperature of the earth due to the presence of such amounts of carbon dioxide. The temperature increase during this century that can be attributed to the greenhouse effect has been evaluated as about half a degree centigrade; the increases in average temperature predicted for the next 100 years vary from 1.5 to 4.5 degrees.

It is still more difficult to predict what consequences may derive from the increases in temperature, both directly and through global climate changes. The higher probability of exceptional sequences of hot days could be more important for agriculture than variations in average temperatures, according to recent studies. This could have major negative effects on the agriculture of temperate zones, while the effects on other areas remain largely to be seen. Another important consequence of the increase in average temperature would be the sea level rise, due both to thermal expansion of sea water and to a partial thaw of the polar ice caps.

The amount of such rise in the next century could range, according to the various hypotheses, from 25 to 140 cm. The lowest figure would have limited consequences, while the higher values would be disastrous for coastal settlements and for low-level agricultural areas.

Much more uncertain but of greater impact would be the consequences of global climatic changes. The global climate derives from a series of interactions between temperatures of continental masses and of oceans, wind, currents, clouds, precipitations and solar irradiation, interactions that are extremely complex and that only today start being understood and simulated by means of computer models which are extremely complex and expensive, but still relatively crude with respect to physical reality (Fig. 8). The global climate is a complex equilibrium situation resulting from these interactions that has a small margin of stability, which could be overcome by modest changes in global temperature. In the past, radical changes (like glaciations) can be attributed to small changes of temperature. The prediction of an instability and its consequences in terms of new global and regional climates is extremely difficult and highly controversial.

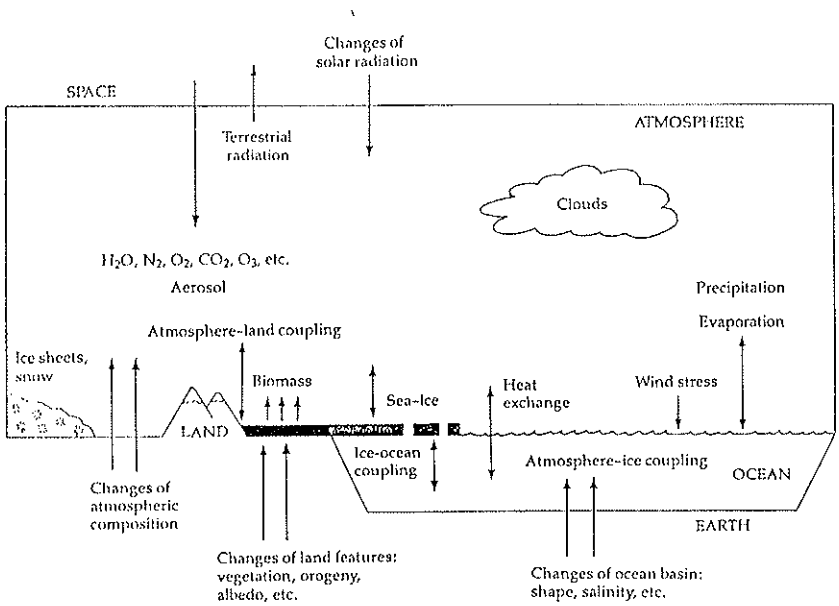


FIG. 8. The components and processes affecting the global climate system. Black arrows represent external processes; gray arrows represent internal processes.

The case of the greenhouse effect has been discussed here in some detail because it is one of the most striking examples of the difficulties met by environmental policies. The uncertainties in the prediction of the evolution of the phenomena, of their consequences but also of their causes, make decisions in this respect a terrible responsibility and burden. Imposing limits on the use of fossil fuels (as advocated by some environmentalists) could create limitations on economic development of both industrial and developing countries; at the same time, from what we know now, it may not be necessary or it might not be sufficient. On the other hand, the prevailing attitude of doing nothing until more information and greater understanding are available, could delay action until the effects become irreversible. International efforts to collect data, understand the nature and predict the evolution of this potential threat are already in progress, especially through the collaboration of ICSU (the International Council of Scientific Unions) and WMO (the World Meteorological Organization). The global nature of this risk and the worldwide distribution of its causes will also require a concerted action at the international level that has little precedents, if any, in order to take the steps necessary to avoid, delay or limit the most negative consequences.

4. *Energy, Deforestation and Desertification*

Other examples of global environmental effects of energy concern forests and woods through two entirely different mechanisms: acid rains in industrial countries, forest depletion and desertification as a consequence of increasing use of fuelwood in developing countries.

A devastating and complex disease of trees (the so-called "Waldsterben") has been present for over two decades in central and eastern Europe (and more recently in other areas), but it was identified as a common phenomenon only a few years ago, when its diffusion could no longer elude attention. It has since then become one of the major concerns of environmentalists.

There is a wide scientific consensus that an important role in these degradations is played by atmospheric pollution produced by combustion processes and by some industrial processes. On the other hand, there is no general consensus on the identification of the specific primary causes, of the most noxious pollutants, or of the damage mechanisms. Acid precipitations certainly contribute to the phenomenon, but there may also be other causes. Ozone, ammonia derivatives, biological stresses and ionizing radiations have been indicated in different circumstances as possibly affecting the diseased trees. However, the hypotheses that are most credited today are connected with atmospheric pollutants, such as sulfur dioxide, nitrogen oxides, hydrocarbons and heavy metals, that derive mostly from the use of fossil fuels.

A general reduction of the emission of these pollutants is possible, and it is being pursued in industrial countries. Such a reduction is anyhow beneficial in terms of public health, of conservation of monuments, of protection of internal waters, etc. It is by no means an easy and cheap endeavour; for instance, a programme of reduction of sulfur dioxide from coal burning power plants of the United States alone has been evaluated to cost about 10 billion dollars.

At the other end of the consumer spectrum, wood is the main energy source for less developed countries. Statistics are not easy, since wood is consumed mostly outside the commercial channels; but it is estimated that in many poor countries fuelwood accounts for as much as 80 or 90% of total energy consumption. The depletion of forests and woods not only creates global problems for the environment, but endangers the survival of the populations since it becomes increasingly difficult and time-consuming for the member or members of each household (generally women and children), responsible for collecting the wood, to put together the daily quantity needed for cooking.

Fuelwood collection is not the main cause of the disappearance of tropical forests. Where such forests still exist, it is easy to see that their consumption for energy purposes would not by itself seriously menace their survival. The quest for new agricultural land is the main reason behind deforestation, followed by inordinate exploitation for high-valued timber for export. However, fuelwood collection comes into to play in the following phase, when the greatest part of the tropical forest has disappeared, or was not present to start with. The sparse (and scarce) remaining wood is collected for energy use at an alarming rate, producing irreversible effects that lead eventually to desertification. This is most easily observed in areas confining with deserts, like in the Sahel region, where desert expands as soon as sand dunes are no longer blocked by tree lines.

The way out of this situation is theoretically simple. The action with more immediate results would be to improve the efficiency of wood-stoves, which today is very low (sometimes as little as 5% of the energy produced by the burning of wood is actually used). This improvement could by itself stop further depletion of resources. Another course of action is reforestation, which should include plants specifically intended for energy use; and, the final one should replace some of the wood-burning with other sources of energy (as in the case of solar stoves). Actually a number of obstacles make this route extremely difficult to follow. Not only the procurement of the large investments needed is difficult, but there are also obstacles of a non-economic nature, connected with local social and cultural conditions, and with the multiple interactions of such a programme with established ways of life, which are very difficult to modify in a society that is at the limit of subsistence and survival. This remains, however, a first priority both in supporting development and in protecting the global environment.

5. *The Problem of Nuclear Wastes*

Another important problem of the interaction between energy and environment, susceptible of having long-term consequences, concerns nuclear wastes deriving mainly from the operation of nuclear reactors. The fuel elements discharged from a nuclear plant, once they have been used to produce energy, contain highly radioactive substances (the fission products) which present complex disposal problems.

These fuel elements also contain residual nuclear fuel (uranium and plutonium) that has an important energy value and therefore an economic potential as well.

After a cooling period in temporary storage (from two to more than fifty years), the fuel elements, after appropriate conditioning, may be disposed of (renouncing to exploit the value of the fuel still contained in them); or they can be reprocessed, chemically separating the fission products from uranium and plutonium. The fission products are incorporated into a vitreous matrix, and are thus ready for final disposal or further storage; while the fissile materials can be used to fabricate new fuel elements. Reprocessing is considered the standard procedure by France, the United Kingdom, Japan and Germany, while most other countries (including the United States and Italy) are still waiting for a final decision. This deferral is possible, since the solution of storing spent fuel elements for extended periods without carrying out either reprocessing or final disposal is feasible with limited costs and negligible environmental risks. It seems therefore reasonable to postpone to a much later time a decision on the route to be followed.

Adequate solutions have already been identified both for the disposal of unprocessed fuel elements (studies in this direction have been carried out in particular in the USA, in Canada, in Sweden and in Germany) and for vitrified fission products as well as for the synthetic rock (Synrock process developed in Australia).

After a few hundred years, the radioactivity of fission products practically disappears. What radioactivity remains is connected with the content of the waste in terms of transuranium elements (plutonium, americium and curium), which take many thousands of years to decay. Where this content is high (as in the case of unprocessed fuel elements), it is considered necessary to assure a secure segregation of the waste from the biosphere for times of the order of 100,000 years. Present reprocessing plants separate the greatest fraction of plutonium from the fission products; however, the remaining part (about 0.5%) remains in the vitrified wastes. Even this small quantity imposes long confinement times for the waste. Improved reprocessing is possible and is being investigated. In that case, confinement time could be reduced to a few hundred years for the fission products, but it is necessary to find a destination for fissionable materials. They can be used in fast neutron reactors, that burn the majority of them to fission products. For the final disposal of what eventually remains, various solutions have been proposed, but none is yet at a testing stage.

In summary, ways to dispose of nuclear wastes have been studied and are still being studied in most industrial countries and in some developing countries as well. Geological factors, such as depth, stability and impermeability of underground formations can be used to insure very long confinement times. Although actual disposal experiments for high-level wastes have so far not been conducted, there is plenty of geological evidence supporting the assumptions in these studies. The Oklo phenomenon (a series of natural chain reactions in uranium deposits occurred nearly two billion years ago in Gabon) provided a natural laboratory yielding detailed and valuable information on geological deposits. There is no hurry to make a decision on the final fate of nuclear wastes: temporary storage may be extended as long as needed and it might even become the long-term solution without excessive penalties.

Despite all these comforting considerations, the problem of nuclear wastes remains a major obstacle to social acceptance of nuclear energy. The reasons for this opposition relate to a form of fundamentalism which must be taken into consideration. Fission products and transuranium elements are nuclides which do not exist in nature and that are created by human activities. A simple comparison with natural radioactive elements could not be accepted as satisfactory. The long decay times involved point to the existence of dangerous concentrations of radioactivity in some parts, however remote end protected, of the earth's crust that would subsist for the time of many human generations. Our predictions on the long-term stability of geological formations are based on knowledge which could be incomplete or incorrect, even if a specific mechanism through which radioactive wastes could enter the biosphere is not identified. The artificial nature of these wastes, their novelty, their persistence in time are sufficient to create preoccupations that are so much more difficult to dispel as they are general and based on what is not known or is not conceived rather than on what is known and can be predicted.

Of course similar worries could be (and probably will be) extended to the fate of artificial chemical substances, which are stable in time and highly toxic, and the disposal of which, far from having been solved, has not even been studied. Such inconveniences, however, have to be assessed against the long-term socio-economic benefits deriving from the use of nuclear energy and chemicals.

6. *Nuclear Energy and the Problem of Social Acceptability*

Nuclear energy represents an extreme case as concerns the assessment of risks, and this has important consequences on public perception and acceptability.

In normal operating conditions, nuclear energy is probably the most environmentally friendly form of energy. Pollution of the environment is extremely small and well controlled. The problems arise from the consideration of possible accidents, and particularly of very serious accidents that may have large consequences. Such consequences, as the Chernobyl accident has shown, are not limited to the vicinity of the power station, but involve large areas, often across national boundaries, and may even be of a global nature.

Accidents of this kind have a very low probability. In the past, the assessment of their impact has been based on a probabilistic approach that considered the product of the probability of occurrence of a certain accident by the measure of the consequences of this accident (for instance in terms of casualties) as an indication of risk.

Following this approach, nuclear energy ranks as one of the safest forms of energy. It is true that serious accidents are possible, but such accidents are considered to have an extremely low probability.

This approach is now being challenged for two different reasons.

The first reason, which is somehow "internal" to the approach itself, is that the way in which probabilities are evaluated is questioned. In the traditional way of assessing the probability of serious nuclear accidents, the emphasis was on determining the combined probability of failure of various parts of the plant (components, monitoring, control) that could originate such an accident. The operator was supposed not to interact with the system, even when a simple action on his part would have avoided the accident. The probability evaluated in this way is extremely low, because nuclear plants are protected by a redundancy of systems, and the quality of each of the relevant components is carefully assured, so as to make their failure a very rare event.

The Chernobyl accident, and before it the Three Mile Island event (which in itself produced no appreciable damage to man or environment) proved this approach inadequate. These events have directed the attention towards the human factors, and the role of operators in particular. Human intervention, even when meant to improve operation and safety, may in exceptional cases have the opposite effect. Due to the high complexity of the nuclear plant and the interconnected effects of different physical phenomena and automatic system reactions, the exact nature of what is happening may well escape even a well trained operator. A misinterpretation of what is going on can then induce the operator to undertake actions that, instead of mitigating, aggravate the consequences or even are the causes of a serious accident.

The second challenge to this approach is even more fundamental. The product of probability and consequences simply does not represent a measure of risk that corresponds to public perception, especially when the probability is very low and the consequences are very high.

A number of sociological studies have stressed this point and have given indications of the factors influencing public perception and therefore social acceptability of various forms of energy and other human activities (Fig. 9).

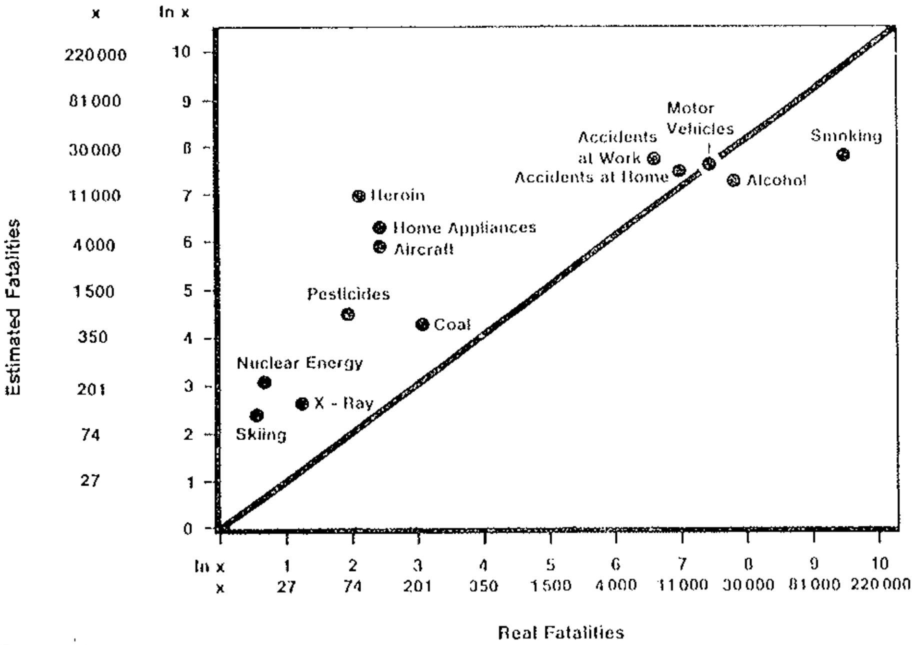
Very small prohabilities escape direct experience. It can hardly be expected that the public discriminate between events which have a probability of, say 10^{-6} per year and those with a probability of 10^{-4}. As long as a zero probability is not assigned to an event by stating flatly that it is "impossible" (a solution that is not acceptable to concerned scientists even if probabilities are extremely low) people perceive this event as "possible" and they look at the consequences of this event rather than at the probability of occurrence. It is therefore much more important, from the point of view of public concern, to reduce the magnitude of the maximum conceivable accident rather than reducing the probabilities for it to happen. This represents a possible turn in nuclear technologies, which up to now have been directed in a more or less balanced way towards the two factors. The exploration of concepts of "intrinsically safe reactors" which are now receiving increasing attention in many countries is essentially based on this consideration, although it is still doubtful whether it is really possible to rule out entirely the possibility of a major accident in a nuclear reactor.

Many other factors have been found to deeply influence the perception of risk by the public opinion and therefore social acceptance (Fig. 10). In particular, risks which have been present for a long time (such as those deriving from tobacco smoking or road accidents) are much more easily accepted than smaller new risks. Observable risks are less feared than hidden risks. If there is a voluntary component in taking the risk (as when riding an automobile) this is considered more acceptable than where the subject has no control. Other factors that negatively influence the perception of risk are delayed effects rather than immediate concentration of

Attribute	Score of zero implies technology has these properties	Score of 100 implies technology has these properties
Unknown risk	Voluntary	Involuntary
	Observable	Not Observable
	Known to exposed	Unknown to exposed
	Effect immediate	Effect delayed
	Old	New
	Known to science	Unknown to science
	Controllable	Uncontrollable
Dread risk	Consequence not fatal	Consequences fatal
	Equitable	Not equitable
	Individual	Catastrophic
	Low future risk	High future risk
	Easily reduced	Not easily reduced
	Decreasing	Increasing
	Doesn't affect me	Affects me

Source: Slovic, Fischhoff and Lichtenstein (1980).

FIG. 9. The components of attributes, unknown risk and dread risk.



Source: Renn and Swaton (1984).

FIG. 10. Perceived fatality frequency compared with actual fatality frequency.

effects (one large accident instead of many small ones with the same total consequences), the possibility that children are among the victims, etc.

As a consequence, perceived risks or "subjective" risks differ markedly from observed or "objective" risks. In particular, it can be noted that almost all of the factors we have mentioned tend to increase the perceived risk of nuclear power as compared to other forms of energy.

This situation raises difficult problems in establishing energy (and other) policies. If these policies follow acritically public opinion and social acceptance, the consequences in terms of environment and public health will be negative. On the other hand, a policy based entirely on objective consideration would deny the right of citizens to rank the type of risk they are ready to run according to their personal preference. A delicate balance has to be struck, and a wide circulation and discussion of unbiased information is the basis for such a balance (Fig. 11).

Rank		Economic	Technological	Societal	Conserving
Best	1	Nuclear	Conservation	Conservation	Conservation
	2	Hydro	Hydro	Small wind	Hydro
	3	Conservation	Nuclear	Hydro	Small wind
	4	Large wind	Small wind	Large wind	Coal
	5	Small wind	Large wind	Coal	Nuclear
Worst	6	Coal	Coal	Nuclear	Large wind

Note: Ranking of the risk from six technologies based upon combining the risk attribute scores for each technology with the appropriate weights for each special interest group.

Source: Evans and Hope (1984).

FIG. 11. Ranking the risk from six technologies.

7. *Conclusions*

The considerations made so far point to a number of important and difficult responsibilities that scientists, technologists and politicians have to face when preparing or taking decisions, or giving advice, on energy policies.

The first responsibility is towards future generations. We must not transmit to them a world degraded in its environment, impoverished in its biological and cultural richness, depleted in its available resources. We must strive to give them in heritage the best opportunities to improve the quality of their lives according to what will be their scale of values, which may differ from the present one.

The second responsibility is of the rich towards the poor, be it at the level of countries or of sections of a society. The use of non-renewable resources and the depletion of the environment must not be such as to make development or social progress more difficult or impossible.

The third responsibility is towards the general public, which must receive the maximum of unbiased information and whose preferences and feelings must be duly considered when making decisions that will affect them.

DISCUSSION

KECKES

Professor Farinelli started his interesting presentation by suggesting that he needs the darkness so that people can sleep better, but I think his opening remark has awakened me, even if I had tried to sleep, because, if I understood correctly, and I think that I did, in the first line of his speech that was distributed here, it states that the environment is the real limiting factor to development and I would like to take issue with that.

It may be the limiting factor for development, if development is equated with energy consumption in terms of kilowatts per person. Sure enough. Second, it could be tbe limiting factor if we assume that our energy sources or the generation of energy will not undergo serious development but will basically remain structurally the same as it is today. I think that both of these assumptions are probably not correct and Professor Farinelli himself said that today mankind has succeeded to replace raw materials, so I believe that mankind has, is resourceful enough, to replace the present sources of energy with environmentally more friendly resources. That's the first thing, and secondly, we could find a more energy-efficient way of living than we have today. I am not referring to the simple conservation measures that have been applied in the recent past. I wouldn't like to dwell on this too long, but, as I say, I feel strongly that development cannot be defined in such simplistic terms, and particularly in countries which are probably not the nucleus of what we call the Western world, but are a large part of this globe and constitute a large part of mankind. It's seeing development not in such simple terms but in terms of social progress; it is providing a more satisfying lifestyle for people.

Now, in this context I would strongly suggest that environment is not the limiting factor on development, but, on the contrary, disregard for the environment is the ultimate limiting factor for development.

FARINELLI

Our worry, as expressed in my paper, has to do with the time scale. We can very well conceive of a world, maybe 200 years from now, with very low energy consumption, very friendly energy sources, very low material consumption, and so forth. The problem is how to get from here to there. While industrial countries could follow a route of decreasing energy consumption and early introduction of more environmentally friendly energy sources, this is not realistically possible for developing countries. With the pro capita consumption one-tenth of the present industrial society, it is extremely difficult to think of any development route without a substantial increase in energy availability. It must also be mentioned that energy efficiency in developing countries today is much lower than in industrial countries, because it is much more difficult to use energy efficiently when you don't have the appropriate technological and institutional background. One has to change the institutional, social and economic conditions before one is able to adopt a really energy-saving model. Of course, one should not follow the same route as the present industrial countries, and this is accounted for by assuming one-fifth of the present industrial consumption for the development of less developed countries. One-fifth is a small percentage of what we use today to allow for development, and even in that case pro capita energy consumption would go up a factor of 2. And what new sources will be available in the next 30 or 40 years? Very, very few. Fusion will not be available. Renewables will be available but will still be very expensive for some time to come, and it's difficult to conceive of development based on expensive sources of energy, however good they may be. Fossil fuels remain the basic option for the next 30 or 40 years, at least for developing countries. It is the transition which is difficult rather than the final objective.

RAVERA

I have three considerations about your presentation. One is different protection for human beings and for plants and animals. The human being is protected at the individual level and at the population level; animals and plants are protected only by populations and at community level. The other thing is the calculation of risk on the causes of death. It seems to me that these criteria are always doubtful, because it's very difficult to compare the deaths caused by accident, for instance, and those by coal, by smoke and radioactivity. For accidents, there are data, but, for instance, about radioactivity, there is a very large variability of the criteria used to calculate the number of deceased in the United States or in Europe and so on, because there are no statistics, no real statistics. For coal, it's very difficult to assume what may be the number of deaths. For alcohol and smoking, it's very doubtful because more causes combine to cause death.

Another factor is the judgement of the safety level in chemical accidents and radioactive accidents. The level of security of protection against a chemical accident or a radioactive accident is very different — exaggerated in my opinion for radioactive, too indulgent maybe for chemical accidents.

FARINELLI

I agree with what you say. I only have a comment on the calculation of accidents versus other causes of death. Of course there is a lot of uncertainty, but my plot had a double logarithmic scale and these uncertainties tend to disappear.

DE GIORGI

We have been talking about people's understanding of risks. I believe that an important part of this understanding is the greater or less trust that people, on a national or international level, have regarding the reliability of their government. Reliability means, specifically, the capability and the willingness to provide clear, timely and correct information, the ability and willingness to appoint for the most delicate duties persons who, by their technical preparation, character, and equilibrium are most qualified for these duties; and, finally, it means the ability and willingness to provide the people who have been assigned duties of great responsibility, with both the means in the best way to carry out their assignments and the freedom which a technician must have to express his opinions. It means, as well, a prompt reply of these same authorities to eventual requests for action and means which the experts appointed by these authorities regard as indispensable.

This involves the reliability of the Governments in various fields, e.g., regarding the peaceful use of nuclear energy, the reliability of the Government is an important component of public opinion.

Moreover, in this context the presence of independent scientific institutions, both national and international, should have more support and better coordination between them, in order to offer to the public true and acceptable information.

FARINELLI

Professor De Giorgi said that the perception of the public is conditioned very much by its trust in institutions, governments and governmental institutions, in particular, and in their capacity and will to supply the adequate and correct information in choosing the people, in giving to the people having responsibilities the means and the independence to act in the best way they consider advisable, for instance in emergencies.

It would be difficult in a short intervention to compare one government with another in terms of their reliability, but at least Professor De Giorgi wants to stress that scientific institutions, such as academies, universities and other scientific institutions have a role to play in this context, and they should have enough independence, enough means and sufficient organization to supply to the public and to the governments the unbiased information which is needed to help create a sound public opinion. I personally agree with these considerations.

CHAGAS

I would just add to what Professor De Giorgi said that there is some difficulty also with the media in stating the exact measure of the dangers to the environment of energy problems. I think this is quite clear and I have some examples which I could give in which the facts were completely distorted from the real scientific situation.

JEFFERS

I was stirred to speak again (I am sorry if I am speaking too much) by your comment about the media, but in my country it isn't just the media. For example, in the last two weeks some very distinguished people have made statements which are so obviously not true that one wonders why they permitted themselves to make them. For example, the Chairman of the Central Electricity Board made the statement on British television that the risk from all of the radiation from the British nuclear power industry, including reprocessing, was less than the effect of smoking one cigarette in one's lifetime. Now it's a very grand gesture and it's a grand statement to make, but it is blatantly not true. The Chairman of British Nuclear Fuels, who runs the Sellafield reprocessing plant which is only 40 miles from where I live, said on another programme, also on British television, that there was less danger from swimming for four hours in the sea in which Sellafield discharges its waste than sitting for one hour on a beach in Southern England. That also can't possibly be true. I know it isn't true because we happen to run a monitoring programme around the Sellafield reprocessing plant and we are appalled by the level of radioactivity, not merely from the discharge of waste into the Irish Sea but also from what is leaking out of the smokestack from Sellafield.

So, we have a real problem in the sense that these are obviously well-motivated people, at least well-motivated for their own industries, but if you question them, they say they were told this by their scientists and so they pass the responsibility back to the scientists who are advising them. I think it's this kind of desire to prove a point which distorts real scientific information, which is after all very complex.

The other difficulty I have for the whole of this question of radioactivity and radionuclei is that, when it's discussed at all, to simplify it for the public it's called radiation, but we're talking about radiation which is associated with specific chemicals and each of those chemicals has its distinct pathway through the environment, and the particular pathway it takes into man could be very different. One only need a very small piece of plutonium breathed into the lung to have an effect at some future time. The effect of cesium is quite different. It has a different pathway through the human body, a different biological half-life, a different physical half-life. So in the attempt to simplify it for the non-scientist, we have people — including scientists and the media and the people who are in responsible positions — making statements which scientifically are outrageous. What do we, as responsible scientists do about that? Particularly if you are working for a government research agency which then applies the Official Secrets Act to you and says, "Well you can't tell people too much because you are covered by the Official Secrets Act and these things that you know are not to be known except through us to the government."

So, I think we have a very real problem and it doesn't just emerge from something as emotive as nuclear energy. It includes acid rain, it includes chemical pesticides, it includes the whole range of possible pollutants into the environment, and somehow we have to get accurate scientific information about the very complex processes across to the public, the general public, and the media, which is largely non-scientifically oriented.

There remains a question which I have in my mind, if I may come back to the nuclear energy procedure. I have a slight criticism of Professor Farinelli's paper: I think that he does slightly sweep some of the problems of nuclear energy generation under a carpet. Somebody in Britain anyway, and I presume in the rest of the world, say 30 years ago, made an assumption that if you disperse limited amounts of radioactivity into the environment, it would remain dispersed. Now, even thirty years ago, it seems to me that the person who made that assumption was obviously a physicist, he certainly wasn't an ecologist, and even if thirty years ago you had asked an ecologist, he would have said, that is a very unlikely hypothesis. It seems to me that that hypothesis is still very much dominant in the minds of many people in the chemical and nuclear industries: that if you put some substance into our environment, in its dispersed form, that substance will remain dispersed. One of the things I think we have learnt over the last thirty years, if not before that, is that that seldom, if ever, happens and that all of these substances become concentrated, usually at the far end of the food chain, and sometimes at an unexpected point in the far end of the food chain, as in DDT which we only discovered by accident, frankly, that it was accumulating in birds, through the breakage of egg shells, only just in time to prevent a disastrous accumulation in man. Now, somehow it's that fundamental process that we need to get across, so that we can begin to apply it not merely to the things we have found out already, but to all sorts of other situations which we are creating at the present time.

GOLTERMAN

I live in France, although I am not French, but I have always been astonished by the social acceptability of nuclear energy in France, where 50 to 60% of our energy is being produced by nuclear energy. It is not an issue in the press. There is no daily newspaper that ever talks about it, it is just accepted. I think the point is that, at the moment, the people are afraid of a change. If we had coal in France, we would have been afraid of going to nuclear energy. Now we have nuclear energy, and we are afraid of going back to coal. The President of the EDF, the French corporation producing electricity, recently gave a short talk somewhere, stating that he was quite willing to go back to coal; he would love to produce more coal, but did the population realize that that would cause some 50,000 people to have silicosis, the disease of the lungs. That story appeared in all the newspapers. I think we see the same in the detergent industry. We have phosphate which we want to replace with NTA, but the populations are afraid of it. If we had NTA and we would propose to go to phosphate, we would have the same action groups in the street going against phosphate. I think that the problem is that technology is essential for our survivial, but, on the other hand, we are afraid of it, and that is a major problem with environmental issues.

FARINELLI

I have a couple of comments on both. I agree that many statements made even by distinguished people are wrong and known to be so. Of course, in my presentation, I was referring to what is the best available information provided by scientific knowledge. The concentration of pollutants in the food chain is well known and it is taken care of in serious assessments of nuclear energy and in other environmental impact assessments. That does not mean that it is always taken into account, but I was referring at least to the statements which are made in good faith and with good knowledge.

Concerning the observation made by Dr. Golterman, yes, I pointed out that the old is preferred to the new in many cases, and in France nuclear is in a way already old instead of new. But I also think that there is another factor in the acceptance by the French people, and it has to do with the point mentioned by Professor De Giorgi, and, that is, the French in general have a high trust in their government and institutions.

CHAGAS

Certainly you have heard about the dramatic event which occurred in Goiaina, in my country. This was — in my opinion — dramatized by the newspapers. In fact, many people wish to regard it as a new drama, considering it a nuclear explosion similar to that of Chernobyl. When the journalists asked my opinion on the accident (as you probably know I have been involved since 1956 in atomic radiation question, when I was a member and presided over a Committee for the study of radiation at the United Nations), I said that it was difficult to consider it a mere nuclear accident but rather that it was a very damaging and horrible human accident. They did not publish anything because they were convinced that what was important to the public was to make it much more serious, as many people were going to die. This accident was due to the incompetence of two medical doctors, who left this source abandoned for years, and the incompetence of our National Commission for Energy, which had not taken the measures to control what had happened to the source.

What I am saying is that sometimes it's very difficult to bring to the public the real information, because, in the case of nuclear energy, people have still the phantom, the horror of Hiroshima and Nagasaki in mind, and I think this is what makes everyone very much afraid of nuclear energy.

ETHICS OF THE USE OF NATURAL RESOURCES AND OF RESPECT OF THE ENVIRONMENT

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1. - The emergence of the demand for environmental ethics

In its continuous evolution mankind has developed up to the last thirty years practically ignoring the value and the cost of its environment.

At present, however, in the industrialized world and even in the emerging nations, evergrowing sectors of the public administration, of the scientific community, of the school, of the environmental movements and even of the international organizations have produced a demand for new scientific and ethic guidelines in the programming, management and control of the environment and of its natural and cultural resources. Some aspects of this cultural frame are of primary importance. In the last decades, there has been an increasing demand for goods and services in connection with the typical way of thinking of the consumer society, with the growth of human populations and with the economic theory of an unlimited growth uniquely oriented towards the quantitative aspects of development. At the same time, as a consequence of that demand, serious episodes of environmental deterioration — air, water and soil pollution, landslides, extinctions of species, and of active subordinate cultures, urban violence — have emerged.

Also in the South, the environment is endangered by the uncontrolled destruction of the forests, the need of new arable lands and the indiscriminate pillage of raw materials exported to the North. These facts, and others as well, have led more and more citizens to the rediscovery of the environment as a unitary reality, living, complex and fragile, in which every person is necessarily involved.

The members of the scientific community interested in the environment have become the persons announcing of the dangers that menace humanity as a consequence of the drastic modification of natural equilibria consequent to human activities. At the same time, some scholars have given impulse to ecological research and have elaborated some fundamental concepts: environmental systems, processes of the functioning of the environment, environmental equilibrium, carrying capacity, recycling, scientific basis of the management and conservation of the natural resources.

Thus, the demand for a new environmental ethics originates from a wide spectrum of dramatic experiences, and from a situation of uncertainty and uneasiness that characterizes at present the relationship between society, nature and human environment.

The interest in the subject of environmental ethics would not be so widespread if individuals and the society did not feel endangered and if the cultural transition, still under way, would not have led to a crisis of all the codes of ethical behavior.

On the other hand, environmental ethics is still today in search of its own identity, and it is not easily recognizable in our present socio-economic context. Consequently the figure of the scholar interested in the definition of the objectives and contents of environmental ethics becomes strategic. He must follow a path opposite to that of traditional ethics, in which behavioral norms were derived from abstract principles.

The context in which the demand for environmental ethics originates makes it imperative that we start from a scientific knowledge of nature as obtained from ecological research, and from an analysis of deeply mistaken ideologies and praxis in environmental management that have determined a widespread deterioration of environmental quality we must also consider the philosophical basis of the behavior of human populations towards the environment considered in its present social, political and economic dimensions.

In other words the elaboration of environmental ethics starts from the experience of a clear-cut type of relationship with the environment, and from the analysis of the basic cultural traits that have oriented it. Later, it will become the object of consideration and abstraction.

Our present paper will follow the above scheme.

Undoubtedly environmental ethics will gain further enrichment from a consideration of the contributions of theology, both from the Bible and other religions, mainly oriental religions, in view of the symbolism that these attribute to terrestrial realities.

2. - Some ideas for a reflection on the history of the relationships between man and his environment

The essence of an ethics for the environment finds its roots in the type of perception by the individual and by the society of the reality of the environment, and in the perception of it and of the degree of incorporation of nature in history.

The model of the ecological transition represents an effective conceptual frame of the temporal evolution of the relationship between human populations and the environment. This relationship coincides, to a large extent, with the historical evolution of mankind.

Historical research in ecology has singled out essentially three stages in the relationship between man and environment.

The first stage of ecological transition corresponds to the prehistorical period of hunters-gatherers. Primitive man perceived his environment as a living and unitary reality: like any other animal, he participated in natural events, he had a deep knowledge of trees, animal behavior and the rhythm of the seasonal cycles.

Nature had a strict control over human populations, which acted in relation with an environment that was largely deterministic.

The second stage of ecological transition is qualified by the transition from natural equilibrium to a state of disequilibrium between man and his environment, which became gradually deeper according to the means available to human populations for their "domination" of nature.

In this context two events had a strategic role:

— the invention of agriculture, in the Neolithic Age,

— the scientific, industrial and technological revolution of the Modern Age.

The relationship of arrogance of man towards nature began during the food crisis in the Mesolithic Age.

In order to answer the growing demand for food, space, energy and cultural tools, man was compelled to find ways for obliging nature to produce his food through agricultural practices and the domestication of animals.

As a consequence of settling there were born villages and cities, handicrafts, commerce, social, economic, political and religious life. The management of the environment by man produced some changes in natural environments, but did not alter the processes of the functioning of the environment.

Neolithic man and agricultural societies developed a global perception of the environment, as a system — active, complex and fragile — of interrelationships, which man felt himself a part and whose rhythms beat the tempo and determined the modes of man's activity.

The scientific revolution of the 17th century and the following industrial and technological revolutions represent the second event that had a profound effect upon the man-environment relationship. Although some of the choices made in these periods were certainly positive for the human environment, others were largely responsible for the increased gap between society and environment, a gap that reveals today all its dramatic aspects.

Its essential aspects are as follows:

— the loss, during the last thirty years, of the perception of the environment as a system — alive, fragile and complex — of interrelationships, and its reduction to a mere source of materials to be used for the project of economic growth restricted only to the attainment of quantity.

— the emergence of a dualism between man as an active subject and environment as a passive object;

— the development of politics oriented towards power and prestige rather than towards true promotion of environmental quality.

The third stage of ecological transition is that of the perspectives, i.e., of the scientific rediscovery of the environment, and of the emergence of a culture facilitating the transition from disequilibrium to equilibrium in the man-environment relationship.

In the 60s Lynn White, a sociologist of the Chicago School, proposed the term *ecological crisis* to indicate synthetically the grave deterioration of the relationship between human society and environment. In White's thought, and in our own belief, the term ecological crisis has a totally negative meaning.

Instead, the Greek root of the word "crisis" has the stimulating meaning of "*trying to see clearly, to discriminate*" in a situation of risk.

In a word, the correct perception of the crisis is a further step toward a more mature consciousness of the mistakes and the responsibilities of society for its environment and a powerful stimulus for the elaboration of a perspective capable of reestablishing the man-environment equilibrium, through the development of a new culture.

Our present ecological crisis, due to its seriousness, depth and the number of factors involved, is bound to mark a milestone in the history of mankind, as important as the starting of the process of civilization in the Neolithic Age.

This interpretation, both critical and explorative, of the difficult man/environment relation, has started a reflection upon two points of basic importance:

— the cultural rediscovery of the reality of the environment;

— the singling out of the two historical roots of the ecological crisis, i.e., methodological-scientific reductionism, and the doctrine and praxis of the ruling/exploitation of man over his natural and human environment.

3. - The basis of a new environmental culture: from methodological/scientific reductionism to the systemic culture of the environment

The roots of the crisis in the relations between human society and environment lie in the emergence during the two last centuries of a scientific and methodological approach largely insufficient for the analysis, programming, management and government of the environment.

As a consequence of the scientific revolution of the 17th century and of the introduction of the experimental method, the structures to be studied have been subdivided into their components, and each of them has been analyzed separately and regarded as an autonomous entity. Gradually single specialized disciplines developed cultural, scientific, technological and humanistic areas, each of which corresponded to a single research field, and rigidly distinct from the others.

The same methodology has been applied to the study of environmental science. Undoubtedly the scientific method, through the organization of knowledge into disciplines, contributed in a determinant way to the development of knowledge, to technological and industrial development and to the improvement of many aspects of human life. However, along with these positive results, have come many devastating effects, mainly with respect to the environment, that depend less on the scientific method itself, than on a positivistic interpretation of it. In fact, by limiting science to single factors, scientists have failed to perceive the system of interrelationships existing, for example, in a lake or a forest, between the plant and animal species and the micro-organisms that form the food chains and the food web.

Each living organism (cell, person, community, lake, town) is not actually the sum of the single components that form its structure, but emerges from the system of the relationships that develop in time and space between these components and these factors.

The loss of the systemic concept of the environment, and its reduction to the simple sum of its factors and processes, have had negative consequences and may be considered one of the major causes of the crisis of the relationships between human populations and their environment. In effect, no effect had been perceived as long as natural regulation systems were able to buffer mistreatment imposed on them by human mismanagement.

However, when the development of the consumer society, the increase in the demand for environmental goods, and the demographic explosion overcame the capacity of natural homeostatic mechanisms and of cultural adaptation, then there appeared consequences that nobody desired, but that determined a deterioration of the quality of the environment and of its resources.

This culture, impregnated with scientific and methodological reductionism, has deeply permeated all human activities, from the planning of land use to political life, from the action of public administrations and productive systems to the educational systems.

Essentially as a consequence of the action of environmentalist movements, this situation has led to a rediscovery of the reality of the environment. An overwhelming demand for knowledge, methods and techniques has emerged. In the scientific community the answer has been the development of ecology, the science that deals with the processes of the functioning of the environment and with systems analyzed in their spatial and temporal dimension, both in their normal and altered conditions.

Modern ecology proposes today some important principles of the functioning of nature as a basis for environmental ethics:

— The environment of each living form — cell, individual, forest or town — originates from the system of interrelationships between the components, the factors and the processes that form its structure.

— After the appearance of life on earth, there began a close interaction between the living organisms and the systems of conditions characterizing their abiotic environment: the organisms modify their own environment, and the modified environment, in turn, compels the organisms to adapt in order that they may survive and reproduce.

— No living organism can realize itself in isolation. It can do so only through a continued confrontation and interaction with the "system of conditions" present in the environment. Consequently, each organism and its own environment form a functional unit.

— Life in time becomes structured in organizational levels of increasing complexity — macromolecules, cells, individuals, populations, communities of populations, ecosystems, biomes and biosphere.

— Each level of life, from macromolecules to the biosphere, has an internal and an external environment, and a structure, a function and a history.

— In a given environment the quality of life depends on the quality/quantity of the interrelations between its components and factors.

In order that we may solve our present conflict between persons, society, natural and human environments, it is imperative that we make a strategic ethical choice for respecting the "relationships" in nature, for reconstructing them, if they have collapsed (the pedagogic value of the continued use of the interdisciplinary methodology becomes clear at this point), and for the continuous and tenacious building of relationships within human society.

4. - The anthropological basis for a new enviromental ethics: from an existential attitude of domination/exploitation to the awareness toward the reality of the environment, to a wise administration of natural and cultural resources

The appearance of man on earth has enriched the environment on earth. Man is not apart from his physical, chemical and biological environment or the processes that ensure and characterize the functioning of the environment. However, by attaining the consciousness of his own personal reality and of the dynamics of environmental processes, he has emerged gradually from the natural environment. In organizing his relationship with the environment, man has been able to overcome largely deterministic limitation (typical of plants, animals and microorganisms), and has developed a conscious behavior.

Naturally, *consciousness* does not place man out of and above the natural order (man, in fact, belongs to the food chain and to the food web of his environment), but makes him *responsible for a correct management of the environment*. This is one of the basic starting points of environmental ethics.

The term "culture" indicates the distinct complex of beliefs, tools, artistic, ethical, social, political and religious expressions through which a person who lives within a group and the group itself enter in contact with their own environment and confer a form and an identity to it.

Man's environmental system has its own structure, functioning and history, and originates from the continuous interaction between the natural environment, the biological reality of human populations, and their cultural expressions (social, economic, ethical, scientific, political and religious).

Man's environment differs from the natural environment, because of the way, intentional or conscious, by which mankind manages environmental processes. From a functional point of view and in their spatial and temporal dimension, these processes are essentially similar, in the natural and in the human environment. Therefore, if life is a unitary phenomenon, the same holds true for the environment in its dynamic reality. The difference between human and natural environments lies in the medium in which the processes occur (water, air, soils and the various kinds of living forms) and in the modes of management.

It is wrong, from a scientific point of view, to affirm (as many still do) that *in nature all is harmony*, equilibrium and order and that all the evils of the environment should be attributed to man.

In the course of geological eras, terrible dramas have upset our planet and have led to the extinction of a wide spectrum of floras and faunas. In addition, the quality of natural environments derives essentially from the process of predation, on which the food chains and consequently the biogeochemical cycles, the flux of energy and the homeostatic processes are based.

Instead, the presence of man is related to many aspects that are not exclusively confined to the deterministic mechanisms of a purely instinctive behavior: art, poetry, music, social and economic organization of the communities, participation in the joy and sorrow of other people, politics, altruistic behavior, struggle against all those factors (cold, plagues, famines, etc.) that have decimated the human populations for centuries, and the attention for emergent civilizations. All these aspects are part of progress, a process that, compared with the natural environmental processes, has added new wealth of expression to the human environment so that it can be said that the human environment is, at least potentially, richer than the natural one, since the former comprises the latter.

It is also true that mankind, at its appearance in history, has developed, at least in the western world, a process of incorporation of nature into a human project directed at the management of reality that has often been, and still is, strongly conflictual.

Finally, man carries upon himself the responsibility of using his distinctive consciousness for the promotion or for the destruction of the quality of the human and natural environment in which he lives.

Man's behavior toward the environment is best described by the term *ambiguity*. However, the connotation of the word suggests forceful inclination toward projection and a stimulus to act for the promotion of a conscious behavior toward natural and human environments.

The analysis of the historical roots of the crisis in the relations between man and his environment cannot be complete unless we mention the interpretation of the ecological crisis put forward in the 60s by the American sociologist Lynn White, an interpretation that often recurs in the expressions of Environmentalist Movements and mass media.

According to Lynn White, the cultural matrix of the erroneous attitude of man toward his environment has a religious foundation, and derives from:

— Hebrew-Christian anthropology, in which man is considered superior to all other things which are created for his own use and happiness;

— the negative effects on the natural environment of the loss of the mythological perception of nature and of the development of science and technology that is mainly due to the Hebrew-Christian religion.

This interpretation is not based upon sound historical and scientific evidence. To argue against it, it will suffice to consider both the historical development of the man/environment relation and what is actually said in the Bible.

In civilizations prior to the Hebrew-Christian tradition, human populations exploited intensively their environment. This means that the environmental problem is certainly more universal and more ancient than Hebrew-Christian culture. Therefore, independently of geography or religion, some other common root, intrinsic to human nature, must have inspired, and inspires, the attitude of domination upon nature.

Among the factors that have generated this attitude, it is worth recalling:

— the practices of farmers-breeders and the great oriental cultures that have endangered their own existences with ecologically inadequate actions;

— Greek philosophy, in which man is the "measure of all things", and the typical praxis of dominion of the Romans — two cultures that were born and have grown to full splendor out of the influence of Hebrew-Christian thought.

It is also worth mentioning the mercantilistic thought of the 12th century that found its basis in money and commerce (the message of Francis of Assisi as alternative to that culture is very significant), the humanistic renaissance, the social, political and economic thought based on the "use" of nature and its resources for purely quantitative growth.

The thought of the Bible is also important, at least for western culture. The biblical view on the relation between man and his environment is contained essentially in the first chapters of *Genesis* and can be summarized as follows:

— Man must program and govern his relation with plants, animals and other men in the awareness of his responsibility and of the reality of nature. Possibly, this view may have originated the importance attributed to science and technology by the Hebrew-Christian religion. Man can attain this aim in two ways, and the Bible presents this duty as a mixture of dominating the land, working it, looking after it, always in cooperation with God.

— Man can destroy nature, distort God's commandment and use it as a justification for a behavior of domination/exploitation that had already been expressed in ancient classical civilizations.

With this behavior, man shows a tendency to resume the instinctiveness that characterizes the relations between animal and vegetal species and that he is stimulated to overcome, in view of his consciousness, in order to attain a higher quality of life.

— On the other hand, man can respond to God's commandment by directing the functioning of the environment and the relations with other men in a responsible manner, thus increasing the wealth of the environment with the products of his hands, using natural resources with a responsible knowledge of their limits and without any arrogance, either as an individual or as a species. The choice between these lines of action is left to his intelligence, responsibility and creative power, the ambivalence of which has marked in the past the web of relations between mankind, nature and the human environment.

The Biblical view of the relation between man and the environment is truly anthropocentric. Man is seen within nature, but at the same time he is called to a dialogue with God and to a responsible management of creation. His consciousness does not place him out of or above nature, but makes him responsible for its correct management.

A synthetic view of what should be man's behavior toward the environment has been given by Pope John Paul II at the UNEP, in Nairobi, in 1985: "The exploitation of the riches of nature should take place in accordance with criteria which should consider the needs not only of the present but also of the future generations".

5. - A proposal for a new ethics as the basis of better relations between man, nature and human environment

Faced with the dramatic events that have affected the environment in the last thirty years, the first reaction of governments and public administrations (possibly under the stimulus of environmental movements and of the scientific community) has been to pass laws aimed at the recovery of the quality of the environment and of natural and cultural resources.

At first, these norms have not been concerned with the nature of polluting processes (industrial or domestic), but have been directed only at the effects, leaving the causes intact.

However, the insufficiency of such a policy of environmental protection has become evident, and has shown the need for action through the use of clean technologies aimed at prevention.

The serious deterioration of the quality of the environment has shown also the failure of the economic policy of unlimited economic growth in the 60s and 70s. This policy was based upon an ethics of domination/exploitation of nature and its resources. Nature was reduced to a mere source of goods to be employed for a type of development measured only with a quantitative scale.

The more advanced sectors of society have stressed the need for new policies in the programming, management and governing of the environment and, on a larger scale, for new behavioral norms.

In facing the problems of environmental ethics, some scholars have followed an approach based on nature (Holistic Ecosystem School) as the source of intrinsic moral wealth. Others have confined their attention to the claim that the human use of natural resources must be compatible with the dynamics of natural environments.

A second approach, the bioethic approach, starts from man and the system of needs he expresses, and develops the plan for the environment and projects for promoting the quality of animal and plant life, water, soil, natural ecosystems and cultural resources.

A tbird approach, on which the present relation is based, starts from the certainty that the definition of the goals, contents and methods of environmental ethics will undoubtedly benefit from philosophical contributions, but must be based upon a profound scientific knowledge of environmental systems and on the awareness and responsibility of man in the management of the environment.

In fact, ethically oriented research could easily degenerate into some form of preceptive moralism, if the reasons of this new approach are based on an abstract view of environmental problems, on approximative knowledge or, even worse, on emotional proposals.

The message of modern ecology for a reconciliation between man, nature and the human environment is sinthesized well in the *Cantico di Frate Sole* of Saint Francis of Assisi:

— the will to participate and to be personally involved, as men, in the vicissitudes of nature and of the human environment — the systems by which every person is at the same time parent and child;

— the will to be respectful of the interrelations that form the natural environment, in which the promotion of the quality of life shall not remain only a word or a proposal.

In the light of these ideas, it is necessary to read again some fundamental themes of man's project for environmental management, in order to obtain new lines of action for a new environmental ethics.

Tbe "Carta di Gubbio" tbat was published on the occasion of the 8th centenary of the birth of St. Francis of Assisi gives some significant suggestions.

It is urgent:

— to give up the idea that progress can be measured uniquely on a quantitative basis, in terms of ownership and accumulation of material goods in terms of the policy of power, of attention directed only to the present.

Instead, progress must aim at the promoting of the quality of all forms of life, animal, vegetal and human;

— to affirm that technology, one of the most qualified expressions of the identity and creativity of man, is not harmful *per se*. Technology can fulfill the needs of human populations only if it is respectful of the processes of the functioning of the natural and human environments through a widespread practice of recycling and prevention;

— to develop scientific, economic and ethical criteria aimed at the reconcilement between economy and ecology; to replace an illusory and harmful economy based on growth and consumption with an economy capable of reconciling development and conservation and based on a sparing use of the fruits of the earth;

— to replace the present attitude of domination/exploitation by man, especially in the industrialized countries, with an attitude of participation/care, respectfulness and brotherhood among all creatures;

— to take care of the problems of human populations — numerical growth, unequal distribution, aging — and to appreciate them in a perspective of interrelationships with the factors and processes that characterize the functioning of human and natural environments;

— to recognize that respect, conservation and correct use of nature and its resources represent a necessary condition for a fair development and that consequently these are subject to ethical principles;

— to consider again the historical memory, the ethical expressions, the identity of cultures and ethical commitment for the future;

— to refuse once more the mass society traits of human existence (from political unanimity to uniform consumption) and to emphasize the individuality of each person and population through forms of social and political organization aiming at the greatest possible distinction, diversification and qualification of activities and single contributions to community life.

A CONCLUSION

The systematic approach to prevention, equilibrium and conservation within development and other emerging contributions aimed at the founding of a new, alternative culture as a basis for a new environmental ethics are undoubtedly long term objectives.

Knowledge and analysis must be transferred through suitable languages to communities, in close connection with their material and spiritual wishes.

This approach shows the importance of:

— the training of scholars, professionals and technicians equipped with a systematic approach, open to the interaction between nature and culture, ready to act to overcome the persistent division between humanistic and scientific cultures, and of scientific methodological reductionism that has caused so many damages to the environment;

— environmental education, an approach that should increasingly permeate social, political, technological and educational projects and actions.

The following must be invited to a constructive consideration of such objectives:

— the public administrators and other regional authorities (in view of the necessary changes of the norms);

— the productive forces and service sectors (in view of an ever-increasing dissemination of the preventive approach);

— the world of school and universities;

— the scientific and humanistic societies;

— environmental movements;

— religious institutions and scientific foundations;

— the jurists, trade unions and mass media.

The complex of research, problems, objectives and proposals for the environment can perhaps be summarized best by quoting the words of two men, who, although they lived in greatly different situations, have expressed their existential participation in the beautiful and dramatic reality of the environment:

"All things are intertwined by invisible links. You cannot pull up a flower without troubling a star." (F. Thompson)

"No man is an island, entire of itself: Every man is a piece of the continent, a part of the main; if a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friends or thine own were; any man's death diminishes me, because I am involved in mankind; and therefore never send to know for whom the bell tolls; it tolls for thee." (John Donne)

These words convey an illuminating message for a new culture, new environmental perspectives and, most of all, for a new ethic for the environment.

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DISCUSSION

Odhiambo

I would like to make a short comment on the issue that Professor Marini-Bettòlo has brought up on the recent rediscovery of the environment. I just want to make three short comments on this. I think the first one is on the question of rationalizing traditional knowledge based on the environment, and what I want to focus on is the very large traditional knowledge of agroforestry. Agroforestry in modern terms was only rediscovered twelve years ago, roughly speaking, and yet we know that, in terms of the health of the environment, agroforestry is very important. I know that we are talking about the deforestation of the Tropics, but you remember that in fact the practices that ensured that the tropical environment would still remain productive on a sustainable basis, was in fact also invented in the Tropics, and one ought to reflect on what took place in between to make Africa and other tropical regions so subject to deforestation. My point here is that science and ecology especially can do a great deal to rationalize why agroforestry works, so as to make it a much better known concept which can be technologically implemented, not only in the Tropics but also in those areas where the two types of systems, farming and forestry, can work together for the betterment of sustainability of our agrosystems.

Secondly, I want to say that sustainability has now become a very key concept in agriculture and I hope as well also in forestry. When we are talking about this, we are not simply talking about conservation in the traditional sense; we are talking about a dynamic concept. We are taking into consideration increased productivity as well as increased needs, and the demands which are made by that increased activity. What we are concerned with is that at whatever level we are talking — Professor Marini-Bettòlo talked a great deal about equilibria — whatever increased needs have to be met, we ought to consider that we should do it in such a way that our soil and water management systems can still sustain the production that we are seeking and therefore meet not only the needs of today, but also the eventual needs of tomorrow.

Thirdly, as was said this morning, ecology as a whole is in trouble. I want to say, to give an example, that over the last six years, a number of us together with the United Nations University have been planning to establish an institute of natural resources in Africa to deal with the wise exploitation of our natural resources on a sustainable basis for the future. It has been a very difficult project because of a number of factors. These include institutional resistance, governmental insensitivity to the problems, and also donor resistance to supporting such a cause which, on ecological as well as economic grounds, one would see as a natural thing to develop and to support in Africa, particularly with the experiences we have had over the last 40 to 50 years.

MARINI-BETTÒLO

Thank you Professor Odhiamho. I think you have raised an important point: agroforestry. I have not mentioned it because it was already a solution. Agroforestry is the establishment of human settlement in the forest, using agricultute. We have a certain numher of examples. I know one in the Ivory Coast, in the great forest there, which is absolutely compatible with the environment. My concern is not with this limited equilibrium which works very nicely and is applied also to other populations in Africa, hut with the wild attack against the forest by people from lands very far away, as happens in South America in many areas, where they destroy, with the system of "slash and burn", and do not maintain the forest as a protective shield for their agriculture. In these conditions the soil will become unproductive in a few years.

I think that agroforestry is important. We should have better management, and my suggestion is that the arable lands that are now available should be better exploited using new means, biotechnologies, new strains of cereals and other vegetables for food, so that they can support, a greater population.

ODHIAMBO

I would like then to extend this because I thought that we were talking about the same kind of problem. Just as you are, so most of us are concerned about meeting the food needs of those areas, including the income needs, in other words, a greater need for agricultural production. But we are equally concerned with energy, and wood is one of the best sources of energy. Combining community forestry production and farming systems is one of the easiest ways of doing this while protecting the environment, and I am not talking only of traditional practices. Indeed, that is why I was suggesting that what we need to do is study why those systems work and upgrade them to modern practice. I am saying this, knowing very well that tropical soils are very fragile, and that it must be combined with what we all realize is important: high yielding varieties, but high yielding varieties, without a compensatory system, will only be mining the soil. So, we have to be very careful how we balance immediate production on a short-term basis with what is likely to be a long-term practice for sustainability of that production level.

MARINI-BETTÒLO

I would like to add something. I used to pass my summer in a village in the Alps near a forest. I think what 50% of the energy of the village is supplied by the wood collected in the forest. The people go and take the rotten wood, the fallen trees, or even shrubs in the undergrowth. This happens according to the laws established by the single village communities, where each family has a right to take a certain amount of wood and bring it home. This is, I think, a common rule all over northwestern Europe. This system is widely used and also keeps the forest clean and alive. The danger is the overuse of the forests. In many countries one can even utilize timber and cut trees in the forest, but according to a plan. In many countries, there is strict control by the State. Although one owns the forest, one may cut only the trees which have been indicated by the forest guard. This is a question of management; easy in some countries; more difficult in the Tropics. Certainly what has emerged in the discussions is that we have to face also the question of poverty. I realize that in Africa electric power is available but it cannot be bought and thus used, because of lack of money. I think that, beyond all ethics, we should move also to another ethic, that of better social justice, in order to give these people the possibility to earn more and to buy energy, in which Africa is very rich. You know that the dams of the Nile produce a large quantity of energy, the Congo even more, and not all this electricity is used as power, because of lack of industries.

RAVERA

I appreciate very much that you don't consider animals and plants isolated from the physical environment, but consider both animals and plants as a unit with the physical environment. I also think that we must separate the concept of ecology from that of environmental science. For instance, ecology is a branch of science and consequently cannot be judged from the ethical point of view. Only its applications, that is, definition what is ecology. Ecology is the science which studies the environment.

MARINI-BETTÒLO

I agree, Professor Ravera. I think that we must make clear in this definition also what is ecology. Ecology is the science which studies the environment, and sometimes this term has been misused. Ecology is a complex science because it's not a single science. It is the integration between all the sciences that study ecosystems, that is, botany, chemistry, physics, biology, geochemistry, geology, etc. It is a global approach to the study of our surroundings, which we call environment.

CHAGAS

I hope that ecology will revive botany, because, in all laboratories of botany that I visit, I find an electromicroscope; a laboratory of molecular biology and I find no physiology or taxonomy.

RAVERA

I would like to add that this is true for ecology and also for other sciences. For instance, geology is based on chemistry, physics, mineralogy, paleontology and so on; this science is based on other sciences. It's not a unique case that ecology that uses knowledge from other sciences; there are other examples: physiology, for instance. It uses biochemistry, chemistry, physics, mathematics, and so on.

MARINI-BETTÒLO

I agree, but I believe that no part of knowledge, as much as ecology, needs a great number of various components: from botany to physics, to climatology, to meteorology and so on, and even to anthropology and to the human sciences. It is a very complex science that we cannot simplify or oversimplify. I totally agree with you.

In reference to what Professor Chagas was saying about botany, I think we have a great need of good botanists and good taxonomists, beyond all the molecular biologists and physiologists who have made such great advances is science in the last years.

LIKENS

A very short comment. You've been talking about the ethics of organizations in our field. I would like to suggest that we should also consider the ethics of individuals. Dr. Jeffers talked about outrageous and wrong statements that were made publicly. I think that happens very often. Two years ago, I was told by the second largest coal company in the United States that it had hired a room full of Ph.D. scientists to minimize (and I quote) "the acid rain issue at every opportunity". There is an ethical question involved when scientists in developed countries are for hire, and also their words are for hire. I think that ethical questions are very important, and I wonder if you might want to include the individual ethic component in your considerations.

MARINI-BETTÒLO

Thank you, Professor Likens. I agree with this position and I think it can be developed.

DE GIORGI

If we turn to the various religions, we can find a common point on which we can agree. The Hebrew culture of Solomon and the Greek culture of Socrates and Plato were built on the love of wisdom, which can be summarized in three points. First, we must be aware of our ignorance. Second, we possess the will to overcome ignorance and, therefore, to search for truth. Third, in our search for truth, we must collaborate with all other human beings who are also searching for truth. I think these three points are important for our attempt to eliminate differences and to find a single philosophical basis for science and culture.

MARINI-BETTÒLO

I agree that we cannot separate man from his environment or from his culture. Indeed, culture is the only way to wisdom. I would add that a new culture or a new philosophy of the environment is necessary if we have to protect the environment and, consequently, man.

CHAGAS

I would like to make one comment which, I think, is very pertinent to what Marini-Bettòlo said now and to what Likens, Farinelli and Keckes said earlier. I think the limit of development is man. Man in his activity, in his egotism, in the way in which he portrays life, in his commercialism, in the way in which he has driven our civilization, is really the limit of development. Dr. Keckes and Dr. Likens, I would say that if we don't have an ethical component in human behaviour, there will never be an ethics in ecology.

II.

STRATEGIES FOR THE PROTECTION OF THE ENVIRONMENT

MANAGING TROPICAL RESOURCES: A CHALLENGE TO US ALL

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Difficult as it is for us to accept fully, we are the citizens of a world in which far more people are adequately fed, clothed, and housed than has ever been true before, and at the same time a world in which up to fifty thousand of our fellow human beings starve to death every day; a world in which we are consuming or wasting a major proportion of the total net biological productivity of the land; and in which up to a quarter of all kinds of plants, animals, and microorganisms are likely to become extinct during the course of our own lives.

As His Holiness Pope John Paul II put it in his address at the Center for the United Nations Environmental Programme in Nairobi in 1985, "The capacity to improve the environment and the capacity to destroy it grow enormously from year to year". In this connection, the loss of biological diversity greatly damages our ability to improve the environment and thereby our own lives. We base our civilization almost completely on our ability to utilize different kinds of organisms for our benefit, and the loss of so many of them threatens to limit permanently the options that will be available for our children and grandchildren — the very options that would allow them to lead prosperous and full lives.

One way of measuring our collective impact on the global ecosystem is simply to count ourselves. Our population has doubled since 1950 and passed the 5 billion mark for the first time earlier this year. It is growing at an annual rate estimated at 1.7%, and constitutes a dominant ecological force that greatly exceeds any other such force that has existed for at least tens, if not hundreds, of millions of years. Judged from present rates of growth, our population level will double again in 40 years, according to careful estimates made by the Population Reference Bureau (1987). The support of human populations at such levels in any sort of reasonable condition and dignity will require the very best efforts of which we are capable.

We have already mentioned one of the most direct ways of measuring our impact on the sustainable capacity of the global ecosystem. This is the calculation of how much of the total net biological productivity of land is used directly, co-opted, or foregone because of human activities. This proportion, estimated recently by Vitousek *et al.* (1986), amounts to nearly 40%. As these authors have pointed out, people use this amount of the total available material either directly or indirectly. It flows to different consumers and decomposers than it otherwise would (in managed systems such as pastures), or it is lost because of human-caused changes in land use (such as forest conversion to pasture, or desertification). In view of this sobering estimate, it must be questioned how we will manage our resources in another 40 years or so, when there may be twice as many people as there are now.

Another way of indicating the extent of human impacts on the global ecosystem is to point out that the rise in agricultural productivity by about 2.5 times since 1950 has been made possible by a seven-fold increase in the agricultural use of energy (Brown *et al.*, 1987). This and other heavy uses of our stocks of fossil fuels have not only depleted them considerably, but also have contributed significantly to the rising levels of carbon dioxide in the atmosphere, with all of the problems that this trend implies. Widespread acid precipitation and the destruction of the ozone layer are two other clear indications of the worldwide effects of human activities on tbe environment — effects that are often even more pronounced in developing countries than in industrialized ones. In many ways, and regardless of our reluctance to admit it and to act accordingly, we are affecting the whole globe as if it were a single gigantic ecosystem. It is evident that a strong, collective effort must be made in response to these trends. What response are we actually making, however? And why should those of us who live in the relative comfort of the industrialized nations even care?

The Situation in the Tropics

In this paper, I shall speak primarily about the tropics and subtropics, the regions where human suffering is most extensive; where biological diversity is concentrated and is being lost most rapidly; and to which we who live in industrialized nations feel the most distant connections, intensely preoccupied as we are with factors such as domestic inflation, unemployment, defense, health care, social security, and farm subsidies as determinants of the quality of our daily lives.

Three principal factors are involved in continental-scale ecological destruction that is ravaging all tropical regions at present. These are (1) the explosive growth of a human population that has already attained record levels; (2) widespread poverty, which affects an average of 40% of the populations of tropical countries; and (3) ignorance of the properties of undisturbed tropical ecosystems and the ways in which to convert them to sustainable, productive agriculture or forestry, coupled with an unwillingness to apply the information that is available to the solution of local problems. I shall discuss each of these factors in turn.

The Pressure of Numbers

In 1950, about 45% of a global population of some 2.5 billion people lived in countries that lie wholly or partly in the tropics; today, the figure is about 55% of a global population that is more than twice as large. If present trends continue, by the year 2020, nearly two-thirds of the people in the world will be living in these countries, in which I have not included China. In actual numbers, the 1.1 billion people who inhabited countries that are at least partly tropical (excluding China) 37 years ago will have grown to about 5 billion people in another 33 years: a *quadrupling* of the total within a space of 70 years!

For various reasons, population growth is slowing down throughout the world. So many of the people of developing countries are young, however — some 40% or 45% of the people, typically, are under 15 years of age — that their numbers will continue to grow rapidly for two or three more generations no matter what the overall trends may be. Nonetheless, the global population is expected to stabilize during the second half of the 21st century. As the growth decelerates, there will be increased opportunities for raising the standards of living of the people of a given area (for a recent review, see National Research Council, 1986a). As this trend occurs, it will be of the greatest importance to realize the full potential afforded by the lessened pressure on the environment.

Poverty

Our collective unwillingness to come to grips with the problem of poverty is the most important factor that underlies the rapid destruction of tropical ecosystems and is ruining the productive capacity of great portions of the globe. Poverty can be measured in various ways. First, great differences exist between the wealth of industrial countries and that of developing countries; the standards of living often differ by a factor of ten or more. Currently, the per capita GNP in the United States is estimated at US$ 16,400 and that in Western Europe at $ 10,270, with the comparable figures for many developing countries measured in hundreds of dollars. Summing up gross national products worldwide, one finds that the industrial nations, with less than a quarter of the global population, control about 80% of the wealth, while the largely tropical developing countries, with 54% of the population, control about 15% of the wealth. During the 1970s, Africa became the first region to suffer a decade-long decline in per capita income since the Great Depression; during the 1980s, per capita income is projected to decline both in Africa and in Latin America (Brown *et al.*, 1987). The industrial nations control 80% to 90% or more of virtually all commodities that contribute to the standard of living, such as industrial energy or the consumption of metals and other materials.

Within the countries of the developing world, the difference between rich and poor is characteristically profound, and increasing rather than becoming narrower. Of the 2.7 billion people who live in tropical or subtropical regions, the World Bank estimates that about 1.2 billion exist in absolute poverty. People who live in absolute poverty are unable to count on adequate food, shelter, and clothing from one day to the next. Of these, approximately two-tbirds ate fewer than 90% of the calories that international standards deem necessary to lead an "active working life", and 300 to 400 million people consumed less that 80% of this standard, an insufficient number of calories to prevent "stunted growth and serious health risks" (World Resources Institute, 1986). Up to several million of these people starve to death each year or die of hunger-related illnesses.

In addition, hundreds of millions of children in developing countries are growing up in poverty, without the ability to apply pressure on their governments or any other institutions to help them. They sleep, work, and beg on the streets, exploited in the most brutal ways imaginable.

UNICEF has estimated that more than 14 million of these children under the age of four starve to death unnecessarily each year in tropical and subtropical countries: 40,000 young children die from starvation and associated diseases each day (Grant, 1986). Worse, many millions of additional children exist only in a state of lethargy, their mental capacities often permanently impaired by their lack of access to adequate amounts of food. To allow such a situation to exist is a great evil morally, arising directly from our constant preoccupation with ourselves and our own perceived needs, which allows us to remain detached from these unpleasant realities.

Ignorance

We do not, unfortunately, know a great deal about how to replace many kinds of tropical vegetation with productive agriculture and forestry systems; our ignorance accelerates the effects of poverty and greed in leading to the consumption of the potentially renewable resources of most tropical countries as if they were in fact expendable.

One of the reasons that people living in temperate regions have tended to minimize the role of deforestation in the tropics is the implicit notion that deforestation will lead directly and easily to productive agriculture or forestry. Unfortunately, this is more often than not an unwarranted assumption, since about two-thirds of tropical soils are oxisols and ultisols, which are highly acid, infertile, have low cation-exchange capabilities, and high potential for immobilizing phosphorus (National Research Council, 1982). Such soils can be productive if they are fertilized and managed carefully, but that rarely has been the case. Some of the remaining soils are quite fertile, while others cannot be cultivated at all by known technologies.

In ecosystems that develop on infertile soils, the meagre amounts of nutrients that circulate are often held chiefly in the living plants. Most of the tree roots spread only through the top few centimeters of soil, recovering nutrients efficiently from the leaves that fall to the forest floor and transferring them back to the plants from which they came originally. Felling and burning the trees releases large amounts of nutrients temporarily to the soil, which may then be used to cultivate crops for a few years. Once the fertility falls to the original levels, however, such cultivation is impossible. Given adequate time, the original vegetation may recuperate, if there are source areas nearby; but adequate time is rarely available today, since the large numbers of rural poor living in most regions simply overwhelm the cut-over lands, using them as sources of firewood and repeated, low-grade cultivation because they are needed. Moreover, it has traditionally been considered simpler, both for planned large-scale development and the usually unplanned displacement of rural people to regard undisturbed forests as resources to be "mined", while simply ignoring the potential of the cut-over lands for forestry and agriculture and as cattle pasture. In the interests of global stability, development activities must urgently be re-directed to the lands that have already been cleared.

Some traditional systems of cultivation combine trees, which are usually more productive than herbaceous crops, with other plants on relatively infertile soils; *agro-forestry* systems of this sort offer important promise for the future, if they are developed further and put in place, and if the people who might use them are encouraged to do so through appropriate loans for fertilizers, credit for seeds, information about markets, and the like. In addition, food self-sufficiency for tropical regions can be won only through the intensive cultivation of the relatively fertile soils by the best methods available, with the most suitable crops. To solve the problem, we must both become better informed about the best agricultural and forestry practices for various tropical conditions, and find ways to put our existing and new knowledge into practice (Lal, 1987).

Linkages

The decline in forests and other productive resources in tropical countries is due not only to the internal needs of these countries, but to consumer demand in industrialized countries. Such developed nations derive many material benefits from the genetic resources of the tropics, since they have the greatest technological capacity to exploit these properties (Myers, 1986). For example, oral contraceptives for many years were produced from Mexican yams; muscle relaxants used in surgery worldwide come from an Amazonian vine; the cure for Hodgkin's disease comes from the rosy periwinkle, a native of Madagascar; and the gene pool of corn has recently been enriched by the finding, on a small area in the mountains of Jalisco, Mexico, of a perennial wild relative. In addition, many foods and other substances we consume regularly come from the tropics: coffee, tea, bananas and other fruits, cassava (increasingly used in Europe), much of our sugar — the list is very extensive.

The production of beef in southern Mexico and Central America for United States markets provides a particularly striking example of these connections. From the 1960s on, the U.S. government authorized growing imports of beef from these regions, thus apparently keeping the price of a hamburger in the U.S. about a nickel lower than it would have been otherwise. The clearing of pastures to provide this beef has been the major factor leading to the elimination of more than half of the forests of the region during the same period, however: to produce a single hamburger, a patch of forest about the size of a kitchen has to be cleared. A growing proportion of the beef produced on these pastures is consumed in the countries where it is produced, but the forests have been lost permanently and many of the pastures are steadily becoming less productive. Similar linkages can be found in all regions.

In addition to these food substances, we who live in industrial nations obtain now much of our supply of timber and pulp from there, and re-planting is proceeding at a very slow rate. In the tropics generally, 10 trees are being cut for each one that is planted, and in Africa, the ratio is 29 to one (Brown *et al.*, 1987). At the same time, vast areas of temperate forests are simultaneously decreasing in vigor and extent, as a result of acid precipitation and other forms of atmospheric pollution (World Resources Institute, 1986, Chapter 12) — a sure sign of global interconnections and of the necessity of human beings starting to manage the whole global ecosystem as one system. The developed-world consumption of tropical hardwoods has risen 15 times since 1950, while in-country consumption has increased only three times. Japan accounts for about three-fifths of the developed-world consumption of these hardwoods, while reducing the production of its own forests by half over the past 20 years; recently, however, the Japanese government has begun to address this problem seriously. Few nations have developed forestry plans for themselves, and the global situation is certainly threatening.

In global climatic terms, deforestation also contributes to increases in atmospheric carbon dioxide — the proportion of this gas in the atmosphere has risen by 30% since 1860 — and thus to what climatic modelers assume will be a steadily rising world temperature. The large-scale cutting of forests likewise is impairing the capacities of some tropical systems to recycle rainfall inland. In the Amazon, for example, where more than half of the precipitation is recycled, continued deforestation is likely to lead to increased erosion and water runoff, together with reduced evapotranspiration and ultimately reduced precipitation (Salati and Vose, 1984). Reduced precipitation in the Amazon could severely affect the climate and present agriculture in south-central Brazil. Although the correlations have not been demonstrated as convincingly as for the Amazon, Africa has essentially been experiencing drought years since 1967, as compared with its pattern of rainfall earlier in the century: could this drought have been caused by the removal of well over half of the forests there (Brown *et al.*, 1986)? More locally, the effects of deforestation on accelerated erosion and the loss of water supplies are well known.

Recent findings suggest that the implications of widespread deforestation may be even more extreme. At the December 1986 meeting of the American Geophysical Union in Boulder, Colorado, Robert E. Dickinson of the National Center for Atmospheric Research and Ann Henderson-Sellers of the University of Liverpool reported that the absence of closed forests in South America would cause a decrease in evaporation of moisture, precipitating a temperature rise by 3 to 5°C in that region. A decrease in evaporation accompanied by an increase in temperature would cause the period of driest soil conditions to increase from one month to several, and would likely have a detrimental effect on the survival of the remaining forest, including reserves, and on attempts at cultivation in the deforested areas. Dickinson and Henderson-Sellers also pointed out that they could not exclude the possibility that the changes would also be important for regional atmospheric circulation.

Against this background, the inauguration of the International Tropical Timber Agreement in 1986 — an agreement that involves all the major producers and consumers of tropical woods — is a development of high importance. This agreement has as its goal the preservation of tropical forests so that they may be managed as a renewable resource. In addition, the organization of the Tropical Forest Action Plan by the World Resource Institute (WRI) is of great importance, both for a stable supply of the commodities involved, and for biological conservation as well. This plan, which grew out of WRI's 1984 Global Possible Conference, was developed in cooperation with the World Bank and the United Nations Development Programme. It urges action in five areas: fuelwood and agroforestry, land use on upland watersheds, industrial forestry, conservation of forest ecosystems, and research and institutional needs. In addition to all of its more obvious benefits, the implementation of this plan, by increasing the area of forests, would help to decrease the carbon dioxide in the atmosphere and thus alleviate the danger of rising temperatures and melting polar ice caps. The Tropical Forest Action Plan recommends expenditures of U.S.$ 8 billion over five years, jointly provided by development assistance agencies, the private sector, and the governments of tropical countries. Efforts are under way worldwide to implement the plan on a national and regional basis, and a promising start has been made.

Although the consumption of tropical forests by the poor who live in these regions is an even more important factor, the permanent depletion of these forests to satisfy the needs of a global cash economy is significant also. Most countries in the tropics have greatly increased their export of cash crops over the past 20 years; for example, intensive cultivation has made possible massive exports of peanuts and cotton from the Sahel mostly to Europe during this period of time. Partly in consequence of this development, many traditional farmers have been displaced, migrating into areas less suitable for agriculture and contributing to the destruction of the productive capacity of these areas through desertification. Similar trends are taking place in both Latin America, where areas occupied by lowland evergreen forests are being attacked by small farmers displaced from more fertile regions, and in Asia, where the transmigration schemes that are basically necessary to reduce the population of the central islands of Indonesia, for example, have often led to the destruction of additional forests without the development of stable, productive systems in the new areas. The more frantically tropical countries seek to pay off their huge international debts, the less likely they are to put in place sound development strategies that will lead to sustained productivity in their lands. All too often, much of the productive farming of the tropics and subtropics has been turned into an adjunct of the world trading system, with the implication that the people living in such countries then must import their food from abroad, either paying for it or receiving it as relief in times of famine. As the prices of commodities such as coffee, tea, cotton, and sugar slump, the system falls apart, and hundreds of millions of people are consigned to poverty and starvation. Unfortunately, development assistance programs are usually directed to the production of cash crops for export, rather than to the development of self-sufficiency in the regions themselves, so that the situation tends to perpetuate itself.

Countries such as those of the Common Market and North America often act as if the increasing production of agricultural products in developing countries constitutes a threat to their own agricultural establishments, beset as they are with huge surpluses and subsidies. In some wholly mystical way, it is implicitly assumed that a country in which half of the people are starving will be a good customer, eager to import and pay for food and other commodities with non-existent financial reserves. Fortunately, some authorities are starting to realize that a country cannot be stable — cannot really afford to import anything — unless it has a reasonable self-sufficiency in agriculture and forestry, or some other means of providing a reasonable standard of living for its people.

Since it now drives economic relationships, a word about the international debt is in order. In 1970, the external debt of Third World countries was about U.S.$ 72 billion; today, it is approximately $ 1 trillion. The existence of this debt clearly encourages many Third World countries to overexploit their natural resources, without the creation of stable, productive alternatives: logging restrictions are eased, poor farmers are displaced to regions that will not support them in the long term, the production of foods that the people can eat (remember that on the average, a fifth of them are malnourished) is decreased in favor of the production of export crops, and the associated austerity measures can throw large numbers of people out of work, thus increasing the extent of poverty in the nations involved (Myers, 1986). Pollution often becomes widespread as developing nations struggle to increase their production of cash crops. DDT, which has long been outlawed in industrial countries, is widely manufactured and used in the Third World. Indeed the World Health Organization has estimated that there are about 1 million pesticide poisonings and 11,000 pesticide-induced deaths each year in the tropics, while other agencies consider these estimates much too low. Throughout the Third World, the question is how to strengthen sustainable productivity without tearing society apart. The farmers and the institutions of these countries, assisted by other countries that recognize their own interest in ecological, economic, and political stability there, afford the best hope for the future.

As Alan Alpern and Peter Emerson put it in their essay in *The New York Times* for February 7, 1987, "Debtor countries that must allocate scarce resources and export earnings for debt service cannot generate new capital investments. This leads to a decline in standards of living, political and economic instability, drug trafficking, illegal emigration, escalating insurgency and increased capital flight". The existence of principal and interest obligations that cannot be met under any reasonable scenario of economic events ultimately tears apart the structure of a country and leaves it no options short of unilateral action. In concluding their article, the authors quote a New York investment banker as saying: "Somehow the conventional wisdom of 200 million sullen South Americans sweating away in the hot sun for the next decade to earn the interest on their debt so Citicorp can raise its dividend twice a year does not square with my image of political reality". Still more succinctly, Willy Brandt (1986) termed the effects of the debt, "A blood transfusion from the sick to the healthy".

In essence, the very existence of the debt is causing agonizing reappraisals in most Third World countries — reappraisals that will certainly have worldwide repercussions. In Latin America, for example, the World Bank found that world recession and debt in the early 1980s led to a 13% drop in per capita income, ending some 30 years of progress in the region. The region's struggle to maintain payments on its U.S.$ 360 billion international debt simply makes the resources that are necessary for social programs unavailable. Indeed, in many of the countries of Latin America, the economic situation is fully comparable to that of the Great Depression of the 1930s in industrialized nations. A January 1987 study by the UN Economic Commission for Latin America and the Caribbean concluded that the well-being of people throughout the area has deteriorated to "a point that could not have been imagined a few years ago (both because of its depth and the broad social spectrum affected)".

Clearly, the debt is making it increasingly difficult for Third World countries to accept exports from anywhere; they must instead export competitively in an attempt to repay the debt itself. In this light, it may be said that the repayment of the debt is actually weakening the economies of industrial countries in the medium run. The net effect of extracting U.S.$ 22 billion from the world's poor countries and paying it to the rich ones in 1985 was destabilization on a global basis; with increasing efforts to extract sums of this magnitude, the problem can only become worse. In large measure because of the debt crisis and its associated social deterioration, political problems are arising throughout the developing world. In Brazil and Ecuador, for example, recently elected democratic governments are being threatened severely by the strenuous efforts that are being made to repay the debt and their social consequences.

Political stability cannot he attained in any country where nearly half of the people live in absolute poverty. Allowing such situations to exist invites political interference from all sides and increased misery for millions. In Central America, for example, the most rapid military buildup in history is threatening weak governments doing their best to create stability for the region. Such foreign influence, accompanied by minimal development assistance, dominates the countries involved without contributing to the welfare of the people; in an effort to create a kind of politically motivated stability, it creates instability instead.

As His Holiness Pope Paul VI put it so succinctly, "Development is the new name for peace" (*Populorum Progressio*, 87). In his address at the Center for the United Nations International Programme in Nairobi in 1985, Pope John Paul II clearly outlined the relationship between development, the protection of the environment so that the fruits of development could be sustainable, and peace, which he characterized as the fruit of reconciliation. One of the most obvious outcomes of extensive poverty is the large number of refugees who move throughout the world homeless, such as the more than 10 million Africans who were estimated by the United Nations to have left their homes in search of food in early 1985, often crossing national borders in the process. Such patterns occur because of mounting ecological pressures in the developing world, and because of our collective failure to recognize stable land management as a vital factor in achieving stability of any kind, or simple social justice. If we fail to cooperate in the development of environmentally sound and stable productive systems worldwide, the poor people of developing countries clearly will continue to topple any government or upset any political system, because they have nothing to lose by promoting instability. As the problem continues, more and more people will starve and live lives of hopeless despair, unable to enter into any stable systems or to play an indispensable role in the management of common resources.

The Biological Consequences

In 1981, the Tropical Forest Resources Assessment Project of the Food and Agriculture Organization of the United Nations (FAO) estimated that 44% of tropical, lowland, evergreen forests had been cut by the late 1970s, and that 1.1% of the remainder was being cleared each year. In 1987, the area of tropical evergreen forest remaining is about 6 million square kilometers, about half of the original total, and at least 100,000 square kilometers are being cut each year. About half of this area is logged, and another quarter is cleared for cattle pastures (Myers, 1984). The existing forests constitute an area about two-thirds the size of Europe, but if clearing were to continue at the level of ten years ago, they would all be gone in 60 years. Because shifting cultivation and fuelwood gathering are likewise destroying large tracts of the forests, however, and the pressures on them are increasing, it is clear that they will be gone much sooner — mostly by the early years of the next century (Myers, 1984; Melillo *et al.*, 1985). There are now so many people engaged in such activities that the forests they are exploiting simply never have time to recover. It is important to realize that the *total* number of shifting cultivators, who are causing major damage to tropical, evergreen forests, is only about 200 million people worldwide (National Research Council, 1982). By revising global economic policies so as to incorporate these people in the economies of their countries, much of the pressure on the forests could be alleviated, and they could become a sustainable, rather than a non-renewable, resource.

The fuelwood crisis in the tropics merits special consideration in this connection. About 1.5 billion people — a third of the world population — are cutting firewood in their regions faster than it can regrow; most of these people have no feasible alternative source of energy. Of these, nearly 100 million people in 22 countries (16 of them in Africa) cannot meet their minimum needs for fuel even by overcutting the remaining forests (World Resources Institute, 1986); diseases that had become rare are now increasing because of the consumption of improperly cooked food. In Africa and elsewhere in the tropics, urban centers are surrounded by a ring of devastated forest tens or sometimes hundreds of kilometers in diameter. Between 1972-75 and 1980-82, the forested areas within 50 kilometers of India's 41 largest cities decreased by a third (Brown *et al.*, 1987), while fuelwood prices rose sharply.

Taking clear-cutting and the severe disturbance of tropical, evergreen forests together, their current rate of destruction may be calculated at more than 200,000 square kilometers per year — an area two-thirds the size of Italy. At such a rate, all tropical, evergreen forests would be gone in less than 30 years, but, in fact, the rate is accelerating. In addition, the rates of destruction in many areas — tropical and subtropical Asia, for example, or Central America and the West Indies — are much faster than elsewhere.

While we are accustomed to thinking of clearing forest as desirable and leading to human prosperity, such is rarely the case in the tropics. Instead, the unplanned and runaway exhaustion of potentially rich resources denies hundreds of millions of human beings access to a reasonable standard of life, and all too often leads to the creation of wastelands.

By incorporating the needs of poor people into well-reasoned development schemes, and by using the knowledge that we have available now about the proper management of tropical lands, we could alleviate all of these losses. By failing to do so, we will inevitably be exasperating the problems that we face today.

Of the three tropical regions of the world, sub-Saharan Africa faces the worst outlook. The Food and Agriculture Organization (FAO) of the United Nations estimates that per capita food production in Africa has dropped 20% since 1960, and projects another 30% drop during the next 25 years, as the population-food gap continues to widen, unless both population and production trends change. In most of the countries of the region, the intake of calories is below the U.N.-recommended minimum for the maintenance of health. Currently, food production in this region is growing at about 1.3% per year, the population at just under 3%. The economic growth rate in sub-Saharan Africa for 1986 was 1.2%, and the International Monetary Fund projects that it will fall to about 1% in 1987, so that the overall standard of living will clearly continue to fall. Large-scale foreign assistance has thus far been unable to turn the situation around, and takes place in the face of an external debt of about U.S.$ 90 billion, accumulated during years of falling prices for African exports, rising interest rates on loans, and weak local currencies. In most countries, the burden is simply unbearable; for example, the 13 African nations most deeply in debt would consume 66% of their export earnings if they kept up scheduled payments, this clearly making it impossible for them to purchase needed food and industrial supplies.

All of these problems in Africa are made much more severe by political and organizational problems, which, for example, greatly favor urban dwellers over poor, rural farmers. Although there has been some recovery from the droughts of the early 1980s, nearly 18 million Africans depended on food distribution for survival in 1986. Relatively little attention continues to he given to the problem of stable food production in the region, and most uncultivated land in Africa is marginal at best. Meanwhile, there are about 1 million more mouths to feed in sub-Saharan Africa every three weeks, a sure prescription for increasing human tragedy (World Resources Institute, 1986).

The global dimensions of extinction will be stressed below, but some of its consequences will be mentioned here. Starting with first principles, we base our livelihood almost entirely on our ability to manipulate the properties of other organisms. Many new kinds of crops and domestic animals might be used for the full exploitation of the available sites, and in the search for self-sufficiency throughout the tropics. Unfortunately, many such organisms are becoming extinct during the course of our lives, and as we shall discuss below, the ones that are disappearing are often largely or wholly unknown. Three species of plants — rice, wheat, and corn — supply over half of all human energy requirements; only about 150 kinds of food plants are used extensively; and only about 5000 have ever been used (National Research Council, 1982). It is estimated, however, that there may be tens of thousands of kinds of plants among the estimated 250,000 that exist which could provide human food if their properties were fully explored and they were brought into cultivation. In addition, many other plants offer extraordinary possibilities as sources of medicines, oils, waxes, fibers, and other commodities of interest to our modern industrial society (Myers, 1983; Oldfield, 1984), but our exploration of these properties has scarcely begun. Genetic engineering affords us additional possibilities for the transfer of genes from one kind of organism to another, even though the donor may itself be of no economic interest whatever; indeed, as our techniques become more sophisticated, we shall come to depend even more heavily on biological diversity than we do now.

Finally, the uses of plants and algae as sources of biomass, and therefore of energy, should be mentioned. The sun is clearly the ultimate source of clean, abundant energy, and plants and algae are probably the most efficient means of obtaining it. As the temporary illusion that energy obtained from fossil fuel is unlimited and should be used as such comes to an end, biomass will be investigated intensively and selections of plants and algae to grow under certain specific conditions will be made. For tropical countries, which are often energy-poor, biomass-producing or direct solar converters are especially attractive.

As His Holiness John Paul II said in Civitavecchia in March, 1987, addressing the energy workers of the area, new modes of producing energy must be developed as a matter of urgent priority so that we can avoid the negative effects of the various technologies that are used now and still provide for future energy needs. Only in this way, as he said, can we guarantee our respect for and conservation of all the possibilities and beauties of the universe. As a result of our assiduous commitment to the development of energy resources, we have reached truly fearsome levels of pollution of the natural environment. Only by developing and utilizing appropriate technologies, some of wbich would involve biomass.

produced by plants and algae, could these worrisome trends be reversed (Goldemberg *et al.*, 1987a, 1987b).

Extinction

The most serious, long-term global problem that we face is the elimination of a large part of the biological diversity on earth within a few decades. Whether this process of extinction is viewed from a scientific, aesthetic, or moral standpoint, or simply as the loss of opportunities that could otherwise have been used for human benefit, it is unquestionably the most serious problem of all those that confront us, and the one that will have the most long-lasting consequences. At least half of the species of plants, animals, and microorganisms in the world live only in forests that will be cut or severely damaged during the next 15 years or so; many of these will disappear forever, some after surviving for a time in the small patches of vegetation that will last for a while longer in places too steep, too wet, or too rocky to cultivate. The loss of more than a million species of organisms, fully a quarter of the world's total biological diversity, during our lives, represents a crisis of unprecedented dimensions. By allowing this catastrophe to happen, we are clearly abandoning our responsibility for wise stewardship of the world's resources — a responsibility that is so clearly enunciated in the Bible.

What makes matters even worse is that no more than one in six of these organisms — roughly 500,000 out of several million, or more — is known to scientists. Not only are we unaware of the properties of the rest, we do not in most instances even know that they exist! We can only calculate that they are there by comparing them with the ratios and proportions of species that are characteristic of better-known groups of organisms, such as vertebrates or flowering plants. We certainly know nothing at all about the ways in which they might be of use to human beings, but are simply allowing them to disappear forever, passively and as a result of our greed and preoccupation with our own lives.

The pattern of extinction might be ameliorated by the creation of parks and reserves, if the social and economic structures of the countries where these exist would allow their continued maintenance. If enough people are denied the necessities of life on a daily basis, there is no hope for sustained preservation in this way: they must cultivate all lands in a continuous struggle for survival. By coupling wise development with conservation, however, and learning how to utilize the forests and other tropical lands better, there could be some hope for saving the genetic resources that will serve the needs of the future.

Numerous areas where the natural vegetation has been reduced to a small proportion of its original extent — Hawaii, Madagascar, and western Ecuador, for example — provide examples of the kind of major loss of species that we shall be observing on a wider scale as the 20th century comes to a conclusion. In view of the destruction of the vegetation that is home to half of the world's species, we may assume that at least a quarter of the world's total — more than a million species — are likely to pass from existence during our own lives, and many more soon thereafter. Over the next 30 years, then, we can expect the rate of extinction to average more than 100 species a day, with the rate increasing from perhaps a few species a day now to several hundred by the early years of the next century. The great majority of these species will not have been collected, and therefore will never be represented in any scientific collection or preserved in any way.

In order to put such a rate of extinction into perspective, we may consider the geological record. It is difficult to estimate exact proportions, but nonetheless likely that about two-thirds of the species of terrestrial organisms became extinct at the end of the Cretaceous Period, some 65 million years ago (D.M. Raup, personal communication). As far as we can calculate, many fewer species of organisms were in existence at that time (e.g., Niklas, Tiffney, and Knoll, 1985), so that the absolute numbers of species that are becoming extinct during our own individual lifetimes are far greater than have ever vanished during any single event at any time in the past. To find a comparable proportion of terrestrial species becoming extinct, we must go back 65 million years, and it is entirely possible, unfortunately, that a higher proportion of terrestrial species will have disappeared by the time the human population stabilizes at its projected level of about 10.5 million toward the end of the next century than even at the end of the Cretaceous. Furthermore, the geological record suggests that it is likely that the proportion of species that became extinct then may have disappeared over a much longer period of time than we are witnessing now.

What Should be Done?

From any point of view, the situation that has just been described is extremely serious. Scientifically, we are losing the opportunity to understand the nature of much of the diversity of life on earth. Aesthetically, we are losing the chance to appreciate fully the results of the process of evolution over the billions of years since life appeared on our planet. Economically, we are denying to ourselves, our children, and our grandchildren the opportunity to utilize many of the plants, animals, and microorganisms that exist now for their benefit. By our passivity, selfishness, and preoccupation with our own national problems, we are allowing the chance to study and utilize these organisms to slip through our fingers. The period of worldwide disorder that is becoming more pronounced is avoidable if we begin to view ourselves as members of a human race that has reached unprecedented levels and is growing explosively at the present time. The fact that we are already utilizing 40% of the earth's net biological productivity on land at a time when our total population is growing so rapidly ought to alert us to the problem, and cause us to take action to address it on a scale far beyond any that we have contemplated so far. The fact that one out of every four people is living in absolute poverty, that at least one out of ten is malnourished, and that the life expectancy in sub-Saharan Africa is 20 years shorter than that in industrial nations — these are all indications of severe imbalances that threaten global stability profoundly and need attention urgently. They cry out for our attention.

Sustainable Development

Human needs will be met in a sustainable way only if development is carefully planned (e.g., National Research Council, 1982). In the tropics and subtropics particularly, the intensive utilization of those extensive areas that are already deforested or clothed with secondary forest ought to be undertaken as a matter of first priority. Virtually all of the food, timber, and fuelwood needs of these regions could be met by the intelligent use of such lands. In using intact forests and other vegetation types, management practices that leave much of the respective ecosystems in place, while allowing for the production of such commodities as wood, other useful plant products, animals, and the regeneration of the forests, ought to be stressed. Finally, substantial natural areas ought to be preserved as an integral part of development plans, to serve as parks and reserves, natural sources of germplasm, and as means for facilitating the maintenance of air and water quality and for erosion control.

Ecological information and environmental considerations ought to be integral parts of development planning, and such projects ought to be conducted and monitored in such a way as to add to the information base on which subsequent development plans could be developed. For this reason, careful natural resource evaluation ought to precede, accompany, and be maintained after the completion of all major development schemes. If such efforts are coupled with the strengthening of institutions in Third World countries, the outcomes are likely to be positive and lasting.

The potential role of biotechnology in providing cheap, efficient ways to improve important Third World crops, such as millet, cassava, and yams, deserves special attention (Elkington, 1986; Brown *et al.*, 1987). Such improved crops, combined with appropriate levels of chemical and mechanical support, as well as economic and political reform, could dramatically assist in the effort to make small farms sustainable in the tropics.

International Assistance

International development assistance, carefully planned and targeted, is a critical factor in building global ecological stability. Because environmental effects are now expressed on a global scale, and because a recognition of our shared humanity demands it, those of us who live in industrialized countries cannot afford to ignore the rest of the world, or regard our relationships with it as a mixture of commerce and charity. We must cooperate with the peoples of tropical countries to improve their stability, whether our aims be economic, political, conservation-oriented, or moral. As Pope John Paul II said in Nairobi in 1985, the vastness and complexity of these problems require not only a concerted response at the local and national level, but also concrete assistance, in the form of a coordinated effort, on the part of the international community. The words of Pope Paul VI to the Stockholm Conference in 1972 are highly relevant: "Interdependency must now be translated into common responsibility; common destiny in solidarity".

The creation of stable ecological systems that support human beings depends in part on the transfer of technologies from industrialized nations, but it depends even more fundamentally on the training of people living in developing countries and on cooperation with their institutions. Only by helping to create a group of well-trained individuals in the developing countries themselves can we insure the sustained application of the fruits of development to the problems of these regions. For example, in sub-

Saharan Africa, the problem of the sustainable production of food in adequate quantities is largely one of sound resource management, including the management of soils (Lal, 1987). Nevertheless, here, as elsewhere in the Third World, the number of technically trained people is small: fully three-quarters of the world's population, but only an estimated 6% of its scientists, live in developing countries, with proportionately fewer in Africa (Cross, 1987).

International aid needs to be re-focused in part on small farmers and landless peasants in the tropics. Very small amounts of money would be sufficient for them to live relatively stable, productive lives and to attain a measure of dignity. Their plight rarely seems to attract our attention, however; major schemes involving industrialization, dam-building, or construction seem rather to capture our interest and command our support, despite the fact that they rarely contribute to regional stability in a meaningful way.

In October, 1987, Prime Minister Rajiv Gandhi of India and Prime Minister Robert Mugabe of Zimbabwe, addressing the United Nations during a debate on the report of the World Commission on Environment and Development, made clear the common role of rich and poor countries in contributing to environmental destabilization. In this connection, Mr. Gandhi stated, "The compulsions of development and limitations of financial resources tempt many developing countries to exploit their natural resources beyond endurance, ignoring environmental safeguards". Both men called for industrial countries to assist the economic development of the poorer nations so that their people do not need to live in ways that damage their land, and for the amelioration of the debt.

Recent debt exchanges for the interconnected purposes of sustainable land use and conservation, notably in Bolivia and Costa Rica, offer great hope for the future. Neither these successes, nor anything else, however, should allow us to distract our attention from the fundamental need to transfer resources from the industrialized world to developing countries in order to promote global stability. In the United States, the wealthiest nation on earth, with a national budget of more than U.S.$ 1 trillion, public opinion, mirrored in Congress, regards $ 15 billion as a very high sum for all foreign assistance, including military assistance. Whether or not the United States has the ability to spare 1.5% of its budget, or approximately $ 62 per person, on such assistance, is hotly debated, while it is readily accepted that other national programs deserve a sum a hundred times as great. Against all the evidence, the United States, along with other industrialized countries, acts as if, with a rapidly declining minority of the world population, it can continue to control about 85% of the world's wealth, and that global stability — allowing for the perpetuation of the current standards of living into the 21st century — can somehow be achieved, as if by a miracle, with only a minimal degree of attention and a great deal of wishful thinking. This is an exceedingly dangerous myth, to say the least, and one that can only lead to disaster.

Conservation

The conservation of biological diversity should also be a matter of deep concern, and should receive much more attention than it does at present. Such conservation will be successful, however, only when it is linked with appropriate, sustainable development. The threat of extinction on a global scale should be enough to mobilize us, considering our dependency on organisms. The effort will involve learning more about the organisms of all groups and redoubling our efforts to make this information available for scientific and societal purposes. An appropriate network of parks and reserves must be created and supported internationally on a continuing basis, and steps must also be taken to preserve representative samples of groups of organisms of particular actual or potential economic and scientific interest in zoos, botanical gardens, seed banks, tissue culture centers, deep-frozen, as cloned DNA, or in any way that is appropriate. The opportunities to find and to study such organisms will never be greater than they are at present, owing to the continual loss of species, and these opportunities are therefore far more critical to our future than many others to which we give priority.

It is important to note and take advantage of the increased awareness of the problem of conservation in developing countries that has grown markedly over the past five years. In India, Brazil, Indonesia, Malaysia, Sri Lanka, Costa Rica, Ecuador, Kenya, and many other tropical countries, grass-roots conservation movements, often privately funded, have begun to show real promise, leading to the preservation of forests and to the stable use of resources. Privately generated, government-stimulated tree planting programs in India, for example, show great promise for reversing the historical trend towards deforestation in that country. Even though the trees being planted are not for the most part native, and massive extinction continues, the plantings will certainly relieve the pressures on the remaining native forests, in the best spirit of the World Conservation Strategy.

At any event, the choices that we make and the ways that we pursue them will increasingly determine which animals and plants still exist beyond the middle of the next century, so we must make them with care and determine in the most rational way possible what we wish to survive.

Research

Through the cooperative efforts of scientists and technicians throughout the world, new information bases must be developed and maintained, and the information from them must be made widely and directly available for the common good. For example, satellite imagery can be used effectively to monitor the condition and rate of decrease of tropical forests worldwide (Melillo *et al.*, 1985), and an international scheme to do so would be relatively inexpensive in relation to the advantages of having up-to-date and accurate information in this area. Remote sensing affords the opportunity to investigate the global ecosystem in new ways, and to add greatly to our understanding of the interactions between life and the planet that we inhabit (National Research Council, 1986b).

The detailed investigation of the biota, and the relationships between them, at certain selected localities in the tropics, should be undertaken on an urgent basis. Only in this way can comprehensive scientific information bases be developed for scientific purposes or for development. The outstanding centers operated by the Smithsonian Institution at Barro Colorado Island in Panama and by the Organization for Tropical Studies at La Selva in Costa Rica, or the rich fund of information that has been developed at Serengetti in Tanzania, may be taken as examples of the kinds of development that should be undertaken at selected sites throughout the tropics.

At the same time, biological diversity can logically be catalogued throughout the world (Wilson, 1985), with emphasis on relatively well-known groups and those of known or potential economic importance (National Research Council, 1980). Only by increasing our knowledge of key groups of organisms can we know better how to deal with them while they are still in existence, and to better utilize and conserve them. The construction of comprehensive data banks about the properties of organisms through electronic data processing will be an important element in the realization of such goals, and will help in the necessary selection of priorities for action in this area. For conservation purposes, it will be necessary greatly to strengthen our knowledge about the dynamics of forest conversion, and the ways in which it leads to species loss.

As mentioned, the cooperative development of institutional capabilities, as well as the education of individual scientists and technicians, in developing countries must receive the highest priority as the only possible means of dealing with the global ecosystem effectively. Only by involving and supporting the experts who live in the countries involved, and are in a position to understand their problems well, can genuine progress be made.

Resource Management

In the industrialized nations of the world, the realization that the promotion of stability of tropical, developing countries is vital for us all is spreading, and governments are starting to take action appropriately. The Tropical Forest Action Plan, now being considered actively by many nations, and by the FAO and similar agencies, constitutes an imaginative effort to reverse the destruction and degradation of forests throughout the tropics. National assistance programs, and international lending agencies, such as the World Bank, are building a concern for biological diversity, part of the key to stable productivity, into their plans. All of the efforts should be cherished and strengthened, and used as a basis for improving the world situation, rather than simply passively watching it disintegrate further.

The rate of destruction of tropical forests can be slowed most dramatically by developing lands that have already been cut over or degraded rather than opening new lands, a principle that has been recognized explicitly hy the World Bank and other development-assistance agencies. Both the commercial logger and the fuelwood gatherer can clearly grow the crops that they need in these lands, and the cattle rancher could easily produce more than twice the world demand for beef in the pastures that are already available. For the slash-and-burn cultivator, a more complex approach is necessary, involving the development of agroforestry and the credit to make it work, intensive tree crop systems, and market advice to make cultivation profitable. Increasing attention to the rural poor will be necessary if our common prohlems are to be addressed effectively. In general, greatly increased investment in rural areas, and in agriculture, essentially the policy that China has followed consistently in recent years, will be necessary to achieve regional stability and also to control the runaway growth of major cities in the Third World (Brown *et al.*, 1987). Arable lands must be managed for high, sustained yields, and the potential of biotechnology, already mentioned, must be utilized to develop energy-efficient crops. Such trends as the rise in world consumption of fertilizer between 1950 and 1986 from 14 million to 131 million tons, or in tractors from 5.6 million to 23 million, simply cannot be sustained on a global basis (Brown *et al.*, 1987). Taken together, however, the possibilities outlined above offer ample hope for the future, if they are taken seriously and pursued with vigor.

A very promising new trend in the conservation of natural areas concerns their better integration into the human systems of their regions. Lands bordering the reserves may be occupied by people and utilized in a way compatible with the long-range future of the reserve itself. The imaginative scheme developed by Daniel Janzen to develop the 1000 square-kilometer Guanacaste National Park in Costa Rica by rehabilitating several hundred square-kilometers of degraded deciduous forest breaks important ground in this area. Portions of the park will be used for recreation, farming, and other uses, and simply to remind Costa Ricans of the role of this ecosystem in their national history. This scheme clearly provides a model of global importance for the preservation of biological diversity in the tropics in a way consistent with human values.

The world today is one in which it is all too easy for a nation to "export" its ecological problems through economic means. Industrialized nations, for example, have tended to seek commodities, such as beef, timber, and cassava, in developing countries without regard to the environmental cost of producing them for those countries. Acid precipitation is exported from one country to another, making relationships between neighbors increasingly tense, and other forms of pollution are simply shifted in location in ways that benefit the richer nations. No nation can really safeguard its own long-term ecological interests any more — if it ever could — only by tending to its own internal policies (Myers, 1986). Rather, a new form of thinking about global interrelationships will be necessary if our common ability to utilize the biosphere productively is to be protected — recall that we are now using directly, foregoing, or converting about 40% of net global terrestrial productivity, and that these numbers are projected to double in the next 41 years, if anyone doubts that necessity.

The unplanned consumption of natural resources in tropical and subtropical regions, epitomized by the loss of the rain forests, often amounts to permanent or at least long-term loss of the resources. In attempting to alleviate this problem and to implement stable ecological and economic systems, the governments of the less-developed countries that we are discussing, already faced with staggering debts, a sluggish world economy, and the rapid loss of the productive capacity of their lands, face challenges of the most serious nature. Their economic gains must be devoted largely to the attempt to continue to care for the needs of their people at late-1980s levels. Even if they were able to do so, however, the numbers of their people living in absolute poverty would continue to increase as rapidly as their populations as a whole. Poor people would obviously continue to destroy their forests and to consume other natural resources more rapidly with each passing year. The net effect of these processes is global instability at a number of different levels.

Conclusions

In general, an awareness of and compassion for all life, and an appreciation of the fact that we are all part of a living world that is capable, in its full development, of capturing energy, originally from the sun, and making it available for the life procesess of living organisms, are the key to an orderly development of the world. We cannot avoid profoundly modifying the global biosphere, and in fact have already done so; our use or waste of some 40% of the total net global production of photosynthesis is but one way in which our intense influence can be demonstrated most dramatically. Nevertheless, we should not allow ourselves to respond only when the crises that we have caused are so extensive that they threaten our lives. In the words of Pope John Paul II at Civitavecchia earlier this year, "We live in a world which must be valued and respected, and we must not give in to the temptation to alter its equilibria".

As His Holiness Pope John Paul II stated in Nairobi in 1985, "It is a requisite of our human dignity, and therefore a heavy responsibility, to exercise dominion over the created world such that it may truly be for the enjoyment of the human family. The exploitation of the riches of nature must happen according to criteria that take into consideration not only the present needs of people, but also the needs of future generations. ... Progress in the field of ecology, the growing awareness of the need to protect and conserve limited natural, non-renewable resources, are in harmony with the demands for a healthy governance. *God is glorified when the created world serves the needs of global development of the entire human family*".

Beyond the extinction of species, we are participating passively in the promotion of unstable world conditions, in which it will simply become impossible to continue to enjoy the benefits of civilization as we know them. The utter immorality of knowing these facts and offering no response to them should be apparent to each one of us. As the Pope has stressed so often — for example in Punta Arenas, Chile, and among the beautiful forests of the Dolomites earlier this year, on the feast of Saint Giovanni Gualberto — we must resolve to manage the riches of the world so that they will be available to future generations, and not simply consume them for our short-term benefit. Let us resolve as a consequence of the discussions we are holding here to strengthen our activities in this most critical area, and to do the best of which we are capable for the common good.

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DISCUSSION

Odhiambo

Indira Ghandi said, at the beginning of the Stockholm Conference on the human environment in '72, that the greatest factor in the degradation of the environment is poverty. I think that what Peter Raven has said this morning underlines this message, which at that time was very controversial. In fact, all those years, nearly 20 years, have shown again and again that poverty is at the crux of the matter, at least insofar as the Tropics are concerned.

Now, one of the issues that concerns me and many other people in the Tropics is how to deal with the question, how to make the poor communities in the rural areas have a turn around in their lives and therefore participate in sustainable development for their own generation as well as for future generations. I think this is a question that the international community as well needs to be concerned with, and I have a belief that the utilization of science and technology to address the problems of the rural poor is probably the greatest challenge we have in the Tropics. That is very easily said but extremely difficult to translate into action, because we are probably dealing there with problems that have not been addressed in the past. When you are talking about how to manage your agricultural production for the resource-poor farmer, you are really asking a great deal of science, and even more of technology, to devise methodologies that can address their problems.

Here we are talking not simply of appropriate technology in the usual terms; rather we are talking about very sophisticated science to develop technologies which will be simple to utilize. The challenge is great, and it is in that respect that I particularly like what Professor Raven has said, that the answer is not simply technology transfer. In fact, I would say that's only an emergency measure. The question that we have to address is how to capacitate the scientific communities in the developing regions of the world to address those problems themselves and how they can develop their own competence over a period of time to continue to address those problems. It is in that respect that we can begin to have what has now become very fashionable, but I think really important: to develop technologies which will lead to sustainable development. The Brundtland Commission on the Environment and Development addresses this question again and again in economic and ecological terms and also in terms of human development. I think it is a great challenge for us to translate what her commission undertook into concrete terms as scientists and technologists, and as those who are concerned with the ethical issues of this generation and future generations.

MARINI-BETTÒLO

Thank you, Professor Odhiambo. I think you've indicated a very true point about poverty. We should overcome this problem. I think it's a challenge that we must meet. I remember, 50 years ago the rural areas in Italy, mainly in central and southern Italy, were rather poor. In the last years, I have found a great change, due to a new approach to land management and to the integration of small industry and agriculture. If we could develop and expand these systems all over the tropical countries, it would benefit all and end poverty. I know that Professor Odhiambo is working in this field.

Now, I should like to announce the presence here of Dr. B. Wayne Luscombe, representative of the World Bank, whom we have invited to participate in this meeting because the World Bank, in recent months, has taken a particular interest in the environment. I think it is useful that our opinions, our ideas, should flow directly, without any intermediary, to the World Bank for future action.

PRZEWOZNY

Obviously I am not going to be stating anything that you probably do not know about, but what I would like to say about Professor Raven's presentation, especially keeping in mind what Professor Marini-Bettòlo said yesterday, is that there are obvious ethical issues that will have to be considered and cultural changes that will have to be introduced to face all of the problems that Professor Raven presented. To cite one case, a francophone conference was held in Quebec toward the end of August. The Province of Quebec had an ongoing investment in quite a number of French-speaking African countries which were heavily indebted, over 2 billion Canadian dollars. Rather than manage that debt, the Province of Quebec simply wrote it off as aid to the development of francophone African nations.

I personally don't think that is the best solution. Rather than continually manage that debt, the Province washed its hands and eliminated the problem.

IVES

Endorsing what Professor Raven has been saying, and keeping in mind our concern, expressed yesterday, is the need for doing everything we can to promote biodiversity. I would like to add something that I think is integral to it, and that is the need to promote cultural diversity along with it.

MALER

I would like to take up one subject that was discussed by Professor Raven, namely, the potential connections between bad environmental management and domestic and international political and military security which I think is very, very important. We have at the Royal Swedish Academy of Sciences, for a couple of years, tried to carry out studies in this field which we think is a very important one. We started out by formulating various hypotheses about linkages, from environmental degradation and bad management of natural resources, through different social mechanisms, environmental refugees, urbanization, political instability in large cities, and other similar social mechanisms. We have tried to initiate eempirical studies in order to see whether these hypotheses can be verified. Although this research programme has not been concluded yet, we hope that a year from now we will have ample evidence to show that some of these hypotheses are, unfortunately, very true, that environmental degradation may very well cause military conflict between nations. It may very well cause domestic, political, instability, which in turn will aggravate the environmental problems within the country. We are in a vicious circle because of these linkages. I think that's a very important topic that Professor Raven addressed.

SCARASCIA MUGNOZZA

I would like to make a comment on what Professor Raven said so firmly and Professor Marini-Bettòlo supported; that is the problem of the underdeveloped world. It is not only a problem of increasing agricultural productivity or global productivity in the world, but mainly a problem of education, of professional formation of people, of the single human being, men and women and young people. I think that the root of the problem is the elaboration of new and appropriate techniques, and the promotion of the rural families and each human being living there.

RAVEN

Well, I have little to add. I certainly would agree with Professor Scarascia Mugnozza and with Dr. Odhiambo. Only the incorporation of individual human beings and individual human families into the economic, political, and social systems of their countries will solve this problem. Doing so involves not only agricultural and forestry technology — the ability to manage small amounts of land on a sustainable basis — but also employing people in some other way in the economy. Over all, it involves a great deal of education, the diffusion of knowledge to the people, and the provision of the financial means whereby they can utilize this technology. No region can attain stability and peace until it attends to the needs of its poorest people. One quarter of humanity lives in absolute poverty at present, a factor to which we must all address ourselves urgently.

SCARASCIA MUGNOZZA

As far as the problem of soil conservation and of soil fertility is concerned, there are now, I think, new methods for maintaining soil fertility. I think that this is maybe one of the main problems for the promotion of agricultural productivity in the tropical areas. What do you think, for instance, of so-called alley-farming in Nigeria?

RAVEN

Many different suitable methods have been developed in different regions. For example, the chinampa system used by ancient peoples in Mexico consists of irrigated terraces where crops can be cultivated permanently. Research would lead to the development of additional systems, if we had the collective will to carry out this research and to provide the financial and political means to make the utilization of the results of this research feasible. To achieve this, governments will need to assign a central importance to the problems of the poor.

There are many difficulties. In Brazil, for example, the efforts of President Sarney to implement land reform met with an immediate widespread negative reaction. He has had to defer his program to the needs of Brazil's poor, who constitute nearly half of the population, even though only such a program offers promise of stability for the country. The kind of internal opposition is, unfortunately, mirrored to a large extent by the attitude of the international family of nations.

EVALUATING STRESSES ON TEMPERATE FOREST ECOSYSTEMS

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Introduction

The Temperate forest biome covers much of eastern North America, Europe, much of China and Japan, eastern Australia and portions of southwestern South America. These disjunct forests are rich in biological diversity and productivity, and are characterized by a moderate, seasonal climate. As a result, they have been major foci for the development of modern civilization, and, consequently, have been subjected to extensive disturbance and general environmental degradation.

The vegetation in this biome is characterized by deciduous trees and shrubs, but extensive areas of conifers (hemlock, pine, spruce, fir) are found at higher elevations, along coasts and at higher latitudes. In more moderate (less seasonal) climatic regions of the biome, broad-leaved evergreen trees and shrubs predominate.

Temperate forest ecosystems are stressed periodically by both natural and antbropogenic factors. Numerous types of natural disasters have affected forests in the Temperate Zone including wind storms (e.g., Bormann and Likens, 1979, pp. 199-201; Secrest *et al.*, 1941; Smith, 1946), fire (e.g., Heinselman, 1973), ice and snow storms (e.g., Bruederle and Stearns, 1985; Bennett, 1959; Lemon, 1961), defoliating insects (e.g., Barbosa and Schultz, 1987), pathogens (e.g., Davis, 1981) and landslides (e.g., Flaccus, 1958). To these natural stresses must be added those that have occurred as a result of modern human civilization, e.g., forest clearing for timber harvest, agriculture, urbanization and road-building, erosion, air pollution, introduction of exotic pathogens and herbivores, etc. The effects of natural disturbances provide a perspective for judging the effects of anthropogenic disturbances.

Because of my interests and experience, I shall focus my comments on anthropogenic disturbances, particularly the effects of timber harvest and air pollution on northern hardwood ecosystems (a mixture of deciduous species and conifers) in the North Temperate Zone. These ecosystems are highly variable and complex and, as a result, the effects of disturbance are complex and difficult to quantify.

Forest Clearing - Timber Harvest

Deforestation (e.g., through harvesting of timber) sets in motion a complex array of responses within the northern hardwood ecosystem (Fig. 1; and see Likens and Bormann, 1974b; Bormann and Likens, 1979). Drastic changes in the hydrologic, biogeochemical and erosional characteristics of the ecosystem occur when trees are killed or removed (Fig. 2; and see Bormann and Likens, 1979). Because transpiration is decreased when vegetation is destroyed, streamflow may be increased several-fold annually, and more than a hundred-fold during the summertime. In addition, greatly increased concentrations of dissolved substances in this drainage water result because of (1) accelerated decomposition, mineralization and nitrification of organic matter particularly in the forest floor, and (2) the absence of nutrient uptake by vegetation. Increased erosion may result because of greater increased runoff and reduced biotic regulation of erodability (see Likens *et al.*, 1978; Bormann and Likens, 1979).

Nevertheless, the northern hardwood ecosystem has remarkable redundancy and may recover rather quickly after such disturbance (Fig. 2), through (1) growth of seedling and sapling populations that were present before cutting; (2) growth and expansion of clones and stump or root sprouts, principally by pioneer species; (3) staggered germination of buried seeds; and (4) germination and growth of seeds that were produced just prior to the disturbance or that were transported to the site afterward (Likens *et al.*, 1978).

Nutrients lost as the result of disturbance can be regained from various external sources such as wet and dry deposition of atmospheric chemicals, and nitrogen fixation, and from weathering of minerals (see, e.g., Likens *et al.*, 1977; Likens, 1985). The amount of time and rate at which an ecosystem will recover hydrologically and biogeochemically following

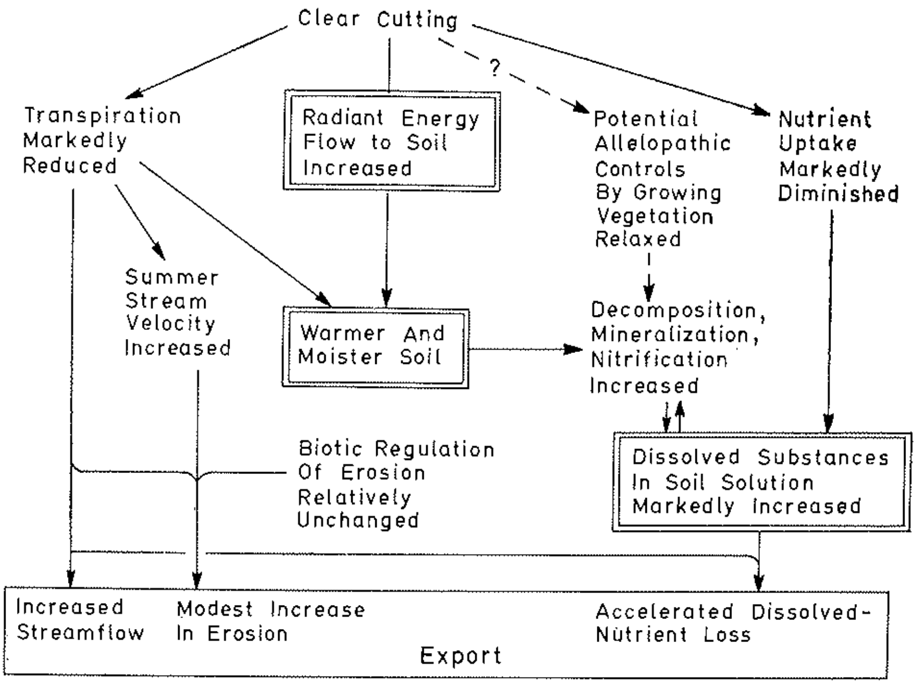

FIG. 1. Hydrologic and biogeochemical responses of the northern hardwood forest ecosystem during the first two years after disturbance such as clear cutting (from Bormann and Likens, 1979).

disturbance will depend on the type and severity of disturbance, nature of the site (e.g., slope), type of vegetation, climate, etc. In addition, recovery may be delayed by various additive effects of successive disturbances (see Likens *et al.*, 1978; Bormann and Likens, 1979). Based on a variety of studies in the northern hardwood forest ecosystem, we would suggest, for example, that this forest in the northeastern U.S. should not be clearcut for timber harvest more often than once every 70 years or so. This rotation period is compatible with natural regenerative processes (see Likens *et al.*, 1978; Bormann and Likens, 1979).

Endogenous or exogenous disturbance of Temperate forests can initiate a large and complicated assemblage of hydrologic, biogeochemical, energetic and behavioral responses, which in turn can cause other effects, such as eutrophication and acidification of surface waters and soils (Likens *et al.*, 1970; Likens and Bormann, 1974b; Likens and Bormann, 1979;

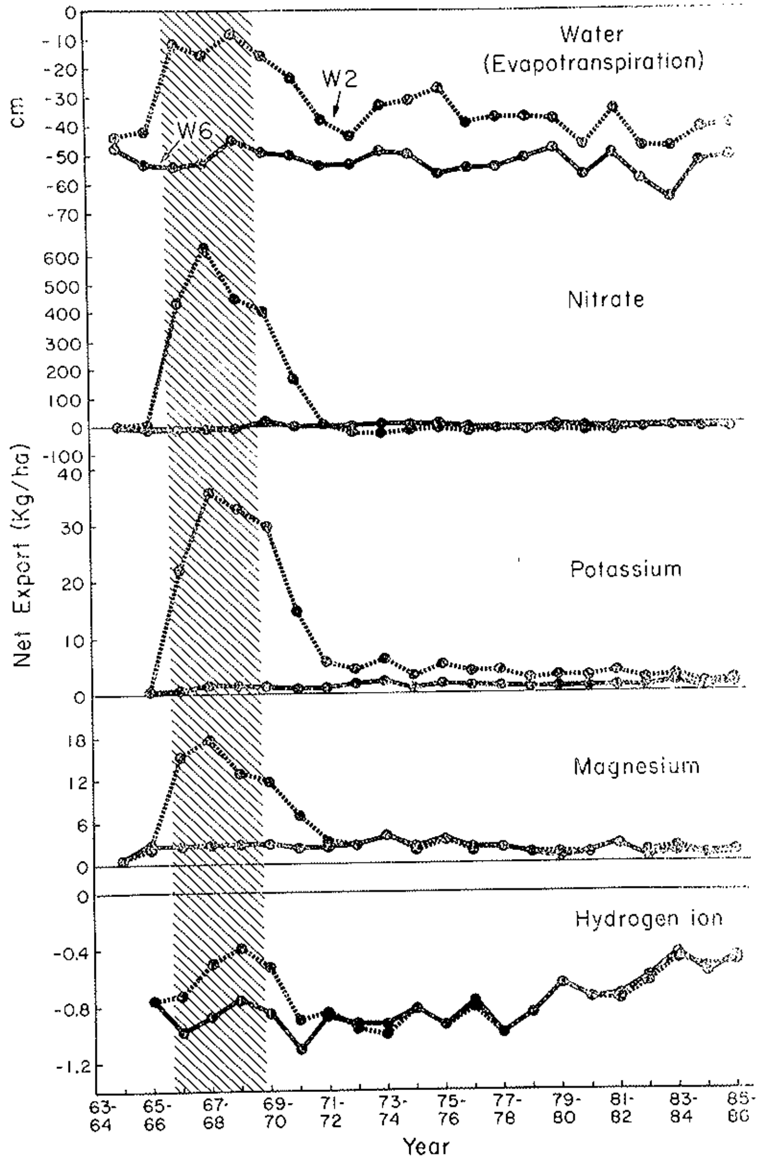

FIG. 2. Annual evapotranspiration and net export (input in bulk precipitation minus output in stream water) for dissolved substances in experimentally deforested Watershed No. 2 and undisturbed reference Watershed No. 6 of the Hubbard Brook Experimental Forest, New Hampshire, U.S.A. Watershed No. 2 was deforested betwen December 1965 and May 1969 (see Likens *et al.*, 1970).

Bormann and Likens, 1979). As the northern hardwood forest ecosystem develops with time, endogenous and exogenous disturbances produce a patchwork of trees of different ages throughout the landscape. As a result, the ultimate steady-state condition has been termed a "shifting-mosaic" steady state (Bormann and Likens, 1979).

Air Pollution

A large variety of chemical wastes or their by-products is being added to the atmosphere from numerous human activities. Some of these, such as ozone, sulfur and nitrogen oxides producing acid rain, metals and hydrocarbons, have reached high concentrations over widespread regions of the globe and are degrading natural ecosystems. The disposal of such toxic materials in the atmosphere represents a long-term threat to the structure and function of natural ecosystems and to human health and welfare.

There are many components of air pollution, but most are related to the combustion of fossil fuels, including carbon dioxide, carbon monoxide, sulfur and nitrogen oxides, metals (e.g., lead, mercury, cadmium, zinc, arsenic), hydrocarbons, ozone, and particles. The rapid increase in the amount of air pollutants and their widespread dispersal during the past few decades, primarily because of taller smokestacks, now provides a real as well as a potential threat to Temperate forest ecosystems.

Many of the problems of air pollution are linked either through similar origin, e.g., combustion of fossil fuels, through chemical interactions in the atmosphere, e.g., oxidants, fluorocarbons and hydrocarbons, or through synergistic ecological effects, e.g., combined stress from ozone and acids. These commonalities provide at the same time added complexity and optimism for control and regulation (Likens, 1987).

Forest trees are generally unhealthy, growing slowly or dying in several regions of eastern North America (Fig. 3) and Europe. The so-called prohlem of forest decline is widespread in Europe (Table 1), but the exact causes are not clear. Recent studies indicate that air pollutants can adversely affect reproductive processes in northern hardwood forests (Van Ryn *et al.*, 1986), can affect vital symbiotic, mycorrhizal fungal associations with tree roots (Reich *et al.*, 1986a), can acidify soil (Nilsson, 1986; Hallbäcken and Tamm, 1986) and can reduce net photosynthesis and growth in tree seedlings (Reich *et al.*, 1986b). Nevertheless, it is exceedingly difficult to sort out the relative importance of natural and

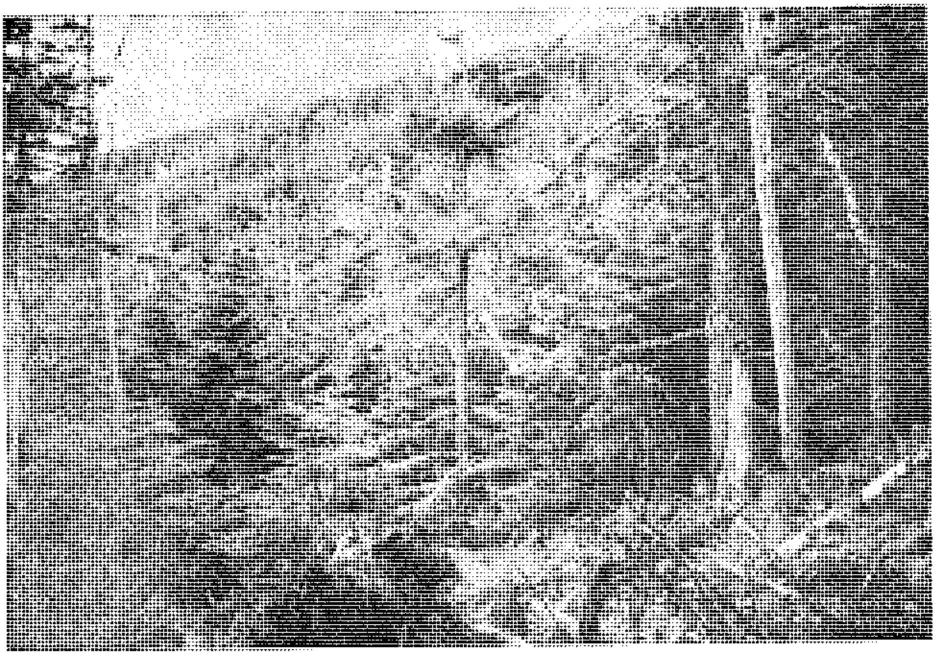

Fig. 3. Forest decline on Camel's Hump, Green Mountain, Vermont (photo by Gene E. Likens, July 1984).

anthropogenic stresses, which are variable and complex in space and time, under ambient field conditions.

A combination of factors can reduce vigor of individual plants to the point where any added stress can cause reduced growth or death. In addition, individual plants may respond uniquely to such stresses. The order in which the stresses affect plants also may vary in space and time. For example, a prolonged drought, unseasonal temperatures, plus acute impacts from ozone and acid deposition may cause widespread dieback where each of these factors acting independently may not. Such complexity of nature and biological response will tax our most able scientific minds to sort out, particularly from a regulatory point of view, the relative importance of the various environmental stresses on natural forest ecosystems.

Bormann (1982) has attempted to identify some patterns of damage in forest ecosystems under increasing levels of air pollution stress (Table 2).

TABLE 1 - *Estimated Forest Damage in Europe, 1985* (Modified from Postel, 1986).

Country	Estimated Area Damaged (ha × 10³)	Percent of Total Area
Austria	910	24
Belgium	111	18
Czechoslovakia	1,250	27
East Germany	350	12
Hungary	176	11
Italy	400	6
Luxembourg	42	51
Netherlands	138	45
Norway	400	5
Poland	600	7
Sweden	1,000	4
Switzerland	408	34
West Germany	3,824	52
Yugoslavia	1,000	11
TOTAL	10,609	8

It would appear that many Temperate forests in Europe currently are between stages II B and III A and in eastern North America between stages I and II B because of air pollution. Indeed, the combined impact of numerous air pollutants is much greater than was perceived some 15 years ago (Bormann and Likens, 1987).

Hinrichsen (1986) has attempted to rank in order of importance the primary pollutants causing forest decline in eastern Europe (Table 3), western Europe (Table 4), and North America (Table 5). The actual causes of forest dieback are poorly known, however, and thus schemes such as this, particularly the rank importance, are controversial and hotly debated by scientists and politicians. For example, Federer *et al.* (1987) have suggested that the recent decrease in growth of spruce and fir in the northeastern U.S. is simply a consequence of forest aging. A closer look at the complicated relationship between air pollution and forest health is in order.

TABLE 2 - *Patterns of Decline of Forest Ecosystems Under Air Pollution Stress* (Modified from Bormann, 1982).

Stage	Level of Anthropogenic Pollution	Severity of Impact on Ecosystem	Expected Ecological Effect
0	Insignificant	Pristine	None
1	Low Level	Relatively unaffected	Ecosystem is a sink for pollutants
11 A	Levels inimical to sensitive organisms	If continued, possible significant changes in competitive ability of sensitive species	Reduced photosynthesis, changes in reproductive capacity, changes in vulnerability to insect or fungal attacks, deleterious effects on nutrient cycling
11 B	Increased pollution stress	Resistant species substitute for sensitive ones	Sensitive species lost from the system, mostly due to secondary effects like fungal or insect attacks, failure in pollination
111 A	Severe levels of pollution	Large-scale changes in original system	Large plants of all species die, toxic concentrations of accumulated pollutants limit many species. Severely diminished regulation of biogeochemical cycles
111 B	Very heavy pollution	Completely degraded ecosystem	Ecosystem collapses

TABLE 3 - *Primary Agents Causing Forest Decline* (Ranked in Order of Importance: modified from Hinrichsen, 1986).

EASTERN EUROPE:
1. Gaseous Pollutants (e.g. SO_2 and NO_x)
2. Ozone
3. Acid Deposition, Particularly Cloud Water and Fog
4. Toxic Metals

TABLE 4 - *Primary Agents Causing Forest Decline* (Ranked in Order of Importance: modified from Hinrichsen, 1986).

WESTERN EUROPE:
1. Ozone
2. Acid Deposition, Particularly Cloud Water and Fog
3. Excess Nitrogen
4. Growth-Altering Organic Chemicals

TABLE 5 - *Primary Agents Causing Forest Decline* (Ranked in Order of Importance: modified from Hinrichsen, 1986).

NORTH AMERICA:
1. Ozone
2. Input of Nitrogen
3. Other Phytotoxic Gases
4. Toxic Metals
5. Acid Deposition
6. Growth-Altering Organic Chemicals

Ozone

Ozone is produced in the atmosphere by photochemical reactions utilizing both natural and anthropogenic precursors, such as nitrogen oxides and hydrocarbons. Atmospheric concentrations vary seasonally as well as during the day. Mean daytime concentrations for clean air during the summer in the U.S. range from 0.01 to 0.04 ppm, whereas the average 7-hour daily mean in the eastern U.S. varies from about 0.04 to 0.07 ppm (Reich and Amundson, 1985). Thus, the average dose of ozone to Temperate forests in the eastern U.S. for a 10-week growing period in summer would range between about 30 and 45 ppm-hour. Short-term peak concentrations exceed 0.10 ppm during summer in the eastern U.S.

Long-term records of ozone concentration in the lower atmosphere are rare, but it appears that average concentrations in rural areas are increasing in Europe (Fig. 4).

Increasing dosages of ozone have been shown to cause visable damage to plants (e.g., stippling of leaves and necrotic spots), and reduction in net photosynthesis in tree seedlings in controlled chamber experiments (Fig. 5). Of potentially greater significance, other studies have shown statistically significant reductions in the growth of numerous species of tree seedlings from *ambient* ozone concentrations in the eastern U.S. (e.g., Duchelle *et al.*, 1982; Wang *et al.*, 1986). These studies strongly suggest that current ambient levels of ozone are reducing the growth of Temperate forest trees even without visible effects such as stippling.

Acid Rain

Acid rain is a popular term for the wet and dry deposition of acidifying substances from the atmosphere. The phenomenon of acid rain was first described by R.A. Smith over one-hundred years ago (see Smith, 1872), but the regional implications were not reported for Europe until 1968 (Odén, 1968) and for North America until 1972 (Likens *et al.*, 1972; Likens and Bormann, 1974a). Currently, acid rain is widespread in North America, Europe and Asia (see Likens, 1987).

These strong mineral acids in the atmosphere of the Northern Hemisphere originate primarily from the oxides of sulfur and nitrogen, which are released during the combustion of fossil fuels, such as coal and oil (see Driscoll *et al.*, 1985; OTA, 1984, p. 60; Dovland and Semb, 1980). The sulfur and nitrogen are returned to landscapes in wet (rain, snow, and cloud and fog water, sleet, hail) and dry (gases, particles) deposition.

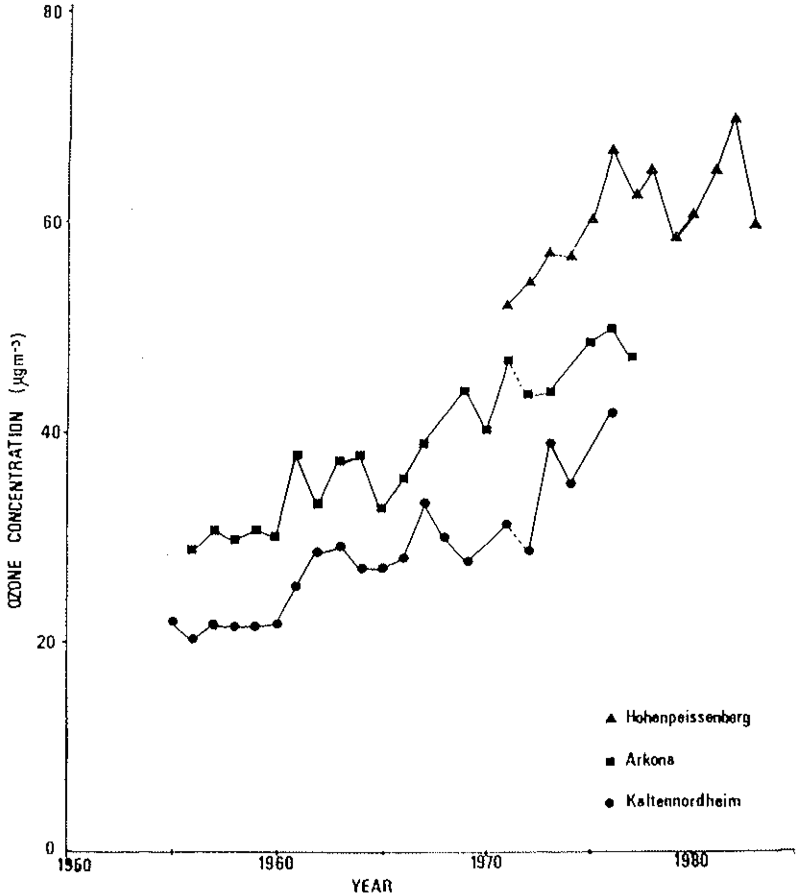

FIG. 4. Trends in mean annual ozone concentration at three rural monitoring stations in East Germany (Arkona) and West Germany (from Ashmore *et al.*, 1985).

Inputs to natural ecosystems from dry deposition are poorly known, but dry deposition of sulfur may be equivalent to 30% to more than 100% of inputs from wet deposition (Likens *et al.*, 1977; Eaton *et al.*, 1978, 1980; Grennfelt *et al.*, 1985). As a result, *acid deposition* is a more informative term than "acid rain".

Recently Rahn and colleagues (1985 and 1986) have shown, using various elemental tracers which give unique regional signatures, that about 85% of the sulfur in rain and about 45% of the sulfur in aerosols collected in Narragansett, Rhode Island, USA, originated from sources several hundred to a thousand kilometers to the west. The remainder came from local northeastern sources.

There have been important changes in the emissions of sulfur and nitrogen oxides to the atmosphere of the U.S. and Europe since the beginning of the century (see Husar, 1986; Dovland and Semb, 1980). In the U.S. emissions of both have increased since 1950, but SO_2 emissions peaked in the early 1970's and then decreased following emission-control regulations of the U.S. Congress' Clean Air Act of 1970. In contrast, emissions of NO_x generally have increased since 1950 and currently are almost as large as emissions of SO_2 (Fig. 6). Emissions of SO_2 in Europe have increased more rapidly and exceed those in the U.S. by about 2 times (Likens *et al.*, 1979).

At the same time that the amount of emissions were increasing, the height of industrial smokestacks was becoming taller in the U.S. and elsewhere (see Likens, 1984, 1987). As ever increasing amounts of SO_2 and NO_x were discharged at greater heights in the atmosphere (particularly for SO_2; see Figs. 7 and 8) the acids were spread to a greater extent regional-

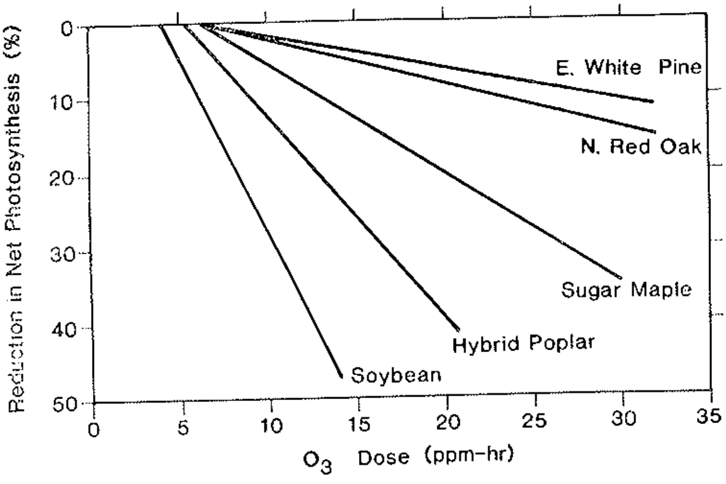

FIG. 5. Percent reduction in net photosynthesis, relative to background dose, for increasing dose of ozone. The natural background of ozone might be about 0.01 ppm or a 10-week dose of 5 ppm-hour (Kulp, 1987). By comparison, ozone dose "in most of the eastern United States during a 10-week period in the summer ranges between 30 to 45 ppm-hour" (modified from Reich and Amundson, 1985).

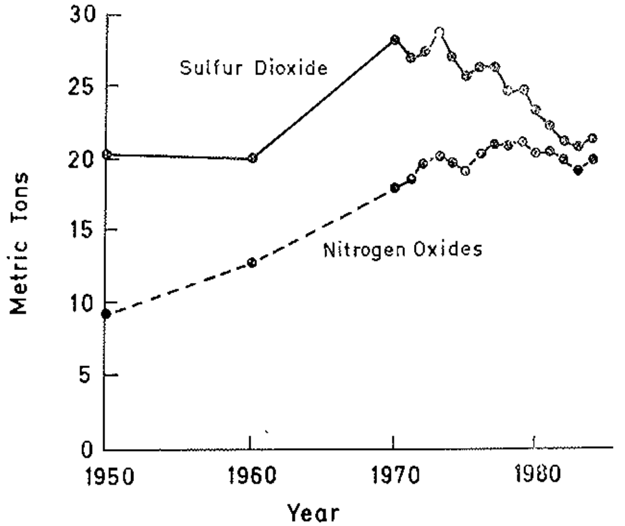

FIG. 6. U.S. emissions of sulfur dioxide and nitrogen oxides, from 1950 to 1984 (from U.S. Environmental Protection Agency, 1985).

ly, rather than being deposited locally (see Likens and Bormann, 1974a). Tall stacks are built in direct response to local pollution, and have been a major factor in converting local, frequently urban, air pollution problems in the early part of this century, into regional problems in the latter part of the century.

The concentration of sulfur and nitrogen in rain and snow in the northeastern United States currently is 10 to 15 times greater than in remote areas of the Southern Hemisphere (Fig. 9; also see Galloway *et al.*, 1984). About 60 to 65% of the acidity of precipitation in the eastern United States is derived from sulfuric acid and 30 to 35% is derived from nitric acid (based on data from the United States MAP3S Precipitation Chemistry Network). The proportions in Europe are generally similar (Granat, 1972). It is thought that most of the environmental damage occurs because of the sulfuric acid (e.g., Driscoll and Likens, 1982; Galloway *et al.*, 1984).

Even though concentrations of sulfate are declining in the northeastern U.S. (e.g., Fig. 10), wet deposition of sulfur is still 2 to 4 times greater than that thought to cause chemical change and ecological damage in sensitive aquatic and terrestrial ecosystems (Dickson, 1978; Gorham, 1984; Nilsson, 1986b). Inclusion of dry deposition would make these loadings of sulfur 4 to 8 times greater than acceptable levels (Likens, 1987).

Operationally, rain and snow at a pH of less than 5.6 (lowest value for pure water in equilibrium with atmospheric concentrations of CO_2) have been defined as "acid rain". Natural emissions of sulfur, nitrogen and organic compounds, however, may lower the pH below 5.6 (see Charlson and Rodhe, 1982). Careful studies in several relatively unpolluted environments of the Southern Hemisphere would suggest that a pH of about 5.0 is a better reference value for unpolluted rainfall (Galloway *et al.*, 1982a; Likens *et al.*, 1987). At Katherine, Australia, for example, strong mineral acids produce a volume-weighted, annual mean pH of 5.08 (Likens *et al.*, 1987). Organic acids (e.g., formic and acetic) lower the pH below 5.0 at this site, but have little, if any, ecological impact on

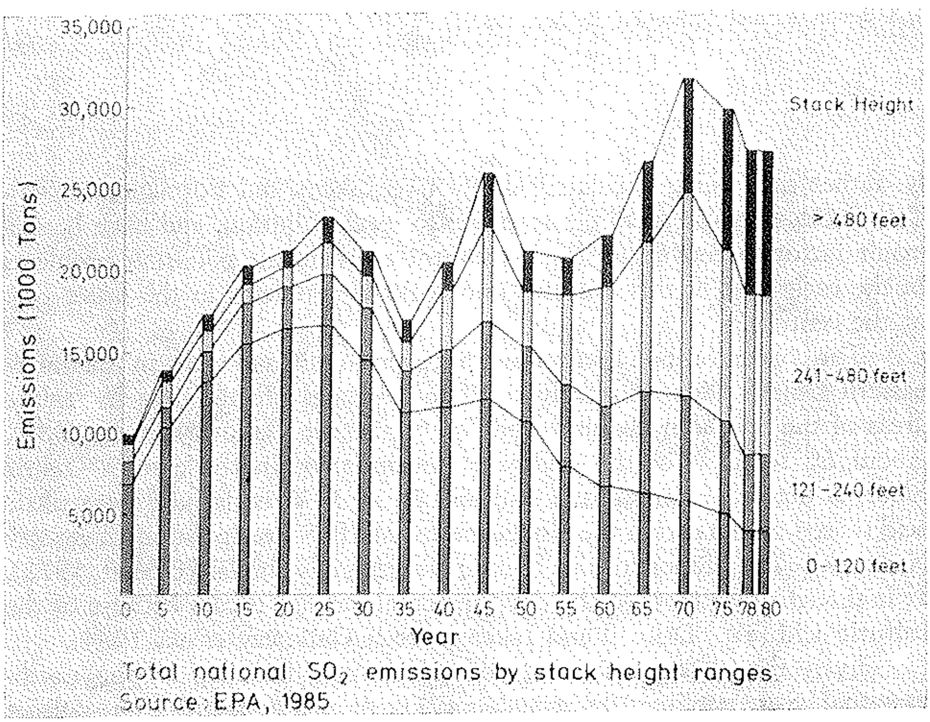

FIG. 7. Total U.S. emissions of SO_2 by stack height ranges (source, U.S. Environmental Protection Agency, 1985).

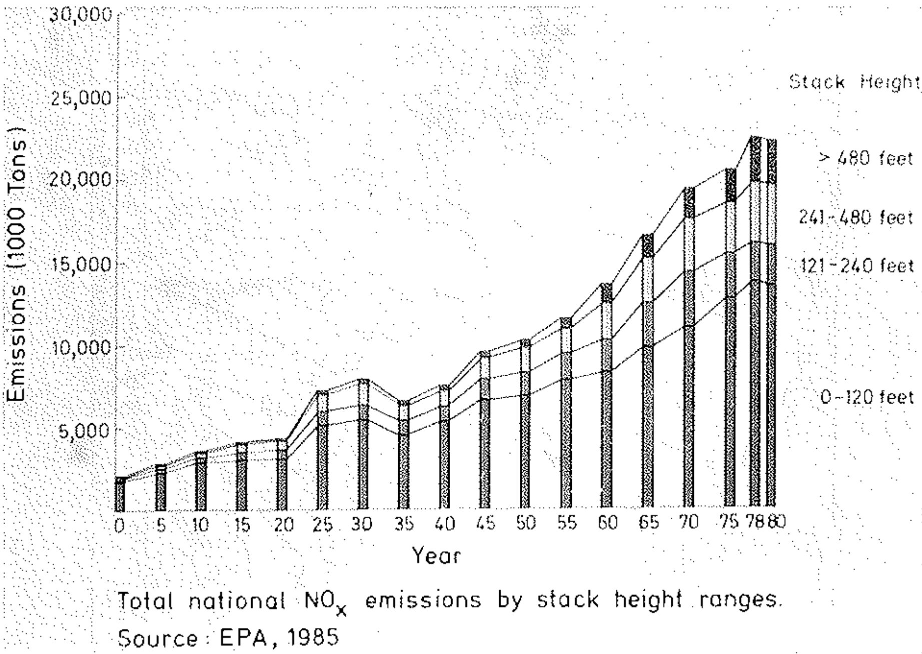

FIG. 8. Total U.S. emissions of NO_x by stack height ranges (source, U.S. Environmental Protection Agency, 1985).

natural ecosystems because the organic acids are decomposed rapidly to CO_2.

Currently, large areas of North America, Europe and Asia receive precipitation whose annual average pH is < 4.5, but annual values vary (Fig. 10). Individual rainstorms are also quite variable, and occasionally rainfall events have pH values < 3 (Likens *et al.*, 1979). The lowest value recorded for a rain event during 1968-1986 at the Hubbard Brook Experimental Forest in New Hampshire, USA, was pH 2.85.

On the average, cloud and fog water is 3 to 10 times more acid than rain water at several locations in the eastern U.S. (Weathers *et al.*, 1988), and individual events may be especially acid (Table 6). The lowest pH value recorded for cloud and fog water was 2.4 along the coast of Maine, U.S.A., in 1984 (Weathers *et al.*, 1988). In comparison with the rain water in remote regions of the Southern Hemisphere, cloud and fog water in the eastern United States is highly polluted from anthropogenic emissions (Fig. 11).

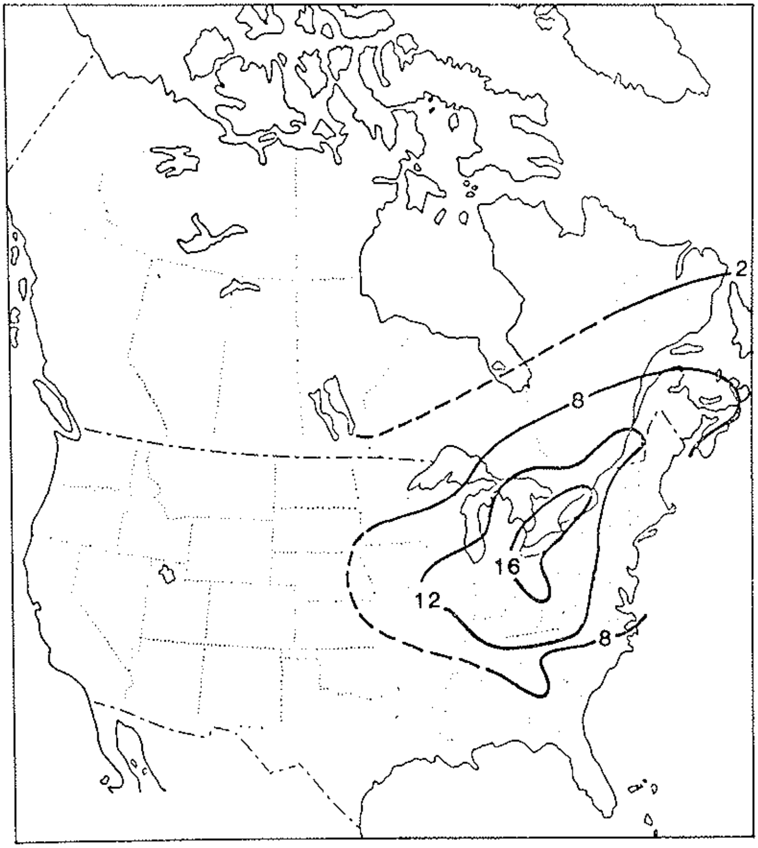

Fig. 9. Enrichment of sulfate in precipitation in eastern North America above that in remote areas of the Southern Hemisphere (from Galloway *et al.*, 1984).

Concentrations of sulfate, nitrate, hydrogen ion and other chemicals in precipitation vary with time depending upon changes in emissions to the atmosphere, changes in weather, changes in air-mass trajectories, etc. For example, long-term records of precipitation chemistry at the Hubbard Brook Experimental Forest show significant trends in precipitation chemistry and wet deposition over the past two decades (Fig. 10; also see Likens *et al.*, 1984, 1985).

Inputs of acids to natural ecosystems may vary during the year. For example, rainfall in the summer is usually more acid than snow and rain in the winter in eastern North America (Likens *et al.*, 1977, 1985).

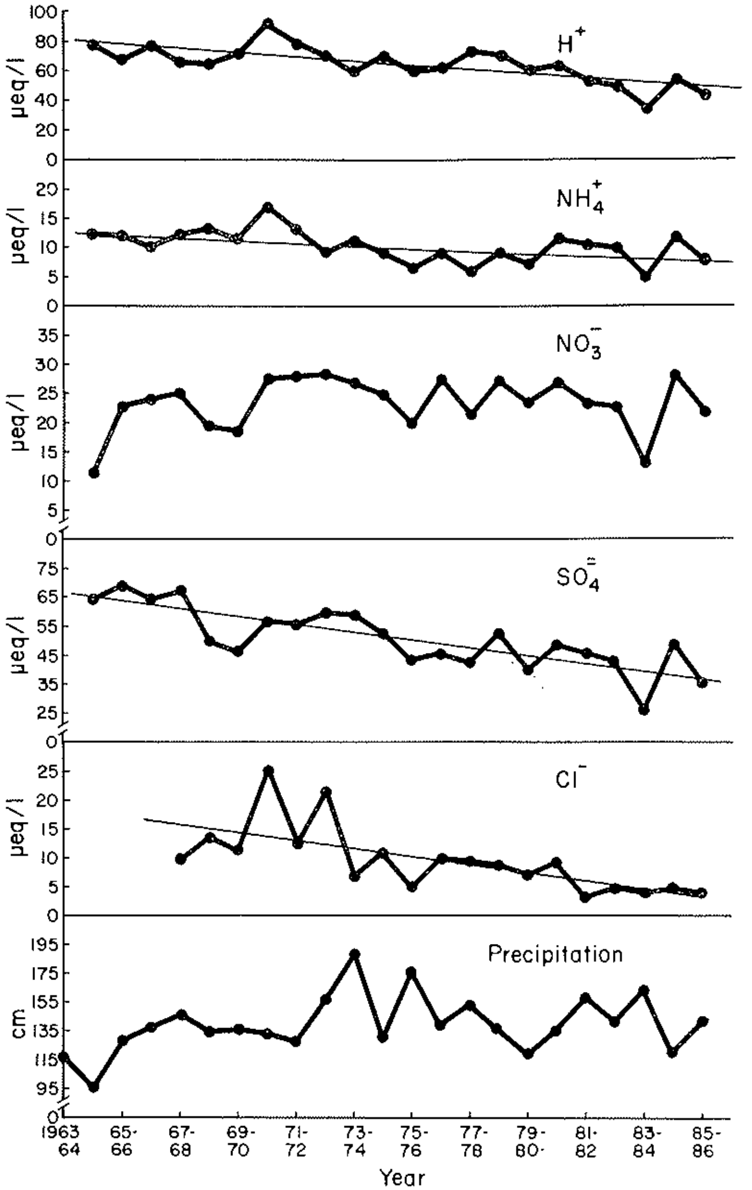

FIG. 10. Volume-weighted mean concentrations in bulk precipitation for Watershed 6 of the Hubbard Brook Experimental Forest during 1963-64 to 1985-86. The regression lines have a probability for a larger F-value of < 0.05.

TABLE 6 - *Minimum pH values of Cloud and Fog Water in the Eastern U.S. during 1984* (After Weathers *et al.*, 1986).

Site	Elevation (m above sea level)	Date	Cloud/Fog Field pH
Bar Harbor, Maine	10	7-8 August 1984	2.90
Bar Harbor, Maine	10	8-9 August 1984	3.00
Bar Harbor, Maine	10	9 August 1984	2.95
Mt. Washington, New Hampshire	1,524	10 August 1984	2.97
Mt. Lafayette, New Hampshire	1,220	10 August 1984	2.97
Mohonk Mountain, New York	467	11 August 1984	2.80
Hubbard Brook, New Hampshire	765	12 August 1984	2.97
Loft Mountain, Virginia	990	13 August 1984	3.09

Essentially, the opposite is true for northwestern Europe (Granat, 1978), but the cause is unclear. Moreover, meltwater from an accumulated snowpack in spring may be much more acid than the snow itself because of the separation of ions during the freeze-thaw process (e.g., Johannessen and Henriksen, 1978; Johannessen *et al.*, 1976, 1980; Hornbeck *et al.*, 1976). Mobilization of dissolved aluminum from the soil by acid drainage waters enhances the toxicity of these waters within the soil and in surface waters.

Effects of acid deposition on terrestrial ecosystems are very difficult to quantify because these systems are exceedingly variable and complex. Nevertheless, there is evidence suggesting that acid deposition (particularly for events of very low pH, i.e., less than 3.5), may be damaging to plants. Many rainfall events, and particularly cloud and fog water, are well below a pH of 3.5 (Weathers *et al.*, 1986, 1988; Falconer and Falconer, 1980; Lovett *et al.*, 1982; Waldman *et al.*, 1982; Scherbatskoy and Bliss, 1984). The acidity of cloud water in the eastern U.S. frequently occurs in the range known to cause injury to plants under experimental conditions (see Figs. 11 and 12; also see Crang and McQuattie, 1986; Van Ryn *et al.*, 1986; Funk and Bonde, 1986).

Highly acidic events may be coupled with high levels of ozone and toxic metals (Weathers *et al.*, 1986) with high potential to cause plant

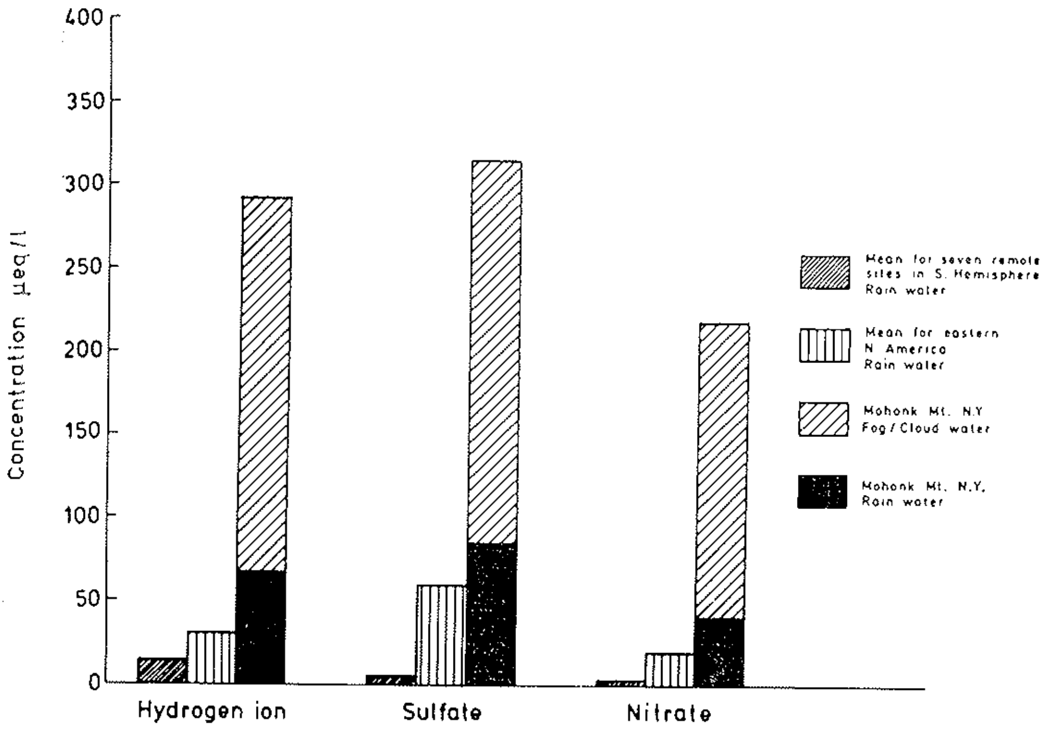

FIG. 11. A comparison of the average chemistry of precipitation in remote sites of the Southern Hemisphere, in average precipitation in eastern North America (both modified from Galloway *et al.*, 1984) and in cloud and rain water at Mohonk Mt., New York, U.S.A., during 1984 and 1985.

damage. This topic is receiving intensive study currently in the U.S. and Europe.

Toxic Metals

Large quantities of toxic metals have been released to the atmosphere from anthropogenic activity (Table 7). In high concentrations these metals have caused drastic effects on Temperate forests (e.g., smelter operations of Ducktown, Tennessee, U.S.A., and Sudbury, Ontario, Canada). At lower rates of deposition toxic metals add to the general stress on terrestrial ecosystems. For example, Temperate forest ecosystems seem to be excellent filters for lead added in rain and snow (Smith and Siccama, 1981). The forest floor at Hubbard Brook accumulated lead at a rate of about 27 mg/m^2-yr during 1975-1979. By 1979 the total lead content of the forest floor had risen to worrisome levels of about 8.6 kg/ha (Smith and Siccama, 1981).

Interaction Between Pollutants

Other environmental variables or pollutants may affect or enhance the effects of ozone on trees. For example, it appears that ozone damage may be enhanced by high relative humidity and increased surface wetness of leaves (Wilhour, 1971; Davis and Wood, 1973; Chappelka *et al.*, 1986). Ozone-acid rain interactions may be minimal at pH values > 4.5 (Kulp, 1987), but the much higher acidities in cloud and fog water in combination with damaging levels of ozone have a high potential to cause additive damage (e.g., Weathers *et al.*, 1986).

The uncoupling of various biogeochemical cycles is another important effect of combined air pollutants on natural ecosystems (Schindler, 1985; Ulrich *et al.*, 1980), but the final results are difficult to predict.

— Does forest decline from air pollution increase nitrification in the soil and acidity of drainage waters (see Fuller *et al.*, 1987)?

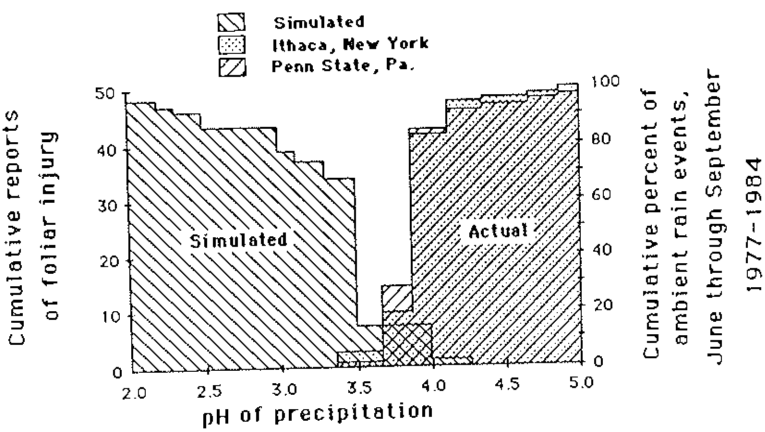

FIG. 12. Cumulative foliar injury from simulated rain in greenhouses or experimental chambers at different pH values in comparison with the pH of ambient rain at Ithaca, New York and Penn State, Pennsylvania (modified from Jacobson, 1984).

TABLE 7 - *Estimated Annual Global Emissions of Selected Metals to the Atmosphere circa 1980* (from Galloway *et al.*, 1982b).

Metal	Human Activity	Natural Activity	Ratio of Human to Natural Activity
	(*thousand metric tons*)		
Lead	2,000	6	333
Zinc	840	36	23
Copper	260	19	14
Vanadium	210	65	3
Nickel	98	28	4
Chromium	94	58	2
Arsenic	78	21	4
Antimony	38	1	38
Selenium	14	3	5
Cadmium	6	0.3	20

— Can there be long-term effects on erosion and transport of sediments from catchments with forest decline because of changes in erodibility, and particularly in the maintenance of organic debris dams in streams (see Likens and Bilby, 1982; Hedin *et al.*, 1988)?

The answers to these questions, and others, at the ecosystem level will be important to evaluate fully the impact of air pollution on aquatic ecosystems and to devise sound restoration and management policies.

International/Global Considerations

Air pollution in developing countries has several interesting and important political and policy dimensions. As developing countries strive to increase their gross national product a greater demand will be placed on energy generation (largely from fossil fuels). The People's Republic of China, for example, has an acid rain problem (Zhao and Sun, 1986a,b; Galloway *et al.*, 1987) and faces a series of major decisions relative to tradeoffs between the regulation of air pollution and economic development (see Likens, 1987). What is the optimum mixture of energy sources between coal, oil, hydropower and nuclear for such countries? What are the impacts of burning high- versus low-sulfur coal and oil? Currently, particles in the atmosphere are neutralizing much of the acidity of rain in eastern China, but the particles themselves represent a serious air pollution problem (Galloway *et al.*, 1987; Zhao and Sun, 1986a,b). Will the removal of particles exacerbate the acid rain problem? Which has a greater impact on human health, natural ecosystems and economic growth? Overall, conservation of energy must play a prominent role in these matters, particularly in developed countries, but awareness and support for such measures seem, unfortunately, tied to crises, such as the global oil crisis in 1973.

Global Climate Change

Global climate change caused by increases in CO_2 and other "greenhouse gases" in the atmosphere may represent the ultimate stress on Temperate forest ecosystems. Margaret Davis (personal communication) has suggested that Temperate forests may be devastated if the climate change is rapid (e.g., a mean annual temperature change of 0.45°C/decade). Such rates are suggested from current modelling efforts but uncertainties are very large.

Conclusions

Natural disturbances are severe on occasion, but to these must be added acute and chronic anthropogenic stresses such as caused by air pollution. There is little if anything we can (or should?) do about natural disasters, but we can and should stop the indiscriminate disposal of wastes from human activities in natural forest ecosystems.

Anthropogenic pollutants affecting Temperate forest ecosystems are complex and variable in space and time, and may act singly or in combination with natural stresses. The complex mixture of pollutants affecting natural ecosystems may be referred to as a "pollution climate". In turn, these stresses act variably and simultaneously on the myriad of components within the forest ecosystems (e.g., microorganisms, plants, animals), each of which may be more or less sensitive in space and time to the various components of this pollution climate.

Air pollution problems are not confined by political boundaries and frequently have regional if not global proportions. Thus, the solution to these problems requires the cooperation of numerous political entities,

TABLE 8 - *Spending on Military Versus Environmental Security* (Modified from Brundtland, 1987).

The World Spent over $ 900 × 10^9 on Military Purposes in 1985, more than $ 2.5 × 10^9/day

In comparison...

Environmental Problem	Cost $ × 10^9/yr	Equivalent Annual Military Expenditure
Action plan for tropical forests	1.3	0.5 day
Lack of clean water in third world	30	10 days
Acid rain - halving emissions of SO_2 and NO_x		
— Eastern U.S.	6	2 days
— European EEC	5-7	3 days

such as cities, states, provinces, countries. The problems cannot be solved independently as the individual recipients have little or no control on what they will receive from the atmosphere. Because Temperate forests are found in the regions of greatest air pollution, the biotic damage is most severe in these areas.

Forest decline and acidified lakes appear to be the first signs of a serious threat to Temperate forest ecosystems. Because of the enormous value of this natural resource to humankind, including cleansing effects on air and water, there is a clear need to minimize promptly the anthropogenically derived deterioration of this biome.

The cost of reducing air pollution is large, but it is insignificant relative to other expenditures made by political entities for their apparent military security (Table 8). Because of the enormous economic, social and environmental value of Temperate forests, it would be prudent to devote more of our efforts and more of our financial resources toward their protection and continued productivity. New and better bilateral and multilateral agreements between political entities must be established to promote the protection, health and maintenance of Temperate forest ecosystems.

Acknowledgements

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DISCUSSION

LUNDBERG

I think Professor Likens made an excellent presentation on how serious the problem is, but I would like to emphasize that the problem is probably more serious than the real figures on forest damage show, especially in the central Eastern Europe. The figure on the proportion of damaged forests in Poland is 7%, and in the southern part of the country as great as 25%. The trend of decreasing pH values in European forest soils will become a very serious problem in the near future. Linked to this problem is the release of heavy metals.

The third issue I would like to highlight is the question of global warming, which has been intensively discussed. Among scientists there is a consensus that we will have a global greenhouse effect, but we do not know how or when. Ten years more are needed to achieve the accurate date. Even small changes in temperature may have significant impact on terrestrial and limnic ecosystems.

KECKES

It was a very interesting presentation, and I was particularly struck by the statement, which is supported by a reference from Davis and Solomon, that the expected climatic changes may very seriously affect the temperate forests. If I understood correctly, your conclusion is that, if the expected climatic changes will really occur on the scale that is now predicted, within 50 years we may see very serious damage to the temperate forests. Could you elaborate on this? Is it based on some research or predictions based on past changes occurring in systems which have been stressed by temperature? Particularly, I would like to know if certain predictions in that respect have been made concerning the tropical forests also.

RAVERA

One comment and one question. You have shown before that in some parts of China you have a very high concentration of calcium in the rainfall, with a low concentration of hydrogen ions. This is the same situation in the zone of Venice, fortunately for tbe monuments of Venice.

The other is a question: why in Sweden — where was observed a series of very deep and important damages to the fresh water life in the lakes, we have only 4% of the forest damaged over all, from the acid rain, acid deposition and other causes. There is, in my opinion, a certain discrepancy between the damage observed in fresh water and in the forest in Sweden because also the swedish soil has a low concentration of calcium.

LIKENS

These are all interesting questions. First of all the question about soils. Soils are one of the key components in the long-term health and survival of forest systems. As I indicated in my talk, this is one of the important differences between disturbance to tropical forests and to temperate forests. In general, tropical forest soil is more fragile in response to disturbance than is temperate forest soil.

Temperate forest soils have developed over thousands of years and they are rich soils with thick organic layers. If major changes occur, they are probably serious and long-lasting. Some very interesting Swedish data, for example, from Carl Olaf Tamm, have shown that soils in Sweden on some plots, measured 60 years apart, have become appreciably more acidified, presumably from atmospheric deposition of acids sulfate. Such changes occur in temperate forest ecosystems very slowly, but in turn these systems will recover very slowly. It is always difficult to talk about irreversible changes when referring to natural ecosystems because, as I tried to emphasize, the biology of these systems is very robust. There is much redundancy and the capacity to recover is very large, but when it takes thousands of years to recover from disturbance, we approach the definition of irreversibility at least in terms of a human lifetime.

I agree that we won't know the answer to climate change for some time. There are very large uncertainties about changes in atmospheric carbon dioxide and global climate change, and it is not just carbon dioxide. Ozone and a series of greenhouse gases affect the atmospheric environment and global temperature. But a point of major concern is that we may not be able to wait for ten or twenty years to find out if a change has occurred. Chlorofluorocarbons and ozone are a good example of chemical reactions that once begun cannot be stopped. We must decide, as soon as we possibly can, what we think is correct and then take action accordingly. We don't have the luxury in some cases to wait until all uncertainties are resolved.

The effect of global climate change on temperate forests was studied by

Margaret Davis and Al Solomon. They have attempted to look at the temperature at which temperate forests could exist, as best they can put this information together from paleo records. The forests in the temperate zone are responding to a variety of different environmental factors, and acid deposition is just one of those. It seems to me perfectly feasible that the forests in Sweden are responding to this array of atmospheric pollutants and natural stresses in ways that are different from those in, say, East Germany, Poland, or the state of Vermont in the United States. Lakes in those areas are responding to the chemical environment that is produced by direct deposition from the atmosphere, plus any ion exchange and geochemical weathering that occurs as water passes through the system. The trees not only respond to this land/water environment, but they stick up into the atmosphere and respond to sulfur dioxide, to which the lakes don't respond directly. They respond to ozone, to which the lakes don't respond at all, as far as I know, and so forth.

If a forest has just suffered through a drought of two years, has just had an attack from defoliating insects, and a number of other factors have by chance stressed the forest, and then along comes a major outbreak of one hundred parts per billion of ozone, that is probably enough to tip the balance; or if the forest has had all those things and then it is hit by an acid fog of pH 2.4 lasting for five days, that is enough to tip the balance. I believe this is a very plausible way of thinking about how those pollutants and other stresses interact in natural ecosystems.

GOLTERMAN

When we are talking about physical protection against environmental disasters, e.g., about building dikes in Holland, because otherwise we would have been washed away by the sea, tbe Swiss protecting themselves against avalanches, or populations protecting themselves against being flooded by rivers, we do not make a cost-benefit analysis. We take it for granted that we have to protect ourselves. In the protection against the chemical dangers in the environment, we seem to have accepted that there should be a cost-benefit effect. That's very nice for the economic people around here, but I'm upset by it because I want to have the same protection against chemical/environmental changes as against the physical ones. I don't need a cost-benefit analysis, although personally I am convinced that there is always a cost-benefit profit. I am quite sure that every dollar spent on the environment will in the end be repaying itself three of four times. The only problem is that by then we have other politicians who are not getting the benefits during the periods they are in office. Can we explain why we make this distinction between the physical and the chemical danger?

The second point I would like to make is about what you have called natural damage. I think that under natural damage you have classified some of the damages which are not natural at all. In Holland, we had a storm which destroyed 50% of the forest, because only a very small percentage of the country is covered by forest, and I am quite sure that if we had more forests, the damage would have been much less. Insect damage is very often due to the fact that we are not looking at a natural forest, but we are looking at monocultures, which are known to be much more sensitive to diseases and disasters than a natural forest. Actually, I don't think that in Western Europe we have any natural forests left. They are all cultivated forests. Do you agree with that point?

LIKENS

I would elaborate very briefly on the first point. As I said yesterday, I don't believe that it is possible to develop a true and accurate cost-benefit analysis for something like a natural ecosystem.

I agree that it shouldn't be necessary, but when our politicians in the United States demand it, it's not possible to do fairly because one cannot put a monetary value on some of the biological and ecological components in natural ecosystems. In a recent discussion, I suggested that each bacterium in a lake is worth one dollar, and I asked that it be proven that it's not worth one dollar. Each cubic centimeter of water in a lake contains about one million bacteria. Thus the lake is very valuable. That was my argument.

JEFFERS

Professor Likens raised what is to me a very interesting issue, and tables 3 to 5 in his paper also illustrate this issue, that is the importance of different pollutants in various parts of the world. I was at a meeting of scientists from the European Community earlier this year, where we tried to interest scientists who were working on air pollution in this topic of pollution climates, but with very little success. Part of the reason for this lack of interest is the extraordinary reductionism with which we have invested science at the present time. We had, at this meeting, experts on SO_2 who didn't know anything at all about ozone. We had experts on ozone who knew very little about SO_2, and still less about oxides of nitrogen. I was dismayed to find that there were many scientists there who were not even prepared to make some estimates of the likely levels of pollution. I was astonished to find the extent to which very highly reputed scientists were totally unwilling to even hazard a guess about the pollution climates in their own country, let alone in anybody else's country.

It seems to me that we are very quick to blame the politicians, the World Bank, or anybody else, but we don't often criticise our own institutions. I suggest that we often approach the very complex problems of ecology, economics and sociology by over-simplistic reductionist subdivisions. We cannot study ecology by looking at one species in a limited range of habitats, or even by looking at one predator and one prey in a few habitats. We have to be able to look at a whole system.

I am really making a plea, stimulated by what Professor Likens has said, for us to abandon some of the academic boundaries we draw around ourselves, in order to look at the wider system, and I believe this whole question of pollution climates is a very important one because we need to look at those climates in relation to other things that we are doing to the system. For example, one of the problems, certainly in Europe, with temperate forest is that there has been much undercutting of the forest for a considerable period. There is a far too high growing stock of forest in many countries in Europe, so that the forest is actually an over-aged forest. I remember standing on a hillside in Switzerland where the damage through air pollution was being pointed out to me in a spruce forest that was 250 years old. It was spruce forest growing on an area where I would never have planted spruce in the first place. So, if we impose a pollution climate upon that kind of man-made system, then clearly we are likely to have a problem, but we can only identify that problem if we look at the system as a whole.

MALER

I would like to defend cost-benefit analysis. Being an economist, I think it's my obligation to do that. First of all, I think one should remember that cost-benefit analysis is above all a way of organizing information in a logical way and that is the main purpose of carrying out the cost-benefit analysis.

Secondly, there is no such thing as a free lunch, we cannot get anything without paying, and we have to make some kind of a trade-off between what we are giving up and what we are getting in exchange. Now, assume that we have to consider an improvement in the environment and that that improvement will require that we use some resources which could be put to other uses. Is that improvement worthwhile? That is, would we be willing to give up those resources?

Some people would perhaps say immediately, "I would be willing to give up those resources for having an environmental improvement", and, for that case, we have the individual's personal cost-benefit analysis. All individuals may not share that view, however, and in order to get information on how the improvement will affect all individuals, we have to carry out a social cost-benefit analysis, to see what this improvement means for all individuals concerned.

What in fact Professor Likens did in the last minutes of his speech was carry out a cost-benefit analysis, by using data from the Brundtland Commission and trying to show that the benefits from increasing the supply of clean water in the tropical area is a good thing.

Di Castri

As an ecologist, I would also like to defend the cost-benefit analysis, not really because I am totally convinced of it, but because I realize, to my own regret, that this is the only statement that is debatable with some economists and decision-makers. A point has been made on the possibility of giving a dollar value to bacteria. I like it, but I doubt that it could be acceptable to decision-makers. I think that some new "expert system" can deal not only with quantifications, but also with some qualification.

As regards the point made by Dr. Jeffers, that is to say, whether ecology has to be simply considered as a biological discipline, or as a more integrative science, I want to stress that this also implies an aspect of career incentive. In many countries, only a very specific disciplinary approach can lead to a career at the university or research level, while interdisciplinarity is badly rewarded.

As regards the comparison between temperate and tropical forests, I have the feeling that too many different tropical forests are being included in the same basket. First of all, tropical soils are extremely different, ranging from very poor leached soils to more robust volcanic ones. Secondly, acidification is also a problem in tropical ecosystems. The acidity of rainfall in the Amazonian Basin is very high. It has been found, moreover, that rainfall acidity is higher in the natural Tai Forest, on the coast of Ivory Coast, than in the industrialized Abidjan capital.

Just a word of caution in the use of the term "civilization". It would not be fair to say that there have never been civilizations in tropical countries. On the contrary, there have been rich (both from a cultural and technological viewpoint) and old civilizations, like the Mayas in south Mexico, Incas, Nigerian, Thai, Balinese, Nepali and Tibetan, among others. Admittedly, some of them have been on the mountains, that is to say in a "less tropical" environment, but others really corresponded to flat tropics.

My final remark is about the usefulness and impact of very large conferences. It has been ironically said sometimes that there is a positive correlation between the number of meetings on tropical deforestation and the rate of deforestation in the tropics. While admitting that action does not automatically follow the publication of a large report or the holding of a large conference, it is undeniable that they have had, at least, the effect of increasing awareness of the problem.

RAVEN

I differ from the preceding speaker, do believe that our views may help lead to action through an improvement in international awareness. Although no one effort will lead to a solution of the world's problems, our continued attention to them offers our only hope.

With respect to the differences between tropics and temperate regions, it is important to remember that even though there are many similarities, some two-thirds of tropical soils cannot be cultivated successfully using available technology. For the better soils, we need to apply the best available technology as part of our scheme to achieve or at least to approach regional self-sufficiency in food.

Finally, I would like to say that I do believe that cost-benefit analyses have an important role to play in finding optimal solutions to the problems confronting us. The analyses of acid precipitation, offered earlier, provide clear examples of this role. In this area, cost-benefit analyses clearly point the way to specific action that we can take. They offer us the means of ordering the factors involved and choosing the actions that we wish to take.

ODHIAMBO

I think that the two speakers have put a very important focus on advocacy and the actions arising from advocacy, and I think that is an important issue. First let me say that the Brundtland report as well as the IUCN World Development Study have played a very important role in the last half dozen years in that the world has become more conscious. These are, of course, not the only, instruments for making the world much more sensitive about these issues, but they are certainly some of the more important ones. I would say that the way that the Brundtland Commission has gone about telling the world what it has done is a very potent way. People have attended at least three meetings in different parts of the world where Mrs. Brundtland has explained what the Commission tried to do, how it reached its results. I think the question really is where do we go from information and advocacy to actual action. One of the distressing points — I see in many of these initiatives — is that in many fora the people who are directly involved are really not represented; they have not really taken part in the decision-making process. I think we have to alter this. We have to be in a position where the scientists and the technologists and policy makers are actually participating in the recommendations and decision-making, and eventually in actual implementation of those decisions.

Let me give you a description of what my own community, the scientific community in Africa, has done. In the last 18 months, the African Academy of Sciences has mounted a mission to visit some of the African countries and explain the problem not only within the national scientific community but also to the policy makers at the governmental level and, in some cases, at the head of government or head of state level. We have already visited 8 countries and that sensitization is beginning to change. I am not saying that it's changing, but it's beginning to change the way that the government will be approaching development issues, including forestry and agriculture. The Academy has now gone further in the last 6 months; it has mounted a different kind of mission of experts to deal with both water and soil management, because we believe that in Africa, with its very fragile tropical soils, the key resources are water and soil. Thirdly, we are beginning to develop methodology and other kinds of workshops to bring the scientific community itself to deal with these issues. In other words, the third resource, human capital, is very important to the solution. I am not saying that this is the only way that the African scientific community can address the issue, but it's a beginning, and I think that the scientists are being involved in that decision-making process.

DI CASTRI

I would like not to give the impression that I am totally cynical as regards any kind of report. I agree with what Dr. Odhiambo said in that the reports should not be the climax but just the starting point for action. Unfortunately it has happened too often that the conference reports have raised great expectations, reaching a stage of climax, and that this phase ended in an anticlimax of little or no action. I sincerely hope that the Brundtland report, which is in fact a good report, will represent this time the pioneering stage for far-reaching action.

KECKES

Your problem here is that the Brundtland report has been commissioned by the United Nation and submitted to the United Nations last week. It is very typical and characteristic that the governments which have commissioned this report have not gone into action but only taken note of the report. I am not trying to say that the report is excellent or marvelous or what not, but that a lot of work went into it. Nobody had problems with the basic ideas expressed in this report. The General Assembly took note of the report and prepared a two-page recommendation extracted from it. You should not blame the Brundtland Commission and similar commissions set up by the wish of a government. I think the fault is in policy makers. All the reports on various topics end up, you know, as nice declarations without real action. The problem is somewhere else. Probably the monstrosity of military spending, to which Dr. Likens has referred, is so huge that it escapes our human imagination, and that is why we can't understand it. It is beyond our comprehension that by spending half a day of military spending you could solve a serious problem, and nobody takes it as a serious proposal, and so on and so on.

LIKENS

I want to argue with Professor Raven a little about cost-benefit analyses. I wouldn't argue against putting your facts together and then arguing from those facts. That's a totally logical, reasonable way to proceed. However, in the United States, cost-benefit analysis is clearly based on monetary values. That's where I have problems with cost-benefit analysis. It is like my bacterium example that's worth a dollar. You would have difficulty saying what any of the species in the tropics was worth in terms of dollars. But they are worth more than that. Some of them are priceless treasures because, in fact, we can't put a monetary value on them. A plant chemical with enormous medical value to mankind is a priceless treasure. When cost-benefit is defined so narrowly that something as complicated as a national ecosystem can have monetary value only in comparison with an engineer's cost for a smokestack or for a bridge or for a road, then that's where cost-benefit analysis falls short.

ENVIRONMENTAL PROBLEMS IN ARID ZONES

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In this paper, we plan to discuss some of the aspects related to ways in which environmental problems of the arid zones of the world can be treated.

First, it will be necessary to discuss briefly some features of land deterioration in the arid and semi-arid areas and the seriousness of this situation.

The arid lands in their various degrees of dryness constitute the arid ecosystem, and, while occupying one-third of the earth's surface, are responsible for a large part of man's food production [1].

Of the eight-hundred and fifty million (850,000,000) inhabitants (1983) of these zones, about five-hundred million (500,000,000) live predominantly in the rural areas [2].

According to information of the United Nations Environmental Program [2], 75% of the earth's total productive land area is affected by some kind of deterioration. Annually, while about 20 million hectares of fertile lands also become exposed to deterioration problems, the world's rural population, which is seriously affected by the difficulties generated, increases by about 135 million inhabitants.

These problems of the environmental deterioration which occurs in the arid and semi-arid areas were classified at the United Nations Conference on Desertification as "the diminution or destruction of the biological potentials of the land which finally leads to desert-like conditions. Desertification is one feature of the generalized deterioration of those ecosystems resulting from the pressures of an adverse and fluctuating climate combined with excessive exploitation" [3].

According to Rodrigues [5], land deterioration can be identified in a general way based on the influences of this process on the different component parts of an ecosystem:

1. Elimination of the original vegetation cover and the appearance of an invader's vegetation cover;

2. Partial or total loss of the soil as a result of either physical factors (erosion) or chemical effects (soil salinity or alkalinity);

3. Qualitative and quantitative reduction in water resources;

4. Reduction in the duration of the runoff period;

5. Increase in the occurrence of dust-storms, whirlwinds or sand-storms;

6. Reduction in the fertility and productivity levels of the soil, which in turn negatively affect both animal and agricultural productivity-production;

7. Increase in waste areas, due principally to human activity such as mining;

8. Increase in food gathering behaviors in areas where more organized productive activities were formerly practiced;

9. In relation to the human population, a reduction in density with a relative increase in the number of young and the aged, a predominance of the female sex and a high migration rate among younger men who move into the ghettos of large urban centers;

10. With regard to socio-economic activities, a reduction occurs in the income rate and in the production-consumption relation, that is, an economic activity which was once basically primary or productive now becomes secondary or consumption-oriented. At the same time, there is an increase in unemployment, a reduction in investments and a growth in the importation of basic food items. Finally, a sense of self-rejection is generated by giving-in to survival problems and of neglect and withdrawal on the part of governmental institutions since such areas normally lack political and/or economic importance.

In discussing the causes of desertification, we commonly find ourselves in a conflicting situation which can be expressed thus: Is desertification fundamentally caused by human activities or a combination between these and ecological factors? And if the deterioration of the soil is a result of the combined effects of both ecological and human factors, how does each one actually contribute to this process?

According to several authors quoted by Rodrigues [4], it is very difficult to attribute desertification to climatic factors alone because no extensively drastic climatic changes have been found to exist in the semiarid regions of the world.

Owing to such explanations, it remains rather more difficult to accept that ecological factors, such as aridness or droughts by themselves, could provoke desertification in a relatively brief span of time.

Nevertheless, it is probable that an ecosystem, which presents predispositional conditions favorable to desertification and is subjected to the activities of man, could manifest in a short time period the consequences of desertification much more rapidly than in a different ecosystem.

With respect to this situation, we should make some remarks about droughts. The lack of rain over long periods of time, in conjunction with other determinants, leads to the phenomenon known as drought.

On account of the inexistence of records which prove recent regional climatic changes, it could be advanced that droughts are constant events and that, irrespective of their unpredictability, the inhabitants who live in these areas should already be adjusted to them.

It goes without saying that if a dry period exists, then there is a wet season too. The probability of having a dry season is almost equal to or higher than that of a wet period. Unfortunately, the people who inhabit regions more prone to droughts prefer to think of the dry season as sporadic and the wet periods as more normal. Such a predisposition accounts for two basic problems:

— the inhabitants are almost never ready to face the long dry season, and,

— in the wet periods, so much pressure is exerted on the ecosystem that it loses its inbuilt resistance mechanisms for supporting the following dry season.

Eckholm and Brown state: "Even though no great climatic changes have taken place, our experiences of the world's arid regions demonstrate that droughts are inevitable in dry environments. Consequently, although not precisely predictable, a drought should not come as a total surprise" [6].

In these areas natural phenomena are almost always present in their relatively extreme degrees. Disasters caused by droughts or floods take place frequently and in relatively short time spans. It appears that man still does not know how to live adequately well in either the dry or wet seasons, which are the two basic climatic periods of arid ecosystems.

According to Daubermire, "man's survival capacity while confronting those ecological problems which arise from the climatic cycles is relatively limited because of the fact that these periods are not systematic. Notwithstanding this situation, man can still estimate with some precision the extreme limits of their intensity" [7].

Thus, according to the above considerations, only human factors seem capable of creating conditions which can lead to desertification within a relatively short time.

From the various cases analyzed in the study conducted by Rodrigues, the most common causes of desertification could be listed as the following: overgrazing, irrigation farming, forest removal, excessive cultivation and the land tenure system. On the other hand, this author affirms in his study that "it was impossible to establish a relationship between environmental characteristics and the phenomenon called desertification" [4].

Considering all such information, we could then logically ask: How should the process of desertification be attacked? It could be proposed that to combat desertification, we should adopt two basic actions:

— the presentation of locally adaptable, scientific and technical solutions, and

— political decision-making policies to adopt such solutions.

Above all, it is implied that in addition to these actions, which could lead to combating desertification, there is the necessity to interfere in the social, economic and political behavior of the people.

On account of all these considerations, to combat desertification does not necessarily mean to prevent erosion, soil salinity, deposition on riverbeds or many other consequences, but fundamentally to eliminate those determining factors which provoke these consequences. In addition, if we consider this phenomenon in the short run, these factors would be found to be necessarily connected with the activities of man.

From the political-operation standpoint, it is important to make a clear distinction between man and human activities when treating the causes of desertification. Establishing that man is the primary cause is a sure way to visualize no real solution to the problem, considering that it would be impossible to eliminate him from a desertified area. However, if we state that man's activities are the basic causal factor, it would be possible to picture some real solution to the problem since it is conceivable to eradicate a certain number of these human activities through behavior modification. Even though man as such should be held responsible, on no account should he be considered the direct cause of desertification.

It is very important to emphasize that the level of precision with which we analyze human activities is a determining factor in the search for adequate changes. For example, to say that animal husbandry is a human activity is not equivalent to the raising of cattle using a system of pasture rotation!

Those activities of man considered as determinant forces leading to desertification could be considered in two concrete ways: those which result from inadequate utilization and others which are due to intensive use. Unfortunately, many a time, it is difficult to establish a human cause-effect relationship when dealing with desertification since the so-called consequences manifest themselves in a general context.

Notwithstanding the tendency to point to man as the major cause of desertification, one observes that in case studies no necessary and specific details which can allow the establishment of more concrete relationships between the causes of desertification and man's activities are offered. In this context, for example, we could cite mining activity, one of man's activities considered to bring about desertification. However, much more important than the mining in itself, are those concomitant activities which arise in this situation.

Normally, what happens in a mining area is that there is a peak period which is characterized by a sudden population explosion, which in turn leads to an over-demand on the environment and the development of secondary, disorganized and irrational agricultural activities. In this case, in order to combat desertification, we should not attack the mine itself, but rather those secondary activities which evolve around the mining. Besides, there is a more complicated issue, that is, how do we convince the local community to substitute its mining activities, with all the profits involved, with another which certainly brings less economic benefits?

Nonetheless, we uphold that human activities, either through intensive or inadequate land utilization, always do affect the physical environment. At this stage we are confronted with one question: What does inadequate mean? Does it refer to the appropriateness of the available means or the capabilities of the man who uses these resources?. If we agree that the management of desertification first of all entails the control of human activities, then inappropriate utilization does not exist. In one way or the other, the use of available resources is always adequate in attending man's interests either due to his knowledge/skills, the profit level involved or in response to the demands of an external market. Therefore, in order to control desertification, we must regulate the effects of man's activities in terms of intensity and extensiveness, more especially in those regions where alternative activities are limited.

We could also ask the following questions: Are sheep and goats causes or consequences of desertification? Could they be considered causal elements due to their inappropriate use or by their intensive and extensive uses? Probably, there are various case studies that present some affirmative answers to the different aspects of our questions. The case of Coquimbo in Chile and some parts of the Northeastern Region of Brazil show that goats and sheep were only introduced after the cattle arrived. Its is clear that if we analyze the introduction of sheep and goats as a response to the problems generated in an area already deteriorated, over a short time we would change these animals from being a result to being a causal factor because of the necessity for extensive pasture. A consequence of this extensive use without control would show the effects of intensive utilization. In such a situation we should try working with the local community in order do acquire a new meaning for inadequate use in the long run, a concept characterized by intensive and extensive utilization.

Although there exists a great diversity in the kinds of cultivation that could be developed in such areas, these alternatives would appear very limited because of the reduction in the productive potential of the soil and the choice between growing food-crops or non-food-crops. Even though the primordial objective of a farmer is to make profits like any other human being, in many cases his urge to produce crops for food prevails. This drive can allow the possibility of trying different control methods with the objective of recovering the land's productivity and the introduction of commercial crops.

Despite the fact that it would appear radical, we could say that in order to combat and recover desertified areas would only imply the bringing about of changes in the social structure and the use of the available local resources. Modifications in the social structure are directly related to the land tenure system and overpopulation. With regard to the land tenure system, we could forward that large land areas-privately, state or community owned-tend to give the wrong idea about land size and consequently a feeling of unlimited resources.

With this background information, it becomes clear that in order to combat desertification, it is implied that, above all, we have to find out:

— at what exact stage changes should be provoked in the system, and,

— the best ways in which the local population should be treated.

At this point it is important to state that local communities of desertified areas can be characterized by some problems, such as:

— unjust and inappropriate land ownership systems;
— high emigration rates within the labor force;
— low socio-economic standards; and,
— low formal educational (schooling) levels.

Unfortunately, for those who work in desertified areas, most of the studies existing about this topic have so far proven to be of little or no use because such research has not considered the environmental interactions in conjunction with human factors. In order to become clearer, such investigations should point out the stages at which the activities of man begin to influence those environmental variables being studied. Such studies should also make some specific and realizable suggestions concerning human activities with the objective of reducing or eliminating the problem.

On the other hand, those environmental protection efforts which are made in the arid and semi-arid zones normally encounter difficulties due to the perceptions of the community, the scientists and the government institutions, about the problem.

As a general rule, the people who live in these areas fail to distinguish between the consequences of wrong soil use and the subsequent reactions of an adverse climate. Moreover, their options for survival are so limited that they do not even worry about environmental problems.

With regard to the scientists, the difficulty is that they almost always do not live the realities of the arid zone and, so, their perception of the inherent problems are very different from those who live in these areas. As a result, what they frequently call technical-scientific "solutions" never turn out to be definite answers to the problem.

On the part of government institutions, especially in under-developed countries, even when they have evidences demonstrating the destruction of the soil's potential productivity, the hydrological resources and the exodus from the rural areas because of the reduction in the quality of life, these institutions always try in strange ways to ignore the existence of the grave socio-economic and environmental effects of such a situation. This is because of the fact that governmental actions are always motivated by short-term political and economic interests. Thus, the resulting gains become private profits; the damages are social. It is important for governments to realize that in the short and long run, environmental problems are social problems above everything else.

Having discussed and understood the various ways of looking at and some forms of treating the process of environmental deterioration in the dry and semi-arid zones, we now go on to give a brief description of the research we are conducting in the Northeastern Region of Brazil.

In the south of the State of Piauí in Brazil, more specifically in the Gilbués desertified nucleus, two projects, "The Evaluation and Control of the Process of Desertification in the State of Piauí" and "The Recuperation of Desertified Areas", are being developed.

From the beginning of the 1970s, the state of Piauí was invaded by large agricultural and animal raising projects which devastated the original vegetation cover of the land. These projects also led to intensive erosion processes which in turn not only provoked a drastic reduction in the productivity levels of the agricultural lands but also caused the drying up of main rivers.

The present state of the quality and quantity of both the water resources and the soils is really preoccupying. In the extreme south of Piauí, a land area of roughly 1,240 km^2 is totally exposed to the effects of water and wind erosion. As a consequence of the use of fires and excessive mechanization which have been destroying vegetational cover, it can be observed that there is a grave reduction in alimenting the subterranean water deposits which in many cases form the principal water source for the local inhabitants.

Today, serious flooding processes, which are observed in the lower parts of the river basin due to superficial drainage and the deposition in the main canals of the valley, have caused significant social and economic losses to the State. Only in the last few years, more than 150 thousand family units were expelled from their settlements while agricultural and animal farming production levels dropped by more than fifty percent (50%).

In the light of this situation, the two research projects mentioned above plan to do the following about the desertification process:

— generate subsidies for programming soil conservation and land utilization practices; propose corrective and preventive strategies for regaining soil productivity, vegetational cover and an improved quality of life;

— identify and evaluate its physical, micro-climatic, biological and socio-economic effects;

— evaluate its intensity level;

— characterize its principal causes.

With reference to the second project, especially, indigenous forms of resistance to desertification are being studied with the aim of diffusing the findings among the whole community.

Conclusions

Pointing out recuperation and control methods for the problems of environmental deterioration in dry land areas depends basically upon:

a. the level at which we want to work (national, regional or local);
b. the available manpower and its interdisciplinary character; and,
c. the availability of financial resources and government aid.

Even though several traditional methods for the study of these problems do exist, some basic points that have to be considered are:

— the underdevelopment character of a large part of the dry land areas, which, for the most part, are being exploited by alien economic powers which violate local cultural values of those who suffer from droughts;

— formation of manpower: the training of desertification experts is fundamental. Later on, groups of interdisciplinary researchers, who can understand, handle and suggest efficient and realizable plans of action in the political and socio-economic contexts of the arid land areas, can be formed.

— transference of experiences and technologies: the indication of practices to combat and prevent desertification must originate, as much as possible, from the local community affected because the more foreign such actions are, the more difficult it is for the local population to accept and adopt them. We must remember that, among tbe people who suffer from the effects of land aridity, there exist, almost always, simple but realistic solutions.

— governmental recognition: the problem of desertification is really very complex, though most of the time, the difficulties involved in its combat do not lie in the complexity itself, but in the lack of interest on the part of those responsible for working out such problems.

Finally, though distant and difficult, solutions do exist when the political barriers are laid aside and the concept of technical-scientific impartiality is partially modified. The search for concrete solutions to the problem will basically depend upon having *lived and felt from within oneself* the process of environmental deterioration in those zones that are arid, semi-arid and subhumid.

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DISCUSSION

ODHIAMBO

I want to refer to the fact that although in North Eastern Brazil the goat has been only recently introduced, in fact, in Africa, was first domesticated seven to eight thousand years ago, and indeed long before sheep, cattle and pigs. In this respect, over the years the goat has become notorious in Africa as a livestock species which has been rather implicated in desertification by scientists who are not familiar with the African environment. I want to quote a study made by Dr. French when he was working at FAO about twenty years ago. He was saying that goats in fact are very important livestock species for resource poor farmers, particularly in those semi-arid areas where getting good pastures is not easy. I now quote: "Because of their small size and clean habits, goats can be kept in areas and in quarters which would be unacceptable for cows. They can profitably utilize underdeveloped or degenerated land on which cows would starve. They are patient, attractive and affectionate animals which are easy to feed, manage and maintain. Consequently, they constitute valuable domestic animals and profitable commercial milk producers and in both cases pay for themselves as well as for the feed supplies and the labour involved in collecting and handling their milk. This indifference — he was referring to our scientists — to their attributes and commercial possibilities, is rather surprising". What I would like to suggest here is that, as Professor Rodrigues himself says, we do need to have careful experimental studies on utilization of goats in these rather difficult environments.

Secondly, in our own experience, at the Institute over the years, mid-Seventies, we found that in many cases of semi-arid lands, e.g., in Masai land, a semi-arid and savana area, we found that frankly over-grazing was not by cattle, particularly in drought years. The over-grazing was more likely to be by termites. Indeed, termites after drought years caused more over-grazing than cattle. Again, I think one needs to be very careful when one is talking in global terms about over-grazing: cattle are very visible, but, in fact, we are dealing with other harvesters.

DI CASTRI

In the Case Studies on Desertification, goats have been mentioned several times, sometimes as a consequence of desertification, more often as a cause of it. Nevertheless, there is no really comprehensive analysis of this problem in any of these case studies. New research should be undertaken in this respect. I believe that adopting an appropriate management of goats represents an indispensable resource for most people living in arid zones of developing countries.

MARINI-BETTÒLO

I wish to recall that in Italy this problem was very serious about 60 or 70 years ago. It was controlled by the State by putting a very heavy tax on each goat in order to reduce the numher of goats, mainly in the South: Calabria and Sicily.

PRZEWOZNY

What I appreciate in this presentation by Dr. Rodrigues in the reminder that the solutions to environmental problems must be implemented at the local level and must take into consideration not only ecological problems but also social and cultural values, economic factors and governmental policies. I remember a meeting I attended in which problems were discussed using the social theory of knowledge, that is, the principles of the social construction of reality proposed by Thomas Luckmann and Peter Berger. What you are saying here on the basis of your own expertise and disciplinary approach is valid, but the modern approach to the protection of the environment must also take into consideration social values. The importance of how man perceives his relation to the environment and how he interacts with it according to his self-perception, and the social values which this implies, seems to be confirmed by Dr. Rodrigues.

DI CASTRI

I would like to make a personal comment now. I have been involved for many years in problems of arid zone planning. There are conspicuous differences if arid lands are within an industrialized country or in a developing one, and also if they constitute the totality of the territory of a given nation or just a part of it. Solutions are completely different if there is the possibility of establishing some complementarity between arid and non-arid lands of the same country.

On goats, I am in agreement with what has been said by Dr. Rodrigues. Goats are absolutely irreplaceable in many parts of the world. In many cases, they are an important resource even to a shift towards a more profitable market economy, through the production of high quality cheese for export or national consumption.

As regards arid lands, and in addition to traditional land use practices, one should not disregard the possibility of transforming some of these lands into very intensive agricultural lands through irrigation, for instance for fruit export. The examples of Chile, Israel, and Morocco are supportive of this point.

Another remark concerns land tenure systems. Sometimes, large expanses of land, state or privately owned, may be preferable in preventing desertification risks. A greater fragmentation of land implies an almost unavoidable desertification, unless management is an extremely careful one. Again, I would like to resist the excess of generalization in one direction or another.

It is also important to highlight the fact that arid lands represent a particularly fragile environment as regards the impending climatic change. Water stress on plants is likely to increase, and extreme events (mostly droughts) will be even more frequent than at present. I want to recall how serious have been the effects on arid lands of the climatic anomalies of 1982 and 1983 because of the El Niño phenomenon, or from change in the monsoon regime.

As regards the Case Studies on Desertification presented at the United Nations Conference on Desertification, organized by UNEP in Nairobi in 1977, I would like to make a brief comment because I was myself in charge of their coordination. I want to stress, in particular, how difficult it is to get reliable data from official governmental sources, sometimes because of geopolitical considerations, and more often due to the fact that data are just missing or improperly processed. It will be very difficult to monitor environmental modifications unless a better data base is established, which includes built-in mechanisms of quality control.

CONSERVATION OF MARGINAL LANDS

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Definition

Less than a quarter of the land surface, mostly in humid and subhumid regions, is highly productive, well populated, and intensively cultivated. Large parts of the remainder are subject to severe natural constraints which limit their biological productivity and make cultivation impossible (hyperarid deserts, highly saline areas, ice caps, and mountain peaks). Areas between these two extremes are "marginal lands" (Ayyad and Glaser, 1981). Terms such as "fringe regions", "unfavoured areas", "fragile areas", "sensitive areas", and "areas of low biological productivity" also have been used to designate them (Ayyad and Long, 1984). The term "marginal lands" covers widely differing and highly complex situations. It applies to steep slopes in mountainous regions, arid and semi-arid lands bordering the world's great deserts, fringes of the tundra regions, or near the peaks of high mountains, and areas of low productivity in regions of bigh precipitation. Thus, natural constraints in marginal lands are either climatic (low and irregular rainfall, and extremely low temperature), edaphic (high salinity, low fertility, skeletal structure, and water logging of soil), or topographic (steepness of slopes).

There are 300 million hectares of marginal lands in arid (precipitation: 100-350 mm) and semi-arid (precipitation: 350-600 mm) regions, and 100 million hectares in subhumid (precipitation: 600-900 mm) and humid (precipitation: > 900 mm) regions (Ayyad and Long, 1984). The great majority of these lands are in developing countries. Some 80 million people and their livestock (over 200 million ovine units) inhabit this total area of 4 million km^2.

Land Degradation

Cyclical changes within life-support systems (ecosystems) due to natural constraints in marginal lands are normal processes, as long as there is some degree of balance between human needs and sustainable yields of these systems. But marginal ecosystems are inherently fragile and vulnerable to drastic changes that can be irriversible, due to overexploitation or misuse of vegetation and soil. Croplands are overcultivated, rangelands are overgrazed, trees and shrubs are cut, overirrigation turns croplands into salty abandoned fields. In such cases, ecological degradation takes place through loss of vegetation cover, soil erosion, depletion of soil nutrients, dune encroachment and salinization. A threshold of deterioration may be reached at which recovery and rehabilitation become impossible.

Overcultivation has led to widespread degradation in marginal lands in every continent. Although only 15% of the world's drylands are croplands, these hold 85% of the drylands' rural population (Timberlake, 1985). Average crop yields have been reduced by the extension of agriculture into shallower soils, steeper slopes or the more arid fringes of cropping regions. The IUCN Sahel Report (IUCN, 1986) describes the consequences of the agricultural expansion during the higher rainfall periods of the 50s and the 60s. Sudanian agriculture expanded northward into formerly hostile areas of the Sahel. Mali witnessed an 80% increase in the area supporting rain-fed agriculture between 1952 and 1975. In many areas this has resulted in the removal of vegetation for field clearance. Further losses of vegetation occur as village-based and nomadic herds are forced to "overgraze" the remaining less productive land base. The UNEP report on "The State of the Environment" (UNEP, 1986) refers to another cause of deterioration by overcultivation in Africa. Shifting cultivation that was once successfully practised persists in only a few communities, intervals between cultivation have become shorter, the capacity of the land to regenerate itself has been overstretched, and soil fertility has been reduced.

Brown and Wolf (1986) indicate that since mid-century, the combination of advancing technology and rising investment in agriculture has enabled most countries to override the negative effects of land degradation; but some 14 nations have failed to do so (Table 1). The most pronounced decline occurred in Sudan, where the average yield in 1982-84 was 44 percent below that of 1950-52. As recently as the late 70s Sudan was slated to become the breadbasket for the Middle East and one

TABLE 1 - *Countries with Declining Grain Yields per Hectare, 1950-52 to 1982-84* (after Brown and Wolf, 1986).

Country	1950-52 (kilograms)	1982-84 (kilograms)	Decrease (percent)
Sudan	780	436	−44
Tanzania	1,271	900	−29
Niger	458	379	−17
Mozambique	610	521	−15
Zambia	952	819	−14
Ghana	764	686	−10
Lebanon	869	786	−10
Rwanda	1,122	1,010	−10
Nigeria	760	694	− 9
Guyana	2,231	2,099	− 6
Iraq	703	657	− 6
Kampuchea	1.002	939	− 6
Algeria	648	613	− 5
Zaire	902	878	− 3

in which food-deficit, capital surplus neighbours could invest. Instead, land degradation has converted Sudan, one of the poorest countries, into a nation of refugee camps and feeding stations. More than 40 developing countries are producing less grain per person in the mid-80s than they did in the early 50s (Table 2). Together, these nations are home to over 700 million people, some 15% of the world total. In almost every Middle Eastern country, the growth in agricultural output is falling further behind population growth with each passing year. Per capita grain production is falling in almost all North African countries, those countries which occupy the lands that were once the granary of the Roman Empire.

Wood-cutting is the second major cause of deterioration of marginal lands. It is undertaken for land clearing, and for providing fuel and timber. UNEP (1986) considers that the provision of fuel has been the most devastating, so that in several countries wood gathering has exceeded land clearing as a major cause of deforestation. At present, there is no practical alternative to wood gathering, particularly in arid and semi-

TABLE 2 - *Developing Countries with Declining Grain Production per Person, 1950-52 to 1982-84* (after Brown and Wolf, 1986).

Country	1950-52 (kilograms/year)	1982-84	Decrease
North Africa			
Algeria	219	79	−64
Libya	106	69	−35
Marocco	258	177	−31
Tunisia	196	154	−21
Sub-Saharan Africa			
Mozambique	97	36	−63
Mali	242	134	−45
Angola	81	45	−44
Kenya	226	139	−38
Nigeria	171	111	−35
Ghana	66	44	−33
Uganda	155	107	−31
Guinea	131	95	−27
Rwanda	58	43	−26
Zaire	39	32	−18
Benin	124	103	−17
Senegal	139	118	−15
Cameroon	112	97	−13
Togo	121	108	−11
Liberia	153	139	− 9
Niger	286	260	− 9
Sudan	114	104	− 9
Sierra Leone	155	143	− 8
Ethiopia	202	189	− 6
Burkina Faso	181	177	− 2
Middle East			
Lebanon	54	8	−85
Jordan	138	44	−68
Iraq	269	105	−61
Syria	315	215	−32
Iran	193	176	− 9
Turkey	472	446	− 5
Latin America			
Haiti	135	75	−44
Honduras	194	133	−31
Nicaragua	188	136	−28
Panama	174	136	−22
Chile	192	153	−20
Peru	105	85	−19
El Salvador	142	129	− 9
Cuba	55	52	− 5
Costa Rica	142	141	− 1
Asia			
Kampuchea	401	267	−33
Afghanistan	417	324	−22
Nepal	296	243	−18
Bangladesh	240	235	− 2

arid areas in developing countries, until other inexpensive sources of energy become available on a suitable scale. Clearing for agriculture, and cutting for fuelwood in marginal lands, all consume trees and shrubs for their population benefits. These uses are often short-term, but developing countries in particular cannot afford to conserve untouched their woodlands. In the meantime, proper woodland management is necessary in order to avoid squandering economic and social benefits. The degree of imbalance between demand and sustainable yields of wood varies widely. Brown and Wolf (1986) provide examples of both semi-arid Mauritania and mountainous Rwanda, in which firewood demand is 10 times the sustainable yield. In Kenya, tbe ratio is 5 to 1, in Ethiopia, Tanzania and Nigeria demand is 2.5 times the sustainable yield, and in Sudan, it is roughly double. Sudan's wood imbalance illustrates the interaction between rapidly expanding populations and their biological support systems (Figure 1). Shortly after the sustainable yield threshold was crossed around 1965, forests in Sudan changed little, but, after 20 years, forested area bad contracted by one-fifth (Figure 2). In the next twenty years, expanding demand is likely to deplete all the remaining woodland. The loss of vegetation cover of trees and shrubs results in the depletion of nutrients held in the system. Rainfall runoff and erosion of soil increases. The hydrological cycle is affected, as the ability of land to absorb and retain water diminishes, and rainfall that runs off directly to the ocean increases.

Overgrazing makes its own contribution to the loss of vegetation

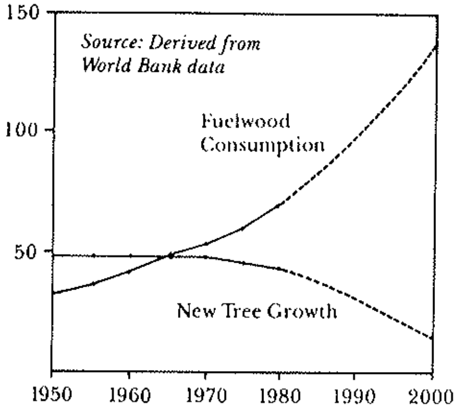

FIG. 1. Fuelwood Consumption and New Tree Growth in Sudan, 1950-80, With Projections to 2000 (after Brown and Wolf, 1986).

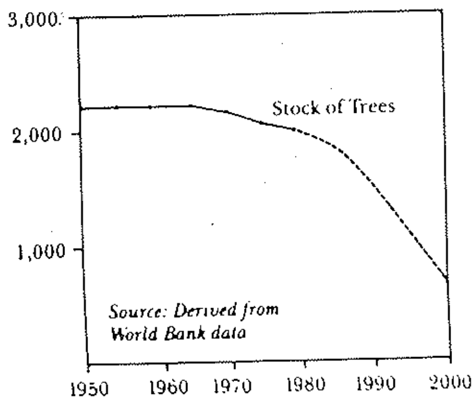

FIG. 2. Standing Stock of Trees in Sudan, 1950-80, With Projections to 2000 (after Brown and Wolf, 1986).

cover. Together with wood gathering, overgrazing enhances the replacement of perennial grasses and woody shrubs by annual grasses. Brown and Wolf (1986) state that the loss of trees such as the acacias in the Sahel for example, means less forage in the dry season, when the protein-rich acacia pods formerly fed livestock on otherwise barren rangelands. Annual grasses that come to dominate the landscape are far more sensitive to water stress than perennials, and may not germinate at all in drought years. The IUCN Sahel Report (IUCN, 1986) asserts that the proliferation of cattle in the Sahel (a five-fold increase during the 25-year period preceding the 1966 drought) enhanced degradation of rangelands. Their selective grazing and browsing increases pressure on perennial grasses, often eliminating them. Soil compaction by cattle also results in high levels of mortality in tree species, such as *Acacia senegal*, *Commiphora africana*, and *Guiera senegalensis*. The net results is shifting from perennial to annual plant cover, and the invasion by relatively unproductive trees and shrubs, such as *Calotropis procera*. In the Tamesna region of Niger, primary pasture production dropped between 1500 and 2500 tons/ha to 360 kg/ha, and late dry-season forage is even more reduced. As a consequence of deterioration, livestocks have been greatly affected. The World Bank (as quoted by Brown and Wolf, 1986) reports, for example, that in 1983 and 1984 Botswana lost 600,000 head of cattle, Lesotho lost 58,000 head of cattle and 243,000 sheep, and Zimbabwe lost 50,000 head of cattle. Many other

African countries have experienced similar herd reduction during the eighties.

Brown and Wolf (1986) write: "Ecological deterioration, an insidious process resulting from mismanagement of resources, eventually affects economic development adversely. Real production costs and imports rise, while land and labour productivity, output, exports, and tax revenues fall, ... the relationship between wasted and abused resources and economic stresses has become readily apparent. Even more apparent is the tendency of ecologically induced economic decline to ignore national boundaries". In Africa, for example, ecological deterioration is slowing economic growth and in some cases causing economic decline, which contributed to the one-fifth reduction in *per capita* income since 1970. In the Third World in general, ecological deterioration is clearly connected with poverty. Each factor reinforces the other; witness the impoverished peasant who cannot afford to safeguard the soil cover of his farmlands, whereupon his neglect leaves him yet more impoverished.

As ecological deterioration is closely connected with economic development, there is also a close interaction between ecological deterioration and sociopolitical factors. Many of the environmental problems of marginal lands are linked with high population growth. Countries in sub-Saharan Africa, for example, have experienced rapid rates of population growth — from 2.5 to over 3.0 percent a year — in recent decades (IUCN, 1986). Although pastoral populations have probably grown slower, the pressure of agricultural population growth has pushed farmland into pasture land. Rapid population growth, averaging 2.0 percent a year and urbanization, running at over twice this figure, have commonly been blamed as the root cause of the woodfuel crisis in developing countries (Goodman, 1987). If this trend continues, this population-driven demand potential is likely to rise by 60 percent by the year 2000 for an expected population increase of 45 percent and an urbanization increase from the current 1,000 million to 2,000 million in developing countries. As over-population exerts pressure on land and leads to severe ecological deterioration, underpopulation may also have adverse effects on land. For example, most of Africa is certainly not densely populated. The average population density of sub-Saharan Africa is only 16/km^2, much less in the rural areas (Timberlake, 1985). Urban development bias is also sucking people into African cities. This widely dispersed population in rural areas hinders agricultural development, often making it both difficult and uneconomic to care for the land, or to gather and market agricultural products.

Another sociopolitical factor is explained by Goodman (1987). In many developing countries, a great deal of the good irrigable or rain-fed arable land is increasingly taken over by governmental parastatal concerns or by large private investors. This is done in order to grow non-food cash crops for export (tea, coffee, cocoa, cotton, etc.) so as to earn foreign exchange needed for purchase of imported goods or to service a growing external debt. This places heavy pressures on the land that remains for subsistence agriculture and forces farmers into marginal lands, which become exhaused or erode away after a short period. A further knock-on effect is where land is taken over from pastoralists, who are in turn forced onto even harsher terrain with their grazing herds, mostly of goats, in order to exploit even more unpalatable grazing. Goat grazing aggravates vegetation removal, accelerating toposil erosion and creating a rocky or infertile landscape. Thus, a sociopolitical process creates devastating ecological impacts. Another case is mentioned by Timberlake (1985). On the rich soils near the Nile, the Sudan's Mechanised Farming Corporation rents vast tracts, usually in 4,000 hectare units, to private entrepreneurs at nominal rents. This has led to "agricultural strip mining" or "suitcase farming": the growing of cash crops for a few years, running down the soil and moving on, often before the corporation has even registered the lease. This has encouraged investors to mine the soil, take a few quick crops, and get out.

Among the more worrisome sociopolitical consequences of ecological degradation, particularly in developing countries, are food riots and the forced migration of people in search of sustenance (Brown and Wolf, 1986). Ecological degradation is causing a swelling tide of refugees fleeing famine, disaster, and poverty. In Africa, millions of migrants are leaving their villages in search of food and water (Table 3).

Basic Needs and Carrying Capacity

Any consideration of the conservation and development of marginal lands should be preceded by a discussion of the basic needs of their populations and the carrying capacities of their ecosystems. It is remarkable that global predictive models (e.g., Club of Rome) have not taken marginal lands into consideration; they are assigned a "zero" value, probably due to lack of relevant data. Although classified economically as "unusable", these lands do exist and are inhabited by people. Besides, these lands are often bordering developed rural or urban areas, and play an important

TABLE 3 - *Distribution of Refugees in Africa by Country of Refuge, 1984* (after Brown and Wolf, 1986).

Country of Refuge	Number of Refugees	Primary Countries of Origin
Sudan	1,100,000	Ethiopia/Uganda/Chad
Somalia	700,000	Ethiopia
Zaire	304,000	Angola/Uganda
Tanzania	180,000	Burundi/Zaire
Algeria	167,000	Western Sahara
Uganda	132,000	Rwanda/Zaire
Zambia	104,000	Angola/Zaire
Angola	96,000	Namibia/Zaire
Rwanda	49,000	Burundi/Uganda
Zimbabwe	44,000	Mozambique
Ethiopia	40,000	Sudan
Djibouti	23,000	Ethiopia
Kenya	8,000	Uganda/Ethiopia
Central African Rep.	7,000	Chad
Egypt	5,000	Ethiopia

complementary role. For example, oases and bordering subdesertic areas may complement each other by integration of grazing and cultivation of fodder crops. Some marginal lands may become cultivated under irrigation and alleviate population pressures on areas of intensive agriculture and grazing pressures on neighbouring rangelands; such is the case of the western coastal region of Egypt.

Two types of basic needs may be considered: cereal requirements for human consumption, and fuelwood requirements for domestic uses. In North Africa, as an example of marginal lands, the basic needs of cereals is equivalent of 200-300 kg of wheat grain per person per year. These needs may be met by the transfer of necessary quantities from more productive areas, or by the development of local production. Some countries have decided to prohibit rainfed cultivation of cereal crops in arid and semi-arid regions, thus encouraging cereal cultivation in irrigated areas, where it comes in competition with cultivation of other essential crops. On tbe other hand, some countries have permitted rainfed cereal cultivation on every type of land and under annual precipitation as low as 100 mm, using multidisc ploughs. The annual average yield in areas with mean annual precipitation between 100 and 600 mm, ranges between 200 and 500 kg grain/ha/year. Thus, a family of 6 adults must cultivate at least 6 ha to meet its requirements. If we consider that population density in some arid regions of North Africa ranges from 10 to 90 inhabitants/km^2, vast areas would be required to meet the basic needs of inhabitants. The first problem that should be tackled is where to grow cereal crops to achieve sustainable yields in order to meet those needs, and which areas should be preserved for other uses as range management and stock raising.

The minimum "fuelwood" needs in marginal lands are estimated at about 400 to 500 kg of dry woody material per person per year. In North Africa, for example, lands in good condition have a standing above-ground woody phytomass ranging from 250 to 1,500 kg/ha. The annual rate of accumulation of woody matter is indeed very low; some shrubs of 10-15 kg crowns are several hundred years old. In order to meet the needs of a single inhabitant, the woody vegetation covering an area of 0.3-2.0 ha must be removed every year. The basic needs of the North African population would call for the removal of woody vegetation at tbe rate of 1-2 million ha/yr, which means its disappearance by the year 2000. This has already occurred in some areas of the Near and Middle East, and in the Sahel south of the Sahara.

Any ecological input to rational land use planning in marginal lands must be based on reliable estimations of the primary harvestable productivities. Ayyad and Long (1984) estimate the overall amount of photosynthetically utilizable solar energy received at the earth's surface of these lands as $6\text{-}10 \times 10^9$ kcal/ha/year. Assuming an average energy use efficiency of the plant cover of 1 percent, a storage potential of $6\text{-}10 \times 10^7$ kcal/ha/yr may be expected. Under unlimited conditions of water and nutrients, the theoretical primary production potential in North Africa, on the basis of an energy use efficiency of 1 percent, and assuming 100 percent plant cover throughout the year, would come to about 18 tons of dry matter/ha/year. In all arid and semi-arid regions, however, the photosynthetically active vegetation is generally lower than 25%, including rainfed crops. Furthermore, water and nutrients are limiting factors. It may be noted that 200 mm of precipitation, which corresponds to 2,000 m^3 of water per hectare used entirely by plant cover, could yield a potential net primary production of 2-8 tons of dry matter/ha/yr, assuming that 1 m^3

of water is necessary to produce 1-4 kg of dry matter. Besides water and nutrient constraints, temperature constraints (e.g., low temperature) also can affect primary production. Thus, if we consider the harvestable portion of plant production in marginal lands, the net primary production ranges on the average from 500 to 750 kg dry matter/ha/yr in fairly good rangelands, which corresponds to $2.5\text{-}3.75 \times 10^6$ kcal/ha/ year for the harvestable portion of primary production, on an energy use efficiency of 0.03-0.04%. In most marginal lands, severe degradation reduces this efficiency rate to 0.01% in the areas with annual average precipitation of 100-350 mm.

What number of people and domestic animals can be sustained in marginal regions without destroying them? IUCN (1986) provides three substantially different answers for the Sudan-Sahel region, one by FAO, and two by the World Bank. FAO finds excess current population in terms of food supply. One World Bank study finds enough land to support a much larger population until the end of the century, with regional variations. Both studies assume a continued "low input" and predict much higher carrying capacities with increased inputs, by which is meant more capital-intensive methods. The FAO study assumes but does not demonstrate that these are consistent with improved conservation. The second World Bank study did not find an excess of population over carrying capacity in terms of food production. Its conclusions are interpreted and represented in Figure 3. These conclusions direct attention to the critical zones and critical limiting factor for populations. It is evident that the critical zones are the Sahelo Sudanese and the Sudanese, and that fuelwood supporting capacity is a far more critical factor in sustainability than crop and livestock supporting capacity. For each agroclimatic zone, the figure shows the population (left hand bars) which can be supported by sustainable agriculture on present inputs, and the excess of population over capacity, or capacity over population, in terms of wood. The right hand bars show the population which can be supported by fuelwood, and also the excess of population over carrying capacity.

The discrepancies between these studies must be due to the lack of information at the ecosystem level, and should serve to make us cautious in predicting long-term prospects. The carrying capacity of ecosystems varies with local variations in the average annual and the seasonal distribution of rainfall, physiographic features, and inputs of energy and nutrients. Such variations are indeed very large in marginal lands, particularly in arid and semi-arid regions. There are examples in many

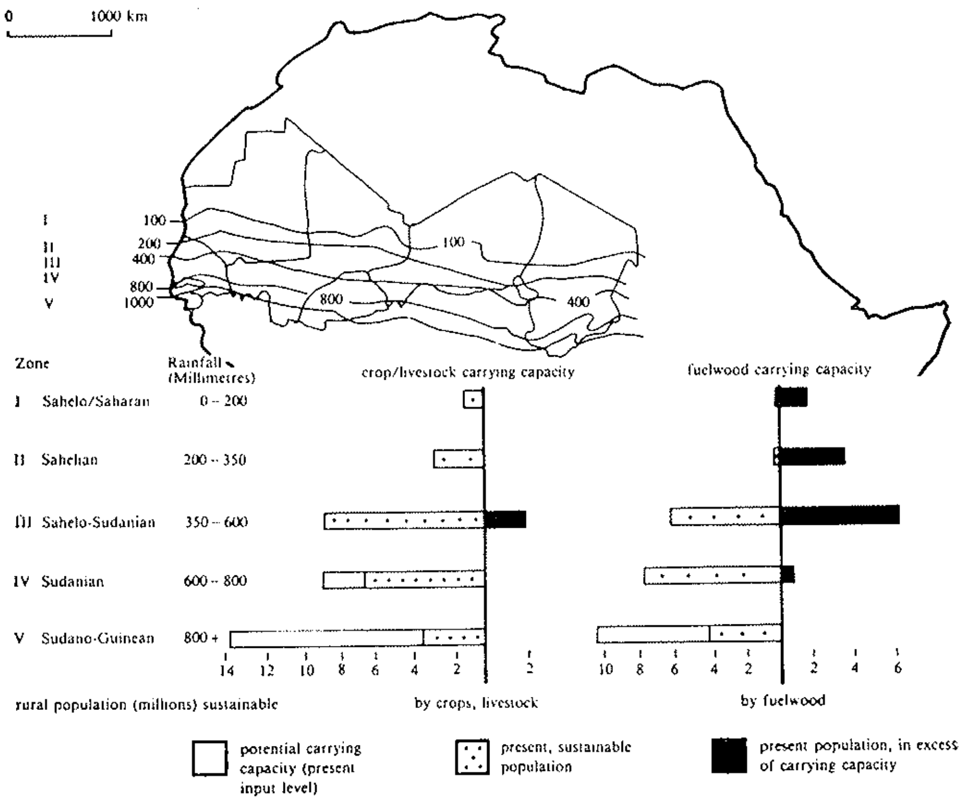

FIG. 3. Sustainable and actual populations in the western Sahel (after IUCN, 1986).

areas of Africa which indicate that rural populations are at twice or more the computed threshold of sustainability. Obvious examples are Senegal's Groundnut Basin and the Yatenga area of Burkina Faso, in which densities exceed 60 and 70 persons per km^2. Yet these are not areas suffering famine.

ADAPTATIONS TO CONSTRAINTS

Despite the severe natural constraints in marginal lands, their inhabitants have often managed to adapt to these constraints, and to turn them to their advantage. Examples of these adaptations are reviewed by Ayyad and Glaser (1981). In the Nochixton valley in southern Mexico, side slopes are ravaged by active gully erosion which strips off the surface soil and destroys the vegetation cover. The farmers, over the past thousand years, took advantage of this erosion by directing the flow of eroded material to the main valley floors, thus doubling their cultivable area.

The high culture of the Incas in the Andes is another outstanding example of adaptation to natural constraints. Instead of concentrating in the coastal and lowland areas, they preferred the high mountains, the "altiplanos", at altitudes ranging from 2,800 to 4,000 m, and the large valleys of the central and northern Andes, where they evolved one of the most remarkable pre-Columbian cultures in the New World. On the slopes they developed a very efficient terracing system, on the altiplanos they combined llama and alpaca herding with limited agriculture adapted to cold and oxygen deficiency. The potato, which was to become a staple food over much of northern Europe in later centuries, originated from tbe marginal lands of the Incas. Their economy provided for tropical fruits and bananas from the low-lying foothills, maize from the temperate altitude levels, and grain, potatoes and animal products from the colder high altitude levels.

Transhumance provides another example of adaptation to natural constraints in marginal lands. In France, sheep and goats graze in the Alps during summer, and in the Mediterranean maquis or the Camargues during the winter, thus adapting to two constraints: low temperature of the Alps in winter, and the summer drought of the maquis and the Camargues. On a very much larger scale, transhumance in arid and semi-arid zones of Africa takes advantage of the rigour of aridity. In the past, traditional nomads roamed with their herds over hundreds of kilometers, after the rare days of rain, for grazing. With the adoption of the sedentary way of life, herdsmen now move their flocks between three complementary grazing zones: Sudanese zone (6-7 dry months), Sabelian zone (8-9 dry months), and fringes of the Sahara (10-11 dry months). The Sudanese zone, which has a strong agricultural element, is used in rearing of young livestock and the fattening of cattle; the Sahelian zone, where the nomads are beginning to settle, is devoted to the reproduction phase; the fringes of the Sahara are only grazed for a few months to relieve pressure on the Sahelian zone.

Rehabilitation and Conservation of Resources

Positive action is needed at local, national, and international levels in order to arrest and reverse the process of degradation in marginal lands, to improve their management and to conserve their species and life-support systems. Basic principles should guide such action, among which the following may be mentioned: (a) knowledge about the structure and dynamics of life-support systems and the relationships between their components; (b) analysis of the intricate relationship between life-support systems, the basic needs of inhabitants, and the socio-political variables; (c) analysis of the interactions between economic trends and life-support systems; (d) assessment of the compatibility of traditional land-use methods and innovative technologies with life-support systems and socio-political variables; (e) monitoring the impact of management alternatives on ecological, social and ecological variables; (f) ensurance of the complementarity of life-support systems in space and time; (g) diversification of resource use; (h) conservation of biological diversity.

Inventories of Life-Support Systems

It is often claimed that "there is enough scientific information", and that "what is needed is action". Admittedly, information does exist, but it has to be either made accessible or subjected to appropriate analysis, or much of it may be irrelevant and its estimates may be inaccurate. For instance, small-scale resource maps cannot be taken as a basis for making decisions on land-use planning and allocation of funds for development projects. Research on the flora and fauna of marginal lands is still needed in order to provide information about plant and animal populations, and the non-biological components of their ecosystems. Training of systematic botanists and zoologists, and preparation of reference collections are equally important. Inventories and evaluations of plant, animal, land, and water resources are necessary for any development projects, and should preferably be presented as thematic maps for different land uses. The main themes could be bioclimatological, land capability (physiognomy, structure and composition of natural or man-made plant cover and degree of man's impact), phytoecological (relationships between vegetation and environment), phytodynamic (vegetational changes with times), plant and animal production, water resources, production potential, risk of degradation, vulnerability to degradation, etc.

Economy and Life-Support Systems

Broad-based advance of knowledge has led to a high degree of specialization, but the need for interdisciplinary research has increased. Relationships between life-support systems, economic and socio-political variables are little explored. There is a need for generalists who can integrate these fields of knowledge. Brown (1985) and Brown and Wolf (1986) discuss some aspects of the "economy/ecosystem interactions". Throughout much of the rapid economic expansion since World War II, economists have ignored ecological concepts (e.g., carrying capacity) because the human needs were well below the sustainable yields of life-support systems. Human needs, however, are beginning to exceed sustainable, yield thresholds in many parts of the world. In the Third World, where this is most obvious, planning commissions are almost entirely composed of economists while long-term economic planning calls for a command of basic ecology. Thus, agricultural supply and demand projects, for example, ignore issues such as the effect of soil loss on land productivity, and the relationships between the hydrological cycle and the loss of vegetation, both being key issues in marginal lands. Brown and Wolf (1986) suggest that one of the important links between the economy and the ecosystem that seems destined to attract attention soon is that between soil erosion and Third World debt: "Soil erosion can undermine not only a country's food production capacity but its debt servicing capacity as well for it leads to widening food deficits, mounting debt, and eventually to food shortages". In Africa, there may be a great difference between reforestation planning at the scale needed to satisfy only future firewood demands and that which may be required to restore the hydrological cycle of a generation ago. The latter could easily require 10 times as many plantings as the former.

It is remarkable that the economic aid received by countries suffering from food shortages in marginal lands has largely been directed to short-term economic relief, without utilization in long-term economic gains through environmental rehabilitation projects. Africa, for example, has more aid than other parts of the Third World, but seems to have benefited less. Timberlake (1985) estimates that aid amounted to \$19 per person for all sub-Saharan countries, and \$46 per capita for the poor semi-arid nations, but only 1.5% went to ecological projects such as tree-planting, and soil and water conservation, to improve the resource base upon which rainfed agriculture depends.

Socio-Political Relationships

The relationships between socio-political variables and life-support systems also suffer from lack of analysis. Models of population projections are almost exclusively demographic and do not incorporate the effect of population growth on the local resource base by deforestation, soil erosion and cropland abandonment. Closely related to this analysis is the assessment of the effect of reinforcing trends (Brown and Wolf, 1986): "At what point does ecological deterioration begin to contribute to political disintegration? And at what point does political disintegration undermine efforts to manage ecological systems intelligently?".

Populations in most marginal lands are increasing, which puts pressure on environmental resources. But the interrelationships are complex and call for careful analysis. Although it is hard to see how Africa, for example, can continue to cope with the high rates of growth of its populations, most of this continent is certainly not densely populated (Timberlake, 1985); the average population density of sub-Saharan Africa is only 16/km^2, much less in the rural areas (compared with 100/km^2 in China, and 225/km^2 in India). This widely dispersed rural population hinders agricultural development. It also makes the monitoring and planning of development extremely difficult. Timberlake (1985) cites Brian Walker, president of the International Institute for Environment and Development: "I would go so far as to suggest that no African government and certainly no development agency, from the World Bank to Oxfam, knows with any real accuracy either the birth rate, the mortality rate or the food production of any African state. Yet these three fundamental figures are crucial to the success or failure of any programme of development, if it is to be sustainable".

Another demographic problem that needs careful analysis is the rural-urban migration. There are economic, as well as political, incentives to feed cities with imported food, despite farmers' needs to grow and sell a surplus. In 1980, almost 80% of Africans lived in rural areas and small towns; in the year 2000, if present trends continue, this percent will come down to 69%, which means that relatively fewer farmers are available to grow food crops. The muscle of the countryside is further weakened because it is mainly the young and the males who are leaving to seek their living in the cities. It is therefore apparent that the relationship between population and resources in marginal lands is far more complex than merely a population growth effect. IUCN (1986) suggests for example, that a change in the style of consumption of the better-off strata in both developing and developed countries could do far more than family-planning in terms of relieving environmental pressure and spreading the resources needed for development of the poor.

Inhabitants of marginal lands must have the opportunity and be encouraged to participate in the identification of their needs and problems, and in the design and implementation of land rehabilitation and development programmes. Brown and Wolf (1985) provide examples of successful local participation in rehabilitation programmes in the Third World. Kenya, with the assistance of the Swedish International Development Authority, designed a national programme that by mid-1983 had trained some 1,300 agricultural officers and 3,500 technical assistants in soil and water management, established 50 tree nurseries, and distributed 127,000 fruit trees and 3.5 million fuel or fodder trees to farmers. Terraces had been constructed on 100,000 farms. Farmers themselves had constructed roughly 10,000 kilometers of cutoff drains designed to reduce the erosive runoff water. The keys to this success appear to be a committed leadership and local participation in the design of the programme. Local participation in securing domestic fuelwood supplies in marginal lands can only be provided if families themselves are engaged in growing and caring for the trees they will later burn. Brown and Wolf (1985) cite examples of a few successful efforts. In the Indian state of Gujarat, where free seedlings have been distributed by the government, tree farming has become the main source of income for some farmers. In 1980, 50 million seedlings, enough to plant 25 thousand hectares were distributed by the forestry department, and in 1983, the state distributed 200 million seedlings. This has created an interest in tree planting that will almost certainly spill over to other states. Nepal has also mounted a vigorous campaign to replant its denuded hillsides by giving its people the means to grow trees for themselves. Tree nurseries and plantations have been established in 350 villages, from which a variety of fruit, fodder and fuelwood species are distributed. Technical assistance and funding for the programme have come from the World Bank, several United Nations agencies, and some national and private aid agencies.

Timberlake (1985) argues that the fact that wood is generally scare in an area does not mean that everyone is suffering from the shortage to the same extent. Farmers can grow trees for fuel, but they are most unlikely to choose to do so. Studies indicate that often people grow trees for fruit, timber, shade browsing, and renewal of soil fertility. Trimmings and dead branches will go a long way towards meeting their fuel needs. But trying to convince them to plant trees just for fuel is often a classic case of presenting a solution to a problem which people do not see they have.

Another aspect of sociopolitical impact on life-support systems of marginal lands is discussed in the IUCN Sahel Report (IUCN, 1986). Governments have often denied rural communities' traditional laws and institutions designed to share and manage their life-support systems. Pasture land, forests and much water have largely been controlled by governments and national legislatures, while most states do not in general have the means to carry out these tasks equitably or efficiently. A major policy objective should be to devolve more control to communities of rural users. This should include creating laws and institutions through which discrete areas of land can be administered and managed communally by those users. There is a correlation between degraded life-support systems and politically marginalised and powerless people (Timberlake, 1985). IUCN (1986) also calls for major revisions in national policies which influence the quality of land-use, and for introducing environmentally-positive or neutral policies, rather than those that are likely to be harmful. Government policies on "subsidies and prices of food and agricultural inputs, policies aimed at altering the balance of investment and incentive between cash crops and food crops, policies on rural institutions and participation, the impact of rural taxation, the pattern of provision of rural infrastructure, especially roads and waterpoints, and more generally the balance of expenditure between development sectors, have to be examined for their potential positive or negative impact on sustainable land-use".

It has become increasingly evident that local knowledge and skills of inhabitants of marginal lands is a valuable untapped resource for rural development (e.g., IUCN, 1986). Often development programmes have been planned and implemented as though inhabitants of these regions were ignorant or willingly destructive. Recent studies have indicated that the societies of marginal lands have gained extensive experience and a large body of information, and have developed techniques which are most compatible with their life-support systems. If this knowledge and experience are combined with modern scientific information and technologies, it could provide much better and more socially acceptable development plans.

Most traditional societies evolved common property resource management systems and indigenous methods and institutions for management of their resources in sustainable ways. Colonial and post-independence governments have often been insensitive, oblivious or even hostile to these systems. Nowadays it is hoped that these systems be identified and characterized, and that local populations be helped to revive, update and modify them into effective resource management institutions. This has, for example, successfully taken place in Saudi Arabia and Syria through the revival of the ancient "Hema" system of range reserves, which incorporates conservation measures with the creation of herder cooperatives. In "Hema" systems, cooperative rangelands are allocated, often on the basis of traditional claims, and grazing is prohibited except for herds of cooperative members. In this way, "Hema" cooperatives have been responsible for the regeneration of the vegetation of some seven million hectares of rangeland in the Syrian steppes. Complementary to reviving successful traditional systems is the designing of new types of rural institutions for sustainable land use involving full local participation.

Traditional Land-Use and Innovative Technologies

Application of capital-intensive schemes based on imported technology have often been expensive failures and a constant drain on national budgets of developing countries of marginal lands. Some of these schemes may have their place, but they will not rehabilitate the degraded lands of ordinary farmers and nomads. Herders and farmers of marginal lands have been confident of the rationality of their land-use methods, and have responded favourably to innovative technologies when their compatibility with their systems has been demonstrated.

Rain-fed (dryland) farming in arid and semi-arid regions is risky. There is no guarantee that rain will be sufficient to grow crops. Efficient management of rainwater is always needed. Water harvesting, the reduction of evapotranspiration, and the selection of drought-resistant crops are the keys to enhancing land productivity. "Runoff agriculture" has been practised for 4,000 years in the Middle East, North Africa, China, India, Mexico and the American Southwest. Advantage is taken of topographic variations in capturing and channelling rain-water to fields or to cisterns for later use. It is believed that, if combined with today's knowledge of crop water needs and local rainfall patterns, modern variants of runoff agriculture could increase production of life-support systems in arid and semi-arid regions and greatly lessen the risk of crop failure (Postel, 1986). Microcatchment farming is another promising farming method in arid and semi-arid regions for small-scale subsistence crop production. The terrain around each plant is shaped so that rainfall from a larger area gets directed to a small basin in which the plant grows. This works especially well with tree crops, and could bolster reforestation efforts that combine production of food, fodder, and fuelwood.

Production under well planned crop-fallow rotations in marginal lands can increase remarkably compared with those under continuous cropping. The practice known as minimum tillage involves leaving crop residues and stubble on the field after harvest, trapping rainwater, slowing runoff and reduces evaporation from the soil. Attention should also be given to exploiting crop characteristics, selecting cropping systems that make optimum use of soil moisture, and that are drought-resistant and salt-tolerant, and setting planting dates so that their growing season corresponds with the maximum probability of getting sufficient moisture. Salt tolerance is a useful trait, especially in desert regions such as the Middle East, where a large share of the extractable groundwater supply is salty.

New analytical tools are now available for assessing the relationship between soil loss and land productivity. Brown (1985) refers to a productivity index (PI) that calculates the ratio between actual and potential crop yields at various levels of soil loss, and which has been applied to soils in the major crop-producing regions of the United States and has been tested on soils in India, Mexico and Nigeria.

Ecological Monitoring and Reduction of Risk

Life-support systems in marginal lands are prone to risk from natural disasters and interannual environmental variations. A major policy objective should be to reduce this risk. A basic ingredient in fulfilling such an objective would be to establish efficient units for ecological monitoring which are capable of demonstrating the changes with time of the components of ecological systems due to the effects of the physical environment and of man-made manipulations, and which are capable of projecting the consequences of these effects in the future. Monitoring should be undertaken at three complementary levels: ground monitoring, aerial monitoring, and remote sensing (Clarke, 1986). The first level is concerned with the ecosystem components and its processes, in which changes are recorded in physical and chemical characters of the soil, the abundance of species of plants, animals and micro-organisms, above and below the soil surface, and their roles in energy flow and nutrient cycling (Ayyad, 1983). These records may then be used to construct simulation models for predicting future changes at the ecosystem (life-support system) level. The second level includes monitoring of changes in the patterns of vegetation composition, animal populations, human settlements, etc., and of the physiographic features in limited sectors of land. The procedure involves the preparation of thematic maps using aerial photographs and ground-truth data. If aerial photographs of successive years are studied, the rate of change in these patterns may be assessed. The third level includes comparisons of the salient features of large areas in successive years using remote-sensing techniques.

In this connection, the IUCN Sahel Report (IUCN, 1986) calls for the establishment of "early warning systems". It views the Sahel famine as the culmination of a series of precursor events that can be observed and identified, a view which in fact applies to other marginal lands. An early warning system can be established which records these events and informs land users, decision makers and aid donors to take appropriate precautions before the crisis occurs. Observations, records, and predictions are to be made on local as well as regional and national scales, and seasonally rather than annually, since crises may be localized and related to farming cycles.

Complementarity of Life-Support Systems

To ensure sustenance from arid ecosystems that are hazard prone, harsh, and of unpredictable productivity, an array of production systems should be tested and established. Development strategies must take into account a multitude of integrated land-use systems (rangeland system, dry agriculture system, irrigated agriculture system, local industry system, etc.). Such integration not only supports a subsistence economy but may provide a base for a market economy. Each land-use system can be subdivided; each subdivision possesses its own demographic characteritics, socio-economic and socio-political organization and institution, technological application, and system characteristics. It does not operate in isolation, but rather is linked to and dependent on other systems. Range livestock industry, for example, may be very dependent upon cultivated lands for supplemental feeds. Economically, as well as ecologically, harvest of food from grazing lands often has a delicate relationship with areas of agriculture. It is important to study this relationship before any management strategy is established. Many irrigated lands are also dependent upon adjoining range watersheds for both quantity and quality of water. Food production in these irrigated lands may, therefore, be linked to range management in the surroundings.

Conservation of Biological Diversity

With the increasing pressure of man on marginal lands, their ecosystems are drastically changing. Many species populations are losing their capacity to propagate, and some are endangered to become extinct. For the preservation of these species and their ecosystems, the "World Conservation Strategy" (IUCN, 1980) emphasizes that "... conservation is concerned with human survival and sustainable development". Such an approach could be more perceived by inhabitants of degraded environments. The World Conservation strategy defines three objectives for conservation of living resources, summarized by Hanks (1987). The first objective is the maintenance of essential ecological processes and life-support systems. This is one of the easier concepts to get over to relatively unsophisticated people, particularly to those who live in such close contacts with resources that are being depleted. For example, a poor and hungry family living next to a well-protected and inaccessible national park that emphasized the aesthetics of species conservation would be much more receptive to supporting the park if it were packaged more in terms of ecosystem services (Ehrlich, 1982). If present rates of extinction are not reversed, ecosystem services will increasingly depend on substitutions, but these species are unlikely to be found at the rate at which plant and animal communities are being destroyed. The conservation of ecosystems and thus of the species that function within them is a priority concern, if this first objective is to be met (Ehrlich and Mooney, 1983).

The second objective of the strategy is to preserve genetic diversity, a much more difficult concept to present, mainly because there are so few immediate short-term benefits. The preservation of genetic diversity for future genetic engineering and agricultural use could be a hopeful starting point. Our breeding programmes and domestication have resulted in a narrowing of the genetic base, resulting in a loss of genetic determinants controlling such things as adaptation to marginal environments (Prescott-Allen and Prescott-Allen, 1982). The conservation of genetic resources is a neglected aspect of conservation biology. Very few of the protected areas in developing countries have a comprehensive list of the plant species that occur there. This ommission not only reduces the value of the area concerned but also makes its conservation and management more difficult.

The third objective of the strategy is to ensure that any utilization of species and ecosystems, as rangelands, which support millions of people living in rural communities as well as major industries, is sustainable. This utilization gives the species concerned a value as a resource and could well ensure that the community using that species (or an entire ecosystem) does not allow it to be exterminated. A land capability analysis might even show that using indigenous fauna and flora in a region on a sustained yield basis is the optimum form of land-use, in some cases to be preferred to the introduction of livestock and crops.

The "Biosphere Reserves" of the UNESCO/MAB programme provides a forum to meet these objectives. These reserves are protected areas recognized for their value in conservation and in providing scientific knowledge, skills and human values to support sustainable development. There are three main concerns in the biosphere reserve concept: (a) conservation concern: the need to reinforce the conservation of genetic resources and ecosystems, and the maintenance of biological diversity; (b) logistic concern: the need to set up a well identified international network of areas directly related to MAB field research and monitoring activities, including the accompanying training and information exchange; (c) development concern: the need to associate concretely environmental protection and land resources development as a governing principle for research and education activities of the MAB programme. A biosphere reserve normally consists of three areas: a core area (or areas) in the center, a buffer zone surrounding the core area, and an outer transition area. The core area is to be protected according to well defined conservation objectives. The buffer zone is also strictly delineated and has a legal or administrative status. It is devoted to research, environmental education and training, as well as tourism and recreation, and often serves to protect areas of land that could be used to meet future needs for experimental research. The transition area promotes development function. It may include experimental research areas, traditional use areas or rehabilitation areas. Usually, it is not strictly delineated but corresponds more to bio-geographic than to administrative limits, and extends into a larger and open area where efforts are made to develop cooperative activities between researchers, managers and the local population. The objective is to ensure appropriate planning and sustainable resource development while maintaining harmony with the aims of the reserve.

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DISCUSSION

Marini-Bettòlo

Thank you for your very interesting presentation on fragile lands which tomorrow may become deserts if we don't take appropriate and adequate measures.

Odhiambo

Talking about the conservation of genetic diversity, I note that among the agricultural centres and also related agrobusiness and industrial complexes, the conservation of seed is very important. Special measures were taken by FAO which have been very forward in their outlook in this respect. We can say now that something like 40 to 50 species of crops are fairly well studied in terms of conservation of germoplasm, so that we now have some very impressive gene banks. We do not see this so much for trees or animals and certainly, except in small university departments, not for the conservation of seed of other species, the tropical species. When you are talking about the more fragile environments like the mountain areas, which in many cases even for crops have been the areas of rapid evolution or in some cases even of domestication, a great problem arises. I wondered whether you have some comments on the question of conserving our diversity in a system which is different from conserving them in a biome, or, as you say, biosphere. We know that this is probably the best way of conserving them, but it cannot be the only way because of pressure of utilizing this, as you yourself said, so dramatically.

The second question is that in many of these fragile areas, in the Middle East and in Africa, we have very important plants, including medicinal plants, but we have also some very important animals and I do not consider that we are, as ecologists, as biologists, really protecting these very unique animals. I am talking referring to the camel and the ostrich, which are really neglected in these areas. In fact, probably the best work, at the moment, on the camel is being undertaken in Israel and in Australia, not in the areas where they are normally a major animal in trade as well as husbandry. Similarly, I don't know of anybody doing any research on ostriches, except again in Israel in the last four or five years. We have a major gap in our knowledge, and I would like to know whether you have any advice on this particular question.

Ayyad

Thank you, Dr. Odhiambo. The question of genetic diversity by protection of certain areas, whether it be in the form of national parks or biosphere reserves, is actually conservation, which means not only protection but re-habilitation of the degraded ecosystem so that local species which are disappearing mal be-introduced into the system, and, thus, we can get the benefit of having them in larger numbers to have sustainability in the system. It's not only the protection of the species itself, but also the protection of its whole system with all its biotic and abiotic components. If we do not consider the soil in the system, we will lose also the species in the long run. It's not only the protection of the species *per se*, but the protection of the supporting system and the re-introduction of species which are becoming rare due to misuse, by propagation in the system.

As we all know, camels, for example, are the animals most adapted to desert conditions in arid areas, and research in our universities on camels proves that it's more profitable to raise camels than sheep and goats in the area. This is a field of research which I think it would be advisable to undertake.

Di Castri

The problem of biological diversity also embraces that of the decreasing genetic diversity of the various breeds of domestic animals and of cultivars of plants. For instance, all around the Mediterranean Sea, hundreds of local breeds of domestic animals (cattle, sheep and goats) have been selected in the past. Some 90% of them are under threat of extinction. The same applies to the varieties of cultivated plants that are replaced by a few highly productive cultivars. I want to highlight the importance of wild relatives of domestic species of animals and plants for breeding with high yield varieties, in order to increase their resistance to pests, their adaptation to drier conditions, etc. This can also be achieved through genetic bioengineering. Finally, I fully share the statement of Dr. Ayyad that conservation of varieties and species has to be envisaged over a long lapse of time.

SCARASCIA MUGNOZZA

On this problem of species conservation, or genetic resources, I wish to say something because in the Mediterranean area, especially in Italy, we have made an effort to preserve such materials both for animals and plants.

In Italy, two institutes are working in this field. Answering also Professor Odhiambo, I would say that both ways of preserving plant material, "in-situ" and also "ex-situ" conservation (gene-banks), should be followed. These methodologies should be applied for those plants which are already of agricultural interest as well as for those of potential relevance for future agriculture. I take the occasion to underline the great problem of the conservation of vegetatively propagated plants (fruit trees, forest plants), for which, besides the very expensive (in terms of space, time and operation) method of "in-situ" conservation, new techniques are being developed: tissue culture, pollen conservation, cryo preservation. Conservation of plant genetic resources is carried out and guaranteed by several institutes, especially in the advanced countries.

Nevertheless, a network of germplasm laboratories has been, or is being established in many developing countries, especially in the international institutes belonging to the system of the Consultative Group of International Agricultural Research and located in economically less developed regions.

As for the problem of animal conservation, allow me to say something about the Italian experience. At the end of a national research program (1978), an experimental institute was organized by the National Research Council, with a net of substations, in which groups of animals of different species and races, selected for centuries, by farmers, are bred in typical or more suitable environmental conditions.

Among the numerous problems, one is represented by the minimum size of the group, in order to avoid both consanguineity and consequent changes in genetic diversity and vigour.

In Italy, as well in other countries, these complex and expensive studies are generally limited to animals of agricultural importance. I think that nothing has been done on animal species of relevant value in tropical areas.

In general, the role of plant and animal genetic resources is receiving increasing political consideration, also in less developed countries, in which the majority of the genetic resources are present. I think it's important that at this meeting such a fundamental problem has been raised.

DEGRADATION, PROTECTION AND RECOVERY OF LAKE ECOSYSTEMS

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1. General Characteristics

Before discussing the methods to protect and recover the lake ecosystems, it seems opportune to consider their general characteristics and their degradation due to the activities of man.

Lakes and rivers form a network connected with the underground waters. The volume of fresh water represents only 0.02% of the total waters of the earth. In spite of this small percentage, fresh water is the basis of life and, then, also of civilization. Lake protection is justified, in addition to its aesthetical and ecological values, from a social and economic point of view because lakes are utilized for drinking water, irrigation, fishing, recreational activities, hydroelectric power and navigation.

A lake is a temporary event, if the duration of its life is measured on the geological scale. Indeed, from the Quaternary glacier regression up to today, several lakes dried and the surface of the greatest part of them has been reduced more and more. As all the plant and animal species (man included) have common characteristics, but each one is different from the others, all lakes have the same general characteristics, but each lake has its own "unique personality". For example, the mean hydrological renewal time is a common property of all lakes, but its value varies widely in relation to the morphological and hydrological characteristics and the pattern of the thermic stratification of the water body. Production and degradation of the organic matter, biogeochemical cycles and the energy flow are common processes to all lakes, but they vary from one lake to another and in the same lake are not constant in time. As a consequence, the conclusions drawn from studies on a lake may be generalized to others, but with great caution. The lake, like any ecosystem, is not an isolated "microcosm", but an open system and, then, it exchanges energy and material with the surrounding environment, which consists in its watershed and atmosphere.

A lake is so strictly dependent on its watershed that any event occurring in this has a more or less great influence on the lake. As a consequence, to protect a lake, first of all, any source of damage must be removed from the watershed or neutralized. Another pathway of energy and substances to the lake is represented by the atmosphere. Indeed, the thermic and photic energy and the dry and wet fall-out of useful and toxic substances are transferred from the air to the water. In addition, the hydrological budget of the lake is controlled by the precipitations. The load of substance (liquid and solid) let into a lake is always greater than that lost from its outlet. Consequently, a lake results continuously enriched with mineral and organic substances, several of them (i.e., nutrients) are essential for phytoplankton and macrophyte growth. The nutrients enrichment, increasing the primary production and plant biomass, indirectly sustains high population density of herbivors and, consequently, that of carnivors. As a result, the concentration of organic matter increases, enhancing the microorganism activity, even if this, generally, is lower than the primary production. Consequently, the organic matter accumulates in the water and sediment and the hypolimnetic oxygen is partially or totally consumed by the decomposers. In the surface layers (epilimnion) of the nutrient enriched lakes, the population density of the phytoplankton is very high and produces a great amount of oxygen until the end of the warm season. Conversely, in the deep waters (hypolimnion), oxygen is depleted. Both the decrease of the air temperature and wind produce the destratification of the water column which is mixed and oxygenated. If the volume of the hypolimnetic waters, poor in oxygen, is great in comparison with that of the epilimnetic waters, the mixing produces such a great decrease in oxygen concentration in the whole lake water that it causes often a mass mortality of fish.

From these considerations it is evident that, in addition to the seasonal and annual fluctuations, a lake has a natural evolution passing from the *oligotrophic* stage (that is with low nutrient concentration) to the *eutrophic* (high nutrient concentration) through the *mesotrophic* stage. The rate of this evolution ("natural eutrophication") varies from one lake to the other and it is of the order of some centuries or thousands of years in relation to the lake volume, renewal time and nutrient load.

2. Causes of Lake Degradation

2.1 *Eutrophication*

Natural eutrophication may be accelerated by human activities ("cultural eutrophication"); for example, in few years, the nutrient load due to human activities may transform a middle-size oligotrophic lake into an eutrophic ecosystem with a consequent degradation of its water quality. Eutrophication is the most diffuse and important cause of lake degradation. Municipal and domestic waste waters, chemical fertilizers, by-products of some industries, watershed leaching and atmospheric depositions are the most important sources of nutrient load to the lakes. In addition to the above mentioned influence of eutrophication on the ecosystem (see 1), the following noxious effects have been observed: (a) degradation of water quality by high concentrations of organic substances which often produce disagreable smell and taste; (b) during chlorination of drinking water from eutrophic lakes, toxic halogenic compounds are synthetized; in addition, these waters may have high concentrations of nitrites; (c) the filters used to treat this water are rapidly clogged by algae and organic particles; and (d) sometimes blooms of toxic algae have been observed in eutrophic waters.

2.2 *Acidification*

In certain areas, an important cause of lake degradation is acidification. SO_2 and NO_x, present in the atmosphere and originated by natural events (for example, organic matter decomposition, vulcanic activities) and by activities of man (e.g., thermic plants, domestic heating, some types of industries, fertilizers) are transformed into sulfuric and nitric acid. These compounds and their precursors are transferred by dry and wet depositions from the atmosphere to the surface waters and watersheds and from watersheds to water bodies. With the increased need of energy the acidification of the wet and dry deposition has greatly increased in the last decades. The lakes lying in acid rockbed (for example, granite formation) have been well studied because they are the most susceptible to be acidified. Several lakes lying in the Canadian and Fenno-Scandian shield are a clear example of acidified ecosystems, whereas those rich in carbonates are sufficiently buffered and up to today no damage has been observed in them (for example, the great lakes of Northern Italy). In some agricultural areas of the Netherlands the acidification of the ecosystem is principally due to the nitric acid produced by the oxidation of ammonium salts used as fertilizers, whereas in industrial areas of the same country the acidification is the effect of sulfuric acid, a by-product of fossil fuel combustion.

2.3 *Organic Micropollutants* (*Pesticides*)

Although chemicals to control plant pests and diseases have been employed for a long time (e.g., copper and arsenic compounds), the use of organic pesticides (e.g., organochlorine and organophosphorus compounds, synthetic pyrethroids) on a large scale is relatively recent. For example, in the United Kingdom fifteen pesticides were commonly used in 1950, but their number attained about two hundred in 800 formulations by 1975 (Sly, 1977). Pesticides may be transferred from the watershed and atmosphere to the water body in several ways. For example, from run-off, dry and wet depositions, aerial spraying operations against crop and forest pests and from deliberate application to the aquatic ecosystem for controlling undesirable organisms (for example, mosquito, competitive fish without economic value, sea lamprey, snails, intermediate hosts of parasites). Organochlorine compounds are persistent, whereas organophosphorus compounds have a comparatively short life in aquatic environments. Accumulation of pesticides in aquatic animals has been first demonstrated in Clear Lake, California (Hunt and Bischoff, 1960) and, successively, in middle size and great lakes (for example, Walker *et al.*, 1964; Hickey *et al.*, 1966). Some aquatic plants (for example, *Cladophora*) have also a great capacity to accumulate organic pesticides in their tissue. Because pesticides are effective chemicals for controlling pests and, on the other hand, toxic substances, efforts must be concentrated to apply these substances to destroy the undesirable species at such low concentrations that minimal adverse effects are produced on other organisms (Muirhead-Thomson, 1971).

2.4 *Heavy Metals*

Heavy metals (e.g., As, Cu, Cd, Hg, Pb, Ni) are persistent pollutants and are discharged into the water body with industrial, agricultural and mining effluents and, partly, with wet and dry depositions. Lake Orta (Northern Italy) is a clear example of a lake heavily polluted by copper in addition to ammonia (Bonomi and Bonacina, 1985), and the Wabigoon-English system from Wabigoon Lake to Ball Lake (Ontario, Canada) polluted by mercury (Jackson and Woychuk, 1981). Some heavy metals seem to be unimportant to the metabolism (for example, Pb, Cd); others (for example, Cu, Zn) are essential to the organisms at low concentrations, but they are toxic at high concentrations. The toxicity of the metals also depends on their physico-chemical forms. The ionic form, generally, is the most toxic and the colloidal and chelated the less toxic. Mercury represents an exception, because the organic forms are more toxic than the inorganic ones. As a consequence, a complete ecotoxicological research should take into account the metal speciation and the parameters acting on it (for example, oxygen and suspended matter concentrations, pH, electrical conductivity, temperature, redox potential). Unfortunately, routine methods to quantify the various metal forms are not yet available.

2.5 *Oil Pollution*

Oil is a mixture of hydrocarbons and has a toxicity level according to the mixture composition. For example, the hydrocarbons with a low boiling point are the most toxic, but being also volatile their effects are limited in time, whereas those with a high boiling point are less toxic but more persistent. These pollutants contaminate water bodies from effluents, tributaries, leaching of the watershed or directly from accidents to ships or in harbours and continuous pollution due to touristic and commercial navigation. The degradation rate of the hydrocarbons strictly depends on the characteristics of the microbial activity and of the physical environment. Hydrocarbons, in addition to alterating the physiology and behaviour of aquatic organisms, modify the organoleptic characteristics of the water and fish, lowering their quality. The real problem faced by the aquatic ecosystem is dealing with massive oil pollution over a short time period produced by accident.

2.6 *Thermal Pollution*

For the increased need of energy, power plants increase in size and number. They depend upon the use of surface water as a coolant which is returned to the environment at a more elevated temperature. The greatest part of power plants utilize water from rivers. Temperature changes cause both physical and chemical changes in the water: for example, alteration in pH value, increase in solubility of certain compounds and precipitation of others, decrease in oxygen concentration and decrease in density and viscosity of water. Because thermal pollution influences directly the physiology of the populations, more or less deeply according to the species, the community structure results altered. The community metabolism is accelerated: for example, respiration, production and mineralization of the organic matter. Until a certain level of temperature, the rates of these processes become faster until they are abolished at extremely high temperature. The damages are proportional to the increase in calories addition and in relation to the temperature of the ecosystem before receiving thermal effluents. It has been demonstrated that the most relevant damages are not due to a gradual increase in temperature, but to thermal shock.

2.7 *Radioactive Pollution*

Except for information concerning effects due to nuclear energy used in war, and the areas in which nuclear tests have been performed and the few cases of nuclear accident, there is no reliable information about damages to lake communities caused by radioactive contamination. The Bikini and Enivetok ecosystem destroyed by many successive nuclear tests are said to be recovered. The most important risk consists in using as food organisms living in contaminated areas (for example, fish).

2.8 *Other Causes of Lake Modification*

In addition to pollution and "cultural eutrophication", lake ecosystems may be altered by other effects produced by man's activities. For example, forest clearing increases the silting and nutrient load in water bodies (e.g., Likens *et al.*, 1970; Tutin, 1978). Because silting produces transparency decrease and often precipitation of microorganisms and nutrient substances, lake production and its mean depth decrease; consequently, also the heat budget is modified. On the other hand, silting may enrich the lake in nutrients which may have been adsorbed into the surface of the particles. Agriculture and engineering may modify the morphological characteristics of the watershed increasing the erosion-rate and, then, the material loading into the lake. The modification of the lake border has a negative effect on the littoral community with consequences also on fishing. One of the best examples of the influence of human activities on lake evolution is the research carried out by Hutchinson (1970) on Lake Monterosi (Central Italy). One of the most relevant alterations of the community structure is caused by deliberate or unintentional introduction of plant and animal species into a lake.

Very interesting information on man's impact on lakes, studied by paleolimnological methods, is reported in Löffler (1980).

3. Lake Protection and Recovery

To protect and correctly manage a lake we must consider it under a realistic point of view, that is, as an open system which spontaneously evolves, taking into account that its evolution may be accelerated by the "cultural eutrophication" and altered by the addition of toxic substances.

A lake may be considered as a "black box" with an input and an output of energy and material. This simple model may be useful for several aims; for example, to estimate the amount of nutrient and/or toxic substances yearly accumulated in the basin. For particular reasons, the exchange between water and atmosphere must also be considered; for example, to evaluate the hydrologic budget and the load of acidifying substances. A lake is an ecosystem and not a swimming-pool with an "inlet" and "outlet", that is, it is a very complex and orderly system (that is, with a well defined structure) which is continuously modified. The complexity of the ecosystem is given by several state variables necessary to describe it and the order is clearly demonstrated by the variations of the physical, chemical and biological characteristics with the depth. The dynamics of lake is evident from the changing of the state variables with time. These are the reasons why it is practically impossible to develop a model which adequately describes lake ecosystem. The difficulty does not depend solely on the complexity of the ecosystem, but above all on the rough sampling and analytical techniques, if compared with sophisticated mathematical methods. Therefore, to apply models to lake ecology, a limited number of important parameters must be considered and the interrelations between them simplified. Useful results may be obtained from these models and, particularly, if the model concerns well-defined processes. It is obvious that the results obtained from the model must be verified by experimental data.

The alteration degree of a lake and the effectiveness of the applied interventions must be evaluated on the basis of ecological concepts. To this aim the state of the general structure and the functioning of the lake ecosystem, on the basis of the values and patterns of some fundamental parameters, must be evaluated. For example, in a lake in good conditions, oxygen saturation in the surface water does not exceed 100% and in the deeper layer, oxygen must be always present, although with low concentrations. In surface waters, pH values of about 9-10 are generally indices of an excessively high primary productivity as well as values lower than 5.0 may indicate acidifying processes. High nutrient concentration in water and low phytoplankton production may be the effects of toxic pollutants. Consistent variations of the biomass and structure of phyto- and/or zooplankton may be the result of the ecosystem alteration. Qualitative and quantitative plankton changes may be due to the toxic substances and/or to the variation of the nutrient load, but also to some other causes; for example, overfishing or new fish species introduction. Some criteria have been applied to establish limits between eutrophy, mesotrophy and oligotrophy.

To classify the trophic level of water bodies, the range of the values related to some important parameters (e.g., chlorophyll concentration, water transparency) has been *a priori* decided (Table 1). Conversely, Vollenweider and Kerekes (1981) proposed a probabilistic approach to establish the trophic level of lakes on the basis of total phosphorus and chlorophyll-a concentrations (Fig. 1). For example, a lake with a mean total phosphorus concentration of 10 $mg.m^{-3}$ has 78% of probability to be oligotrophic, 20% to be mesotrophic and only 2% to be eutrophic. Despite their limitations, several indices have been developed because they may be useful as standards and communication channels in quantitative terms with administrators and the public. To this aim some quantitative trophic indices have been developed concerning some important parameters easy to be quantitatively measured (for example, Carlson, 1977). Unfortunately, there are no specific indices for lakes polluted by toxic substances.

By monitoring and surveillance the state of health of a lake may be evaluated. Chemical monitoring consists in sampling and chemical analyses of some compartments of the ecosystem (e.g., water, sediment, macrophytes,

TABLE 1 - *Preliminary classification of trophic state in the OECD Eutrophication Program. Trophic status is assigned based on the opinion of the investigator of each lake. The geometric mean (based on log 10 transformation) was calculated after removing values <or> x 2 SD obtained (where applicable) in the first calculation* (from: Vollenweider and Kerekes, 1981).

Variable (Annual Mean Values)		Oligo-trophic	Meso-trophic	Eutrophic	Hyper-eutrophic
Total Phosphorus mg/m^3	x	8.0	26.7	84.4	
	x ± 1 SD	4.85-13.3	14.5-49	48 -189	
	x ± 2 SD	2.9 -22.1	7.9-90.8	16.8-424	
	Range	3.0 -17.7	10.9-95.6	16.2-386	750-1200
	n	21	19(21)	71(72)	2
Total Nitrogen mg/m^3	x	661	753	1875	
	x ± 1 SD	371-1180	485-1170	861-4081	
	x ± 2 SD	208-2103	313-1816	395-8913	
	Range	307-1630	361-1387	393-6100	
	n	11	8	37(38)	
Chlorophyll *a* mg/m^3	x	1.7	4.7	14.3	
	x ± 1 SD	.8-3.4	3. - 7.4	6.7-31	
	x ± 2 SD	.4-7.1	1.9-11.6	3.1-66	
	Range	0.3-4.5	3. -11	2.7-78	100-150
	n	22	16(17)	70(72)	2
Chlorophyll *a* Peak Value mg/m^3	x	4.2	16.1	42.6	
	x ± 1 SD	2.6- 7.6	8.9-29	16.9-107	
	x ± 2 SD	1.5-13	4.9-52.5	6.7-270	
	Range	1.3-10.6	4.9-49.5	9.5-275	
	n	16	12	46	
Secchi Depth m	x	9.9	4.2	2.45	
	x ± 1 SD	4.9-16.5	2.4- 7.4	1.5-4.0	
	x ± 2 SD	3.6-27.5	1.4-13	.9-6.7	
	Range	5.4-28.3	1.5- 8.1	.8-7.0	0.4-0.5
	n	13	20	70(72)	2

x = geometric mean.

SD = standard deviation.

( ) = value in brackets refers to the number of variables (n) employed in the first calculation.

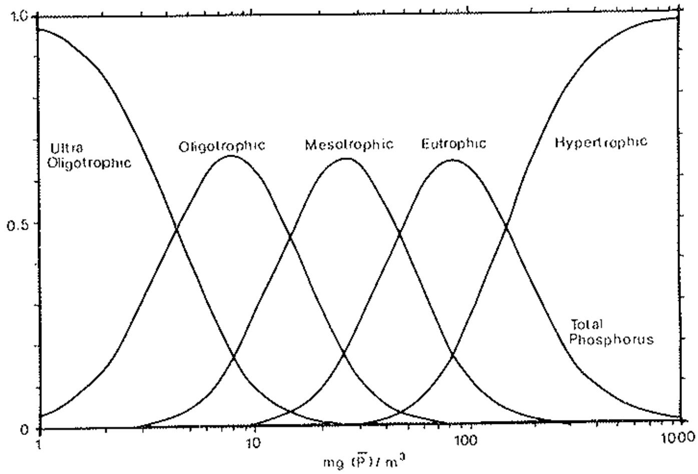

FIG. 1. Probability distribution for trophic categories established on total phosphorus concentration in the water (from: Vollenweider and Kerekes, 1981).

fish). Biological monitoring detects the effects produced by the pollutants on the biota. The latter method has two main advantages: (a) the biota does not react to a single pollutant, but to the global situation; (b) the reaction of the biota is the cumulative result of the present and past situation. It is very fruitful to combine the chemical and biological monitoring. Monitoring concerns the general situation of the environment, whereas surveillance is used for specific pollution problems and is exerted by sampling and chemical and biological analyses. Surveillance is particularly useful to detect the effects produced by new substances.

Methods for recovering a lake are related to the characteristics of the ecosystem, the extent of its degradation, the cause of its alteration and the purpose for which the recovery has been planned. As a consequence, it is impossible to establish a standardized treatment applicable to all lakes. The several methods used to recover the water bodies may be divided into two main groups: (a) interventions on the watershed and (b) interventions directly on the lake (internal measures). The interventions on the watershed produce good results if the size and efficiency of the waste water treatment are proportional to the noxious substance load. Indeed, by removing the nutrient and/or toxic load, an aquatic ecosystem can be returned to a more stable and diversified state, but in many cases this is not sufficient to obtain a satisfactory recovery in a reasonable period of time. To accelerate lake recovery, various methods have been developed to be directly applied to the water body. These techniques must be cautiously applied and in several cases produced satisfying results, particularly when they have been associated with interventions on the watershed. The "internal measures" are limited to small and middle size lakes and reservoirs.

3.1 *Interventions on the Watershed*

The interventions on the watershed tend to reduce the nutrient and toxic load from the effluents. The waste waters, after having been treated, are discharged directly into the lake (e.g., Lake Lugano, Italy-Switzerland; Lake of Geneva, France-Switzerland) or transferred from outside of the watershed by means of the lake outlet or by canalization (e.g., Lake Annecy, France).

Because the efficiency of the treatment plants never attains 100%, the latter decision is undoubtedly to be preferred to the first. The waste water treatment essentially consists in three successive steps: (a) to remove mechanically the more course detritus; (b) to mineralize the organic matter by air bubbling and stirring the waste waters to enhance microorganism activity; and (c) to precipitate phosphates with aluminium or iron compounds. The 3rd phase is very important because phosphorus may be removed with a relatively high efficiency (80-95%) reducing the load of one of the most critical fertilizing elements to receiving waters. In addition to the phosphorus precipitation, a great amount of suspended particles (for example, pathogenous microorganisms) are removed. Some waste water treatment plants also have the 4th phase, which consists in the removal of the nitrogen compounds (e.g., Lake Varese, Northern Italy). If toxic substances (for examples, chromium, mercury) are present in the effluent, they must be removed by techniques chosen in relation to the characteristics of the pollutant. The decrease in the nutrient load has produced a partial or a complete recovery of several lakes. For example, a significant improvement of Lake Annecy has been obtained by the removal of the effluents by a sewer system. A relevant amelioration of Lake Washington (USA) and Lake of Zürich (Switzerland) has been obtained by their effluents treatment (Thomas, 1969; Edmonson, 1975). The trophic level of Greifensee (Switzerland) has continuously increased by domestic waste water and nutrient load from agricultural practice. Now, phosphates from the effluents are removed by several treatment plants and in addition to the phosphate precipitation, flocculation and filtration techniques have been applied. An amelioration of the water quality has been obtained; for example, in 1973 the phosphorus concentration in lake water ranged from 380 mg to 590 $mg.m^{-3}$, but in 1977 it was about 260 $mg.m^{-3}$. In spite of the sophisticated method applied, the water of the lake has not yet attained a satisfying quality; this is principally due to the high amount of phosphates accumulated in the sediments, which are released to the water during the period of hypolimnetic oxygen depletion.

Bernhardt (1983) and Bernhardt and Clasen (1985) applied with satisfactory results various measures to reduce the phosphorus load into reservoirs; for example, (a) treatment of the inlet water with precipitation, flocculation and filtration processes; (b) filtration of tributaries through aluminium oxide filters; (c) biological phosphorus elimination in bioreactors; (d) underground passage of small tributaries with ponds and seepage trenches; and (e) seepage of small tributaries through artificial filters. Reduction of the nutrient load from non-point sources has been obtained by pre-dams in lakes of East Germany (Uhlmann and Klapper, 1985).

3.2 *Direct Interventions on the Water Body*

When sediments, such as those of Greifensee, are an important source of nutrients, the measures taken to reduce the external load are generally not sufficient to obtain satisfactory results. As a consequence, various techniques may be directly applied to recover the water body. For example, Bernhardt and Clasen (1985) recommend direct measures to recover man-made lakes, which have an average depth less than 5 m and which have large proportions of shallow areas.

During the hypolimnetic oxygen depletion, a consistent amount of phosphorus and other nutrients is released from the anoxic sediment into the water column. If this nutrient flux reaches the epilimnetic layer, it may be utilized by the phytoplankton ("internal eutrophication"). To prevent this nutrient release and the consequent algal blooms and fish kill, the superficial sediments may be removed by sucking or dredging or by covering them with amorphous material (for example, sand, crushed bricks). For example, tbe shallow and eutrophic lake Trummen (South Sweden) was recovered by pumping (suction dredging) the surface sediments into ponds. The run-off water from the ponds was treated with aluminium sulfate to precipitate phosphorus and particulate matter and pumped into the lake. In addition, aquatic plant populations along the shore were also removed (Gelin, 1978). An increase in the binding capacity of the sediment for phosphorus and a decrease in the easily degradable organic matter have been obtained by injecting iron chloride, slaked lime and calcium nitrate into the sediments of the shallow and eutrophic Lake Lillesjon, Southern Sweden (Gelin, 1978). These methods must be always applied with great caution (Stefan and Hanson, 1981; Dunst, 1981).

By uprooting and removing macrophytes (great accumulators of nutrient and toxic substances), some temporary benefit may be obtained; consequently, this method must be repeated each year. In some water bodies (e.g., Lake Ostensjøvatn, Southern Norway) the harvesting of macrophytes makes conditions in the lake worse because it favours organisms with higher turn-over rates (phytoplankton) and increases the production of organic matter which may exceed the amount of organic matter removed as macrophytes (Rorslett, 1978; Rorslett and Skulberg, 1976). The evaluation of the consequences by the use of this method is reported by Newrot (1981) and King and Burton (1981).

In some small eutrophic lakes the input of large volumes of water with low content of nutrients has produced satisfactory results (Welch and Tomasek, 1981).

The trophic level of some small lakes, for example, Manensee (Switzerland), Wilersee (Switzerland), Piburgersee (Austria), has been reduced by syphoning the hypolimnetic water rich in nutrients and poor in oxygen during the summer stratification (Olszewski, 1967; Eschmann, 1969; Pechlaner, 1971; Gächter, 1976). On the other hand, the side effects of this method are rather difficult to be evaluated; for example, heat enrichment in the epilimnion during summer stagnation and complete mixing anticipation.

Satisfactory results have been obtained in some lakes where the total water volume has been made to circulate during the summer stratification. This destratification technique, which prevents the formation of the thermocline, must be applied on an adequate information about the pattern of the oxygen concentration from the lake surface to the bottom in different seasons.

Hypolimnetic oxigenation without destratifying the water column could increase both the mineralization rate of organic matter and prevent the phosphorus release from the sediments. The techniques dealing with hypolimnetic oxygenation are the following: mechanical agitation (for example, Mercier, 1955), full-air lift (for example, Bernhardt, 1967; Fast, 1971a,b) and oxygen injection (for example, Whipple *et al.*, 1975; Ravera *et al.*, in press). In some cases, but not always, the results obtained were satisfying. The negative results were probably due to the short duration of the experiment, lack of control and scarce information about the lake characteristics before the aeration. The results obtained and the technique applied have been reviewed by Pastorok *et al.* (1981, 1982) and Fast and Lorenzen (1976). Epilimnetic mixing, suggested by Straskraba (1986), tends to reduce the light available to phytoplankton populations for preventing algal blooms. Air diffusers are located at prefixed depths of the epilimnion, and not near the lake bottom such as the destratification technique.

In some lakes the phosphates have been decreased by flocculation obtained by adding aluminium or iron salts to the lake water (Cooke and Kennedy, 1981); with the phosphorus decrease, algal biomass decreases and transparency increases. Barroin (1981) treated an experimental lake by injecting aluminium sulfate at the top layer of the sediment. In some Scandinavian and American lakes, lime addition has been effective in combating acidification (Krestel and Colquhoun, 1984). Unfortunately, the long term ecological consequences are not well known. The secondary effects produced by the addition of insecticides, herbicides and algicides to the lake are difficult to be predicted. Several of them are surely noxious; for example, macrophyte decay may cause both the release of nutrients from plant tissues and the increase of oxygen consumption; in addition, useful species may be killed together with those for which the lake has been treated (Anderson, 1981; De Mayo *et al.*, 1982). According to Cooke *et al.* (1986), these biocides could be used only when other treatments have been found ineffective.

Biomanipulation seems to be an advanced and useful method to reduce or abolish the effects of eutrophication. This method consists in modifying the community structure to decrease the production and biomass of the total phytoplankton and to reduce or eliminate some undesirable species (blue-green algae) and to enhance the growth of others (for example, diatoms). For instance, the decrease of some species of planktophagous fishes increases the herbivorous zooplankton feeding on phytoplankton. Benndorf *et al.* (1984a,b) introduced carnivorous fishes (pike and perch) to reduce the population density of smaller plantivorous fish in a shallow man-made lake. The results obtained were the following: phytoplankton biomass and bacteria number were reduced, water transparency increased and the oxygen regime ameliorated. Some species of fish (i.e., *Tilapia mossambica*) have been introduced in water bodies to control phytoplankton and macrophyte biomass, and another (i.e., *Gambusia*) to reduce to the minimum the population density of some noxious insect larvae (for example, *Anopheles*, *Culex*). A review on the biomanipulation techniques and the results obtained during the last few years has been published by Shapiro *et al.* (1982.

An evaluation of the results obtained by the application of some of the above mentioned techniques to several alpine lakes has been reported in the final report in "OECD Eutrophication Programme, Regional Project: Alpine Lakes" (1980).

In addition to the technological methods, the lakes must be protected by an opportune land management and up-to-date legislation. For example, some modifications of the quantity, quality and distribution period of fertilizers and biocides reduce the amount of nutrients and/or toxic substances washed down to water bodies. A more rational use of detergents and the decrease in their phosphorus content results in a significant reduction in the phosphorus concentration in municipal or domestic waste waters. To reduce oil pollution in some small lakes, motor navigation (except electrical) has been forbidden (for example, Austria; Lombardy, Italy) by opportune legislation.

4. Discussion and Conclusions

There is a rich information on the biological effects studied in the natural environment, but it is rather difficult to separate the effects due to natural causes from those produced by pollutants. In addition, a lake is rarely polluted by one toxic substance and, therefore, the community is simultaneously influenced by natural stresses as well as by pollutant mixture.

Pollutants influence both the biota and the physical environment; the latter, in its turn, acts on the physico-chemical form of the pollutant and its distribution. For example, for the same pollutant loading its accumulation in the lake increases with mean hydrological renewal time and the toxicity of a pollutant varies with the characteristics of the environment (Fig. 2). The organism modifying the characteristics of the physical environment indirectly influences the pollutant. From these considerations it is evident that there is a series of interrelations between pollutant, biota and physical environment (Fig. 3). This is the reason why it is always difficult to establish a relationship between the pollutant concentration in

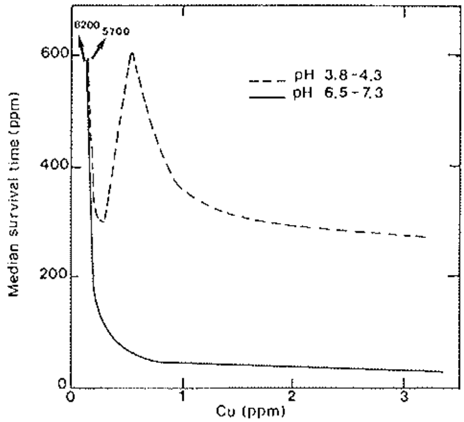

FIG. 2. Relation between median survival time of *Nais communis* (Oligochaeta) and copper concentration in soft water with different pH (from: Learner and Edwards, 1963, modified).

the natural environment and their biological effects, if the three variables mentioned above (pollutant, biota and physical environment) are not taken into account.

Some causes of lake degradation (for example, eutrophication, acidification) principally modify the water characteristics (for example, high nutrient concentration, low pH values) which, in their turn, influence the biota. Other pollutants (for example, heavy metals, biocides) generally attain such a low concentration that they cannot significantly alter the physical and chemical characteristics of the medium, but, although in traces, may be noxious to organisms. As a consequence, the productivity, biomass and structure of the community vary, modifying the water characteristics. Therefore, these toxic substances alter the water quality modifying the community characteristics, whereas the nutrients

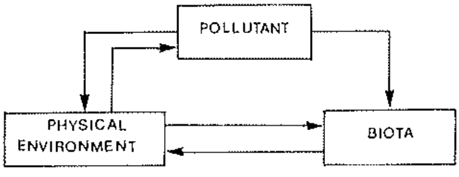

FIG. 3. Interrelationships between pollutant, biota and physical environment.

and acidifying substances influence the biota by the alteration of the physical environment.

Homeostatic processes, which increase their efficacy with maturity of the ecosystem, slow the evolution-rate of the lake. Both these tendencies (that is the evolution and the homeostasis) simultaneously influence the ecosystem, but the importance of each one varies with time. For example, if the nutrient load of an eutrophic lake is reduced by waste water treatment plant, the homeostatic mechanisms tend to delay the lake evolution toward the mesotrophic stage, keeping the lake at eutrophic level for a certain time. This is the cause of the delay between the application of the interventions on the lake and its recovery. If the protecting methods are adequate to the lake degradation, the tendency to the evolution mechanism overcomes the homeostatic ones, ameliorating the lake conditions. The same processes influence the recovery of the ecosystem polluted by toxic substances.

According to Odum (1975) an ecosystem receiving a small input of energy is more stable if the diversity of its community is high. Conversely, an ecosystem with a great input of energy is more stable if its diversity is low. From this statement the following considerations may be made. An oligotrophic lake must be stable if its diversity is high, and an eutrophic lake, if its diversity is low. As a consequence, a decrease in stability may be expected from a nutrient load increase to an oligotrophic lake as well as from a nutrient load decrease to an eutrophic lake. Successively, in the eutrophicated lake the stability should increase with the decrease in diversity, and in the lake with decreased trophy with the increase in diversity. In addition, a considerable input of toxic substances (which generally reduces the diversity) should decrease the stability in an oligotrophic lake, but should increase it in an eutrophic one (Fig. 4).

The community structure represents the combined effect of the characteristics of the physical environment and the adaptation capacity of the populations. As a consequence, there is an equilibrium between the community and the environment and between the species populations. If this equilibrium is altered by any stress, the community structure is modified. These modifications are small and gradual when the environment slowly evolves. Conversely, important and rapid changes in the environment produce qualitative and quantitative alteration of the community, including its substitution by another with a major fitness to the new situation. Therefore, if a lake is heavily polluted by toxic substances and/or enriched by nutrients or calories, relevant changes of the community

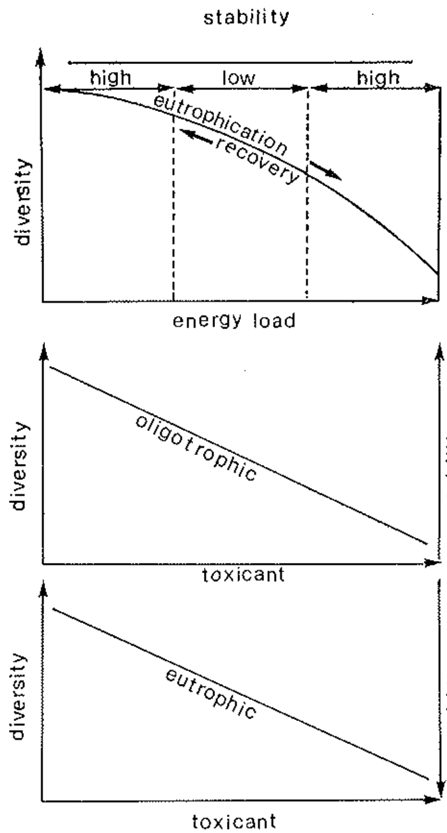

Fig. 4. Relationships between energy load, diversity and stability compared with trophic degree variations (upper); relationship between diversity and stability in an oligotrophic ecosystem polluted by a toxicant (middle) and relationship between diversity and stability in an eutrophic ecosystem polluted by a toxicant (lower).

may be expected. Because the sensitivity to a given pollutant varies with the species (Fig. 5), in a polluted environment some resistant species may dramatically increase their abundance as competitors and predators are reduced in number or abolished. For example, in several eutrophic lakes an increased population density of some fishes of little commercial value has been observed. During the last decades, four zooplankton species disappeared from the eutrophic Lake Lugano (Ravera, 1977; Ravera and Parise, 1978).

Lake protection and recovery must be planned according to a

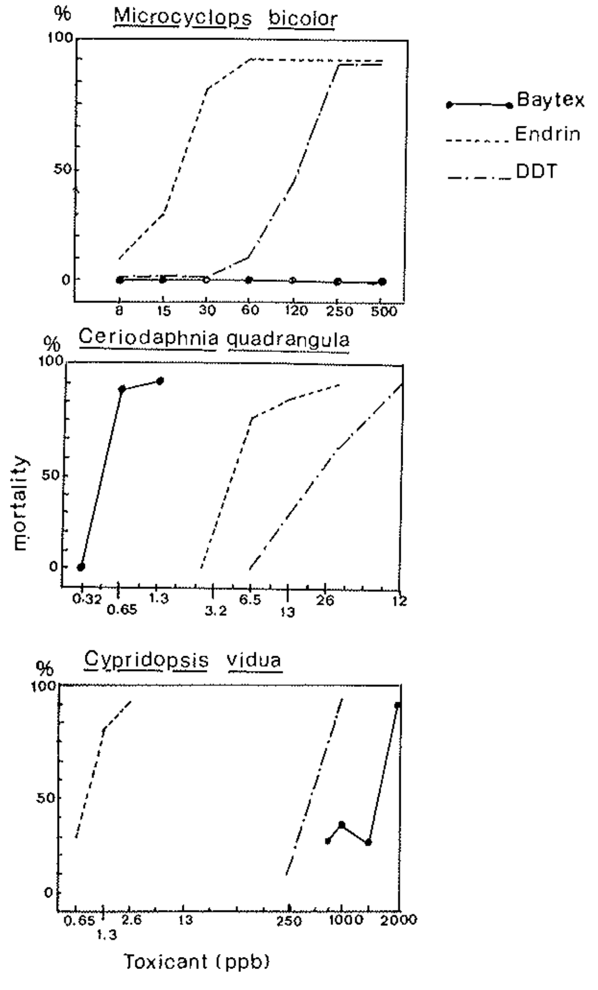

FIG. 5. Twenty-four hour mortalities of Copepods, Cladocerans and Ostracods exposed to different concentrations of Baytex, endrin and DDT (from: Ruber, 1963, modified).

series of steps, which in our opinion, may be the following: (1) to know the most important physical, chemical and biological characteristics of the lake ecosystem, their variations in time and space and their interactions. The number of these fundamental characteristics may be small and the measurements may be limited to the "critical periods" of the seasonal cycle (for example, during the stratification and full circulation period). Particular attention must be paid to the importance and spatial distribution of the potential causes of the lake alteration and the noxious substances load (nutrient and toxic substances); (2) to estimate the present damages produced in a lake by human activities and predict the future ones, assuming hypothetical changes of the human activities in the watershed as well as recovery interventions; (3) to identify the aims to lake protection and the technical and legislative means useful to reach the prefixed goals; (4) to evaluate the size and cost of the chosen interventions and the benefits expected from their application, taking into account the time to obtain them and the eventual noxious consequences (for example, accumulation of solid wastes); (5) after having applied the interventions, their effectiveness must be continuously evaluated, that is, their effects on the lake in relation with the prefixed aims. The effects are evident after a certain time (years or decades) in relation with the degradation level reached by the lake and the efficiency of the interventions; (6) when the interventions do not produce the expected result, they must be modified or substituted by more effective ones; (7) if the lake conditions are satisfying (that is, the lake is oligotrophic or mesotrophic and negligible is the toxic substance load), the protection may be limited to steps 1 and 2. Anyhow, before promoting activities in the watershed (for example, tourism, industries, cattle breeding), the lake capacity to intake their by-products without noxious effects must be estimated. Conversely, if there is evidence that the lake capacity is small in comparison with the influence of the new activities, the predicted damages must be reduced to the minimum by opportune technical and legislative interventions or the activities must be forbidden or limited in size.

It is seldom that the aim of the restoration project is the return of the lake to its original oligotrophic state. The actual scope for restoration principally depends on the uses of the water body. For example, the recovery of an eutrophic lake to obtain drinking water is judged satisfactory when it attains the mesotrophic state. The complete recovery of an ecosystem is impossible, not only for reasons of economics but also because some of its components may have been lost forever. As a consequence, it is evident that it is easier to prevent the degradation of the environment than to repair the damage done.

In conclusion, each lake must be considered in relation to its natural characteristics, the level of trophy reached, the toxic pollutant load and other causes degradating the lake ecosystem. To this aim the lake and its watershed must be considered as a unit which must be protected and/or recovered in the frame of a correct management of the area. This goal may be more easily attained if effective communication channels between scientists, decision-makers and people are established.

From the conference on Human Environment, held in Stockholm in 1972, the most usual subject of the discussion on the environments dealt with the damages produced by man on the ecosystem. Man has really degradated large areas of the earth, polluted soil, air and water, and wasted the resources of many ecosystems. On the other hand, man must transform his environment so as to create a new ecosystem adapted to his needs. This does not necessarily imply the destruction or the degradation of the nature, but its modification. For example, a terrestrial ecosystem may be transformed into an artificial lake. This reservoir, although its morphological and hydrologic characteristics are different from those of a natural lake, is an ecosystem with its own structure, functions and evolution. The English and Tuscan landscapes testify that man is able to build up diversified, stable and productive ecosystems.

To avoid damage to nature and then to man, the influence of human activities on the ecosystem (for example, on a lake and its watershed) must be exerted within strict ecological constraints.

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DE FLUVIORUM NATURA. ILLUSTRATA RHENI RHODANIQUE EXEMPLIS

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Pluebat et pluebat et pluebat. Porcellus secum dixit se nunquam dum erat — et Deus scit quantum sit longaevus: trimus aut quadrimus erat! — tantum pluviarum vidisse. Per dies et dies et dies.

"Aliquantulum perterrefacit", Porcellus dixit "animal parvulum ab omnia parte aquis circumdatum esse. Christophorus Robinus et Pu in arbores ascendo effugere possunt, Canga saliendo, Lepus cuniculos agendo, Bubo sese alis sustollendo, Ior magna voce clamando donec integer incolumisque servatus esset, sed ego hic sum, aquis circumdatus et quodcumque sit agere impotent".

Milne, MCMLXI.

In the opening quotation a little animal is described who after heavy rainfall is completely surrounded by water. He knows what all his big friends may do, but he cannot imagine what he, the small animal, can do. We see exactly the same in the problem of water pollution; all countries know what the other countries can and ought to do, but each thinks it is too small to do something itself. The problem of water pollution is increasing and increasing, not much different from the water level around Porcellus.

It has taken a long time before mankind realized that food production from nature could not be "free of cost", misusing soils, harvesting without management. When the number of people was low, there was of course no problem. But with population density increasing, with industrialization of agriculture developing, problems arose. The worst example so far was probably the so-called "Dust Bowl" of the 1930s. Overcultivation of the high plains west of the Mississipi River caused increasing amounts of dust, i.e., soil, to be blown away and to be deposited in places where it did not produce a workable topsoil. The greatest storm took place on May 12, 1934, when about 300×70^6 tons of topsoil were blown away eastward causing loss of agricultural soil in one place, but depositing disaster in another. There are, remarkably, rather few scientific reports of this event. Vallentyne (1974) used the example to explain problems likely to occur in our rivers and lakes. A more romantic but nevertheless well written account is given by Steinbeck (1948) in his novel *The Grapes of Wrath*, unfortunately a book now forgotten by young ecologists.

Just as nature cannot provide us with food "free of charge", she cannot provide us with a dustbin "free of charge". It is not so very long ago that this mistake was made, and the consequences are still present. The sanitary water engineer for a long time considered rivers as ways and means to get rid of waste.

I will read you a few examples:

A. "Although one member of the Commission strongly felt that the river Vecht *ought* to be charged with the discharge of waste from neighbouring villages, the other members of the Commission do not share this opinion". This report appeared in 1921. The river Vecht was, however, cleaned up seriously only after the 1970s, after many more reports had appeared. And during the 1970s we still heard several leading sanitary engineers express the same opinion about the Rhine!

B. During the final meeting (1972) of the International Biological Programme — a program to provide us with means for sound management of natural resources; a synthesis of the fresh water section has been published by Le Cren and Lowe-McConnel (1980) — the Thames River Water Authority explained to us that the Thames should contain some oxygen, and in due course would begin to do so, but that concentrations higher than 20% would be too expensive, and were not even necessary as at the 20% level the water could no longer produce H_2S.

C. A Dutch minister of water management stressed the opinion that rivers do not have to contain more than 40% of oxygen as fish would feel "lively and healthy" at that concentration. This was said in 1970. Now we have a new minister of water management. She has promised "that the salmon in the Rhine will be back in the year 2000" and that the Rhine will be protected as "an ecosystem". For that purpose she is going to insist that the concentration of the 30 most toxic compounds will decrease by 50%. She does not talk about all the other toxic compounds, nor does she seem to be aware that the salmon can never come back in the Rhine. Such a lack of knowledge is as dangerous as the lack of interest in the quality of the environment in the past.

Today the attitude of doing the absolute minimum has changed — at least officially. There is still, however, a large gap between ecology and economy. The gap remains wide open due to the populations' unwillingness to pay the real cost for a clean environment and due to governments' inability to convey a better message. If ever there was a thing that money can buy, it is a clean environment.

In this paper I will first discuss a few examples of how deep we have sunk, how happy we now seem to be with some of the present situations, what should still be done before ecologists will feel safe and what kind of criteria we ought to develop.

Rivers by the very nature of their currents were "ideal" for the transport of waste. What you dumped into a river would automatically be transported, either to your neighbours, or to the "immense" oceans. That neighbours, or coastal seas, would be affected was not the disposers' problem. The waste they received belongs to the following categories:

— O_2-consuming substances, mainly organic compounds and NH_3

— Heavy metals — often even the very toxic ones.

— Organic micropollutants; in this group we place the organic compounds that are released in such small amounts that they do not alter the O_2 balance. These are listed for their toxic properties.

— Plants nutrients — i.e., those compounds that are normally present in such small amounts that they limit plant growth. Their increased disposal causes enhanced plant growth. The phenomenon is nearly always highly undesirable.

— Inorganic salts. Usually these salts such as NaCl and $CaSO_4$ are not present in quantities causing any concern, but industrial disposal has probably changed the characteristics of many more lakes and rivers than has been realized.

1. *Oxygen-Consuming Substances*

The days that fishes were dying off due to O_2 depletion are over, at least in most rivers, but all of us still known more than one or two cases where this still happens. Especially some small rivers, often in beautiful landscapes, are still overlooked by regional public health officers. Often they receive the sewage of some small villages only, which are supposed to be too small, or too poor to build purification plants. For the larger rivers important improvements have often indeed been made. In the German part of the watershed of the Rhine about 90% of the sewage water is oxidized, in the Netherlands and Switzerland about 80%. On the other hand all textbooks of sanitary water engineers still contain a mathematical description of the so-called "oxygen sack", the depression of the O_2 concentration below a sewage outlet. (See Figure 1).

But what should be the lowest O_2 concentration permitted — 20, 40 or even 80%? As ecologists we feel that "no noticeable" depletion should occur. Only tbe Swiss and Swedish populations have developed such high technology that the effluent can be disposed of harmlessly. In other countries the technique is considered too expensive. In many lakes O_2 consumption due to the disposal of organic matter is still causing anoxic hypolimnia. Since this process is strongly related to the problem of eutrophication, the subject will not be treated further here, since Ravera has just presented it.

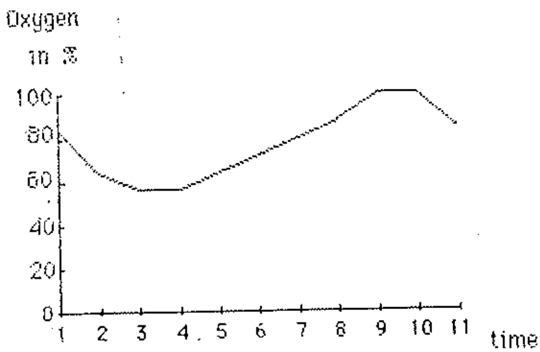

FIG. 1. Oxygen sack in a river.

2. *The Heavy Metals*

We can distinguish between two groups of heavy metals: those that occur in nature and are essential constituents of organisms, such as Cu, Zn, Al, Mo, Mn, Cr, and those that rarely occur in nature and are not constituents of organisms, such as Pb, Hg, Cd. The first group may cause serious problems: if their concentrations are too high, they will become toxic. The second group always causes problems. Except for some cases (volcanic input), their origin is human waste water.

In most countries the worst days are over, but what did happen should not remain undocumented. Therefore in Table 1 some old figures are given.

Table 2 memorizes the total amounts of heavy metals transported through the Rhine in the worst years. Fortunately this table is followed

TABLE 1 - *Heavy metal content of the Rhine and Ems sediments as* mg kg^{-1} (ppm) *of the* < 16 μm *fraction* (De Groot *et al.*, 1971, quoted from Golterman, 1975).

	Rhine	Ems		Rhine	Ems
Fe	54000	112	As	310	60
Mn	2600	3300	La	80	80
Zn	3900	700	Co	43	40
Cr	760	180	Hg	18	3
Pb	850	100	Sc	12	12
Cu	470	150	Sm	7	9

TABLE 2 - *Quantities of heavy metals transported annually by the Rhine* (data from RIWA report, quoted here from Golterman, 1975).

Metal	Tonnes per year	Metal	Tonnes per year
Hg	85	Pb	1500
As	1000	Cu	2900
Cd	200	Zn	9000

by Table 3, giving the present data and therefore showing the improvements made.

Fortunately large improvements have been made (see Table 3). When comparing these tables, it must be realized that the values in Table 1 are expressed in mg kg^{-1} of the < 16 µm fraction. This was done in order to obtain insight into the fraction that really contains these pollutants, without taking into account the inactive sand load. The suspended matter or sediments of the Rhine were compared by De Groot with those of the Ems, because this river was supposed to be unpolluted. Later evidence suggested otherwise. There is, however, still a large problem, i.e., knowing what concentrations of these heavy metals would occur under "pristine" conditions.

Although the decrease of the heavy metals in the Rhine is spectacular, the present values are still high compared with what we think are the "natural" or background concentrations. For most of the metals mentioned the present values are roughly 5-10 times the background values; for Pb only twice, but for Hg still 20-30 times.

3. *The Organic Micro Pollutants*

The list of identified organic pollutants appearing in drinking water contains several hundreds of compounds; peaks in gas chromatograms of the raw drinking water may amount to a thousand. Nevertheless, in the Rhine only the following compounds are being monitored: phenols and homologues, anionic detergents, α-hexachlorcyclohexane (α-HCH), γ-hexachlorcyclohexane (γ-HCH), hexachlorbenzene, and pentachlorphenol, while

TABLE 3 - *Some heavy metals in the Rhine in the period 1971-1985. Total load in* g sec^{-1}.

	1971	1975	1980	1985
Hg	3.9	0.7	0.5	0.15
Cd	6.7	4.2	3.7	0.3
Pb	63	44	40	7.7
Cu	93	41	37	11
Zn	470	275	265	90
Cr	167	70	50	13

it has furthermore been necessary to monitor the toxicity of the water with trout in flush-through aquaria. This system of detection is necessary, although completely inadequate, for both the more or less constant release of these compounds by industry and the sudden release by accidents — the larger ones, like the Sandoz accident, and the smaller ones never detected. The reason for this constant danger is that in the previous century waterways were considered ideal places to establish industries, because of the cheap transport of incoming and outgoing chemicals, and of the cheap possibilities to dispose of waste water. The Sandoz accident has been an example of what may happen any day as long as such a concentration of the chemical industry as is found in Basel remains without a complete net of safety measures. The presence of the Rhine should not be considered as a safety design for eventual disasters.

The presence of these compounds raises the problem of their ecotoxicology. Nowadays this is becoming an increasingly important science, but at the same time it is definitely understood that it will be absolutely impossible to assess the risk of a mixture of several hundreds of compounds on several hundreds of organisms. An improvement could be achieved if the costs of the monitoring system could be estimated and charged to the polluter: the "polluter pays" principle, if applied in its full rigour, would greatly help to improve the situation to clean up our rivers.

In sharp contrast to the very limited, ministerial actions to clean up the Rhine (see above), the drinking water companies in the Rhine watershed (the IAWR, 1987) have insisted to forbid completely the production of 129 chemicals that are mentioned on the "preliminary" black list of the E.E.C., as that is the only way to guarantee safe drinking water supply.

4. *Plant Nutrients*

The amounts of the plant nutrients transported by rivers, especially N and P causing severe cases of eutrophication are enormous. The Rhone brings into the Camargue amounts of Nitrogen and Phosphorus equal to the amounts used as fertilizers (El Habr and Golterman, 1987). These amounts of nutrients enter an ecosystem which is essentially oligotrophic. Data are given in Table 4.

Table 5 gives the amounts of phosphate transported by the river Rhine; it is disappointing to see that, although important limitations are imposed on the amounts of phosphate used in detergents in the Rhine watershed, the total load has not decreased. It seems that what was gained in one area

TABLE 4 - *Loadings of phosphate and nitrogen entering the Camargue with irrigation water and by fertilizer application.*

Loading entering the irrigation channel			*Loading leaving the irrigation channel*		
o-P	=	56 t	o-P	=	36 t
Tot-N min.	=	576 t	Tot-N min.	=	288 t
Part-P	=	24 t	Part-P	=	34 t
Part-N	=	36 t	Part-N	=	52 t
			Tot-P	=	70 t
			Tot-N	=	340 t
Fertilizer used			*Fertilizer used* (after losses)		
o-P	=	250 t	o-P	=	250 t
Tot-N	=	1500 t	Tot-N	=	300 t

TABLE 5 - *Total phosphate transport* (tons per year) *and water discharge* (m^3 y^{-1}) *in two stations on the Rhine during the period 1973-1984.*

Year	Stein am Rhein Tot-P loading	discharge	Bimmen/Lobith Tot-P loading	discharge
1973	n.d.	n.d.	59000	1750
1974	n.d.	n.d.	60000	2200
1975	n.d.	n.d.	45000	2000
1976	270	250	41000	1300
1977	1250	380	48000	2150
1978	800	400	54000	2500
1979	n.d.	n.d.	54000	2500
1980	1500	500	38000	2600
1981	1900	570	43000	3100
1982	1500	520	39000	2800
1983	960	430	45000	2600
1984	1150	430	40000	2550

was lost in another (probably agriculture). It demonstrates the important point that, unlike the old days, when we could consider agricultural activities not to be a source of phosphate because of the adsorption of phosphate onto the soil, this is no longer the case. "Bio-industrial" production of meat is again one of the changes of scale where old, established principles no longer hold true.

No longer have we to deal with increasing concentrations only. The changes have been so important that completely different problems begin to arise: Golterman and Meyer (1985a) have shown that in hard water rivers such as the Rhine and the Rhone the speciation of phosphate begins to be important: phosphate is no longer transported as soluble orthophosphate only, but part of it is transformed into insoluble calcium phosphate, i.e., hydroxy-apatite. This means that when the water of these rivers finally arrives in their deltas or coastal seas the phosphate is partly controlled by the transport in soluble form, but for the larger part deposited as sediment; thus it accumulates on sensitive places.

Evidence for the phosphate-calcium interactions is provided by the fact that the Rhine and the Rhone are saturated with apatite. This was demonstrated by Golterman and Meyer (1985a), who showed that the mean ionic product $Ca^5(PO_4^{3-})^3OH(mol^9\ l^{-9})$ centers around the so-called solubility product 10^{-50}. This means that the concentration of orthophosphate is no longer controlled by the input of phosphate only, but by the Ca concentration, the pH, and somewhat by the temperature, as well. And as both the Ca concentration and the pH are largely changed by human impact (Golterman and Meyer, 1985b,c,d), we have to consider the Ca/HCO_3/CO_3 system in order to understand phosphate kinetics. The changes in the Ca/HCO_3/CO_3 system will be discussed under 5.

First, a few words, however, on the lack of success with the attempts to decrease the phosphate loading of surface waters.

Eutrophication could have been easily fought by decreasing the phosphate content of detergents and removing phosphate from sewage waters. The cost of both operations would have been marginal compared with the total costs of overall sewage purification and of the detergent itself. Nevertheless, ecologists have not been successful with their proposals for these actions, often already made in an early stage. The major problem has been convincing governments — and especially their higher civil servants — who never saw environmental issues as ways and means for electoral success.

Many years have been lost by the irrelevant demands of governments to predict the quantitative changes that would follow potential measures. The defence of the environment should be structured like the defence against possible enemies, where no model predicts the chance of their arrival, or as the defence against natural disasters (protection against floods, avalanches, etc.), where no cost/benefit calculations are made.

5. *Inorganic Salts*

There is a general belief that man has not yet changed the major chemical composition of lakes and rivers, i.e., the composition of the elements or compounds present in relatively large concentrations (meq. 1^{-1}), together causing the electrical conductivity of the water. The example of the drastic change of the NaCl concentration in the river Rhine by the French potassium mines and the German industry is too well known to be discussed again in detail. For Europe a novelty is that farmers have sued the French potassium mines and obtained the right to claim damages through all national and European courts; the judgement is definite, no appeal is any longer possible. I should like to raise the question, however, how is it possible that legal procedures have been fought and won against one of the polluters and not against many others, all well known by name and by the quantities they release?

Changes in the $Ca/HCO_3/CO_3$ system are less known. Golterman and Meyer (1985b,c,d; for summary see Golterman, 1985) have shown that in the Rhine and the Rhone, the Ca^{2+} concentration rises downstream from 2 to 6 meq. 1^{-1} (Rhine) and from 2 to 4 meq^{-1} (Rhone), while the HCO_3-concentration rises from 2 to 4 meq 1^{-1}. Although these figures seem to be small, the quantities per year are large, 14000 tons of $CaCO_3$ precipitating in the Rhine delta and 5000 tons in the Rhone delta. These changes are caused by increasing acidity in the two rivers caused by disposal of organic waste, which after mineralization produces CO_2 in excess. Furthermore, Golterman and Meyer have shown that disposal of large amounts of gypsum ($CaSO_4$) also causes the calcium and the sulfate concentrations to rise. I estimate that the amount of gypsum can easily be up to a million tons per year. These increased amounts of solubilized $CaCO_3$ are important for the speciation and the transport, not only of phosphate, but of heavy metals as well.

Increased quantities of NaCl and of calcium and sulfate are causing problems of water quality for several of the water users, mainly those active in the deltas. Drinking water supply, recreation and agriculture are all affected and are often made impossible or only possible at important costs. These costs are perhaps higher than the treatment costs would be, but even if this is not so, treatment should be directed in such a way that the receiving water body's ecosystem is not affected. That policy will automatically give sufficient protection for all other water uses.

Criteria

If we really want to protect rivers as ecosystems, the criteria for the water quality are easy: changes due to human impact should not be larger than those occurring naturally or fall in the same order of magnitude. These criteria are economically not yet realistic. For me it remains a question whether we should, economically, be realistic when formulating our ecological demands; we have then already lost half our battleground, while when the economists are formulating their demands, they have always already taken the double surface of their battleground. It remains an unequal fight.

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DISCUSSION

Golterman

Dr. Ravera you have touched on the problem of criteria for lakes being oligotrophic, mesotrophic or eutrophic. Actually what has happened is that in the early Sixties we became aware that the constant loading of phosphorus was a great danger for lakes. We noticed that primary production was increasing, whereas it is the remarkable feature of an aquatic ecosystem that primary production should be low. This is the first problem I would like to discuss. If we see that primary production is increasing, biologists know that the lake develops in the wrong direction. If we work this out now in terms of cost and benefit, and if I take the example of Gene Likens and I pay one dollar for each algal species, I think that we will see that the value of the lake is increasing in economic terms (e.g., fisheries may even increase their, yield) although we know that something is entirely wrong and we are changing the ecosystem in the wrong direction. This was very rapidly recognized by governments in the early Sixties. They were, all over the European countries, asking, without quantitative data, to reduce the input of phosphorus into lakes. We could not give exact figures, but one of the few people who could was Eugen Thomas in Switzerland, who, using his intuition, forced the Swiss government to reduce the phosphorus loading of lakes. The lake of Zurich has been recovered and we know that Eugen Thomas was proposing the correct thing. Later, the Swedes, by following the Swiss, did even better: there is no country which has cleaned up its water so well as the Swedish people, without any quantifying model.

Unfortunately, most of the governments in Europe were not willing to do this, and they have forced us to make so-called quantitative models. They said: "You have first to predict how much phosphate may enter a lake, and you have to quantify how much primary production we will get, and then we will take measures".

Now this seems, in the first instance, to be an excellent idea, because we can calculate what kind of measures should be taken, we can calculate the cost and we can calculate the benefit; but, unfortunately, aquatic ecology is a very young discipline. Although about one hundred lakes have been studied with great care, the confidence limits of the final OECD model, which we have been using, span a factor of 10, which means that if I take a certain input of phosphorus, I may expect 3 milligrams of chlorophyll or 30 milligrams of chlorophyll. Nobody knows for specific lake what kind of data we can expect. This is why governments, and I think all the governments in Europe, United States and Canada, have postponed measures. It became typical that they wanted in the first instance reasonable precision.

We need, first, better data before we can take measures. After Switzerland and Sweden, no country has done anything seriously against eutrophication. In this whole procedure, the great uncertainty in the ecological model (which is essential, I think, for any ecological model) has been converted by mathematicians into probability. You have shown this most remarkable graph which indicates that, if we put a certain amount of phosphorus in a lake, there is a 70% chance that the lake will be eutrophic, a 28% chance that it will be mesotrophic, and a 2% chance that it will be oligotrophic. But that is just as bad as saying to somebody who is ill, "There is still some hope for you because there is a 30% chance that you will survive, there is a 2% chance that you will survive without any damage, but, nevertheless, you have a 70% chance that you will die". I think that this direction is entirely wrong, that we have got completely wrong answers to the problem. In the 20 years that we know about eutrophication, nothing has been done against it. We, as scientists, have taken upon our shoulders a very heavy guilt for having accepted money to study these models, while from the beginning we knew that they were not necessary, and we knew that there would be no real answer. I think that the eutrophication issue needs a complete revision of ideas, and it should be completely separated from economic aspects.

Nevertheless, I am very happy that you brought up the issue here. Eutrophication seems to be becoming a forgotten subject at the moment. We had a period when everybody spoke about eutrophication. You could take the daily morning paper, and with your early morning coffee, you would have a new message on eutrophication. This has completely faded away and I really do hope that your initiative to bring up the issue again will revive thinking about eutrophication. I think we are entirely on the wrong track, as you have been explaining with that probability curve.

There is a small point which I would like to raise: What do we think is stability? I think that stability in aquatic ecology is completely different from stability in terrestrial ecology, and I would like to refer to the work of John Lund who has been studying Lake Windermere for about 30 years. He has shown that phytoplankton populations in the course of the year rapidly wax and wane. They grow, but, because they are small, they disappear, and in the course of the year you may have five or six different algal populations developing. In terms of terrestrial ecology, this would not be a stable situation. Nevertheless, I think that what makes lakes stable is what John Lund has shown: that if you leave a lake on its own, these populations will come back for 20 or 25 years, and, that is, I think, what we should call stability in aquatic ecosystems. Year after year, lakes are showing the same kind of changes in the course of the seasons, and one of the first signs we get, when human impact is having its influence on a lake, is that this kind of seasonal succession is disappearing. I think that eutrophication should in the first place be approached from a qualitative point of view. Look at the populations which we find in a lake and protect them.

I would like to finish by asking the economist to make me a calculation of the cost-benefit of changing diatom populations into blue-greens. Thank you very much for your contribution. I think it's very important that we start thinking about eutrophication.

RAVERA

I appreciate very much your comments and I agree on the general line of your criticism. I have exposed some commonly accepted ideas on the classification criteria of lake trophy. These criteria, collected in the documents by OECD, are based on Vollenweider's simple and very diffused model. There are some other models on eutrophication, concerning a greater number of variables, but they are not adopted in practice. On the other hand, it is well known that for some lakes the critical element is nitrogen and not phosphorus. In fact, the critical element of some marine ecosystems is nitrogen. A constructive criticism is always useful. I perfectly agree with you that eutrophication is a very complex and important problem, but few countries (e.g., Sweden, Switzerland) have adopted adequate correctives. About "stability", I have exposed the meaning more currently accepted, although even today it is a matter of discussion. First of all, the stability level of a community or an ecosystem must be related to a time scale. A small pond may be stable for one week and the Mediterranean Sea unstable, if it is considered on a geological scale. I appreciate very much Margalef's concept of stability, but it cannot be exposed in a short time. Odum's hypothesis concerning the influence of the amount and quality of energy on the relationship between "diversity" and "stability" is interesting and probably fruitful.

I have no time now to discuss all these differences, but I agree with you about your criticism. On the other hand, my conclusion is that we do not know enough to make up an ecological theory in this case, and it is also true from the point of view of practical scopes. It is very difficult to intervene if you don't know exactly the particular case and not just the general rule.

MARINI-BETTÒLO

Professor Ravera, do you have any information about artificial lakes, especially those formed by dams in the tropics, where there are two important drawbacks? First the diffusion of diseases like schistosomiasis and malaria, and, second, the concentration by evaporation of dissolved salts. Could you give us some information about these points, which I think are of a certain importance?

RAVERA

Prof. Marini-Bettòlo, I am not an expert on man-made lakes, and particularly tropical ones. Be that as it may, the diffusion of certain parasitic diseases is caused by man-made lakes and irrigation. In addition, a reservoir deeply modifies the ecological properties of the area in which it is located and the resulting high level of evaporation produces salt concentration in the water, if the rainfall-rate is lower than that of evaporation. In areas with the succession of dry to rainy seasons, alternation from high to low salt concentration in the lake water may be expected. On the other hand, we must also consider the benefits of these artificial lakes for agriculture, energy sources and drinking water supply.

About 10 years ago, the analyses carried out on fish species from the Rhine River showed that a great number of organic substances were present in their bodies. In addition to natural substances, organic micropollutants and their metabolites and detoxification products have been identified. These results may be useful as an index of the pollution of the environment, but the most important problem consists in evaluating the concentration of the various pollutants which may be noxious to the fish. Unfortunately, except fo a few substances, our knowledge is not yet adequate to establish a relationship be-ween low concentrations in the fish and their effects. There is a need for more information on the synergic effects of the various pollutants, the influence of the physical environment on both the organism and the pollutant (e.g., the physico-chemical form) and the detoxification mechanisms of the aquatic species. I would like to observe that, differently from human beings, plant and animal species must be protected at population and community levels, and not at individual one. I think that it may be opportune to include this concept in the final conclusions.

The other consideration concerns the positive relation between nutrient concentration increase and phytoplankton growth, for example, the increase of phytoplankton biomass with phosphate concentration. This has been demonstrated by experiments and in many water bodies. Conversely, in "enclosure" experiments polluted by toxic substances, we have noted an increase of phosphate with the decrease of chlorophyll concentration. For example, the phytoplankton decline (as an effect of cadmium contamination) released phosphorus and reduced the uptake of this element, with the consequent increase of phosphate concentration in the water. Consequently, it seems evident that more information on the combined effects of eutrophication and toxic pollution is necessary.

GOLTERMAN

Yes, I have to verify one or two points. The gas chromatographic analysis was done by the State Institute of Drinking Water and not in my old Institute. Some 3,000 peaks on the gas chromatographic scale have been recognized. Only for about 100 is it known from which kind of compounds they are derived. The question about which are the natural ones and which are the toxic ones cannot be answered. Definitely, some natural waters can still be measured and the number of peaks is reduced to, let's say, around 100. The 3,000 peaks are probably mostly due to input by industry.

You have been emphasizing the problems of toxicological work. Perhaps it is a point which we both have forgotten to mention, but which is not evident to everybody. Originally, when the toxicological work started, we were working with one aquatic organism, and we would put it for two hours in a solution of a certain toxic compound and it was possible to define an LD_{50}, the doses when 50% of the population dies off. Then of course some people had the idea not to put these animals for two hours in these toxic compounds but to have their complete life cycle in the presence of these compounds, and the LD_{50} concentrations went down with a factor of 100. I think that is one of the problems which we are facing at the moment: the interaction of several compounds on several components of the systems cannot be studied. I think you completely agree with me that all this kind of work which is being done at the moment is completely out of context in ecological thinking.

LIKENS

I have a question and then a comment. I think you said that the increase in calcium concentration in the river was due to increased carbon dioxide. What caused the change in carbon dioxide?

Then I have a comment. You mentioned the poor quality of the data, and I assume that these data were collected by government or industry and published in what is called "grey literature" rather than in referred journals. The same is true in the United States, and it is probably true everywhere. I believe that publication of poor quality data in reports is a very serious problem. In part it occurs because scientists are often too busy to do their homework and to carefully check, as you have done, whether simple parameters, such as the ionic balance, are correct. Obviously, careful checking of these data should have been done in the first place. The authors should have done what you had to do.

Such data, particularly in issues that have great economical and political importance, as in the case you are describing, produce a very confused situation. With poor quality data, one can argue easily either side of an issue. I believe that this is a large problem in terms of the integrity of science and the way that science is perceived by the general public, and particularly as interpreted by the news media. An example from the United States is given by the acid rain debate, where the Environmental Protection Agency spent many millions of dollars surveying the lakes in the United States to determine whether they were acid or not. Each of the lakes was visited once, mostly in the fall of the year, a time when the lake normally could be fully circulated, it is true, but at a time in which the lake normally would be at its highest pH. Most lakes, particularly in regions sensitive to acid deposition, would have their lowest pH in the springtime, when snowmelt water is running into them. Clearly, these data can be interpreted in various ways. It might be suggested that the lakes are not very acid, or it might be suggested that those weren't collected at the correct time of year. Thus we really don't know if the lakes are acid or not. I suggest again that this is a serious problem in terms of the integrity of science in such political and emotional environmental issues.

GOLTERMAN

First your technical question on the calcium and the carbon dioxide system. I estimate that the calcium goes up from, let's say, 2 ml equivalents per litre to 6, and we can follow the carbon dioxide by looking at the bicarbonate, which goes up to about 4, that is, half the increase of calcium is due to the acidification. You can see that, for instance, in the pH of the Rhine, which should be 8.2, but in the Netherlands it is 7.2. The second part of the calcium comes from the calcium sulfate which is dumped in the Rhine by industry, and, by looking at the ratio of calcium over bicarbonate, as dependent of the sulfate concentration, you get a beautiful relationship. We were using very "dirty" data, but nevertheless, we found a very good correlation, showing an actual slope of 0.5 where, indeed, it should be 0.5. Calcium sulfate is the second source of calcium in those two rivers, and that is discovered just by looking at the ratio of the calcium increase over the bicarbonate increase.

These are data reports, without any conclusion. They are just long lists of tables. Now, if I were an analytical chemist and I had to do this kind of work, I would not be really interested. I think that there are two things involved here. In the first place, the people who are appointed to do this kind of work are apparently not the best scientists, otherwise they would not be willing to do it. Second, they may have been willing to point out to the government that there are problems, but I think you get very frustrated when nobody listens to you for about ten years.

I think these two aspects cause people to produce data, data, data. We've already seen analytical equipment which works completely automatically. The data are going into a computer. The computer is printing the table, and nobody has ever looked at the data before they are circulated to the public. That ought to be changed.

LUNDBERG

Episodic changes are very important, especially for river systems. The pH values may decrease dramatically for short periods of time, causing great mortality in fish populations. This effect has been demonstrated in Norwegian rivers. In order to detect these episodic changes, continuous monitoring is necessary, otherwise the data will be difficult to interpret.

Another problem is the continuous leaking of mercury from lake sediments due to low pH values. There are restrictions in consuming fish from thousands of Swedish lakes, due to the accumulation of mercury in the fish.

MARINI-BETTÒLO

I should like to add a comment and ask your advice. When 20 years ago, I was Director of the Institute of Health of Italy, we had great problems with two rivers. One was the Bormida. Recently I learned that the same problems have not heen solved there. In the upper valley of the Bormida, which flows from the Apennines to the Po Valley in Piedmont, there is a factory which produces colouring materials. Although a lot of work has been done to prevent pollution throughout the course of the river, aromatic compounds and by-products of the preparation of dyes have been influencing negatively agriculture and, particularly, vineyards.

The other river is the Ronco. This small river, which flows from the Apennines to the Adriatic Sea near Ravenna, has been so heavily polluted, mainly by organic matter, that it has no more capacity to restore its self-purification capacity. Indeed, it is considered to be more a sewage system than a river.

I don't know what has been done to solve the problem of the Ronco, but the Bormida is still an open question. In a certain sense, it could be taken as a case study of a certain importance, similar to the Rhine or the Rhone.

Although the Bormida is a continuous problem rather than an accident, accidents should be foreseen and prevented. Last year's Basle accident should lead us to protect the integrity of our rivers.

GOLTERMAN

You raise a very difficult question. To comment on a river which you have never seen is fairly difficult. I also find it difficult to discuss with my Italian colleagues the quality of rivers because it seems that in Italy tbat is indeed a major problem. I have had individual contacts with some of the indeed a major problem. I have had contacts with some of the rivers, and I must say that Italy is not cleaning up as much as the other European countries.

I don't believe that a given river has a certain kind of pollution wbich cannot be traced. If you know which kind of compounds are getting into a river, you ought to be able, by chemical analysis, to trace the origin. The funny thing is that in Germany and Holland environmental action groups have been much more clever in tracing origin of chemicals than the governments. There is a club called the "Clean Rhine", wich has traced some very bad pollutants, polluters, or places of which there were no records. If one really want, to know where a certain compound is coming from, it can be done very easily, I think. But rivers do not clean up as very rapidly as has been thought. Some ten years ago, it was said that rivers have no memory. Tben you take all the measures that you think will clean them up very rapidly; but rivers have a very thick layer of sediment and there are a lot of compounds that accumulate in sediments. If one wants to know about the health of a river, the best thing to do is to look at the sediments. I suggest that taking some samples of sediments (which you do only once every half year, or once in a year perhaps) will give much more information for most of the compounds we have been talking about than monitoring every fortnight, and I am quite sure that you have a very good possibility of discovering the problem in the river you mentioned by looking at the sediments.

JEFFERS

I would like to ask a question and make a comment. First, I would be interested to hear the comments on the connection between the quality of rivers and lakes and that of ground water. A large part of the water which is used in both the developed and developing world actually comes from ground water. I think many of us believe that there is likely to be a problem, if there is not already a problem, with the quality of ground water. In my own country we have tripled the use of nitrates in agriculture and we really don't know where those nitrates are going. They are not in the crops, they are not in the soils, and many of us have an uncomfortable feeling that we have built a time bomb for ourselves: they will appear in ground water in future years and cause a real problem. I would therefore be interested to know from the experts in this field how they see the connection between the quality of lakes and rivers and that of ground water.

If I may make a comment, as a statistician, about the whole question of these collections of data which appear and then never seem to be analyzed, I think it would be that there two problems involved. First, there are people who believe that because you collect data automatically, you don't need any statistical advice. My advice to them is that you actually need more, rather than less, statistical advice if you start to collect data automatically, because you have laid up for yourselves enormous problems of quality control apart from anything else. The other thing I have discovered to my horror is that when I have on occasion taken these sets of data, either in terms of monitoring pollutants in rivers, or even more dramatically, in monitoring radionuclides in the environment, and analyzed them, it has aroused the fury of the people who publish them. I might add that if you really want to upset people, analyze the data that they have published in this form and they will get very angry because they say you shouldn't discover things that they didn't want you to discover. Then, very often you to discover that after a rather weak protest, they then admit that one of the reasons why they didn't analyze them was that they didn't know how to. Many people, or very few people, know what to do with a large number of variables which are presented simultaneously; and, to be fair, we don't actually teach that very well at our universities at the present time. It is a real problem.

GOLTERMAN

Just a brief comment. Actually you should be very happy if you are drinking most of your waters from lakes and underground water. In the lower stretches of the Rhine and in the Netherlands, 50% of the drinking water comes straight out of the Rhine River because there is no accumulation in the ground water any longer. Certain pollutants are now being discovered in the ground water. Some organic compounds are definitely occurring in Dutch ground water, and that is indeed building up an enormous reservoir of products of which we know very little. Most lakes, I would say, but it's rather difficult to make this kind of generalization, are affected directly by sewers. I think that is true for the Swiss situation, but if you look at lakes further downstream than the Swiss lakes, I think it is very clear that, for instance, the Dutch lakes are getting 50% of their pollutants from the Rhine River and 50% from direct disposal.

MOUNTAIN ENVIRONMENTS

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Introduction

The mountain lands, depending somewhat on how we define "mountains", occupy about 15-20 percent of the world's land surface and provide the life support base for about 10 percent of the world's population. However, at least 40 percent of the world's population depend indirectly on access to mountain resources, in the form of hydro-electric power, water for irrigation and industrial uses, timber, and a long list of other renewable and non-renewable natural resources. A considerable number enhance their mental and physical health from use of the aesthetic and recreational resources of the mountain lands. Furthermore, it has been widely claimed that destabilization of mountain environments, through over-exploitation or mismanagement of natural resources, is causing massive detrimental downstream effects in the neighbouring densely populated lowlands, thereby threatening the life support systems of many hundred million people. Mountain environmental problems, therefore, deserve very high priority because, in one way or another, they affect more than half the world's population. The last two decades have produced a rapidly accumulating volume of alarmist literature that casts mountain environmental mismanagement in the role of destroyer of the lowlands. This characterization takes many forms and focusses on many specific mountain ranges. In that it frequently appears to have confused policy makers and has been at least partly responsible for inappropriate and unsuccessful attempts to find solutions, it will be discussed in some detail below.

The UNESCO Man and the Biosphere (MAB) Programme: Project 6 -

Study of Human Impacts on Mountain Ecosystems, was established in 1973 to bring intellectual and applied research forces to bear on the perceived problem of mountain environmental deterioration. Thanks to my colleague, Professor Francesco di Castri, who has made by far the largest single contribution to the development and evolution of MAB, I served for a time as chairman of the international working group for MAB-6. Much of the content of this paper derives from that early experience, augmented by my subsequent role as Co-ordinator of the United Nations University project on highland-lowland interactive systems. This high level of consumption of my own energies, over the 14 years since the initial MAB-6 panel of experts meeting in Salzburg, Austria, together with the contributions of colleagues from all over the world, has been a fascinating learning experience, but it has not done much for protection of the mountain environment. My reasons for this statement are perhaps of no little importance for the deliberations of the distinguished participants of this Pontifical Study Week. I will take the liberty, therefore, of attempting to unfold this enigma of the mountains, as I see it, of providing some generalizations, and of introducing several case studies, by way of example. I will then outline, albeit with a degree of humility, a few basic proposals that, if followed through, should set the stage for real gains in the vital task of stabilizing mountain environments and mountain societies.

To anticipate my conclusions and provide an adequate framework for my presentation, let me at least try to define what I have already referred to as the "enigma of the mountains".

1. Mountains occur practically all over the World in a bewildering variety of climatic zones, altitudes, and topographical alignments; they have been utilized for varying periods of time by a complex of cultures; generalization, therefore, is extremely dangerous. All we can say with confidence is that, together, the mountain lands comprise the most complex set of landforms and land-use systems, and house the greatest range of cultures of any of the world's major divisions.

2. Research on mountains has been pursued in a totally fragmented manner according to disciplinary interest, pure versus applied science, and locality: this, despite appropriate and urgent calls for bridging the gap between the natural and human sciences, to which there has been a lot of lip service but little solid response (with certain conspicuous exceptions).

3. Much of the populist environmental literature, and even much of the so-called scientific literature, has evolved in a bandwagon type of format.

Thus alarmist notions without rigorous assessment or little foundation on fact have become leading paradigms that subsequent waves of mountain researchers have sought to validate. Myths, assumptions, intellectually attractive opinions, have been given the dignity of "truths" and widely acclaimed "theories". Development and aid agencies, because of their inherent large-scale bureaucratic character, which leads to the formulation of policies designed as general panacea, have often achieved more destruction than amelioration. Cause and effect have been confused. The common man, the mountain farmer, has been abused through the debilitating process of his being classified by western-trained elites, as ignorant, overly fecund, and unthinking destroyer of his own environment.

4. The mountain lands, unlike the tropical rainforest, the arid lands, the oceans, Antarctica, the ozone layer, the greenhouse effect, or acid rain, have not yet been able to develop a strong, well-informed constituency. This is urgently needed if there is to be the necessary fuller understanding of mountain dynamics and its effective linkage with the political processes of mountain resource management. The mountains, like the oceans, need their own Jacques Cousteau!

The Nature of Mountains and Mountain Development

Many German geographers have defined mountains as having a relative relief in excess of 1,000 m, whilst geographers from eastern and central North America seem prepared to accept 300 m, perhaps reflecting the landscapes with which individual groups of scholars are familiar. The Germanic *Hochgebirge* (high mountains) and *Mittelgebirge* (middle mountains) describing the Alps (mountains built during the most recent orogenesis) and the Hercynian massifs (uplifted and block-faulted, such as the Vosges and Schwarzwald) make a useful, if limited, geographical formulation. Carl Troll, father of mountain geoecology (1972), carrying to fruition the tradition of Alexander von Humboldt, more vigorously defined Hochgebirge as those high mountains that extend above the Pleistocene snowline, have been glaciated, and have several vegetation belts and an upper timberline. Thus "Alpine" becomes synonymous with "Hochgebirge". We can take this a step further by recognizing the relationship between degree of glacial dissection and interfluve preservation, because landscape personality is in part determined by systems of landforms that recur throughout the high-mountain world; thus two types of glaciated high mountains can be differentiated: Alpine and Rocky Mountain. In the former the higher sections are composed predominantly of precipitous slopes while the gently sloping, low energy enclaves are confined to the broad, alluvium-filled valley floors and characteristic trough shoulders, the results of glacial erosion. The Rocky Mountain type displays wide interfluves, intermixed with arrêtes and horns, which are subject to mass wasting processes and incur low rates of denudation (Figures 1 and 2).

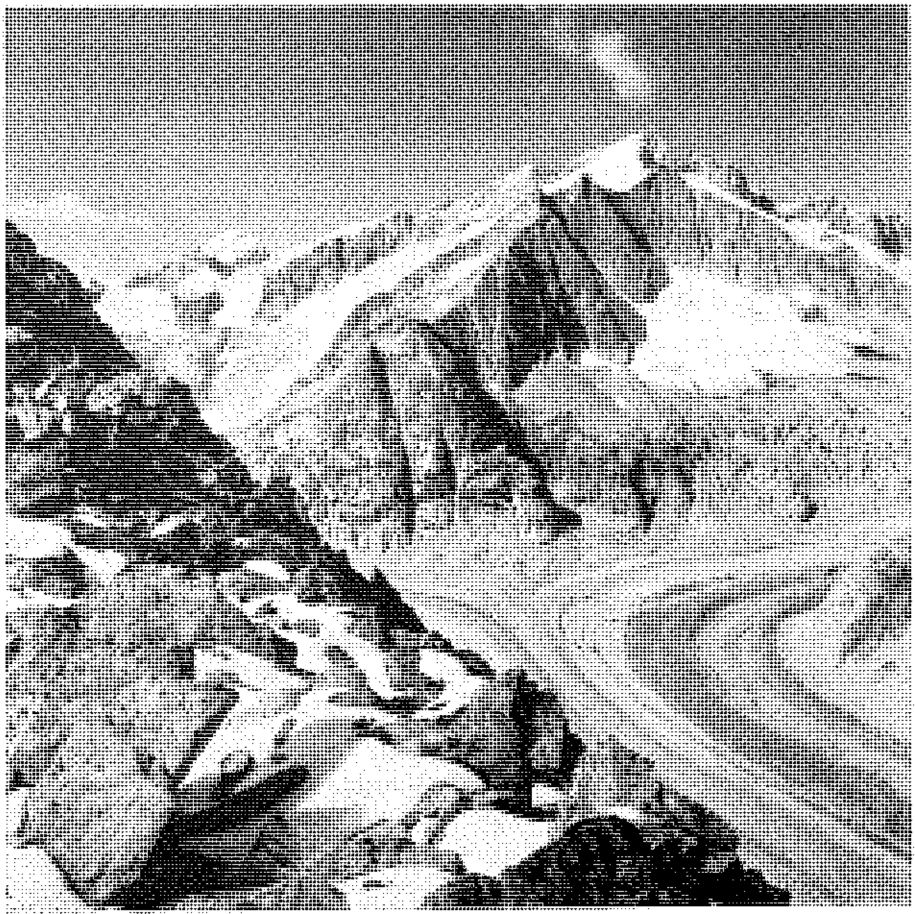


FIG. 1. The Alpine type of high-mountain landscape: This view shows the Aletschorn and the Oberaletsch glacier with its prominent surface moraines. Enclaves of "low energy" slopes are confined to the trough shoulders and glaciated valley bottoms. Steep slopes, peaks, and arrêtes are characteristic.

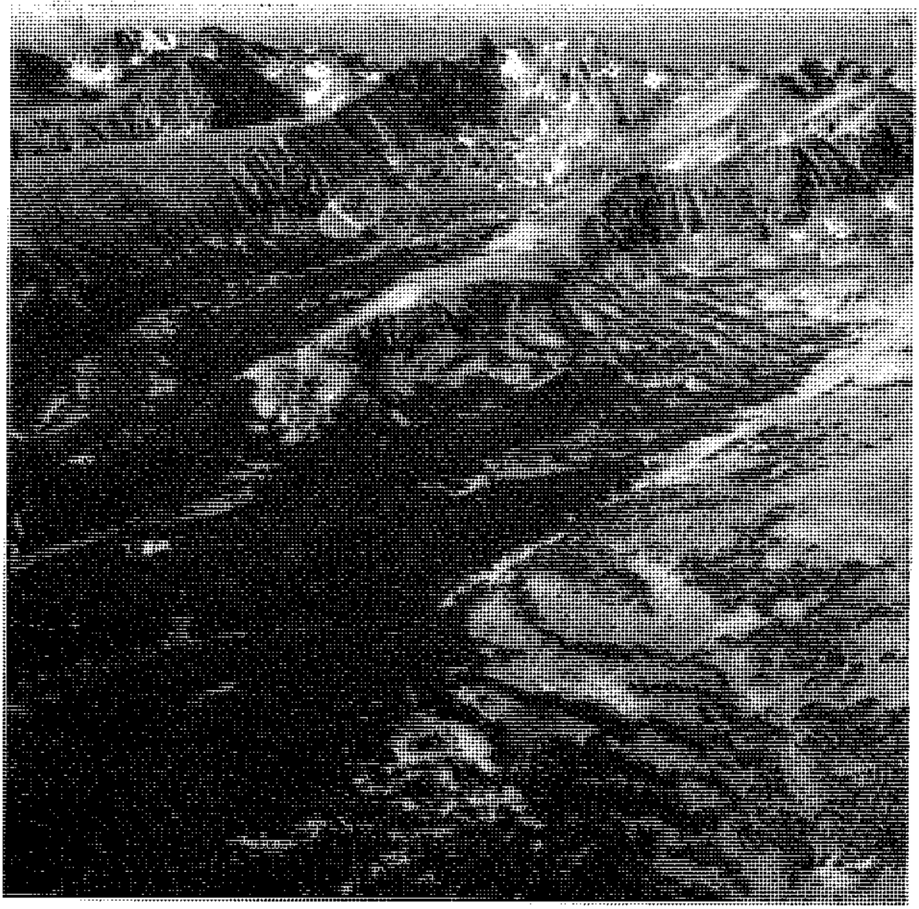


Fig. 2. The Rocky Mountains type of high-mountain landscape: Colorado Front Range, Indian Peaks Wilderness. Note the combination of horns and arrêtes with broad, high interfluves that are subject to slow periglacial mass wasting. The broad ridge on the left is Niwot Ridge, designated a MAB Biosphere Reserve in 1979. View west-by-south onto the continental divide.

When we superimpose the history of human use on these two landscape types, their differences widen considerably. Thus the Alps become the classic example of Old World mountains with the intricate adaptations from centuries of human ingenuity that give us the familiar Swiss mountain picture calendar, while the Rocky Mountains allow us to contemplate the North American wilderness and national park aesthetic.

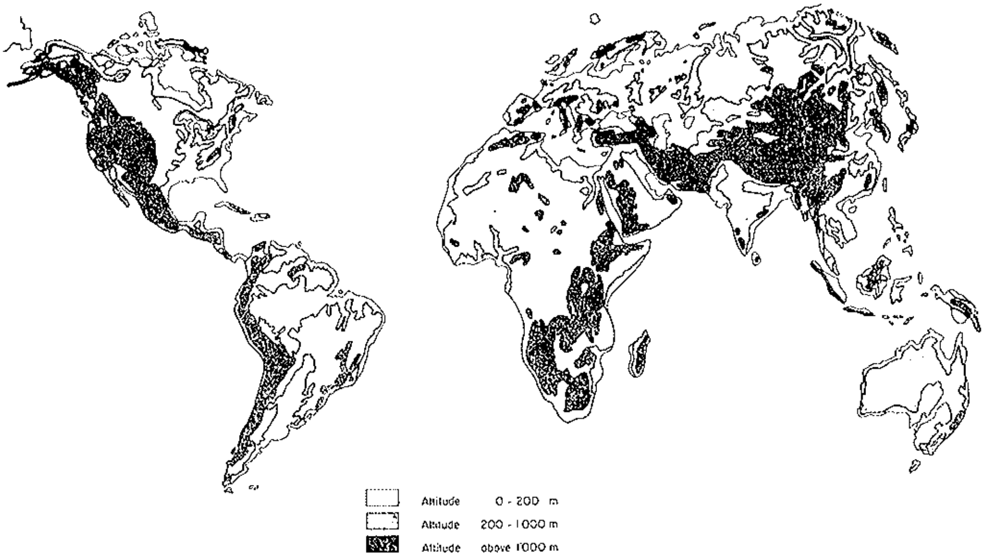
This, so far, has provided no place for the Hoggar and Tibesti, the Kun Lun and Qilian Shan, the Tibetan Plateau, nor even the Staunning Alps of East Greenland (which have no timberline), nor the alpine-like forms of Svalbard. More importantly, those mountain areas of the tropics and sub-tropics which have supported development of sophisticated civilizations based upon sedentary mixed farming with intricate terraced agriculture, plus pastoralism, are also left out of consideration.

The most dramatic scenery, which has attracted most mountain research, is usually associated with the hochgebirge, yet this is a minor, if spectacular, part of the total area of mountain lands. This has led to the recognition that altitude and latitude combine as controls on the limits of this peculiar set of landforms in a high altitude-low latitude to low latitude-high altitude continuum: the arctic-alpine continuum of cold-stressed environments (Ives and Barry, 1974; Ives, 1980). It also tends to explain the special research concentration on mechanical weathering and mass movement (Benedict, 1970; Caine, 1974; Thorn, 1976), and the comparative neglect of the much vaster area of mountain lands below the upper timberline, within which most mountain people live.

This academic disgression will only serve to emphasize the difficulty of dealing with the mountain world, in that no universal definition of « mountain » has yet appeared, and a mountain classification system will invariably provoke tedious semantic argument. For our purpose, in the real world, it is perhaps best to define the mountain lands loosely to include both steep slopes (i.e., high local relief) and high altitude. In this way high Pacific islands (with steep slopes near sea level and no upper timberline) will be addressed, along with the Altiplano and the Tibetan Plateau. This leads us to be concerned with agricultural and other pursuits that have to contend with two primary limiting factors: steep slopes (i.e., gravity) and reduced length of the growing season (i.e., low temperature, due to combination of altitude and latitude). This broad definition of "mountain" justifies our claim for 20 percent of the world's land surface (Figure 3).

A next essential step is to recognize a broad, threefold subdivision of the mountain lands: high-latitude; mid-latitude; and low-latitude. For the purpose of this Study Week I will not consider high-latitude mountains because they have received very limited developmental impact; the serious problems rest with the other two, and the differences between them must be emphasized.

These differences, in large part, relate to the fact that most mid-



Reference: Schweizerischer Mittelschulatlas, Zurich 1969, page 134/135.

FIG. 3. Mountains and plateaus of the world.

latitude mountains are located geographically within the so-called "developed" or industrialized countries while the sub-tropical and tropical mountains of low latitudes are primarily located in the so-called "developing" or "least-developed" countries (LDCs) of the Third World. It is on this basis that we can attempt to evaluate the forces leading toward environmental and socio-economic degradation. For LDCs it is generally recognized that the immediate problem is rapid population growth of subsistence agricultural societies *within* the mountains, leading to increased pressure on finite natural resources. Why is the population growing so rapidly? Poverty and large families! Which is cause and which is effect? These questions must be answered if the primary causes are to be identified and tackled. The issue is compounded by conflicts of interest between ethnic groups, especially by lack of community of interest between national and regional centres of political power and ethnic minorities on the mountain periphery.

For the industrialized countries, in contrast, it is generally understood that the immediate cause of environmental degradation is population growth and increasing affluence of peoples living *outside* the mountains. This has led to rapidly increasing demands for the exploitation of mountain resources: minerals, water, fossil fuels, forests, and especially tourist facilities. Tourism disrupts the remnant traditional cultures within the mountains. Thus depopulation occurs in areas not suited to two-season tourism (or not competitive agriculturally, for a variety of reasons) with the ensuing collapse of buman agro-ecosystems. And depopulation and land abandonment are frequently followed by a significant increase in soil erosion until a new stability is achieved with the establishment of shrub and forest cover. On the other hand, tourism promotes *redistribution* of population *within* the mountains, as the desired infrastructure develops and encourages the influx of even larger numbers of transients. The development of the Austrian (Himamowa, 1974; Moser and Moser, 1986) and Swiss (Messerli, 1986) MAB-6 projects provides a great deal of vital information on these issues.

This differentiation between the mid-latitude and low-latitude mountains, of course, is an over-simplification in itself. While there are many regional differences, nevertheless these generalizations are representative of global-scale mountain environmental problems. The most important exceptions are the expansion of tourism into tbe LDCs and the exploitation of the resources of the tropical and sub-tropical mountains and hills for the benefit of societies located *outside* of them. Such exploitation can be generated within the region (for example, India's industrial sector versus the politically weaker mountain periphery), or from outside the region (for example, forest products and mineral extraction by multinational corporations to supply North American, European, and Japanese markets). Then there is the entire complex of the bilateral and United Nations aid and development machine which, to date, has wreaked at least as much havoc on the mountain lands and their peoples as it has produced demonstrable long-term successes.

Finally, it is important to bear in mind the innumerable exceptions on a local scale and the danger of the imposition of Euro-centric concepts and values. For instance, it can be argued that the development of tourism in Sagarmatha National Park has greatly enhanced the standard of living of the Khumbu Sherpas of Nepal, and the former farmers of Canton Wallis, Switzerland, may not regard the enormous growth of tourist infrastructure on Riederalp as anything less than highly profitable *and* sustainable within their own lifetimes. These two examples are introduced to demonstrate that different groups within society will have different, and perhaps conflicting, value judgements in specific cases of mountain development or environmental protection; the problem of long-term sustainability, however, remains.

Why Are Mountains Difficult to Study?

The simple answer to this question, of course, is that mountains are difficult to study because of their virtually limitless variety, both from a natural and a human science point of view, and because of their relative inaccessibility. Because this issue is very central to the problem of protection of the mountain environment, I would like to go into some detail by way of explanation. To keep the explanation reasonably brief and to avoid falling, myself, into the confusion created by infinite variety, I will illustrate the issue from a simple perspective, that of the mountain geomorphologist.

The development of mountain geomorphology can be divided into three phases. During the first, prior to the 1950s, research efforts were largely descriptive, with an overwhelming concern for form and cyclic landscape evolution. While there were a number of early harbingers of the quantitative, process-oriented era, and a certain degree of overlap, the 1960 publication of Anders Rapp's seminal treatise on mountain slope development in Karkevagge, northern Sweden, provides the critical turning point (Rapp, 1960). A second phase can be identified, characterised by quantification and numerous studies of mountain slope processes (reflecting the powerful impact of the International Geographical Union Commission on the Evolution of Slopes).

The third phase overlaps in time with the second. It is introduced to emphasise the growing need for careful and rational application of our increasing understanding of mountain dynamics to the solution of practical problems associated with the use and management of mountain resources.

Geomorphic knowledge in mountain areas developed primarily from field description and measurement at "natural" sites (often unvegetated), and through controlled laboratory experimentation. Yet geomorphologists recognised man as a major geomorphic agent several decades ago. Human activities range from those of the engineer, miner, dam-builder, logger, road-builder, soldier, to the subsistence farmer. It is necessary, therefore, in order to develop a better understanding of the man-mountain relationship, to include detailed study of the geomorphic implications of subsistence farming and uncontrolled population growth. Political, economic, sociological, and behavioural factors must also be taken into account. Of course, at this point it can be argued that the term geomorphology has been qualified beyond reasonable limits and must be replaced. Nevertheless, this view in no way invalidates the need for more exacting research on the two main aspects of mountain geomorphology: continuous slow-acting process and large-scale catastrophic events of such infrequency that it is difficult to incorporate them into standard process models.

Progress in Mountain Geomorphology 1960-85

Before 1950, mountain geomorphology was primarily descriptive and hypothetical. The interest in high mountains tended to link glaciology and mountain geomorphology and — on account of the broad relationships between altitude, low air temperatures, fluctuations across the freezing point, and high latitudes — it also led to close affinities between arctic and alpine research, and periglacial and permafrost studies.

The early geographers and geologists had outlined the broad lineaments of mountains. Before the end of the nineteenth century the general accordance of summit levels (gipfelflur) had been identified as remnants of old erosion surfaces, though no hypothesis was entirely satisfactory because of the difficulty of dating such "old" surfaces and the lack of information on rates of tectonic uplift and denudation. Nevertheless, outstanding geomorphologists, such as C.A. Cotton (1942), wrote systematic descriptions of high-mountain landscapes which reached the level of literary masterpieces.

The quest for exact measurements began to take form during the last decades of the descriptive era. Highly stimulating disputes on such topics as freeze-thaw cycles and the so-called meltwater variant of the bergschrund hypothesis of cirque erosion between Lewis (1938, 1940) and Johnson (1904) led to Battle's determination to measure processes, both at the bottom of bergschrunds and in the Cavendish Laboratory (Battle, 1951, 1960; Lewis, 1960). Glaciology began to attract engineers, physicists, and mathematicians, and rapidly developed as a respectable science in the 1950s and 1960s. Yet it still has not explained adequately the landforms so graphically described by Cotton. While Battle's work was an inspiring example of geomorphic method, he effectively invalidated the meltwater variant of the bergschrund hypothesis, yet was obliged to fall back on the old descriptive approach in his final statement of a hypothesis for cirque formation.

Also in the 1950s, on a firm basis of Swedish glaciological and fluvial research, Anders Rapp (1960) instrumented many slope facets in Karkevagge, a mountain valley in northern Sweden. Rapp collected data on a wide range of slope processes operating in this arctic-maritime mountain environment between 1952 and 1960. His work fell naturally into two broad divisions:

Qualitative — What types of geomorphic processes are active and what erosion and accumulation forms do they create? Are the processes and forms controlled by certain climatic or other factors?

Quantitative — How frequently do the forms and processes occur and what is their ranking in terms of total denudation accomplished?

The factors of spatial distribution of specific forms and processes were examined, and their degree of continuity and frequency of occurrence (temporal variation) were studied. Rapp's inventories have become classic components of process, or climatic, geomorphology. They included: direct observations; examination of fresh debris upon the snow in late spring; examination of fresh debris upon the vegetation cover in summer; comparison of old and new photographs of the same localities; measurement of the yearly supply of pebble falls from the rock walls on to small carpets of sacking, collection of water samples from snowmelt rivulets and streams and determination of total content of salts and invisible micro-sediments. Eight years of painstaking work indicated that the following processes, ranked in order of importance, were dominant in Karkevagge:

1. transport of salts (solutes) in running water;
2. earthslides and mudflows;
3. dirty avalanches;
4. rockfalls;
5. solifluction;
6. talus creep.

Glacial erosion had been excluded; it was not possible to place slope wash on the list; frost-bursting was not included since it is not a transporting process and is difficult to measure directly. The annual production of rock-waste by frost-bursting on rock walls, however, was calculated at 100-400 tons/km^2 of wall surface, which would probably give it first ranking over the above-listed processes. Rapp concluded that, without more data from other valleys with other types of slope, these six processes may have quite a different ranking.

Rapp's work set the stage for process studies in many parts of the world, but already in his conclusions were recognized the problems that still beset any full understanding of process geomorphology. Despite the arduous collection of data over eight years, the results cannot be extrapolated with confidence to Karkevagge's neighbouring valleys, let alone to Nepal or western Canada, nor can they be extrapolated backward in time, nor used as a basis for prediction. In addition, despite Rapp's ranking of transport of salts in running water, most subsequent research has concentrated on mechanical weathering and transport of coarse debris.

Representativeness in space and time: This problem is best introduced through Rapp's own data. In the Narvik-Karkevagge area 107 mm precipitation was recorded in twenty-four hours, and 175 mm in seventy-two hours (Riksgransen, 5-7 October 1959). The total precipitation from July to October 1959 inclusive was 794 mm compared with the 1901-30 average of 308 mm. The October rains were the heaviest since the Riksgransen climatological station was established in 1904; the recurrence interval of such downpours may exceed 100 years. The ensuing material transfer by mudflows, debris flows, and mountain torrents represented by far the largest single geomorphic event during the entire period of observations. It can be argued that more geomorphic work can be accomplished during a single catastrophic event than all movement minutely measured for a decade. The effects of the hundred-year event also may be dwarfed by even more spectacular occurrences: for example, a very large landslide that occurred in the Langtang Himal, Nepal, 25,000 or more years ago. This landslide displaced approximately 10 km^3 of debris through a vertical distance of up to 2,000 metres. Similarly, at Koefels in the Tyrolean Alps about 9,000 years ago a landslide displaced 3 km^3 of debris through up to 1,000 vertical metres (Heuberger *et al.*, 1984).

Three other examples may be mentioned here. First, in 1970 a debris flow, resulting from an earthquake-induced avalanche near the summit of Huascaran (6768 m) in the Peruvian Cordillera Blanca, covered 150 km^2 with debris, annihilated the town of Yungay, and killed 18,000 people (Patzeldt, 1983). Second, in October 1968, rainfall varying between 600 and 1200 mm fell on the Darjeeling area, Himalaya, during a three-day period at the end of the summer monsoon when the ground was already saturated. Some 20,000 were killed, injured or displaced (Ives, 1970; Starkel, 1972). Third, in southeast Iceland 155 mm rain in twenty-four hours on 29 July 1982 caused several dozen debris flows in a small area of Skaftafell National Park. I have photographed and observed this area qualitatively from 1952 to 1987 (Figure 4), and estimate that (with the exception of the very high rates of glacial erosion, deposition, and associated jökulhlaup and fluvio-glacial activity) this single geomorphic event accounted for more "work" than all other processes combined over the last 100 years.

FIG. 4a. Rupture zone of debris flow released during heavy rainstorm in July 1982. Southeast Iceland.

FIG. 4b. The colluvium from a series of debris flows that cut through the birch forest (bottom left) was spread across the valley floor, Skaftafell, Southeast Iceland.

The regularity, or irregularity, of occurrence of the extraordinarily large events, such as the Koefels landslide, poses a serious problem to any attempt to rank geomorphic processes and deduce long-term denudation rates. There is a wide range of evidence supporting the notion that large-scale landslide activity in the Alps peaked during the latter part of the last glaciation. Late-glacial retreat of large valley glaciers exposed over-steepened rockwalls to mechanical stresses and collapse, leading to the majority of the spectacular landslides and rockfalls. On a lesser scale, the same period was also characterised by much more rapid construction of talus and alluvial cones than is occurring today.

Rates of activity: In the same context as variations in geomorphic activity through long periods of time, rates of mass wasting on Colorado Front Range interfluves have been shown to vary by an order of magnitude during the Holocene; current rates are lower than at any other time (Benedict, 1970). We can therefore see that mountain geomorphology faces some critical problems of variation in rates of erosion, not only by different processes, but also in space and time.

On Niwot Ridge in the Colorado Front Range, current rates of horizontal movement in stone-banked and turf-banked terraces and lobes range from 4 to 43 mm/yr, compared with intervening and more stable areas which indicate a rate of less than 1.0 mm/yr. Movement, however, appears to be largely confined to the upper 50 cm of the waste mantle. This represents an overall denudation rate of 0.01-0.14 mm/yr for interfluves with an order of magnitude variation through the Holocene. Rapp estimated cliff-face retreat in northern Sweden at 5 m in 10,000 years and 30 m in 30,000 years (Rapp, 1960), compared with estimates of 7.6 m in 10,000 years for the Colorado Rockies (Barsch and Caine, 1984). Roughly comparable results have been calculated from measurements of talus accumulation over time in the Canadian Rockies (Gardner, 1979) and other areas.

The comparative neglect of chemical weathering in alpine research has been partly justified on the assumption that low temperatures and absence of free water during sub-zero periods inhibit chemical action; high mountain streams, except glacier-fed ones, are usually clear. This argument is offset, however, by the realisation that low temperatures enhance carbon dioxide solubility, and this may be an especially important factor in limestone regions.

The challenge to conventional hypotheses: To a large extent, the 1960-85 period of intensive alpine process study constitutes a major advance in our understanding because several formerly cherished and intellectually satisfying hypotheses have been invalidated or seriously challenged. Although Battle had demonstrated in the 1950s that temperature fluctuations in bergschrunds are of neither sufficient magnitude nor frequency to support the meltwater variant hypothesis of cirque formation, no further significant work in this area was attempted for some time. School and undergraduate texts, however, perpetuated the assumption that nivation was a dominant high-mountain process. Partly because of the hypothesis of accelerated freeze-thaw activity around and beneath snowbanks, one mode of cirque development was assumed to embrace progressive enlargement of nivation hollows until snowbanks became small cirque glaciers and a further increase in erosion occurred as glacial processes took over.

This hypothesis of cirque formation was re-examined as a result of Thorn's (1976) impressive study of nivation in the Colorado Front Range. He demonstrated that freeze-thaw cycles do not increase in frequency beneath and around snowbanks, and that removal of sand, silt, and clay-sized particles increases to magnitudes of between twenty and thirty times as a result of nivation, when compared with surrounding control slopes, though the specific processes are sheet wash and rivulet flow. Chemical weathering is also accelerated two to four times in a snowbank environment. Nevertheless, this suggests that, at current rates, it would take 500,000 years to excavate a modest-sized nivation hollow (300 × 200 m). Also, once the hollow becomes large enough for snow to accumulate sufficiently for its survival throughout the ablation season, the role of snow becomes protective. Thus the hypothesis that nivation hollow enlargement leads directly into cirque formation breaks down.

The argument that frequency and magnitude of freeze-thaw cycles, assumed to increase in arctic and alpine environments, accounted for the observed increase in quantities of frost-shattered rubble has also been invalidated (Fraser, 1959; Cook and Raiche, 1962; Ives, 1974a). Freeze-thaw frequency in climatological screens actually decreased meridionally from southern to northern Canada, and only the annual freeze-thaw cycle penetrates more than a few centimetres below the ground surface in a high-arctic environment.

These hypothetical relicts of the early descriptive era of mountain geomorphology probably achieved their long-standing prominence because researchers attempted to explain the extensive frost-riven waste mantle of cold-climate environments in terms of contemporary processes. Not enough attention was paid to the probably great age of block-fields, for instance. The long debate concerning the development of block-fields, or mountain-top detritus, has involved discussion of the extent and tbickness of the Late Cenozoic continental and mountain ice-sheets and the survival of vascular plants on nunataks throughout the ice ages (Odell, 1933; Flint, 1943; Dahl, 1955). Tbis long, intense dispute between geographers, geologists, and biologists merely highlights prevailing uncertainties concerning rates of erosion and their variation through time, as well as the difficulty of accurate dating of substrates (cf. Ives, 1974b).

In summary, twenty-five years of progressively more rigorous process studies have led to a number of vital conclusions:

1. We have not gathered, or been able to gather, adequately representative data;

2. Slope processes in mountain areas today are not primarily responsible for the mountain landforms upon which they are operating;

3. Infrequent catastrophic events cannot be compared statistically with slow continuous slope processes;

4. Several major hypotheses have been invalidated completely, or found wanting, and yet not replaced with alternative explanations.

These conclusions should not be regarded with pessimism. Mountain geomorphology has advanced prodigiously since 1960. It is important to have a more accurate understanding of what is happening on contemporary mountain slopes, to dismantle false, if intellectually attractive hypotheses, and to appreciate how and why a wide variety of processes are operating. This leads into the applied aspects of mountain hazards assessment (Dow *et al.*, 1981; Kienholz *et al.*, 1983). It is equally important to understand spatial and temporal lack of representativeness, and to realize that many high mountain areas are rising as rapidly as, or more rapidly, than the processes of denudation are wearing them down. In this regard, the recent Chinese work in Tibet and the Himalaya has demonstrated a very high rate of contemporary uplift (Liu and Sun, 1981). The current progress in plate tectonics (Schaer and Rodgers, 1987), and the advances in dating techniques (Clark *et al.*, 1987), have provided an array of powerful tools for future research. What is important for our present consideration of mountain environmental problems, however, is the current status of mountain geomorphology, which can be best characterized by the word *uncertainty*.

A model of alpine slope processes: The systems of processes which operate in alpine environments have been described by Caine (1974) as a cascade of sediment fluxes involving a variety of materials and controls. These fluxes have not received an equal amount of attention. They are also unevenly distributed, although it may be possible to define general patterns of relative significance, such as variation with elevation. Caine has proposed four systems, each with its own set of controls, responses, and levels of activity: the mountain glacial system; the coarse debris system; the fine clastic sediment system; and the geochemical system. These systems are distinct but they interact and material moves between them. The mountain glacial system and coarse debris system are most characteristic of high mountains for they tend to be restricted to areas of greatest elevation and strongest relief:

1) *The glacial system.* The distribution of mountain glaciers is controlled by elevation and climate, which influence mass balance and thus equilibrium line altitude and glaciation limit. This system is found at the highest altitudes, where the movement of water in the solid phase is important for transporting debris derived from rockfall, as well as from erosion at the ice-rock interface. In presently glacierised mountains this system is probably the most efficient form of erosion, although great fluctuations in the extent of its dominance have occurred over the last 25,000 years.

2) *The coarse debris system.* This system is also highly characteristic of high mountains. It involves the transfer of coarse detritus between rockwalls and talus and associated deposits at lower elevations, as well as large-scale failure. In maritime climates it may be tributary to the glacial system, with glaciers as the main transporting agent. In continental climates it may be considered as a closed system, with rock glaciers forming its down-valley extensions. Climatic changes, which induce glaciation, will open the system and permit intermittent removal of accumulated debris as glacial till. Most studies have concentrated on the talus and rock glacier components; in contrast their source areas, the rock walls, have received scant attention.

3) *The fine sediment system.* This system may be regarded as open. Some material is derived from aeolian dustfall and much may be exported by flowing water to lower elevations. It has received much attention from researchers interested in mass wasting on alpine slopes. It responds most readily to environmental controls involving the hydrological cycle; to freezing and thawing of the ground; form and intensity of precipitation; and distribution of snow cover. There is a great variation in rate of activity between wet and dry sites; in wet sites rates of movement are much faster than those at lower elevations.

4) *The geochemical system.* There has been relatively little work on geochemical exchanges in high mountains except in areas of alpine karst.

As suggested above, the classical viewpoint is that chemical weathering is insignificant. However, recent studies support the contrary view of Rapp. While the total mass of solutes may remain slight, its importance probably derives from the efficiency of transport by running water through the system. It is also highly responsive to hydrologic controls (see also, Barsch and Caine, 1984).

Three case studies compared: Figure 5 summarises process studies from three different high-mountain catchments. They differ in area across three orders of magnitude, and also according to climate, structure, and lithology. While additional data could be added, they would not significantly influence the generalisations. Despite the disparities between the three sites, some important common features are evident which may be applicable to all high-mountain catchments. Two components in the geomorphic mass fluxes dominate in all three catchments. The coarse debris system accounts for between 10 and 60 percent of all erosive power; contrasts between sites are inversely related to catchment size and relative relief — this is most probably influenced by the proportion of the total area of cliffs and taluses. The importance of solute transport almost equals this (from 12 to 50 percent) and is related directly to catchment size. The record from the largest catchment implies that fluvial transport and deposition of clastic sediment is the most important. Although Rapp (1960) and Caine (1976) did not make comparable estimates, it is unlikely that fluvial processes are significant in their much smaller catchments.

Figure 5 and Table 1 also indicate that there are many studies devoted to talus shift, solifluction, soil creep, and other processes of slow mass wasting that are relatively unimportant — less than 15 percent of all work done with relative importance decreasing as the size of catchment area increases. Finally, except for the largest catchment, erosion and transport through the fluvial system, although difficult to evaluate, appear slight. This may indicate a lack of coupling between hillslope systems and fluvial systems in high mountains. It is important to note that this discussion is based upon average estimates and does not include the issues of temporal variability.

Mountain geomorphology, as emphasised above, has concentrated on high mountains. Within this context it must be understood that all geomorphic studies have demonstrated a difference in degree, if not in kind (excepting the glacial system), of erosion between mountain and

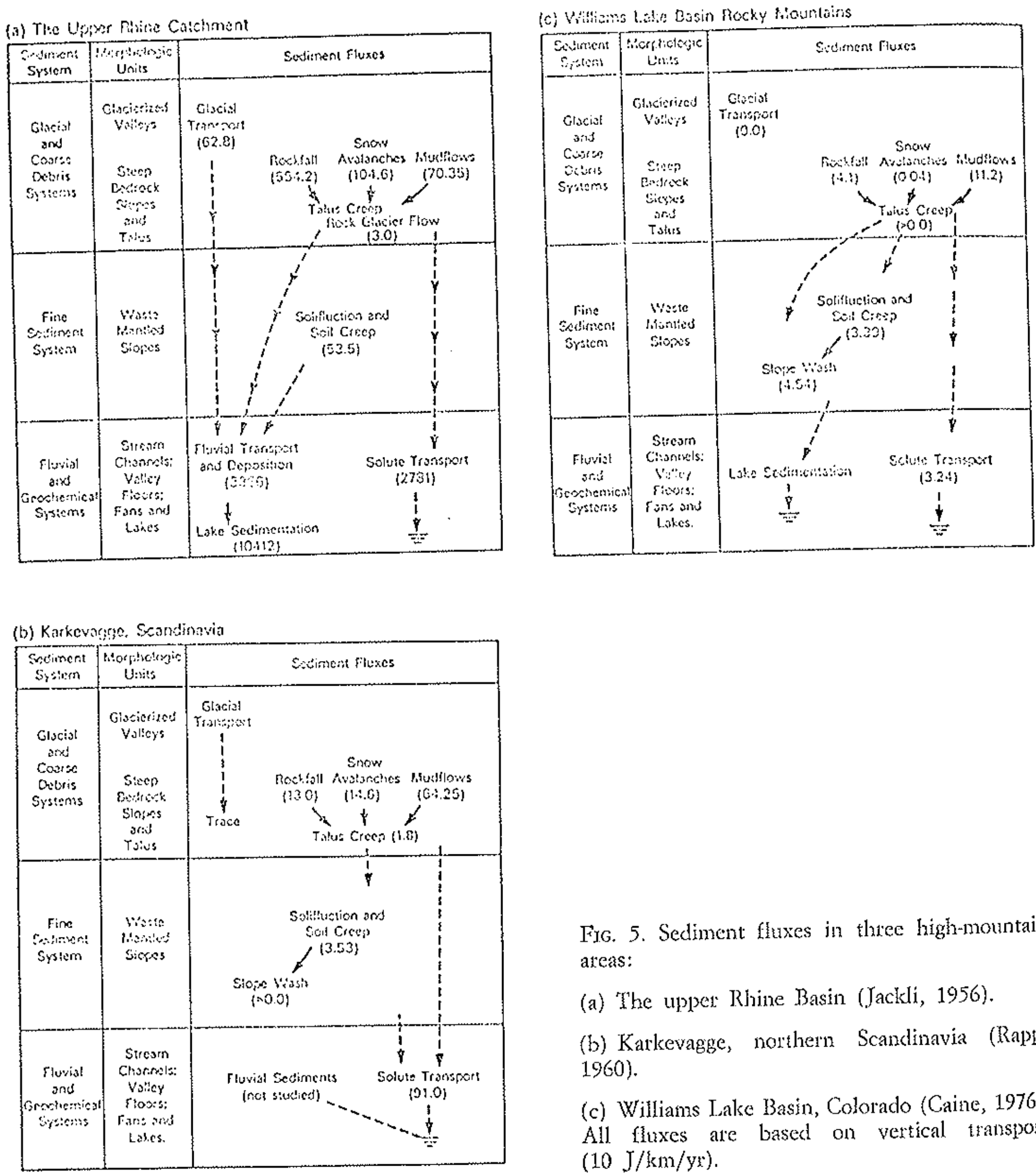


FIG. 5. Sediment fluxes in three high-mountain areas:

(a) The upper Rhine Basin (Jackli, 1956).

(b) Karkevagge, northern Scandinavia (Rapp, 1960).

(c) Williams Lake Basin, Colorado (Caine, 1976). All fluxes are based on vertical transport (10 J/km/yr).

TABLE 1 - *Sediment fluxes in three high mountain basins.*

Catchment	*Upper Rhine*	*Karkevagge*	*Williams Lake*
Area (km^2)	4307	15	0.98
Relief (m)	2800	930	275
Coarse debris and bedrock slopes	729.2 (4.2%)	15.7 (58.4%)	93.65 (49.8%)
Soil and fine sediment mantled slopes	53.5 (0.3%)	7.93 (29.5%)	3.53 (1.9%)
Channel transport and lake sedimentation	13798 (79.5%)	Not reported	Not reported
Solute flux (output)	2781 (16.0%)	3.24 (12.1%)	91.0 (48.3%)
Total	17362	26.87	188.18
Source	Jäckli (1956)	Rapp (1960)	Caine (1976)

Units: 10^6 J/km^2/yr

lowland regions. This difference is consistent, and measurements, however unrepresentative they may be, range from five to one or two orders of magnitude, based upon river load estimates (i.e., the denudation rate), reservoir sedimentation, and geological data. This statement is made with the understanding that much of the coarse debris transfer relates to movement within a generally closed system; in other words, it represents redistribution within the high mountains rather than absolute removal from them.

Summary of the Geomorphological Overview

This overview has attempted to demonstrate progress in mountain geomorphology over the last twenty-five years. While great strides have been made in our understanding of slope processes, the problems of extreme variability in space and time remain as a challenge for the future. The overview has also emphasised that research has concentrated heavily on a very small proportion of the total area of mountain lands, the more spectacular high-mountain belt dominated by cold-climate processes. While the knowledge gained from this concentration probahly justifies the hias, in my estimation the major future challenge lies in the inhabited lower mountain belts, where man may be a dominant geomorphic agent. Nevertheless, further progress in solving the spatial and temporal variability enigma will probably be made most efficiently in the high-mountain belt and, therefore, studies here should proceed hand in hand with human geography to give a holistic approach to mountain landscape dynamics that crosses the traditional divisions between physical and human geography. In fact, a much fuller interdisciplinary approach becomes increasingly important for contemporary research in mountain lands.

It is equally apparent that inhabited mountain regions are even more highly complex fields for study. Thus, international collaborative efforts are vitally needed, including standardization of objectives and methods, shared data banks, and identification of minimum data needs. In these ways research will be able to proceed much more efficiently (world data centres, after the pattern of the IGY Centres, would be a desirable organization goal).

In these closing years of the twentieth century, a period of financial and economic stress and, particularly from our point of view, of increasing scarcity of research funds, this recommendation for an expanded effort, even the establishment of a world network of mountain research activities, may appear impractical. In this respect it is worth considering the fate of some highly expensive development projects in mountain regions. The engineer's estimate of the useful life of a large hydroelectric scheme is often significantly reduced because no attention was paid to the dynamics of the mountain catchment; uncontrolled deforestation, for instance, serves to fill the reservoir quickly with silt. Poorly designed roads lead to instability of extensive mountain slopes and serious down-stream damage. Resources mismanagement in mountain lands in general, often due to ignorance, or to the definition of short-term objectives, has the potential for devastating losses in the surrounding and densely populated lowlands and coastal areas. The problem is exacerbated by the extreme unreliability of much of the available data, and the tendency to generalise to the point of absurdity. Is it not vital, then, that mountain geomorphologists should accept the obligation, and grasp the opportunity, to prove the value of their work?

The argument for the future human-orientated mountain geomorphology can be proposed in another way. With the contemporary pressures and resource-use conflicts facing the mountain lands, much high-mountain research, and its handmaiden, arctic research, begin to appear effete, the perpetuation of an elitism that is a hold-over from the gentlemen adventurers of a previous era who were privately funded. Applied mountain geomorphology need in no way be perceived as lacking in intellectual challenge if this reputation is to be overcome and the potential of the subject is to be realized.

This *polemic* nevertheless leaves us to grapple with *uncertainty*. If we consider the problems of spatial and temporal uncertainty in the context of mountain geomorphology, in the wider perspective of a holistic approach to mountain environmental problems, the uncertainty issue will be at least an order of magnitude more intractable. To bring this statement into sharper focus I will now turn to the United Nations University study of the Himalaya-Ganges Problem as an illustration (cf. Ives and Ives, 1987; Ives and Messerli, 1989).

Uncertainty on a Himalayan Scale

The United Nations University studies of mountain hazards in the Nepal Himalaya (Ives and Messerli, 1981) led to a broader analysis of the "Himalaya-Ganges Problem". This culminated in an international conference held at Mohonk Mountain House, New Paltz, New York, in April 1986. Much of the content of this section of the present paper is taken from the introduction to the proceedings of the "Mohonk Mountain Conference" (Ives, 1987). It involves a statement and critical analysis of the popular and widely accepted notion that the Himalaya are facing imminent environmental catastrophe, which in turn will have a devastating impact on the densely populated plains to the south. This is referred to as the "Theory of Himalayan Environmental Degradation". This section, therefore, first outlines the elements of this popular theory and then seeks to dismantle it, not only because I believe it is flawed from an intellectual or academic point of view but also because its very attractiveness to many policy makers itself constitutes a threat to development of proper resource management and environmental protection strategies. It is also important to bear in mind that uncritical acceptance of such ill-founded conventional wisdom endangers the credibility of both Himalayan scholars and resource managers and policy makers.

A synoptic response to the question — what is the nature of the perceived crisis facing the Himalayan region? — can be compiled from numerous reports in the news media, internal reports of aid and development agencies, and countless published papers available in the scientific and conservationist literature. The most compelling and effectively written characterization is by Erik Eckholm (1975, 1976), and the most startling visual presentation is contained in the superb movie, *The Fragile Mountain*, produced by Sandra Nichols (1982), with substantial financial support from the World Bank and other agencies. In addition, a spate of books and articles has been published, especially in India and Nepal. Some of the most prominent are: Lall and Moddie (1981); Bandyopadhyay *et al.* (1985); J.S. Singh (1985); T.V. Singh and Kaur (1985); and Joshi (1986).

The Theory

Any synthesis of this literature would include all, or most, of the following points that apply particularly to Nepal but which are generally extrapolated to characterize the much wider Himalayan region:

1. Following the introduction of modern health care, medicine, and malaria suppression in the Terai after 1950, there occurred an unprecedented wave of population growth that does not yet appear to have peaked. For Nepal as a whole it appears to have reached 2.6 percent per annum for the 1971-81 census decade (Goldstein *et al.*, 1983) but in many areas it exceeds 3.0-3.5 percent per annum. Nepal's total population today is probably in excess of 16 million. Comparable population growth rates appear to be characteristic of the entire Himalayan region.

2. This veritable population explosion, with an overall doubling period of about 27 years, is augmented by uncounted and uncontrolled illegal immigration from India into the Nepalese Terai across the open frontier. Furthermore, over 90 percent of the 1981 population is rural and subsistence. This has led to rapidly increasing demands for fuelwood (more than 90 percent of Nepal's energy depends upon the combustion of biomass), construction timber, fodder (the domestic animal population has undergone a parallel, or even greater, increase to that of the human population), and agricultural land on which to grow food.

3. The next element in what has been described as a vicious circle, is that the needs of the burgeoning subsistence population are exerting increasing pressures on the forest cover. This has led to massive deforestation, amounting to a loss of half the forest reserves of Nepal within a 30-year period (1950-1980) and comparable losses in large areas of

the Indian Himalaya, and a prediction that by A.D. 2000 no accessible forest cover will remain; it is widely assumed that this situation has reached crisis proportions.

4. The deforestation, accompanied by the cutting of agricultural terraces on steeper and more marginal mountain slopes, has led to a catastrophic increase in soil erosion and loss of land through accelerated landslide incidence, and to the disruption of the normal hydrological cycle.

5. This, in turn, has led to increased runoff during the summer monsoon and an increase in disastrous flooding and massive siltation on the plains, and to lower water levels and the drying up of springs and wells during the dry season. Related ills are: rapid siltation of reservoirs; abrupt changes in the courses of rivers; spread of barren sand and gravel across rich agricultural land on the plains; and increased incidence of disease in downstream areas.

6. The increased sediment load of the rivers emanating from the Himalayan system is extending the Ganges and Brahmaputra delta and causing islands to form in the Bay of Bengal. Among the evidence cited are the extensive plumes of sediment that can be seen on Landsat imagery to extend several hundred kilometers into the bay.

7. The continued loss of agricultural land in the mountains leads to another round of deforestation to enable the construction of more terraces on which to grow subsistence crops. Yet, as the labour of walking greater distances from the village to fuelwood supplies increases with the receding forest perimeter, a critical threshold is reached whereby the available human energy (principally female) becomes progressively over-taxed and an increasing quantity of animal dung is used for fuel.

8. Consequently, another vicious circle is linked to the first one: terraced soils are deprived of natural fertilizer, the animal dung now being used for fuel. This lowers crop yields. Also, the ensuing weakened soil structure further augments the incidence of landslides. Even more trees are cut on more marginal and steeper slopes to make room for more agricultural terraces to feed the ever-growing subsistence population.

Many other facets can be added to the eight-point scenario. These include the pressures generated hy the subdivision of the finite amount of agricultural land as the population continues to double every 27 years; at present it is calculated that there is less than one hectare of land per family. Similarly, the added pressures of collecting and carrying fuelwood and fodder and fetching water fall predominantly on the women. They, in turn, become progressively overworked and undernourished and their next generation of children begins life more and more deficient in essential nutrients, so that the situation worsens further. Domestic animals, essential to the Middle Mountain subsistence mixed farming system as suppliers of fertilizer and draught energy, depend heavily on fodder from the deplenished forests, so that their capacity also diminishes.

It follows from this brief exposition of the theory of Himalayan Environmental Degradation, that a series of vicious circles, each linked to the others, is envisaged as operating inexorably to drive a downward spiral. The apparent impossibility to break any of these circles leads to the prediction of widespread environmental and socio-economic ruin in the near future. There is perceived to be a progressive and accelerating shift from *potential instability* to massive *actual instability*. This includes: mountain slopes, from a physical point of view; hill village subsistence agriculture; and the regional or national economy. All these gathering tragedies will put increasing pressure on the already fragile political balances of the wider Himalayan Region.

In the face of the irreversible destructive processes in the Middle Mountains, for instance, outmigration increases. This in turn not only deprives the source areas — the villages and hamlets of the Middle Mountains — of a proportion of their youngest, fittest, and most creative members, but it adds to the already existing heavy population pressure on the resource base of the Nepal Terai. Population growth in the Terai, for example, including both natural increase and immigration, is calculated at over 4.0 percent per annum (1971-81 census; cf. Goldstein *et al.*, 1983; Hrabovszky and Miyan, 1987). Ten-to-fifteen years ago, it was believed that the opening up to settlement of the previously malaria-infested jungle of the Terai would provide a breathing space by enabling the absorption of excess population of the Middle Mountains, Nepal's most densely populated area. Today it can be seen that the "new land" in the Terai is being rapidly used up, a process accelerated by the surge of illegal immigration across the open border with India. And yet the population increase in the Middle Mountains continues at an unacceptable, or unmanageable rate, in excess of 2.0 percent per annum. Goldstein *et al.* (1983), for instance, characterize Nepal as being in transition, demographically, from a highland rural country to a lowland, urban one.

The net results of the various destabilizing processes in the Middle

Mountains are perceived as absolute deforestation, lowered crop productivity, both in terms of total national production and as yield per unit area, increase in absolute numbers and percentage of the subsistence farming population whose nutrient intake is below a minimum acceptable level, and progressive mountain desertification. Since the mountain desertification is perceived to be occurring on steep slopes, it is assumed that the associated processes of gullying, soil erosion, and landsliding will have calamitous downstream effects. Thus are envisaged the rapid siltation of reservoirs, excessive shortening of the useful life of major hydroelectric and irrigation projects, increased flooding on the plains (already an annual disaster for India and Bangladesh), increase in the levels of river beds, and destruction of rich lowland farmland by the spread of sand and gravel as rivers break their banks and change their courses. In short, the worse-case scenario foresees that the terrain of Nepal and that of adjacent areas of the Himalaya, and certainly the very basis of life, the top soil, will virtually flow down the Ganges by the year A.D. 2000. It has even been suggested that, in preparation for such an event, His Majesty's Government of Nepal should transfer its patronage of the Swiss technical aid system to that of the Dutch. In this manner Nepal can begin the struggle to reclaim (and legally claim) land below sea level and establish polders in the Bay of Bengal, the product of its own topsoil.

More than a decade ago, Eckholm wrote eloquently of the process whereby Nepal was exporting the commodity that it could least afford to part with, namely top soil, to India, in the form that India could least afford to receive it. The broad theory, nevertheless, is an intellectually satisfying concept which seems so reasonable that it is hardly surprising that it is widely accepted as fact. And, of course, there are further ramifications, such as claims by environmentalists that the deforestation, in turn, is affecting the climate in such a way as to reduce normal annual rainfall amounts. This, of course, would set up yet another vicious circle to accentuate the effects of the others.

The eight-point scenario and brief discussion, presented above, lead to a number of critical implications which further enlarge what can be described loosely as the *perceived* Himalaya-Ganges Problem. It *infers* that a few million Himalayan hill farmers are responsible for the massive landscape (and climatic) changes that are affecting the lives and property of several hundred million people in Gangetic India and Bangladesh. This raises two related points: (i) that the downstream countries, as victims of this unwarranted and irresponsible environmental disruption, could justify reprisals in economic, political, or military terms; and (ii) that Nepalese interests are served well (so long as no reprisals are actually taken) by this perceived image of helpless drift into environmental and socio-economic chaos, since it may account for its disproportionate amount of international and bilateral development aid in relation to its total size and population.

A further point is applicable within Nepal itself, and within several of the Indian states that have a plain and a Himalayan component, such as Uttar Pradesh. This is that the popular image of the hill farmer as the cause of the growing environmental disaster makes him a convenient scapegoat; it has been claimed that the relatively few mountain farmers, for instance, are holding hostage the very many more on the plains (World Resources Institute, 1985). Once more, effect is taken for cause, and corrective measures run the risk of being misdirected.

Whether or not the eight-point scenario of disaster for Nepal can be extended along the entire Himalayan system will not be discussed further except for emphasis of several related points. The Kumaun and Garhwal Himalaya appear to fall within this framework with two additional components. One is that the excessive commercial cutting of mountain forest stands to meet timber demands of the lowland population centres (until recently checked somewhat by the Chipko Movement). The other, associated with it, is the extensive development of mountain roads, especially as a military response on the part of India resulting from the border war of 1962 with China. Much of the road construction is substandard and has caused a great increase in landslide incidence; the roads also opened up extensive mountain forests to commercial clear-felling.

As we proceed westward into Himachal Pradesh, Jammu and Kashmir, and the Karakorum and Hindu Kush, we enter a series of mountain and highland landscapes with very different climatic regimes. Increasing aridity with distance from the influence of the summer monsoon greatly reduces the value of comparison with the Nepal Himalaya.

Conversely, eastward from Nepal, into Sikkim and the Darjeeling (West Bengal) Himalaya and Bhutan, we enter mountain areas with increasing amounts of summer monsoon precipitation. Bhutan, and probably the even less accessible and less well-known Arunachal Pradesh, should be viewed as exceptional cases where assumed deforestation and environmental disturbance are modest or insignificant. However, even these regions may be poised to follow the same road to disaster along which Sikkim, Nepal, and the Central Himalaya of India are travelling.

There are several additional contributing problems that need to be introduced. The first is the political processes that beset the region: the border dispute between India and China; the three Indo-Pakistan wars of 1947, 1966, and 1971, and the continued border tensions, especially along the Kashmir cease-fire line; the frictions between India and Bangladesh, and especially the very slow progress in negotiations over management of the flow of the Ganges and Brahmaputra. There are also the political tensions within India (Punjab, Assam, West Bengal) generated, in part, by the competing demands for access to natural resources by different ethnic groups.

The rapid growth in tourism is also an important contributing process. Once again most data are available for Nepal. However, popular access to the Garhwal Himalaya, especially the Valley for Flowers and the Nanda Devi Sanctuary, is seen to be causing a large increase in environmental pressure of an entirely different kind, the result of demands for recreation and adventure from people outside the mountain area. Fifteen years ago the growth of tourism in Nepal was perceived as a panacea for that country's balance-of-payment deficits. Today that perception has changed. Certainly in specific areas, such as Khumbu Himal and the Kali Gandaki and the Annapurna circuit, the numbers of tourist visitors each year now exceed the total indigenous populations. And their demands are seen as increasing the threat to local forest as well as being disruptive of the way of life of the local people, with both positive and negative consequences.

The 1959-60 exodus of approximately 120,000 refugees from Tibet, and their impacts on the natural resource base of Khumbu Himal and Mustang, for instance, and the consequences of China's closing of the frontier with Nepal, must be seen as unprecedented disruptive events. Finally, the much more extensive turmoil in Afghanistan, and the impacts of over three million refugees on the Pakistan Hindu Kush and adjacent northern areas, are a socio-economic problem of world-magnitude in itself, notwithstanding the widespread political implications (Allan, 1987). Without a doubt, therefore, the broader Himalayan Region must be seen as dynamic in the extreme — geophysically, climatically, and in the socio-economic and political senses.

The presumed linkage between mountain deforestation and downstream effects also has been applied to the Hengduan Mountain-Chengdu Basin system, far to the east of the Himalaya proper. Here extensive deforestation in the "River Gorge Country" of western Sichuan and northwestern Yunnan, and its impact on the hydrology and sediment load of the Jinsha Jiang (Yangtze), are credited with increased flooding, siltation, and damage to heavily populated and rich agricultural land downstream in the Chengdu Basin. As with the Himalaya-Ganges system, population growth, deforestation, and soil erosion have been perceived as post-1950 phenomena, in this case with the added overtones of mismanagement during the Mao Tse-tung years with the Great Leap Forward and Cultural Revolution.

It must be concluded that the "save-the-world's-forests" lobby has had a powerful influence on large sections of public and scientific opinion. It has been widely agreed that serious problems will arise from loss of the Tropical Rain Forests, and also from mountain deforestation in the Himalaya and elsewhere. The intent is not to challenge the importance of the world's forest resource stability but to examine critically some of the claims that are made in terms of the assumed effects of mountain forest clearance. It is postulated that this is a vital undertaking, a prerequisite to rational corrective policy development.

Linkages of the Theory and Their Implications

To sum up this overview of the perceived Himalaya-Ganges problem, it is necessary to point out a number of basic assumptions and salient linkages between the component parts of the eight-point scenario. There is also a basic philosophical issue: What should be our attitude to the ignorant subsistence farmer who is seen, unthinkingly, to produce swarms of children, and irresponsibly to devastate the mountain forest cover, and so accelerate landslide occurrence on his poorly constructed and badly maintained agricultural terraces or by his catastrophic slash-and-burn (swidden) agriculture? To take the salient linkages and basic assumptions first:

1. That a population explosion was initiated shortly after World War II due to the introduction of modern health care and medicine and the suppression of malaria and other diseases;

2. That increased population in subsistence mountain societies has led to:

   a) reduced amount of land per family;
   b) deepening poverty;
   c) massive deforestation.

3. That mountain deforestation, on such a scale, will result in total

loss of all accessible forest cover by A.D. 2000 (World Bank, 1984) and is the cause of accelerating soil erosion and incidence of landsliding;

4. That destabilized mountain slopes resulting from points 1, 2, and 3 above cause:

a) increased flooding on the Ganges and Brahmaputra plains;

b) extension of the delta and formation of islands in the Bay of Bengal;

c) massive siltation and drastic reduction in the useful life of highly expensive water resource projects;

d) drying up of wells and springs in the hills and lower dry-season river levels downstream;

5. That deforestation also leads to climatic change in general and reduced rainfall amounts in particular.

It is not the intention to dispute the facts, wherever reliable information exists, but the assumptions that so frequently are not based upon facts. Nevertheless, throughout this attempt to analyse the theory of Himalayan Environmental Degradation the causal relationships between the timing and degree of population growth, deforestation, loss of agricultural land, and downstream effects are paramount. An attempt will be made to demonstrate that most of these linkages and assumptions are founded on latter-day myths, or falsely-based intuition, or are not supported by rigorous, replicable, and reliable data. They are the "sacred cows" of the perceived Himalayan problem, and an effort will be made to strike them down, in part or in whole. However, the claim of lack of reliable data cuts both ways — it cannot be demonstrated unequivocably that *all* the linkages are inoperable in *all*, or even in most, cases. Nevertheless, it is contended that enough of the "sacred cows" can be disposed of and others sufficiently damaged to support the claim that the overall theory of Himalayan Environmental Degradation is untenable and that the Himalayan problem needs to be much more rigorously defined.

The perceived problem, in this view, is in the minds of the vested interests: the World Bank, the Chipko Movement, different national governments, or the scientists. It is likened to a kaleidoscope which will change its pattern depending upon the way in which it is tilted, or upon the angle of view. This is the essence to Thompson's and Warburton's (1986) *Uncertainty on a Himalayan Scale.* The uncertainty is a large element of the Problem. Thus the present claim to demolish most of the underpinnings of the theory itself must be qualified by the very nature of the uncertainty. There must be a qualification: that *in certain instances*, and in *specific areas*, it can be shown that many of the widely preferred assumptions are untenable. The present temptation to extrapolate must be resisted, because not to do so would commit the same error: unwarranted generalization. The single and obvious generalization that can be made, however, is that the Himalayan region is so varied and so complex that generalization is counter-productive. Hence, the application of broad panaceas by aid and development agencies in most, if not all, instances will not succeed; in some instances they may well exacerbate the problem.

But what of the ignorant and fecund subsistence farmer whose well-being lies at the crux of the problem. He has indeed become a convenient scapegoat. This can be exemplified by a single observation, illustrative of many others.

In an otherwise impressive review of the Nepal Agricultural Sector, the following quotation from a report by the Asian Development Bank (1983: II, p. 34) indicates the extent of the misunderstanding of the subsistent farmer's role.

> "Terraces, especially on rainfed land, are often poorly constructed; they are outward rather than inward sloping and do not have a grassed bund on the edge".

The fact is that *bari* or rain-fed terraces in Nepal usually support maize, millet, buckwheat, and other crops. They are constructed usually on the upper, steeper slopes in the Middle Mountains, which are inaccessible to irrigation systems. They slope outward from the hillside so that these crops are not damaged by waterlogging. In the UNU Kakani field area (Johnson *et al.*, 1982; Kienholz *et al.*, 1983), the local farmers are well aware that an increased accumulation of water on the terraces (such as would result from inward-sloping forms) would greatly exacerbate the problem of landsliding by increasing the degree of soil saturation and adding the weight of the ponded water itself. Furthermore, annual repair of the terrace would require a much larger labour input if they sloped inward. The summer monsoon rain is *intended* to run off the outward-sloping terraces.

Although there are undoubtedly poorly maintained terraces in Nepal, and in other areas, many are very well maintained and have vegetated steps (Figure 6); absence of a bund on the *bari* terraces (in contrast to the *khet*, or irrigated, terraces) is deliberate and ensures run-off of rainwater. It

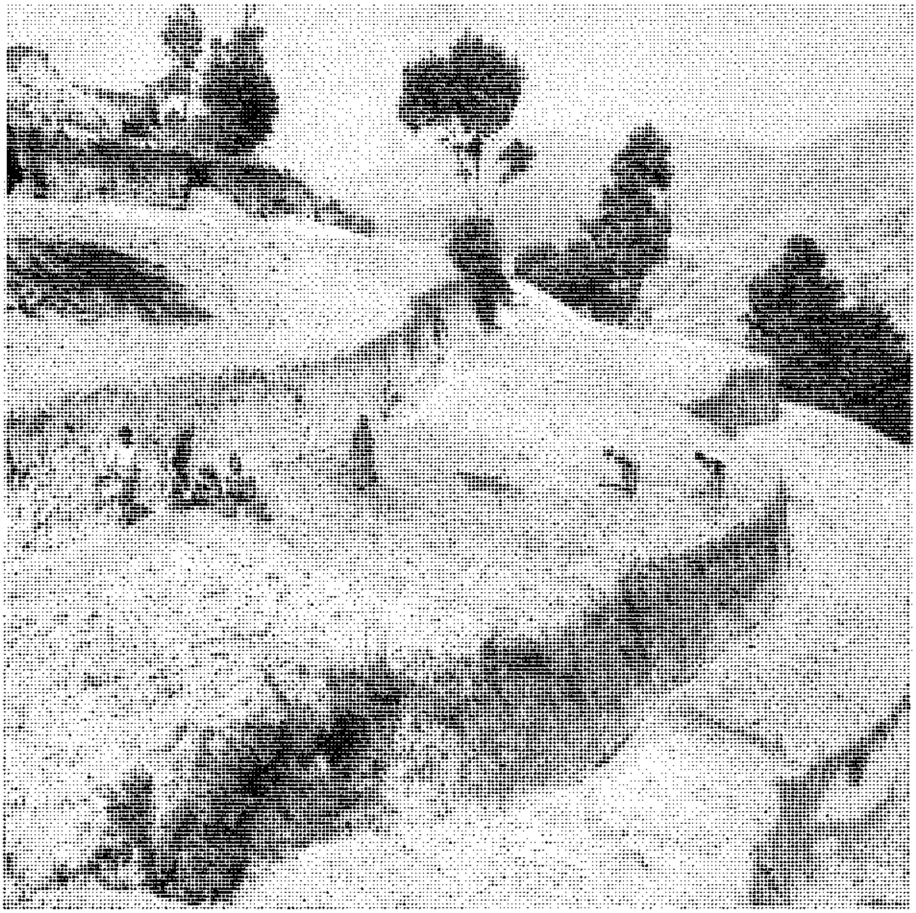


FIG. 6. *Bari*, or rainfed terraces in the Middle Mountains of Nepal during the dry season. Here the local farmers are preparing the terraces for the forthcoming monsoon planting.

can be argued that both *bari* and *khet* terraces are superbly engineered in Nepal. Admittedly, during heavy monsoon downpours available human energy is concentrated on repairing damage to the *khet* and irrigation systems, and the *bari* terraces may have to be left to collapse; this is because the much higher-yielding *khet* terraces, usually under paddy rice, are more vital to the survival of the subsistence family (Figure 7). Any apparent neglect of the terraces may be due to shortage of available labour at the particular moment that they were observed by the visiting "expert" rather than a reflection of the ignorance of the farmer. Frequently the subsistence farmer can be shown to be a highly knowledgeable and intelligent land manager with a wealth of accumulated, traditional wisdom of great potential value to the "educated" elites, if only they would listen (Whiteman, 1985). This leads to the claim that there is a need for gift exchange in contradistinction to *charity* — a synonym for international and bilateral aid (Hatley and Thompson, 1985). Nevertheless, it is not implied that all subsistence farmers are intelligent indigenous scientists, nor

FIG. 7. *Khet* terraces beautifully engineered on the surface of an old landslide scar, Middle Mountains, Nepal.

that even the most gifted amongst them can necessarily control the torrent of change which is sweeping them along; and there are ignorant and foolish farmers, just as there are ignorant and foolish factory workers, tradesmen, scientists, and decision makers.

Two further points must be introduced. First, there are no claims being made here for any individual's academic or scientific precedence, despite the intellectual satisfaction of having the opportunity to fault a widely accepted paradigm. Members of the United Nations University/Nepal MAB-Mountain Hazards Mapping Project began to suspect the reliability of some of the pre-existing claims of the theory of Himalayan Environmental Degradation. They began to doubt that deforestation and increased landsliding were linked in a simple cause-and-effect relationship. They also began to understand, as field work progressed over several years and during different parts of the annual agricultural cycle, that the human impacts, principally those of the subsistence farmer, were not all negative. Part of the farmers' coping strategy was to re-terrace landslide scars and stabilize slopes (Figure 8). They also respond to prospects of immediate landslide initiation by such acts as agricultural de-intensification (Johnson *et al.*, 1982). Similarly, reconnaissance of the Qinghai-Xizang (Tibetan) Plateau, and in the Hengduan Mountains of western Sichuan and northwestern Yunnan (Ives, 1981, 1985; Messerli and Ives, 1984) led to the suspicion that the assumptions of post-1950 massive deforestation were also over-simplifications, and that the actual history of deforestation was a very much longer and more complex process. This gradual growth in understanding of the complex nature of the region and the processes operating therein led to this questioning of conventional wisdom. These doubts about recent mountain deforestation were enhanced by contact with the work of forest historians Richard Tucker (1987) and John Richards (1987), with ecologists and Chipko activists Jayanta Bandyopadhyay and Vandana Shiva, with Tej Mahat, David Griffin and his colleagues (Mahat *et al.*, 1986a and b, 1987 a and b), with Michael Thompson, Michael Warburton and Tom Hatley (Thompson *et al.*, 1986), with David Pitt (1986), Lawrence Hamilton (1987), and Deepak Bajracharya (1983), and many others, together with the spiritual leadership of Chipko Messenger, Sundarlal Bahuguna. It was discovered from these contacts that doubts and challenges had been developing simultaneously along similar lines. It is the coming together of this group, facilitated by the United Nations University's support of the Highland-lowland Interactive Systems project, that has led to this concerned effort to challenge the theory of Himalayan Environmental

FIG. 8a. Landslide scar in the UNU project field study area, Kakani, near Kathmandu, Nepal. This photograph was taken after the 1979 summer monsoon. Note the extreme instability of the still wet and mobile slope.

Degradation and, in turn, to the convening of the Mohonk Mountain Conference.

The second point is equally important. All members of this now considerably enlarged working group do not necessarily agree on all points, or even on any one particular point; nor do they, nor can they, all have the same perspective. But there is agreement that a major arena of enquiry has been opened up that is fraught with an unusual level of uncertainty. It is also emphasized that the enquiry has been encouraged by many individuals

FIG. 8b. The same view photographed during the 1986 summer monsoon (August). The landslide scar has been re-terraced and is supporting a heavy crop of maize with some paddy. Indications of a landslide are virtually undetectable by the unpracticed eye.

within several major agencies of the United Nations Organization, despite the occasional criticisms that appear to be levelled against them in this paper. It is contended, however, that the enquiry has a potentially important bearing on the well-being of several hundred million people and on the socio-economic and political stability of a pivotal region of the world. Further exhaustive pursuit of the enquiry should become a major endeavour, not only for the United Nations University, but also for other relevant UN agencies, bilateral aid and development agencies, and the governments of the region.

Discussion

Having presented in some detail the theory of Himalayan Degradation it is now necessary to review several of the major challenges brought *against* it, both during preparation for the Mohonk Mountain Conference agenda and as part of the Conference deliberations. Many of the points raised for discussion here are analysed in greater detail individually in the Conference proceedings (Ives and Ives, 1987) and in the series of independent papers published in *Mountain Research and Development*. Much additional field work, data analysis, and debate will be necessary before some of the more intractable problems can be resolved. The Mohonk Mountain Conference will have fulfilled one of its major objectives, however, if it builds an atmosphere of healthy skepticism and critical response to the facile argumentation upon which so many perceptions are based.

Deforestation and uncertainty: Thompson and Warburton (1985a, 1985b), Hatley and Thompson (1985), and Thompson *et al.* (1986) have highlighted the "uncertainty issue" that has pervaded many of the Conference deliberations. Only one aspect is introduced here: the 67 factor, the measure of difference between the lowest and the highest estimates (supposed measurements) of fuelwood consumption for Nepal. Thompson *et al.* (1986) have demonstrated most effectively the gross unreliability of available data by use of the fuelwood consumption-biomass productivity equation as an illustration. By showing that consumption estimates vary by a *factor* of 67 and that biomass productivity data are even less reliable, or else totally unavailable, they challenge the wisdom of the recurrent tendency of conservationists, the World Bank, and agencies of His Majesty's Government of Nepal alike (this tendency encompasses the entire length of the Himalaya) to use such "data" to demonstrate the proximity of catastrophe.

Mahat *et al.* (1987a) explore the fuelwood consumption estimation process in great detail and, in general, support the views of Thompson *et al.* (1986). Nevertheless, Mahat *et al.* (1987a, 1987b) do appear confident that they have derived a reasonably acceptable average figure for their field area of Sindhu Palchok and Kabhre Palanchok in the Nepalese Middle Mountains east of Kathmandu. This raises the question: have

Thompson *et al.* caused the pendulum to swing back too far in the opposite direction, leading to spurious over-dramatization of the "uncertainty issue"? Any response to this question requires reexamination of Donovan's (1981) original material since this is the source of the "data" that provided Thompson *et al.* (1986) with a target for their axe.

Certainly, if a possible printing or recording error is eliminated, 67 is replaced with 26 (Donovan, 1981; Thompson *et al.*, 1986). This step does not change the situation, however, since a difference of this magnitude (factor of 26) between the highest and lowest figures for annual per capita fuel consumption is still preposterous. It should deny the "data" of any usefulness except for demonstration of the total unreliability of this and all data deriving from the Himalayan region. This is a prime purpose of Thompson *et al.* (1986).

Prior to re-analysis of the Donovan material (Table 2) it had been assumed that it would prove a grab-bag of fuelwood consumption measurements which grouped separate studies in different areas of Nepal, and for different periods of time, destined to produce widely disparate results. Thus, estimates from Terai villages, where fuel use for household heating would be relatively unimportant, would provide low consumption figures. Those from the Middle Mountains would be relatively high as heating requirements increase with greater altitudes. Finally, those from high-altitude villages, such as Khumbu Himal, where household heating would be a continuous requirement throughout the year, would show the highest per capita consumptions. In exceptional cases these high figures would be further inflated by demands for hot showers, cooking, and heating for large numbers of trekkers and mountaineers, who in places greatly exceed the total indigenous population. A brief glance at Table 2 indicates that the three hypothetical clusters — Terai, Middle Mountains, High Himal — do not appear. There is no rational explanation; for instance, some Terai figures are among the highest, some among the lowest. Many are aggregates for the entire country and even this subset nearly covers the entire range of estimates.

While there are significant numbers of individual estimates that cluster around 1.0 m^3/capita/year, it is suspected that this could be influenced by individual investigators adjusting their computations to more closely match the conclusions of preexisting publications and reports.

It is necessary, therefore, to fall back on the point made by Thompson *et al.* (1986): the figures are simply unreliable, unrealistic, and unusable. They can only be used to raise the spectre of general unreliability of *all* data

TABLE 2 - *Various estimates, 1954-1980, of average annual per capita fuelwood consumption in Nepal* (from Donovan, 1981).

Reference area[1]	Quantity[2]	
	Cubic metres	Kilograms
Nationwide	0.10	60
Bhaktapur	0.13	84
Western hills	0.18-0.36	108-216
Kathmandu valley	0.18	111
Nationwide	0.20	120
Lalitpur	0.22	136
Kathmandu	0.25	155
Central hills	0.26	156
Nationwide	0.33	198
Eastern hills	0.38	228
Far west Terai	0.44	264
Central hills	0.46	276
Hills	0.52	390
Terai	0.54	324
Nationwide	0.57	342
Nationwide	0.67-0.75	400-450
Nationwide	0.71	442
Nationwide	0.75	450
Central hills	0.75	450
Far west Terai	0.85-0.95	638-713
Central Terai	0.87	521
Far west hills	0.88	527
Far west hills	0.89	535
Far west Terai	0.90-1.80	540-1080
Nationwide	0.91	546
Eastern hills	0.91	547
Central hills	0.91-6.06	545-3636
Western hills	0.93-1.05	656-740
Western hills	0.94	563
Nationwide	1.00	600
Nationwide	1.00	600
Nationwide	1.00	650
Central hills	1.00	600
Central hills	1.08	540
Central hills	1.08	540
Far west Terai	1.09-1.49	818-1118
Far west	1.18	708
Central hills	1.23	738
Eastern hills	1.25	780
Western hills	1.33	687
Central hills	1.35	810
Eastern hills	1.40	840
Central hills	1.53	979
Western hills	1.55	928
Far west Terai	1.79-2.42	1074-1452
Far west hills	2.00	1200
Eastern hills	2.08	1300
Western Terai	2.57	1542
Nationwide	3.33-6.67	2000-4000

[1] East, central, west, and far west areas correspond to government designated development regions as of 1979.

[2] The author assumed an average household size of 5.5 persons and the weight of 1 cubic metre of firewood to be approximately 600 kg, although this varied from 500 to 750 kg according to individual authors' estimates.

from the Himalaya, or at least serve to indicate the need for a very strong scepticism. This constitutes the essence of my challenge to conventional wisdom.

This seemingly blunt statement applies as much to precipitation data from a single rain gauge (Byers, unpub., 1987c), to hydrograph charts (Vuichard and Zimmermann, 1987), to stream sediment yield (Ramsay, 1986), as it does to infant mortality rates, life expectancy calculations, and G.N.P. per capita (Pitt, 1986). It is an indictment of the methods that have been used as well as the observers who have used them, and especially of the way in which many investigations are conducted in isolation. It could be argued that a new start is needed, or else a new method of policy formulation.

Two independent studies (Bajracharya, 1983; Mahat *et al.*, 1986a, 1986b, 1987a, 1987b) focus on the actual pressures that are, or are perceived to be, inducing loss of forest cover in the Nepalese Middle Mountains. They serve to reduce appreciably the circle of uncertainty by providing a fuller understanding of both the present-day processes and their historical perspective. Bajracharya demonstrates that in Pangma Panchayat in eastern Nepal, demand for fuelwood is not the driving force for deforestation. He shows that loss of forest cover is resulting from the rapidly growing population's need to replace forests with agricultural terraces to produce more of the subsistent food crops necessary for their very survival. This has important implications for those who would treat the deforestation problem by introducing efficient wood-burning stoves, solar heaters, and biogas systems.

Mahat *et al.* (1986 a, 1986 b, 1987 a, 1987 b) have made a major contribution with their assessment of the subsistence farming systems in Sindhu Palchok and Kabhre Palanchok districts and the provision of a historical overview of deforestation. This leads to a substantially different set of conclusions. They demonstrate that for their field areas, adjacent to the Kathmandu Valley, serious deforestation was already well under way more than 200 years ago, that it peaked between about 1890 and 1930, and that the recent trend has been abandonment of marginal agricultural terraces and their *natural* reforestation wherever grazing pressures have permitted.

In Sindhu Palchok and Kabhre Palanchok, traditional Nepalese patterns of land ownership and taxation, with government encouragement of deforestation, have been the major driving forces behind widespread landscape modification. Mahat *et al.* demonstrate that the area of forested land has not diminished significantly since 1950, although the *quality* of the remaining forests has; hence their viability as an essential component of successful subsistence agriculture is at risk. Again, the spectre of uncontrolled population growth is raised, and it is argued that the greatest single threat to the remaining forests derives from demands for fodder and bedding for domestic livestock resulting from this population growth. They do argue, nevertheless, that continued acceleration of forest product use for fodder and fuelwood will rapidly destroy the remaining forests, at least to the point of collapse of the local subsistence economy. They also demonstrate, however, that this crisis situation can be turned around as local collective community effort is initiated. This then becomes one of the "virtuous circles" that Thompson *et al.* (1986) insist do exist throughout the Himalayan region.

While the findings of Bajracharya and the Mahat *et al.* are mutually supportive in some respects, there are also some apparent contradictions. These are most likely due to the relative isolation and distance from Kathmandu of Pangma Panchayat compared with Sindhu Palchok and Kabhre Palanchok. The latter two districts are also astride a major traditional trade route between Kathmandu and Tibet. It would be interesting to determine how far eastward the Mahat *et al.* findings can be extrapolated and how far both eastward and westward the Pangma Panchayat conditions prevail. This raises another concern: that of the degree of representativeness of even those studies that have been carried out with a reasonable approach to scientific rigour.

In an entirely different setting, Byers (1987 b) has demonstrated that the widespread claims of extensive deforestation and consequent soil erosion in Khumbu Himal are gross exaggerations and even misstatements (cf. also Byers, 1987a; Houston, 1987). Messerli and Ives (1986) and Ives (1985) have commented on the complex pattern of deforestation (and reforestation) in the Hengduan Mountains of western Sichuan and northwestern Yunnan. Many extensive areas from which forest and soil cover have been stripped down to the bedrock appear to have been degraded hundreds, if not more than a thousand, years ago. And of equal significance, some areas have a more complete forest cover today than in the 1920s and 1930s, while still other areas are suffering from current over-cutting.

Continuing with this single theme of deforestation in the context of the viability of the major component of the Theory of Himalayan Environmental Degradation, Tucker (1987) and Richards (1987) indicate a prolonged period of deforestation in the Central Indian Himalaya. This supports the many recent publications emanating from Kumaun University, Nainital, U.P. (e.g., Joshi, 1986; Valdiya, 1985). Nevertheless, Moench and Bandyopadhyay (1986), in a most effective study of relatively remote villages in the Garhwal Himalaya north of Mussooree, describe the "nibble effect" whereby forest area is being reduced, not because consumption of forest products exceeds local biomass productivity, but because the forest perimeters nearest the villages are receiving the brunt of fodder and fuelwood collection. Karan (1987), in contrast, demonstrates recent and alarming acceleration in the rates of forest clearing in Sikkim. Allan (1987), in an entirely different context, describes the current impacts of 3,500,000 Afghan refugees on the forests of northern Pakistan.

In her description of a very different environment, Chatterji (1987), has drawn an effective illustration of Ladakh as an example of a high-altitude arid and semi-arid section of the Himalaya. Here traditional society has evolved with fuelwood scarcity because of climatic constraints, only in turn to feel the pressures of recent population growth. Thus the need has arisen for viable livelihood alternatives.

From the foregoing discussion it is concluded that one of the major linkages of the Theory of Himalayan Environmental Degradation — post-1950 deforestation resulting from rapid population growth and its accompanying demands for fuelwood — is indeed a latter-day myth. This conclusion carries the corollary that the lists of figures that have been offered as "data" are more harmful than helpful in that they serve only to extend the area of uncertainty.

It remains clear, nevertheless, that the *condition* and *extent* of present-day forest cover *is* a critical factor. To maintain a viable subsistence agriculture, some major changes in development policy formulation and foreign aid must be introduced in the near future, and changes in forest management are surely needed. However, unless such changes are made as a conscious adaptation to the extreme variability, which is the main characteristic of the Himalayan region, and unless the infusion of local, indigenous initiatives is facilitated, success will not come easily. This leads to recognition of the need for plural problem definitions and plural solution definitions.

Is Deforestation Necessarily Bad? Hamilton (1987) approaches the forest cover component of the Theory of Himalayan Environmental Degradation from the point of view of its assumed roles as protector of steep slopes from rain-drop impact, rillwash and gullying, overland flow and soil erosion, and downstream flooding. He advocates the elimination from the literature of the totally emotional term "deforestation" unless its use is strictly qualified. Of particular importance are the modes of tree felling and evacuation and the use to which the cleared land is subsequently subjected. He maintains that if hand cutting and carrying is the primary mode of clearance, and if the forested slopes are replaced with well-maintained agricultural terraces (a widespread pattern in the Himalaya) then soil losses may even be less than those prevailing under a forest cover.

This line of reasoning is supported by Gilmour *et al.* (1987). They demonstrate that estimated peak rainfall intensities, when balanced against soil infiltration capacities, lead to the conclusion that reforestation will not likely have significant beneficial impact on soil loss and local flooding, and certainly not on the hydrological character of the Ganges and Brahmaputra mainstreams. A cautionary note is required here, however: Gilmour *et al.'s* work is preliminary, site-specific, one of a kind; it depends, in part, on rainfall intensities extrapolated from Kathmandu. This work does emphasize, however, as do many of the individual studies introduced in the Mohonk Mountain Conference proceedings, and in *Mountain Research and Development* in general, that the new generation of Himalayan research is beginning to attain standards of method and rigour of analysis that will withstand critical evaluation. Their results do demonstrate, once again, that it is unwise to depend upon popular notions, such that deforestation is inherently *bad* and that it inevitably leads to large-scale damage for even a thousand kilometres downstream. Hamilton argues (1987) that the reason for serious flooding on the Ganges Plain is heavy precipitation reaching the ground in a short period of time and need not be related to events taking place in the mountains.

The Mountain - Lowland Linkage? The major linkage — misuse of land and forests in the mountains (whatever its cause and timing) leading to serious disruptions on the plains — is such a large issue that it can only be introduced here briefly. This assumption is being heavily challenged on many fronts (Ives and Messerli, 1983, 1989; Carson, 1985; Ramsay, 1986; Lauterberg and Messerli, unpublished 1987). According to the best available estimates, the continuing tectonic uplift of the Himalayan ranges may equal or exceed rates of regional denudation, which includes soil erosion and sediment transfer. The flood plains of the Brahmaputra, Ganges, and Indus are underlain in places by at least 5,000 metres of sediments derived from the Himalaya over the last several million years. These dramatic geophysical processes, responsible for the very existence of the Himalaya and the plains, are sufficiently impressive that there should be no need to blame the ignorant mountain farmer for the problems facing the lowland land manager *unless there are very reliable data upon which to fix his guilt*, and *these do not exist.* The point sources of sediments, whether the Tibetan Plateau, the High Himalaya, Middle Mountains, or Lesser Himalaya, are not known (Ives and Messerli, 1983). Many, even most, of the undesirable effects of flooding and sedimentation on the plains may result from natural processes aided by human interventions *on the flood plain itself.*

In developing this line of reasoning there is no intention to contest the claims that badly engineered roads in the mountains have rapidly accelerated landsliding, or that large increases in sediment transfer cannot be demonstrated as resulting from land-use changes in small watersheds (Tejwani, 1987; Dhruva Narayana, 1987). The question is one of scale and historical perspective. Thus, on the Himalayan scale, and in the context of the last several hundred to more than a million years, it is contended that human influences, so far, are insignificant. It could be countered that this is an intellectual irrelevancy if the livelihood of a group of villages in Sindhu Palchok district is endangered in the next decade or so due to continued pressure on existing forests. It is nevertheless maintained that this is yet another confusion of scales and relates directly to the responses that have been adopted by the development and aid agencies.

The Human Component: So far the discussion has been confined to the physical elements of the landscape, whether their modification is caused by long-term geophysical processes or by very recent human interventions. Pitt's (1986) treatment of poverty, women, and young people in the Himalaya, introduces a parallel set of challenges to standard assessments of socio-economic conditions, such that serious doubt is also cast on both the relevancy and reliability of much of the associated data sets. The derivation of GNP per capita in subsistence economies, the relevance of female literacy rates in oral societies, the reliability of life-expectancy-at-birth estimates, must all be questioned. Similarly, the tendency for aggregation of data often renders them meaningless. The fact remains, however, that the population of the entire region (with certain site-specific exceptions, such as Khumhu Himal) is growing and this is leading to increased pressure on diminishing resources.

It is necessary to raise the question: Is population growth the cause of increased poverty or its result? Certainly the old adage that increased wealth will cause population growth to level off (based upon the model of the industrialization of western countries) is generally regarded as a myth, or serious misunderstanding. A number of recent village-level studies in the Himalaya (Fischer, 1986; Fricke, 1986) demonstrate, at the village level, that all new-born children are wanted. This, in part, is a reflection that children are capital in a predominantly non-monetary society, and that a large family increases the chances of survival. Certainly, the role of women is central to many Himalayan development issues and this has been neglected for too long. It appears that land tenure and taxation play a critical role in the poverty issue, just as they have in the related deforestation issues. Unequal access to resources, therefore, becomes a focal point.

Conclusions on Himalayan Uncertainty

At this point the reader might well ask the question: Is there a problem? The attempts here to destroy the "sacred cows" of the Theory of Himalayan Environmental Degradation could conceivably lead to this question being answered in the negative. This would contradict the unanimous conclusion of the Mohonk Mountain Conference participants and the very purpose of the Conference would be overturned. Examination of the arguments of Hrabovszky and Miyan (1987), which illuminate the rapidly narrowing gap between subsistence crop yields and available land, on the one hand, and the growing number of mouths to feed, on the other, should serve to guard against this. Similarly, the thought-provoking discussion by Griffin (1987a) on project implementation failure caused by institutional problems further emphasizes the difficulties that lie in the path of workable solutions.

The general conclusion reached is that a crisis of very large dimensions is developing and that it may be advisable, for political and diplomatic reasons, to regard it as a potential supercrisis. It is postulated that the very real magnitude of the problem has been disguised by its over-simplification and exacerbated by the generalized and bureaucratic approach to its solution. Thus, the uncertainty is indeed part of the problem, and it was the intent of the Mohonk Mountain Conference to expose this. Of equal importance is the demonstration that "virtuous circles" do exist; that, given a community-level approach to resource management and sensitized "outside" cooperation, a village, or district, can move from a downward spiral to an upward mode. This conviction lays the foundation for the claim that there is a very urgent need for a much fuller understanding of Himalayan-Ganges dynamics and for a radical change in "development" policy.

Other Examples of Mountain Misdirection

Three examples of mountain misdirection are added here, from the very large number of available case studies, to illustrate the ubiquity of the problem facing mountain environments. Two deal with regional development issues, in Kenya and Ecuador; the third, while building on actual events in the Himalaya, relates to hydroelectric power projects in general.

Mount Kenya Piedmont Zone Development (from Ives and Messerli, 1984)

The semi-arid savanna northwest of Mount Kenya was used for extensive cattle breeding until the late 1970s. Only a relatively small section close to the lower slopes of the mountain was sufficiently humid that more intensive agriculture could be practiced with any degree of success. This indicates that, over a distance of a few kilometres, the ecological conditions change very rapidly from the humid lower timberline of the mountain forest belt to the dry savanna on the plain between Mount Kenya and Mount Aberdare. Within the lower forest belt of Mount Kenya at 3,000 m the annual precipitation is 1,500 mm; at 2,000 m on the northwest side within a distance of 20 km, the annual precipitation is 800 mm; within another 20 km toward the northwest, also at 2,000 m, it is 600 mm, or less.

This dry land was seen as a vital resource for a rapidly growing landless population. During the period from 1976 to 1982 the area was subjected to an intensive land development scheme of purchase, subdivision, and sale. The process of land distribution — or more accurately, the private land development business — and the accompanying financial, social, and political ramifications, were ill-conceived and unfairly implemented. A large number of landless families could afford to buy only very small plots of land (0.5 to 2.0 ha compared with 1,500 to 10,000 ha, the size of the original European farms and ranches). Furthermore, the land was surveyed and subdivided geometrically, regardless of soil quality, availability of water, topography, vegetation type, and road access. The new land owner obtained his farm plot by chance, some in good locations, some in bad. The majority quickly found that they had insufficient land to provide for their subsistence.

How much land is needed for survival? This question was never raised during the planning and implementation stages of the project. The land was subdivided and sold without any idea about soils, precipitation reliability, water availability for drinking and irrigation. There was no thought given to the local market situations, the need for road construction, and the provision of education and health facilities.

Certainly the minimum farm size for subsistence in humid areas will be much less than that required in arid and semi-arid areas. The decision makers at the various levels did not take into consideration the elementary minimum data needs required for rational decision making. In addition, the immigrant farmers came into an often new and marginal area without any experience of the conditions of climate and soil to which they would have to adapt. In this situation *marginality* implies *potential instability*, and lack of experience implies a high risk for sustainable development. This raises the next question: What happens in the future when it becomes apparent that a large number of small land owners cannot survive, even at the level of modest subsistence agriculture?

In this example it can be seen that the bottleneck, or obstacle to successful development, is the lack of data, both economic and ecological, for decision making, and the absence of socio-political responsibility. However, it must be emphasized that a minimum amount of data was essential. What is the purpose of decision making and its implementation if the outcome is failure, and is dangerous from both socio-political and ecological points of view?

Mount Kenya and the surrounding area is an excellent example of a highland-lowland interactive system. Mistakes made in one part of this system can have serious consequences for all the other parts. The scientific community is responsible for collection of basic data and for evaluation of the potential for, and limits of, resource utilization, as well as for informing the decision makers about the potential impacts of development alternatives.

The Ecuadorian Andes (from Ives and Messerli, 1984)

The growth of Quito, at 2,800 m above sea level, has led to a shortage of water and to a serious lowering of the water-table. Population continues to grow, and, as a response to the increasingly pressing problem, a large water diversion scheme is being funded by an international development agency. This project will tap the headstreams of rivers to the north of the city and divert them southward, at considerable expense and not a little environmental disruption.

The main aquifer supplying Quito is believed to be recharged largely from rain and snow melt in the neighbouring highlands which support paramos and sub-paramos vegetation. One of the most important areas is the Cotopaxi highland.

Extensive areas of the Cotopaxi highland (Cotopaxi National Park) are being converted to pine plantations (*P. radiata*) at the expense of the natural sub-paramos vegetation. It has been hypothesized that the pine plantations, because of greatly increased evapotranspiration, may be causing a serious lowering of the water-table.

It could be argued that the two development projects (pine plantation and water diversion) are in conflict because the decision makers never asked the fundamental questions nor acquired the appropriate data upon which to base rational decisions. It is conceivable that elimination of pine plantations from Cotopaxi would not only reduce, or even overturn, the need for an expensive water-diversion project, but would result in a much more aesthetically attractive and ecologically appropriate national park. And the much-needed timber could be obtained from further destruction of the tropical rain forest, or from pine plantation establishment in more appropriate localities.

The foregoing discussion is hypothetical and deliberately argumentative. Clearly, a full cost-benefit analysis is required. Minimum data needed to undertake such an analysis include precipitation data, evapotranspiration data for pine plantations and sub-paramos vegetation, and determination of rates of ground-water recharge and sub-surface flow. Should the more conservation-oriented approach prove practical, then an unnecessary environmental disturbance and the wastage of funds would be averted. Should the actual, current development schemes prove the only feasible alternative, then at least the growing numbers of skeptics who are complaining about irresponsible squandering of public money may recognize the need for rational decision making and international development aid.

Mountain Water Resources Development and Mountain Hazards

Part of the response to check the perceived environmental destruction in the Khumbu Himalaya of Nepal was the establishment of the Sagarmatha National Park. Another component, with Austrian government aid, was to reduce the Sherpa's dependency on the forests for heating and cooking by the installation of a hydroelectricity facility on the Bhote Kosi, near Namche Bazar. On 4 August 1985 a glacial lake in front of the Langmoche Glacier, 12 km above the nearly completed power plant, drained suddenly.

This sent a 10-15 m high surge of water and debris down the Bhote Kosi and Dudh Kosi rivers for more than 90 km. An estimated 1,000,000 m^3 of water was released, creating an initial peak discharge of about 2,000 m^3/sec. This spectacular natural event destroyed completely the power plant, eliminated all the bridges, including new high suspension bridges, for 42 km downstream between Thamo and Jubing. Four or five people lost their lives, more than 30 houses were destroyed, as well as much cultivable land, livestock, and forest, together with long stretches of the Lukla-Namche Bazar main trail. If the flood had occurred two months later, during the trekking season (this is the route to the Mount Everest base camp), the death toll could have been as high as 100 to 200 persons (Ives, 1986; Vuichard and Zimmerman, 1987).

Such events are termed jökulhlaup (= glacier leap or burst, in Icelandic) since they were first recognized and studied in Iceland. They are not unusual in the Himalaya. In 1981 a much larger jökulhlaup devastated the China-Nepal road with much loss of life and property on both sides of the frontier. A similar event, actually triggered by a landslide in July 1987, destroyed two villages, severely damaged the Lama Sangu power plant, and eroded 9 km of the China-Nepal highway, isolating the new Swiss constructed Jiri Road. In 1977 a potentially lethal jökulhlaup originated from a glacier on the slopes of Ama Dablam, also in the Khumbu, and destroyed bridges for 35 km downstream.

With the accelerating development of small hydel projects, engineering works, and trekking tourism in the Himalaya, the potential for major disaster during the next decade is very high. Of equally serious concern is that jökulhlaup cause massive changes to the river channels along which they flow. They induce landslides and slumps, and undercut sections of river terraces, thus dumping vast amounts of debris into the river beds, forming a source of high sediment yield for years, if not decades, following the initial catastrophe. This also can lead to excessive silting of reservoirs and the possibility of damage to large-scale hydroelectric and irrigation facilities far downstream and at lower altitudes.

What is of particular concern in this context is that such potential for catastrophic destruction (paralleled also by the sudden drainage of ephemeral lakes dammed by landslides) has not so far been taken into account by the planners who are intent on developing mountain water resources. Development of mountain hydroelectric potential is a top priority in Nepal's current five-year plan. India, Pakistan, and Bhutan also look to further large-scale hydroelectric development. As a particular instance, the Arun

Cascade Project can be cited, recently approved by the World Bank and the Government of Nepal at an estimated cost of $ 1.7 billion. The upper headwaters of the Arun lie in Tibet and harbour at least 50 moraine-dammed and ice-dammed lakes that I have observed on the Skylab metric camera imagery. In the Khumbu Himal I have also observed a new lake about 1.5-2 km^2, that has formed on the Imja Glacier located just south of Lhotse. The United Nations University mountain project will undertake a field reconnaissance of this lake in November 1987. From existing sparse data, however, it can be proposed that an outbreak of this lake at the height of the trekking season could conceivably take several hundred lives.

The destruction of the Namche small hydel project in 1985 could be attributed to serious lack of professionalism on the part of the consulting engineers. Despite a modest effort to alert responsible agencies to this general menance, no official responses have so far been elicited. Even access to new high quality air photographs, to facilitate a more detailed study of the glacier lakes of the Khumbu Himal, has been denied with the excuse of national security considerations. This is only one aspect of the dangers of large-scale engineering solutions to mountain problems, but it implies ignorance, lack of concern, or worse, on the part of both national governments and foreign aid agencies. It is also another measure of the lack of an effective mountain development and evironmental constituency. This is needed to provide a scientific base for working in partnership with development agencies; to bring such issues firmly and intelligently before the public eye; and to ensure a major improvement in the planning process.

Conclusions and Recommendations

The problem of mountain ecosystem stability and instability has been shown to be extremely complex (Messerli and Ives, 1984). Even more complex is the development of a full understanding of the man-mountain interrelationships and the infusion of available knowledge into the formulation of policy for the more effective management of mountain resources. We seem to be a long way from achieving general recognition of the thesis that mountain people, rather than being part of the problem, are part of the solution (Thompson *et al.*, 1986). In particular, there does not yet exist an established body of mountain scientific theory. Coupled with these problems is the tendency of development agencies and national governments to apply massive technological "fixes" to the solution of perceived problems without first making a thorough study of the wide range of possible consequences that such "fixes" may bring about, nor to determine the aspirations of the indigenous mountain people (often referred to as the "target" groups) and what resources they themselves have to bring to bear on the formulation and implementation of development policy. Griffin (1987a) furthermore, has highlighted the delicate issue of implementation failure caused by institutional problems. Evolution of institutions should be at the centre of development policy, yet it is usually overlooked.

These general statements can be applied to many of the problems facing the utilization and/or preservation of the global environment at large. They are especially germane to the mountain situation, however, because of the complexity and uncertainty that characterizes the mountain lands. While a great deal of progress has been made in furthering our understanding of the structure and functioning of mountain ecosystems since the initiation of Project 6 of the Man and Biosphere (MAB) Programme (cf. Himamowa, 1974; Chapman and Sabhasri, 1983; Lall and Moddie, 1981; Brugger *et al.*, 1984; Bandyopadhyay *et al.*, 1985; Moser and Moser, 1986; Price, 1987; Ives and Ives, 1987; Ives and Messerli, 1989) the need for greater and faster progress is so critical that a more effective approach is required. Some general recommendations, therefore, are in order:

1. dissemination of information about mountain conditions in a manner that can be easily assimilated by potential user groups:

   a) the general public;
   b) the local mountain people, who must also be involved in the dissemination process;
   c) practitioners and decision makers;
   d) mountain scholars.

2. widespread establishment of policies that ensure the orderly examination of the full range of potential effects of development projects on long-term as well as short-term scales;

3. rigorous testing of assumptions on which policy decisions are based;

4. advocacy of a dual philosophy of basic and applied research leading to what Griffin (1987b) has termed "participatory action research":

a) to provide rapid input on the basis of available expertise and knowledge so that better decisions can be made immediately;
b) establishment of long-term monitoring and data collection with a network of field stations, in order to test currently popular hypotheses and ensure adjustments whenever necessary.

All of this leads to the conclusion that an entirely new approach to both mountain research and preservation of mountain environments is required, which in turn must lead to a reassessment of the existing development and aid policy with its current unacceptable level of failure. Thus aid, development, and conservation over much of the mountain lands must start with recognition of the need for institution building which reflects the societies of which the institutions are a part. I therefore urge the establishment of a network of mountain research institutions with an organizational framework at the global level that can provide the driving force for a radical departure from the current fragmentary and inadequately informed pattern. Examination of the feasibility of such a global mountain network, its possible structure and *modus operandi* will be the objective of a study group under the auspices of the United Nations University during 1988. The purpose of my announcing this here is to begin the process of soliciting the widest possible support and participation for the feasibility study process.

Finally, it only remains for me to admit that, while I have contributed little to the development of a modern approach to the protection of the global environment, I hope I have clarified a number of issues and outlined a strategy which should eventually lead to such a contribution.

ACKNOWLEDGEMENTS

This paper is a composite statement drawn from three major sources (Ives and Messerli, 1983; Ives, 1987 and 1988). It also owes much to the many formal and informal discussions organized by the United Nations University and the International Mountain Society. A much fuller analysis of the Himalaya-Ganges Problem will be published in book form by Routledge and United Nations University, London, in 1989 (Ives and Messerli, 1989).

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DISCUSSION

Marini-Bettòlo

We have now with us Dr. Mustafa Tolba, Director General of the United Nations Environmental Programme (UNEP), who has come for a few hours, having found time between his many important appointments. We are very honoured by and grateful for his presence here. His presence underlines the importance of this meeting, which should give to the Holy See an assessment of the programme for the protection of the environment. I will now open the discussion of tbe paper presented by Dr. Ives.

Tandberg

I wish to congratulate Dr. Ives on his brave plea for the mountain ecosystem, and I'd especially like to dwell a little on the so-called ignorant farmers in the Himalayas. Without romanticism, I'd like to ask you to remember that the ethnic minority groups in the Fourth World live in the fringe areas in balance with nature, exploited in turn by the ruling majorities forcing them into another society and way of life. As a minority scholar, I wish to state that these fringe minorities of the Fourth World, in the high altitudes, or in desert zones, or in marginal lands, generally have a natural approach to the protection of the environment which is modern.

Raven

First, I would like to re-emphasize the central importance of training for individuals and the development of institutions in tropical countries. Many of our individual submissions support such a conclusion. The integrity of the indigenous systems that Professor Ives has stressed for the Himalayas needs to be respected, even in the face of global pressures that are destroying it so rapidly. As these systems change, we must apply the best available modern knowledge for the benefit of rural people everywhere.

Secondly, small-scale projects, in the aggregate, may often be more sensitive to the needs of the people than any large-scale interventions that may be devised. Major projects, which have regional effects, must be designed and implemented with special care. Widespread poverty and hunger in tropical nations must be addressed as a matter of first priority, and long-term solutions must be found. Despite the difficulties of comparing different kinds of economies, we must not lose sight of the fact that a great number of people in the world are living in abject misery. Nearly a third of the 55 million people who die annually throughout the world, for example, are children four years old or less; they starve to death or succumb to disease often related to starvation. The great majority of these deaths occur in the tropics. Deforestation is rampant throughout the globe, even though there may be local exceptions, and is leading to major destabilization in many areas. Many species of plants and animals, some of which have properties that might prove useful for human beings, are disappearing as a result of such deforestation. Only a major, coordinated worldwide effort could conceivably reverse this process.

One may hope for stability in Nepal and elsewhere, but the evidence available to me suggests that we are nowhere near attaining it at present.

TOLBA

I thank you very much for the welcome. It's a pleasure for me to be in a scientific community and be still considered one of you. It is an honour that I always cherish.

I would join in what has been said about Professor Ives presentation. I would also say, Mr. Chairman, that the previous speaker did cover a good deal of the points which I intended to cover myself, but what puzzled me a bit, probably because of my being in the environment field, is the whole idea of rejecting the attractive theory of Himalayan environmental degradation. This is the view of Professor Ives: we don't have environmental degradation in the Himalaya. If we are talking of soil degradation and of a colossal amount of poverty and lack of good production, and all that, what are the relations between these and the natural resource base when it is failing to give enough productivity? What are the causes of that?

I would fully subscribe to the point of the gross national product per capita. There is no way that we can make a comparison between north and south, or the developed and the developing, if we don't have any sort of measure, even if ridiculous. I do agree with you exactly on what is a gross national product per capita, but I am curious, Professor Ives, to know what it means in the United States or in England? Does it mean that 20% of the people are getting ten times as much or that other people are below the poverty belt? It is a misnomer that is mistreating everybody, whether in the north or in the south. It is the concrete level of where you say that whatever is available to some people is ten times, or fifteen times, or twenty times less available to others.

I couldn't get the meaning of not considering women's literacy in an agricultural society or in a rural society I don't know what you mean by that. Were you advocating that we leave these people illiterate, to be peasants who don't understand anything or who cannot read or write?

I think the issue of aid has been overstressed everywhere, whether it is multilateral or bilateral aid. I don't know if anyone can go as far as saying that bilateral aid is made to give work to engineering companies of donor countries. Let us be very frank: donor agencies are quite reluctant because of corruption, because of the fact that a good deal of the money is not soundly administered. Well, these are facts of life, and I don't think that we can look at them from the purely scientific point of view. Either we are prepared to make a point and make it complete or we don't make half the story known and stop there. At the rural level, small-scale projects are useful. But we cannot generalise this. We certainly cannot say that everything small is beautiful. That's a theory which I think has been passing for some time. It's very time-consuming and extremely difficult to control a large number of small projects, unless you have the people, mostly from the developed countries, and the involvement of non-governmental organizations. In our countries NGO's are mostly suppressed. They have to function completely under the supervision of governments. Consequently, a government must have an administration which is top-heavy in order to supervise a good deal of small projects. It's not economical.

Two final notes, Mr. Chairman. First, is the public really voting money for aid? I wish to be educated on where the public is voting aid, because I am one of those who are raising funds. My organization is voluntary, and if the public is raising funds, I would very much like to know where. On voting funds, I know that parliaments vote at the request of governments, and ultimately, somewhere in the voting process, a senator or a congressman or a parliamentarian promised his or her constituents that he or she would support this or that. But when it comes to scientific research in parliament, I don't think it is taken up as a voting issue.

Second, the network of mountain research in these situations is very much welcome. But I would ask whether that is the wish and felt need of the local people that you are speaking of, Professor Ives?

IVES

Well, I certainly set myself up for some hard questions. I thank especially Dr. Tolba and Professor Raven for raising many of them. In a sense I must admit to being guilty of trying to pull the pendulum back too far in the other direction. However, I am anxious to encourage skepticism, to challenge the seemingly facile acceptance of a number of sweeping generalizations, and to attempt to provide a factual basis for this skepticism. Dr. Tolba asked why I am so intent on trying to overthrow the Theory of Himalayan Environmental Degradation. I agree with him that we need an effective device for drawing attention to serious problems; I concede that point entirely. Nevertheless, from personal experiences in such countries as northern Thailand, Nepal, parts of China and India, and with the popular responses to many of the issues from within the industrialized countries, I am very concerned over the manner in which vast generalizations are accepted uncritically. I am even more concerned that this seems to lead to the development of certain perceived solutions, sometimes before adequate effort has been made to ascertain the causes. A good example is the assumption that shortage of fuelwood is driving deforestation in the Himalaya. This is simplistic and, in many areas, actually false. Yet this assumption, the perceived cause of many of the problems, appears to control much policy making. On a much larger scale, I think it is extremely dangerous for policy makers to convince themselves that reforestation in the mountains will solve the problems of flooding and siltation in the Ganges Plain. The mountains subsistence farmer has become a convenient scapegoat for both the people on the plains and for decision makers. I believe that, until the mountain farmer comes to be regarded as a large part of the solution rather than as the main cause of the problem, there will be little hope for successful development. As a colleague of mine so well expressed, there are very many problems, they need to be identified, and a multiple-solution approach applied.

With all due respect, I am tempted to urge that retention of a flawed theory for the sake of its dramatic appeal can become self-defeating if we lose our credibility in the process. What is especially unfortunate is the continued expenditure of vast sums of money on large projects, especially those that entail the development of infrastructures, without the benefit of determined, and properly funded holistic research — and a large part of this should be aimed at understanding the traditional agricultural systems and the manner in which these skillful mountain people perceive their environment.

Thus my talk this morning is a plea that we challenge existing data and conventional wisdom, that we attempt a reassessment of the hypothetical basis that is being advocated, and that we search for a much closer approximation to the truth. This does not imply that we must wait until all the data is in. I think that the development agencies have a right to expect of the scientist a best guess answer by tomorrow morning. But then the scientist, I think, should be able to ask the development agency: "Can you set up the system so that we can make an even better guess, the next month — or year — in such a way that policy adjustments can be made should they appear necessary?"

I should apologize for my unkind remarks about consulting engineers and bilateral and international agencies. I did intend to provoke. However, as Dr. Tolba pointed out, the issue of apparent or real interference in the affairs of Third World countries is an exceedingly delicate one. What is needed, obviously, is a closer partnership, but it may be that the agencies do have a responsibility to be a little more forceful in certain instances.

I am sorry if I have lost one or two of the questions; at least I hope that my reply has covered most of the general topics, if not the specific ones.

PRZEWOZNY

When President Johnson declared war against poverty, a professor of moral theology commented: "That's an unjust war because the poor cannot defend themselves". I think that some of the points made by Prof. Ives fit this observation. To the degree that international aid fails to integrate the abilities and knowledge of local societies to that same degree it can be harmful to the interests of those societies and, therefore, even destructive of the environment.

DI CASTRI

I would like to support some of Dr. Ives' points, but also to warn against the excess of generalization. It is true that some terraces in the hills of Nepal represent a kind of "protective environment", in so far as erosion is not very important there, even when compared with that of some forested areas. However, this protection implies intensive management, and is very demanding in terms of manpower investment. Nevertheless, there are also zones in the Himalayas where terraces have been abandoned, resulting in their total collapse, and strong erosion processes.

I would also like to point out that, on terraces around the city of Kathmandu at a distance of about 50 kilometers, some market agriculture is being introduced, in order to meet the demand from tourists for fruit and vegetables.

Introducing market economy in traditional terraces is a beautiful blend of the new and the old. The real issue in this case is not environmental protection; the most acute bottleneck is the lack of marketing structures, particularly of storage facilities. This represents anyway the beginning of the transformation from a subsistence society to a market society.

Again about generalization, even as regards flooding in the Ganges plain, it is very difficult to differentiate the natural pulses of flooding from the man-imputable floods due to deforestation and erosion.

I feel that you have taken the Kathmandu valley as the symbol of mountain development. Admittedly, this valley is almost a paradise, but it should not be taken as representative of what happens in all mountain environments. For instance in the Andes, there has been an almost complete abandonment of terraces, because of the migration of local populations towards the Amazonia region or to coastal parts such as Lima. This has also implied a kind of loss of the so-called "peasant science", because these populations are facing a completely different environment. Unfortunately, for most of the Andes, it is difficult to envisage an easy transition from the subsistence society towards a cash society, while keeping some of the traditional values. Slopes' disruption and deforestation play here a much more dramatic role than in the Kathmandu valley.

However, I appreciate Dr. Ives' point about a much-needed demystification of man's role in environmental problems. An excess of dramatization, ever and ever repeated, may even decrease the human perception of the seriousness of these problems.

It is also probably true that the resilience of forested areas is greater in tropical mountains than in some of the tropical lowlands. One can see many abandoned terraces that have rapidly recovered in Nepal during the last years. This may partly explain the well-known fact that most of the tropical civilizations emerged in the mountains and not in flat lands, with some exception, such as the Mayas.

On a more general point, I would not like to have us give the impression that we, as scientists, are involved in a kind of attack against decision-makers, giving all responsibilities to decision-makers, and keeping the "beau rôle" for ourselves. I strongly believe that scientific institutions and communities are also guilty for not releasing data in due time so that they could be applied to solve a specific problem.

Finally, while highly appreciating the importance of "peasant sciences", I do not think that these traditional sciences can overcome new situations if they are not backed by appropriate scientific and technological knowledge. The other extreme would be to try to apply modern intensive agriculture without any involvement or awarness of the local populations. The new and the old should be blended. I make again this point to warn against the excess of generalization. Before accusing anybody else, we have to be aware of our own responsibility as scientists.

AGRICULTURE AND ENVIRONMENT

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In this report I will try to illustrate only some aspects of the interaction between agriculture and environment. In this respect I wish to remember that there are people, Monod among them, who hold — and, in my opinion, quite rightly — that the risks of destroying Nature derive from insufficient technology rather than an excess of it.

The technical progress of the last few decades is bringing about a radical change in agriculture, so that several nations are today afflicted by an excess of production. And if in other countries agricultural production is insufficient to meet the needs of a growing population, this is due to shortcomings, produced by various causes — wars among them — in agricultural techniques and means.

Agriculture, too, has therefore felt the impact of a considerable flood of technologies that, unfortunately, often exert a deleterious effect on the environment.

On the other hand, it is not my intention to describe or to quantify once more the damage caused or suffered by agriculture, by animal husbandry and by forestry.

Therefore, this presentation has been organized in two parts. The first part will be dedicated to the perspectives opened by agrobiotechnologies, especially related to fertilizers and pesticides, capable of ensuring both technical progress and environment preservation. The second part will then illustrate the positive role that agriculture can play by managing the soil and the vegetational cover as "filters", that is to say, as a more or less temporary deposit of anthropogenic pollution and, consequently, as fundamental regulation factors of the processes occurring in the environment.

1. Fertilizers

World consumption of fertilizers in 1984-85 amounted to some 70 million tons of nitrates, 30 million tons of phosphates, and 20 million tons of potassium-based fertilizers. Less dependence on fertilizers, without prejudice to soil productivity, can be obtained by appropriate genetic control of the numerous physiological characters connected with a plant production potential (from photosynthesis to ion absorption and to biosynthesis, from transport of the photosynthate to their subsequent storage) and thus constituting cultivars with improved fertilizer-use capability (e.g., plants with extended root system), or by innovative agronomic techniques and thus allowing greater efficiency in fertilizer application and absorption.

We must be aware that few studies have been carried out on the complex genetic control of the processes that regulate the physiology of crop plant production, especially those related to the absorption and utilization of nutrients and the synthesis and accumulation of raw materials of economic value. On the other hand, positive results are now being obtained by means of new agronomic or cultivation techniques of crop species.

1.1. *Innovation in Agronomic Techniques*

Innovation in the sector of cultivation methods is represented by the adoption of minimum tillage soil management, localized manure and fertilizer application, and the combination of the various crop planting practices.

1.1.1. The reduced soil tilling systems, the so-called conservation tillage, allow better control of sediment runoff, and reduce pesticide and fertilizer accumulation in streams and lakes, since the eroded soil particles carried away by the water bring with them also nutritive elements, especially phosphorus and ammonium compounds, and residues of herbicides. Table 1 shows that the non-tilled soil benefited from a reduction of about 50% in surface runoff and, consequently, also in loss of sediments, nitrogen, phosphorus and atrazine.

1.1.2. Local application of fertilizers instead of the traditional spreading over the entire area (Fig. 1) ensures both high crop yields and greater efficiency in their use. Thanks to the fact that fertilization aims specifically at the plant and not at the soil, the overall nitrogen and phosphorus consumption is reduced along with their loss and the risk of surface and underground water pollution (Cavazza, 1983; Miele *et al.*, 1986).

TABLE 1 - *Runoff and percolation loss.*

Runoff and losses (ha^{-1} $year^{-1}$)		Conventional tillage	No-tillage
Runoff	(lite)	89,933	43,875
Sediments	(Kg)	87	38
N - Nitrate	(g)	78	40
P - Total	(g)	34	18
Atrazine	(g)	2.7	1.3

(From: Baldwin *et al.*, 1985; modified).

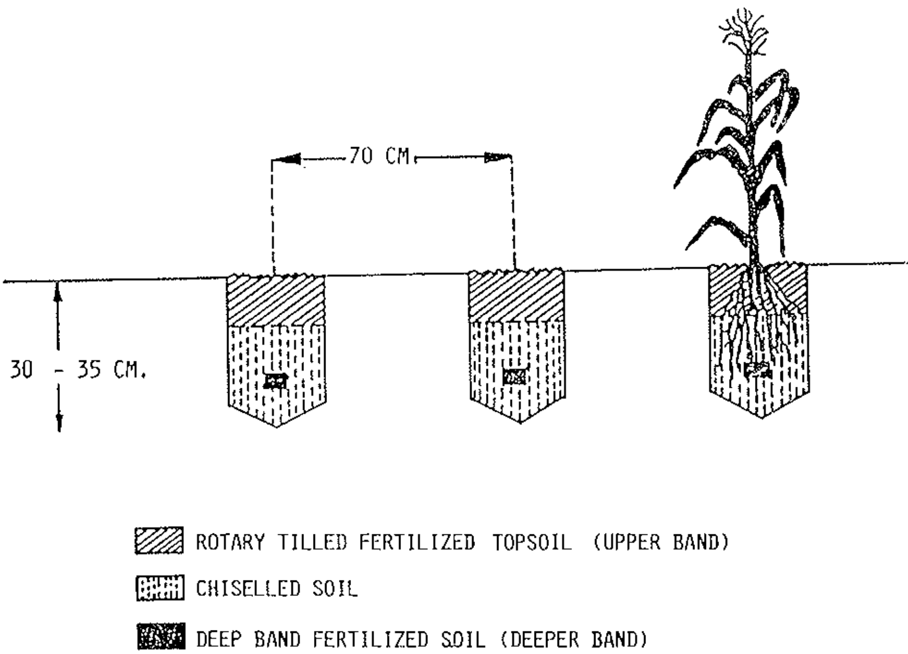

FIG. 1. Maize: "Double band" fertilization (Topsoil and deep bands) (From: Miele, 1987).

1.1.3. Equally of great interest — both from the ecological viewpoint and that of saving cost and energy — would be the use of combined equipment (Fig. 2) suitable for performing all the operations required for tending a given crop in a single passage over the soil: tilling, manuring, sowing, ground disinfestation and weeding.

1.2. *Water Requirements and Other Interventions*

1.2.1. Other interventions, often improvements of "traditional" techniques, are nowadays undergoing reappraisal, as in the case of (1) fertirrigation and leaf-fertilization in critical periods of growth, (2) the use of slow-acting fertilizers capable of releasing the nutritive elements at the time when the plants need them, and (3) the choice of crop rotations that include *Leguminosae* or extend the crop cover period (Giardini, 1987).

1.2.2. Of great importance are also the research activities on the *water requirements* of plants (Lo Cascio *et al.*, 1979; Caliandro *et al.*, 1980; Tarantino *et al.*, 1984), their physiology in conditions of water stress (Venezian *et al.*, 1983; Barbera *et al.*, 1985) as well as groundwater dynamics (Cacchi *et al.*, 1981; Giovanardi *et al.*, 1982), because they allow

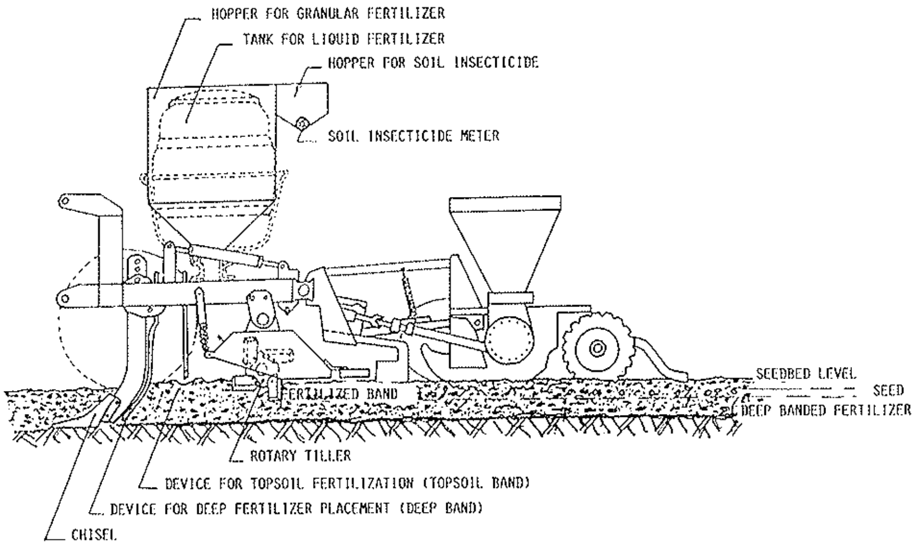

FIG. 2. Combined planter for row crops (From: Miele, 1987).

the optimization of interventions and thus the reduction of the danger of a salt crust forming in arid environments. There is no need to stress that any saving of water resources has considerable impact on the surrounding environment.

1.3. *Mycorrhizae and the Rhizosphere*

1.3.1. As regards the problem of reducing fertilizer consumption, research is now discovering and emphasizing the role that mycorrhizae play in promoting mineral nutrition of crop plants. In fact, it has been found that the endomycorrhizae are capable of enhancing nitrogen and phosphorus absorption (Smith *et al.*, 1986). According to Sieverding (1986), endomycorrhizae inoculation should become an essential practice, especially in South America, in order to balance phosphorus deficiency that limits the productivity of more than a thousand million hectares.

Turning now to the ectomycorrhizae, which are characteristic of forest trees, the growth of secondary rootlets, through a complex auxinic mechanism, is stimulated to a rather incredible extent. These rootlets, equally mycorrhized, ensure an enormous increase of nutrient absorption. Tests carried out using radioactive phosphorus (Bowen, 1973) showed that the absorption of mycorrhizal rootlets is two- to nine-fold greater than that of normal roots. As an example, in the case of *Pinus radiata* this extra growth has been estimated as being of the order of 53% (Rambelli, 1983).

1.3.2. Further information is also becoming available on the presence in the rhizosphere of bacteria, fungi and protozoa that, while drawing benefit from their relationship with the plant, also promote its growth, through the absorption of nutrients, or through the production of antibiotics which may prevent the growth of pathogens, etc.

1.4. *Biological Nitrogen Fixation*

A natural contribution to agricultural production and environmental protection, always in the sense of reducing fertilizer use, is provided by biological nitrogen fixation promoted by prokaryotes (bacteria, cyanobacteria, actinomycetes), which fix atmospheric nitrogen thanks to the action of the enzyme nitrogenase.

1.4.1. The *nodulating symbioses* of certain bacteria (the rhizobia among them) with leguminous plants have been known for a long time.

Symbiotic associations are also known among non-leguminous plants. Mention should here be made of those between the woody species *Alnus* and *Casuarina* with actinomycetes of the genus *Frankia*, or that between the cyanobacteria *Anabaena azollae* and the small freshwater floating fern *Azolla*, a combination extremely useful for enriching rice paddies in nitrogen; and, again, the symbioses between *Azospirillum* ssp. and the cereal crops. Increasing interest, and not only for agriculture in the Third World or in tropical areas in general, is being aroused by some species of leguminous trees and shrubs of the genera *Sesbania*, *Leucaena* and *Acacia*, which form nodulating symbioses on the trunk and the branches.

Other researches are being carried out on agronomical and microbiological processes capable of overcoming the limitations deriving from such factors as soil acidity, aridity, low temperatures, and so on, especially as regards techniques to improve production and the application of inocula, while other work is being done to pinpoint more efficient symbiotic associations (extensive references can be found in Scarascia Mugnozza, 1987).

1.4.2. It is obvious that an extension to non-nodulating plants of the capacity for fixing atmospheric nitrogen, especially cereals above all, would entail a considerable reduction in the use of nitrogen fertilizers, with very positive consequences for both agriculture and the environment. At present, it is known that the genetic system in nodulating microorganism is controlled by the genes *nif* ("nitrogen fixation"), *nod* ("nodulating") and *hup* ("hydrogenase uptake"). Molecular geneticists are currently studying the location, structure, regulation and function of these genes in numerous laboratories, but many aspects have yet to be clarified. Genetic engineering activities through the use of recombinant DNA technique has already made it possible to obtain more efficient *Rhizobium* strains and to transfer *nif* and *nod* genes from nitrogen-fixing bacteria to other prokaryotes and eukaryotes (yeasts) that do not fix nitrogen. Nevertheless, the constitution, among the non-nodulating crop species, of new cultivars capable of fixing nitrogen by the action of the *nif* genes seems not imminent. Not only numerous problems of genetic nature have yet to be solved, but also it seems necessary to obtain a substantial modification of the biochemical and biophysical structure of the plants concerned and, above all, to ensure a greater capacity of photosynthesis, because nitrogen fixation requires a considerable input of energy. An intensification of efforts and a compact international commitment in this research is most urgently needed.

2. Pesticides

The problem of polluting and degrading the environment by the use of pesticides (insecticides, fungicides, herbicides, nematocides, acaricides, etc.) is very substantial. In the following items some new research and technologies, aiming at controlling the impact on man and biosphere, will be illustrated.

2.1. *Plant Breeding for Pest Resistance*

2.1.1. One of the ways of ensuring a reduced use of chemicals consists of improving the parasite resistance of cultivated plants, or at least their tolerance to the pests, through the transfer in their genome of genetic factors that will make them (1) tolerant to the attack of parasites and (2) capable of sustaining a high yielding performance economically worthwhile for the farmer. Genetic improvement of parasite resistance, by limiting the damage due to fungal, bacterial and viral diseases and insect attacks, would enhance the yield stability of a given crop, thus increasing its production near the level of potential yield. Experiments of this type have been performed on numerous plants of agro-economic interest and are being continued, especially in view of the great genetic variability, and, therefore, virulence of the parasites, due also to their much shorter life cycle.

All the methodologies at present available to the geneticist have been employed and extensively exploited, especially selection, crossing and back-crossing, mutagenesis, and the identification in the genetic resources (Scarascia Mugnozza, 1986) — often also of wild species — of new sources of resistance for subsequent transfer into cultivated plants. A start is now being made also with the use of more advanced techniques, including (1) detection and analysis of somaclonal variability in regenerants from *in vitro* culture of cells, protoplasts, and tissues, (2) protoplasts fusion sometimes even of distant species, and (3) transfer and recombination in valuable genomes of alien DNA segments possessing pathogen resistance genes.

2.1.2. Table 2 shows some examples of successful gene transfer from wild to crop species to improve disease and pest resistance. It has proved possible to transfer genes for resistance to many diseases into a great number of crops, such as: wheat, rice, maize, soya, bean, pepper, potato, melon, cotton, sunflower, alfalfa, tobacco, sugar-cane, pear, poplar, tomato (Table 3), etc. Recently, genes for resistance to pest and disease have

TABLE 2 - *Examples of successful gene transfer from wild to crop species to improve disease and pest resistance.*

Crop species	Disease/pest controlled by the transferred gene	Wild species
Oat (*A. sativa*)	powdery mildew	*A. barbata*
Sugar beet (*B. vulgaris*)	*Cercospora*	*B. maritima*
Cotton (*G. hirsutum*)	*Noctuidae*	*G. barbadense*
Common bean (*P. vulgaris*)	virus (BCMV and BYMV)	*P. coccineus*
Wheat (*T. aestivum*)	rusts	*Ae. umbellulata*
Sunflower (*H. annuus*)	several	*H. tuberosus*
Lettuce (*L. sativa*)	root aphid	*L. virosa*
Potato (*S. tuberosum*)	late blight	*S. demissum*
Tobacco (*N. tabacum*)	nematodes	*N. repanda*
Vine (*V. vinifera*)	downy mildew	*V. rotundifolia*

also been introduced into species typical of agriculture in developing countries, as shown by Scarascia Mugnozza (1987).

Fundamental to this possibility of breeding new resistant cultivars through transfer of appropriate genes or gene complexes is the conservation and accumulation of the genetic resources. They are closely linked to agricultural development and are a heritage to be preserved for the generations to come.

2.1.3. Chemical and physical mutagens can be used to induce advantageous mutations or to break up associations between favourable and undesired genes. Detailed information about the use of mutagenesis to obtain improved resistance to parasites can be found in the publications of the International Atomic Energy Agency in Vienna (Micke *et al.*, 1985).

2.1.4. More recent is the use of the methods of cellular and molecular genetic engineering (Scarascia Mugnozza, 1985). Somaclonal variation, which can be detected in plants regenerated from somatic cells after one cycle of *in vitro* culture, is the result of various genetic mechanisms not yet clarified (Larkin and Scowcroft, 1981). This genetic variability has already been confirmed for a wide range of characteristics in plants reproduced by either sexual or vegetative propagation. In this way, sugarcane mutants resisting the Fiji virus, blue mold and helminthosporiosis, potato mutants resistant to several races of *Phytophthora infestans* and *Alternaria solani*, tobacco mutants resistant to virus, and tomato mutants resisting fusariosis have been isolated. Potentially important is also the method of protoplast fusion, i.e., the fusion of cells whose cell-wall has been removed by enzymatic treatment, mainly because in this way it becomes possible to transfer into the protoplasts of commercial varieties advantageous genetic factors from different species and even of different genera, overcoming in this way the incompatibility barriers that often prevent gene transfer through hybridization.

2.1.5. Recombinant DNA methods are used for introducing genes, by means of genetically engineered vectors, into cultivated plants. The

TABLE 3 - *Genes for disease and pest resistance transferred in tomato* (L. esculentum) *from wild species.*

Gene	Pathogen	Donor species
Resistance to fungus diseases		
ad	*Alternaria solani*	*L. pimpinellifolium*
Cf2, Cf3, Cf4	*Cladosporium fulvum*	*L. pimpinellifolium*
Cf6	*Cladosporium fulvum*	*S. pennellii* *L. minutum*
I1, I2	*Fusarium oxysporum, F. lycopersici*	*L. pimpinellifolium*
Ph (race TO)	*Phytophtora infestans*	*L. pimpinellifolium*
pyl	*Pyrenochaeta lycopersici*	*L. glandulosum*
Se	*Septoria lycopersici*	*L. hirsutum*
Sm	*Stemphylium solani*	*L. pimpinellifolium*
Resistance to bacteria and viruses		
oligogenes	*Corynebacterium michiganense*	*L. hirsutum*
Pto, wr1, wr2	*Pseudomonas solanacearum*	*L. pimpinellifolium*
oligogenes	CTV (curly top virus)	*L. peruvianum*
Sw^a, Sw^b, *sw-3, sw-4*	SWV (spotted wilt virus)	*L. pimpinellifolium*
Tm, Tm-2, $Tm\text{-}2^a$	TMV (tobacco mosaic virus)	*L. peruvianum*
oligogenes	TYLCV (yellow leaf curl virus)	*L. pimpinellifolium*
Resistance to insects, acarus, and nematodes		
Hero	*Heterodera rostochiensis*	*L. peruvianum* *L. pimpinellifolium*
Mi	*Meloidogyne incognita*	*L. pimpinellifolium*
oligogenes	*Tetranychus urticae*	*L. hirsutum*
oligogenes	*Trialeurodes vaporariorum*	*L. hirsutum glabratum*

genes to be transferred may be identified and isolated also from taxonomically distant plants or even from microorganisms. Use of these methods should be expanded along with the knowledge of gene structure and regulation in the higher organisms, and more particularly, of genetic control of the characters of interest in both the pathogen and the host plants.

Data obtained from advanced agricultures suggest that the loss of agricultural production due to parasite attack is of the order of 25-35% in the field and 15% during the post-harvesting phases, and this notwithstanding the costly use of pesticides, the high consumption of raw materials and energy, and the use of genetically resistant cultivars. The general situation in this respect suggests four imperatives to be met, namely, reducing the loss rate reported above, increasing food production to satisfy the needs of a growing world population, eliminating the risks of environmental pollution, and diminishing the cost of agricultural production by cutting down on the use of pesticides. The introduction of genetically controlled resistances responds positively to these requirements and therefore represents an operational line that, together with the other methodologies just illustrated, deserves a concentrated and ceaseless effort.

2.2. *Biological Control of Insects by Means of Predators, Parasitoids and Microorganisms*

Several research projects, pilot experiments and applications are already under way. Recent studies show that some 327 species, including 25 species of scale insects, are already being biologically controlled.

2.2.1. Very peculiar and worth being mentioned by virtue of the area involved, the investments in men and means, the economic value of the results, and the international cooperation it has aroused, is the struggle currently being waged in Africa (Fig. 3) against some of the parasites of cassava (*Manihot esculenta*): mealybug (*Phenacoccus manihoti*) and green mites (*Mononychellus* spp.), both unfortunately brought from South America to Africa with cassava itself (Figs. 4-5).

It should be noted that cassava is a basic food for the populations of the tropical areas in Africa and Latin America. For more than 200 million Africans, indeed, cassava consumption accounts for about 50% of their total calorie intake, and the production losses in thirty African countries range from 30 to 80%, the total estimated value being of the order of 2 billion dollars per annuum. The project, which is coordinated by IFAD (International Fund for Agricultural Development) and entrusted

FIG. 3. IFAD project for biological control of cassava pests.
Cassava-growing countries actually or potentially infested.

for implementation to the International Institute for Tropical Agriculture (Ibadan, Nigeria), has been under way since 1985, the three-year budget of more than 9 million dollars being covered by various donors (IFAD, 1987). In short, in order to antagonize these insects, which in America were evidently controlled by their antagonists, a number of their natural enemies have now been brought to Africa from South America, including the small wasp *Epidinocarsis lopezi* (Fig. 6), a scale parasitoid, the coleopter

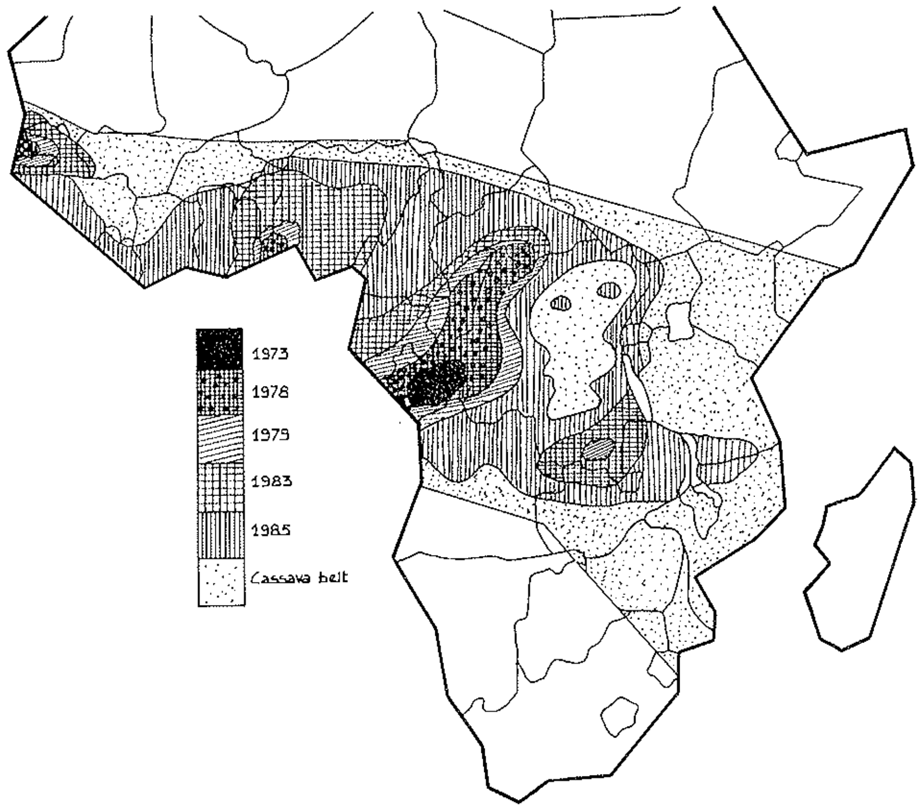

FIG. 4. Spread in Africa of *Phenacoccus manihoti*, between 1973-1985 (From: IFAD).

beetle *Hyperapsis notata*, which preys on scale eggs, and a number of mites (*Ambyseius idaeus*, *Euseius concordis*, and *Galendromus annectens*), all of which are predators of green mites that infest cassava. The wasp *E. lopezi* proved itself to be particularly well adapted to the African environment and, spreading rapidly, has drastically cut back the scale insect populations; techniques have been developed for mass-rearing and for maintaining large permanent colonies of this beneficial insect, and it was distributed in 1986 to some fifteen countries in equatorial Africa, ranging from Senegal to Zambia and Malawi and covering a wide range of different ecological conditions. The effective and demonstrative value of this programme for safeguarding both agriculture and the environment calls for no further comment.

2.2.2. Microbe, fungus and virus parasites of harmful insects are also being studied and used as means of biological control. Although more than forty years elapsed between the discovery (in Germany, 1905) and their first practical application (in France, during the fifties), *bacilli* and their products were the first pest-control microbes to be marketed and employed on a large scale. The microbic pesticide seemingly used most often — being effective against many lepidopters — is the toxin produced by *Bacillus thuringensis* (Deacon, 1983), an aerobic bacterium that produces a protein crystal which is inactive until the alkaline intestinal juices of the insects degrade the crystals with the production of toxic molecules. The latter interact with the plasma membranes of the intestinal cells and block the ion exchanges, thus paralyzing the intestinal muscles and causing the host insect to die within few minutes.

As for *viruses*, scientific literature shows that some 1200 viruses are now known as capable of controlling more than 800 species of insects and mites, mainly, lepidopters, hymenopters and some arachnids, combining considerable virulence with high selectivity.

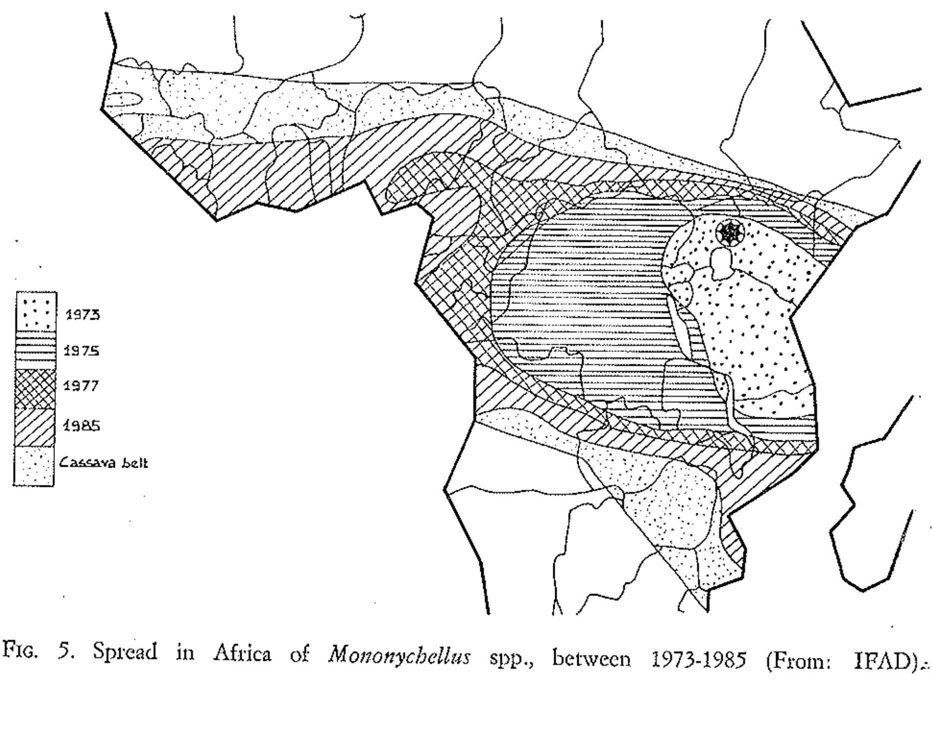

FIG. 5. Spread in Africa of *Mononychellus* spp., between 1973-1985 (From: IFAD).

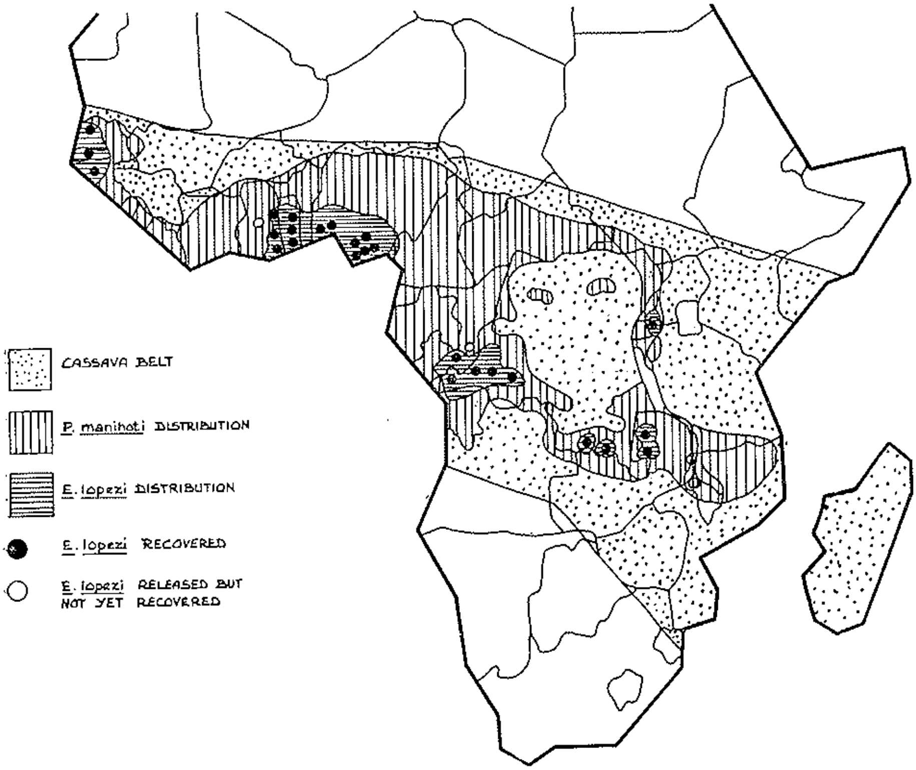

FIG. 6. Release and dispersal area in Africa of *E. lopezi* (From: IFAD).

Bioinsecticides obtained from several *fungus* species are already available on a commercial scale (though more than a thousand had to be tested to this end). Unlike bacteria and viruses, they do not necessarily have to be swallowed to become active, for they can penetrate directly into the cuticola of the host or be breathed in. The host's capacity for providing points of adhesion, germination and mechanical or enzymatic penetration governs action specificity.

Moreover, many protozoa can be used for pest control. The results, however, are not very spectacular because the diseases they cause tend to be chronic rather than acute.

2.2.3. Finally, a number of commercial products have also been obtained from various groups of nematodes that are intermediate or final hosts of insects. Given their interactions with bacteria, the possibility of combined interventions is also being studied. Successful results have already been obtained in controlling *Agrotis* on lettuce and *Zeuzera pirina* in orchards (Deseö *et al.*, 1984).

In conclusion, it seems worthwhile to urge more intensive use of bioinsecticides, recalling that out of the 969 million dollars spent in the USA in 1982 on insecticides, no more than 10 million dollars (i.e., 1%) were used for purchasing microbic insecticides; in Italy, likewise, no more than 3-5% of the 176 billion lire spent on insecticides in 1984 were used in this way.

2.3. *Biochemical Control of Insect Pests*

Another series of substances that can be used to control insects harmful to crop species is produced by the insects themselves.

The growth hormones, the first examples of which were discovered early in the sixties, regulate insect molting and metamorphosis, typical examples being neotenin (juvenile or juvenoid hormone) and ecdysone (moltin hormone). These substances can be used to arrest the growth of insect pests, and they can also induce sterility or egg-killing effects.

2.4. *Interventions on Behaviour*

Considerable progress is now being made in identifying and formulating products capable of modifying insect behaviour: sexual attractants, egg deposition deterrents, and so on. Researchers have paid special attention to the so-called pheromones, highly selective sexual attractants and among the safest chemicals from an ecological and toxicological point of view. With the help of various kinds of traps, the substances can be used to attract, capture and destroy masses of insect pests; alternately, they can be distributed in such substantial quantities as to mask the call of the free females and thus create confusion and disorientation among the males, who will no longer succeed in finding and fertilizing their partners (Birch and Haynes, 1982; Campion, 1984).

2.5. *Genetic Interventions*

Sterility induction can be obtained by radiosterilization of the males, generally by subjecting the pupae to radiation treatments. Such programmes made it possible — albeit with the limitation that every technology imposes, especially when it is highly selective — to achieve already in the sixties effective control of various species of insects. These methods are currently being applied on a large scale in Central America to control *Ceratitis capitata*, the Mediterranean fruit fly, and in Equatorial Africa in the fight against *Glossina morsitans* and *G. palpalis*, the tsetse flies.

Sterility as a means of suppressing a harmful species can also be induced by other means: by the production and spreading of sterile F_1 hybrids, by the use of genetic sterility factors, or — following in the footsteps of the successes of molecular genetics in *Drosophila* — by transferring into the genome of a parasite (using appropriate recombinant DNA techniques) deleterious genes that will prevent it from adapting to the environment.

2.6. *Integrated Insect Control Systems*

Notwithstanding the successes obtained in controlling insect pests by means of their natural enemies, the recourse to synthesized agrochemicals is inevitable, even though, as recently estimated by Pimentel and Levitan (1986), less than 1% of the insecticides distributed in the USA actually reaches the target insects, the remaining (about 5 thousand tons) entering the ecosystem.

On the other hand, it is most unlikely that mere chemical defence, even when scientifically guided and carried out with the utmost timeliness, will succeed in preventing or wholly eradicating an infection or infestation, also for the well-known phenomenon of natural selection of resistant strains. The rapid and continuous increase in resistance, consequence of the natural genetic variability existing in the parasite populations, is documented by the evidence of at least 430 species of insects and mites that became resistant (Dover and Croft, 1986).

It is for this reason that towards the end of the fifties entomologists began to consider the possibility and advantages of integrating and harmonizing the different means of crop protection. This is the basic concept of integrated control, i.e., the combined use of biological, agronomical, mechanical and physical methods, complemented by only limited use of chemical products, to regulate and control insect attacks and to keep economic and nutritional damage within tolerable limits. But the success of such programmes depends greatly on the scale of the intervention. In the United States, for example, formidable progress in developing appropriate systems of integrated control for cotton, soya, apple and alfalfa has been achieved by the "Consortium for Integrated Pest Management".

Several goals can therefore be pursued even with a greatly reduced use of synthesized chemicals: reduction of environmental risks, greater selectivity to ensure lesser harm to the generally useful insects, better cost-benefit ratios, and lesser contamination of food supplies.

2.7. *Bioengineering Interventions*

Integrated control is based on the acquisition of a great deal of meteorological data (temperature, rainfall, humidity, microclimate in the vegetation cover, wetting of plant organs, etc.), and agronomic information (type of crop, preparatory soil interventions, etc.), all of which must then be subjected to very complex elaboration. Only a computer can make possible proper examination of these complex biological and environmental factors, can manage the enormous mass of data required, can allow its constant updating in relation to changes in weather conditions and, finally, permit the drawing-up of suitable strategies in real time.

Several programs and crop defence models have already been realized, most of them in the USA, but some also in Europe.

2.8. *Herbicides*

The herbicide problem has become serious even for public opinion, ever since sophisticated analyses have shown that some of these chemicals, albeit in small doses, can reach the groundwater.

Research is now being sharply reoriented to find compounds that can be blocked and degraded before they reach the lower levels of the ground and contaminate water supplies. Research commitment in this direction must he massive and urgent because herbicides are a class of agrochemicals of rapidly rising consumption, especially in advanced agriculture, though with crop-dependent differences from one area to another. In the USA, for example, one third of the consumption is used for soya growing; rice paddies account for half the Japanese market; and cereal crops constitute the major destination in Western Europe.

Crop species genetically resistant to herbicides should be available in the near future, making it possible to synthesize new products that, without damage to crops, will exert maximum action on weeds, thus permitting smaller quantities to be used in a more purposeful manner, with consequent benefit for farming economies and the agricultural ecosystem.

It seems likely that such new cultivars, probably the first practical realizations of molecular genetic engineering techniques applied to plant improvement, will be marketed within the space of a few years. A mutation in the gene *aro-A*, conferring resistance to glyphosate (which kills plants by suppressing the activity of EPSP-synthase, an ezyme needed for the synthesis of some essential aminoacids like phenylalanine, tyrosine, trytophane), has already been transferred from a mutant of the bacterium *Salmonella typhimurium* into tobacco plants and, subsequently, also into tomato, cotton, soya, rapeseed, maize, poplar, etc.

The genetic approach is also being used in the attempt to provide plants with resistance to other herbicides (Scarascia Mugnozza, 1987).

3. The Soil

Agriculture, by definition, must look after and protect the soil, its basic resource, considering that on average it would take five centuries to reconstitute a 2.5 cm layer of soil. And since the soil is the most efficient environmental cleansing system, agriculture must also be credited with the function of guaranteeing this unique and colossal ecological "filter".

3.1. *Adsorption and Filtration*

As far as *agrochemicals* are concerned, their persistence in the soil is governed not only by the characteristics of the pollutant itself, but also by the type of soil and the effect of various factors, especially pH, temperature and humidity (Fig. 7). In fact, Table 4 shows that persistence can vary greatly not only from one compound to another, but also for the same compound in different environmental conditions. An organic and humid soil can retain a *herbicide* like promethrine to the point where 40% will still be bound to the soil after 150 days; likewise, up to 40% of trifluralin may persist in the soil even three years after application; whereas, in the case of pentachlorophenol, residues up to 30% can be measured only during the first month. Table 5 shows that irrigation is undoubtedly an efficient means of changing this situation: irrigating at a rate of 2 litres/hour, will reduce the amount of napropamide in the

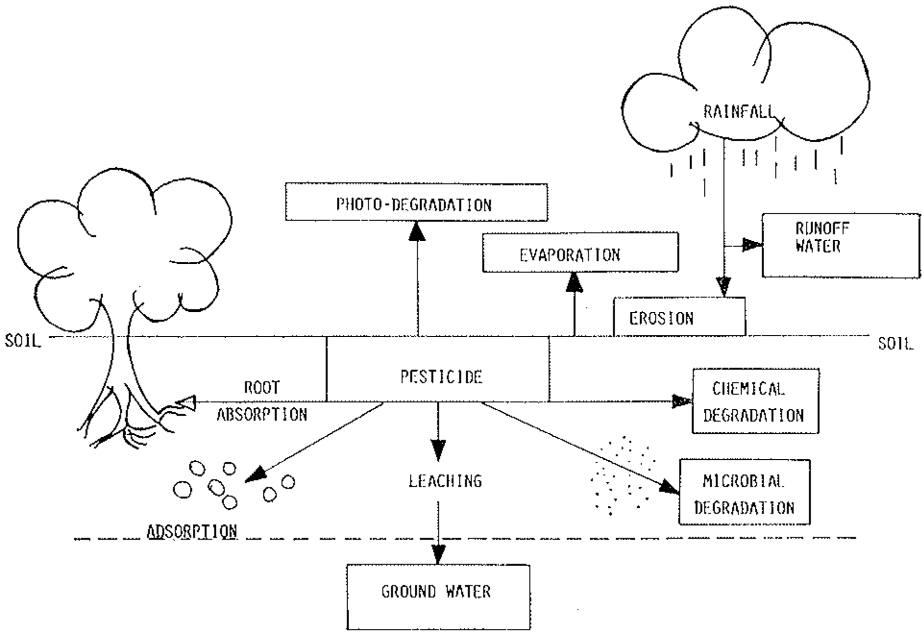

Fig. 7.

first twenty centimeters of soil from 75 mg/kg after seven days to 1.3 mg/kg after 45 days. Irrigation, therefore, detoxifies the soil but drags the agrochemicals down to deeper layers, with consequent risk of groundwater contamination. Knowledge of the geochemical destiny of agrochemicals and their persistence is therefore essential to the evaluation of the effective risk of water supply pollution.

Special mention should also be made of the *heavy metals* (Leeper, 1978), which are immobilized in the soil, becoming bound to the clays and the humus. All the agricultural operations (crop rotation, manuring, green manure) capable of maintaining a high content of organic substances are valid means of reducing toxicity. But as the pH diminishes, heavy metals, such as cadmium, lead, mercury, thallium and chrome, tend increasingly to pass into solution and can therefore be absorbed by the plants, with preferential deposition in the leaf apparatus.

Despite the search for existing cultivars particularly suitable for removing metals, the knowledge of genetic control — although undoubtedly complex — of such functions as absorbing and translocating

TABLE 4 - *Soil-bound residues of some herbicides.*

Herbicide	Time elapsed from the treatment	Bound residues (% of applied)
2,4-D	35 days	28
Pentachlorophenol	24 days	45
Prometryn	150 days	43
Trifluralin	365 days	50
Trifluralin	1095 days	38

(From: Khan, 1980; modified).

heavy metals, could allow the constitution of new types, more efficient in subtracting pollutants from the soil and depriving it of its heavy metals content.

3.2. *Recovery*

Once the soil is recognized as a complex system of chemical, physical and biological components that unceasingly adsorbs, blocks, degrades and recycles the byproducts and wastes of living organisms and, more particularly, of human activity, mankind cannot and must not consider the soil simply as an enormous rubbish-bin and run the risk of destroying its self-cleansing capacity. For the alteration or blockage of system functionality would have a twofold negative result: serious consequences on the other two environmental components, water and the atmosphere, and inability of the soil for agricultural purposes.

It is quite true that the deterioration of soil fertility deriving from the presence of agrochemicals, being applied in quantities of the order of parts per million, is almost irrelevant, since the soil flora rapidly adapts itself to consuming all the available energy sources. On the contrary, degradation caused by wastes and atmospheric pollution can be dramatic, because the mass of wastes due to human activity is impressive. In Tables 6 and 7 are shown the amount, type and composition of these wastes in Italy, and Table 8 brings out the fact that the nitrogen, phosphorus and potassium contents are comparable to those of animal manure.

Recovery of polluted soil and re-establishment of its original properties is a long and costly process (Vigna Guidi and Sherwood, 1987). At present, after removal of the solid components (metals, glass, plastics), the best solution for utilizing this huge amount of materials is to make a compost of them by microbial degradation of the putrescible material. Its distribution on the soil surface increases both soil fertility, because of the introduction of plant nutrients (N and P, above all), and soil structure, thanks to the supply of organic substances.

In short, polluted soils that have become agronomically sterile represent a net loss for both agriculture and the environment. The proper functioning of the "soil" filter is therefore a basic interest that agriculture and ecology have in common.

4. The Vegetational Cover

The vegetational cover — forests in particular — represents another system of filters (or deposits) capable not only of dealing with atmospheric pollution, be it natural or caused by man, but also performing a cleansing action with respect to water and soil.

Table 5 - *Effect of irrigation rate* (2 L/hr) *on the distribution of Napropamide (N) and Bromacil (B), expressed as mg/kg of soil, in a "terra rossa" profile.*

Depth (cm)	7 days after treatment		42 days after treatment	
	(N)	(B)	(N)	(B)
0-5	15	17	1.0	1.0
5-10	40	5	0.2	0.3
10-20	30	2	0.1	0.0
20-40	6	6	0.2	0.1
40-60	1	10	0.4	0.1
60-80	1	2	0.2	0.0
80-1000	3	3	0.2	0.0

(From: Gerstl and Albasel, 1984; modified).

TABLE 6 - *Annual waste production in Italy according to its origin.*

Type of waste	Tons/year (x 10^6)	Available for composting	Compost obtained
Solid wastes	14.5	9.5	4.7
Industr. wastes	33.0	3.0	1.5
Agric. wastes	150.0	40.0	16.7
Sewage sludge	1.5 (D.M.)	0.7 (D.M.)	0.7 (50% H_2O)

TABLE 7 - *Average composition of solid wastes in Italy* (% of weight).

Paper and board	30	Fabrics	3
Perishable matters	35	Metals	3.5
Plastics	4	Glass	5.0

TABLE 8 - *Average chemical composition of sewage sludge, compost, and manure* (% of dry weight).

	Sewage sludge	Compost	Manure
Carbon	32	32	38
Nitrogen	3	1.3	2
Phosphorus (P_2O_5)	5	0.8	0.5
Potassium (K_2O)	0.8	0.4	1.7

However, the multiple functions of woods are as yet poorly understood by the public at large, there being a marked tendency to identify the primary function of forests with timber production and more recently as potential sources of alternative energy especially in the Third World. Their filtering capacity as well as their function in regulating climatic conditions and water circulation are generally ignored.

4.1. *Interception and Adsorption of Contaminants*

The positive action of forests derives from the fact that this particular ecosystem is characterized by far greater "roughness" than any other plant formation, i.e., it has a very large and highly irregular surface in contact with the atmosphere. The vegetation cover is therefore capable of intercepting or absorbing atmospheric pollutants and storing them for variable periods of time: solid particles, dusts, aerosols, gaseous substances (sulfur, nitrogen-oxides, carbon oxides, acids, ozone, etc.). These substances, produced by industrial, civil, and agricultural activities, pollute the atmosphere and, falling back to the ground, become the cause not only of forest degradation (acid rains, for example), but also of damage to crops, and of soil and water pollution. Recent researches (Smith, 1984) carried out in laboratory and in wind tunnels, though unfortunately not yet complemented by large-scale experiments and appropriate models in natural conditions, show that, generally speaking, the interception and deposition of particulate matter increases with the roughness and the geometry of the leaf surface, with the size of the particles and with the windspeed. As regards gaseous contaminants, our present knowledge suggests that absorption increases with the solubility of the pollutant and the humidity of the plant surface: hydrofluoric acid, sulfur-dioxide, nitrogen-oxides and ozone are therefore readily absorbed, while carbon-monoxide and the nitric ions are either not absorbed at all or absorbed only very slowly and in small quantities. The absorption of gaseous pollutants through the stomata remains almost constant during the day, provided that the plant has enough water; but when it is water stressed, as often happens in urban areas, the stomatal aperture is reduced and absorption declines considerably. Anyway, plant respiration ensures that the absorption of sulfur-dioxide and the nitrogen-oxides will continue during the night, though at a greatly reduced rate. The action of the vegetation cover is therefore of considerable benefit for air quality, particularly important, for instance, in densely populated areas.

4.2. *Effects on Water*

The vegetational cover performs an equally beneficial function with respect to *water quality*, since it regulates, preserves and enriches the groundwater, both deep and superficial, and limits the negative influence of polluting substances. But water quality becomes severely and rapidly compromised when this cover is either wholly or partially removed. In Oregon (USA), for example, road construction in a small watershed with steep side slopes increased the solid matter content of the surface runoff by as much as 250 times as compared with that observed in an adjacent valley where the vegetation remained intact (Fredrikson, 1970).

It is evident that the creation of large urban areas, the extensive infrastructures and large road networks represent a heavy disturbance of the delicate hydrological system that supplies the underground water resources and regulates the surface runoff. Thus, there is an urgent need to extend the vegetation cover in order to limit this water unbalancing phenomena and satisfy the increased needs of pure water.

Once again, forest and agroforestry systems parallel the protection of the environment. As a matter of fact, the vegetation cover, despite its great variability in structure and elements, constitutes an essential component of the biosphere, and every damage inflicted in it depletes resources important for man's survival. Unfortunately, this obvious and elementary insight has its counterpart in a dangerous scarcity of studies regarding the characteristics and functions of this vital "filter".

In conclusion, the planetary importance and extent of these "filters" is in striking contrast with our limited knowledge of the manifold problems connected with them. This is probably due to the fact that the action of the "filters" relies on a series of phenomena and complex interactions between biological organisms, chemical compounds and physical conditions (ranging from atmospheric to soil physics). Interdisciplinary analyses and specialized interpretations (physico-chemical, physiological, genetical, engineering, agronomical, silvicultural, etc.) are therefore needed to ensure the proper functioning and self-cleansing of the two "filters", which act not only simultaneously but also, and above all, in combination, because soil and vegetational cover complement each other: they jointly contribute to the characteristics of the environment.

5. Conclusions

The aim of this paper was to underline the status of the art regarding some innovative agrotechnologies introduced in modern farming systems. These technologies are completely modifying the general opinion that modern agriculture is becoming harmful to the environment. Furthermore, they enable us to conceive and practice an agriculture that is not only economically viable but also suitable to protect the environment. Although inevitably limited by space and the subject that I intended to discuss here, I trust to have adduced ample material in support of this thesis and to have shown that the interests of farmers and of the community at large can effectively be conciliated, and that economic and ecological needs are not antithetical categories.

Consequently, being confident in human wisdom, we hope that coherent economic and ecological policies will be studied and applied at national and international levels.

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DISCUSSION

TOLBA

I don't think that there should be a contest between good agriculture or modern agricultural technology and the protection of the environment. However, what we are seeing in fact does not lead us to reach that conclusion, particularly in the Third World. The use of tremendous amounts of agrochemicals — I am not talking about biotechnology, which didn't take off yet in the developing countries, where it is extremely new — i.e. fertilizers and pesticides does not seem to us to be accompanied by enough knowledge of the negative impacts, so that people would use the most appropriate amounts. There is still a sort of very strange feeling that the more you put in, the more agricultural output you get from the lingering thinking of all modern technology, which started the second agricultural revolution. This will continue until we reach, in many of the developing countries, the law of diminishing returns, that agricultural output does not praise particularly the present producing systems for input, labour and agricultural chemicals. There is a tremendous shift from agriculture in the developing countries to other work, at a time when we are all crying wolf about 400 million people starving or being undernourished, because of the real health (I am not saying environmental effects) impacts of the misuse of the so-called agricultural technologies.

The second serious problem in agriculture which Professor Scarascia Mugnozza didn't touch on is the real issue of subsidy, the subsidizing of high level products of agricultural technology in the developed world, whether because people in the European Community are competing with the Americans and the Americans want to get agricultural production at a lower cost than what is being produced in Europe, or because you are trying to put the cost down in order to be able to export the excess production available to the Third World. I don't know how we can handle this situation. Agriculture is now producing relatively less in most of the Third World because of conditions which have actually nothing to do with agriculture but rather with the international economic situation.

What is the solution? We have to talk within the real area which is creating problems for everyone, even destroying the environment. Agricultural productivity is going lower, the soil has been disbanded, exposed to erosion and disruption, as a result of political and trade decisions.

SCARASCIA MUGNOZZA

I agree with you about the situation in less developed countries and that an international agreement is needed in order to make agricultural production in those countries an economic enterprise. But a lot of other variables have to be introduced into our discussion if we are going to examine the problem of agricultural sustainability in less developed countries. The title of this study was the comparison of the interference of agricultural activities on the environment. To discuss sustainability of agricultural productivity in Africa, other variables must be added: access to credits, international agreements, formation of experts at all levels, etc.

I think there is another point to be made: we are speaking about cash crops instead of discussing food production in developing countries. I think that this is the main problem, for example, in Africa, where governments prefer cash crops in order to obtain foreign currency, forgetting the importance of food production. This policy will not balance their budgets and will induce farmers to abandon agricultural areas for urban centers. This complex problem merits a study week.

As far as the negative impact of agrochemicals is concerned, I think that, except in some cases, such as the production of cash crops, the use of agrochemicals is rather low. I therefore do not think that there exists a big problem for the environment or a negative impact on the areas where agrochemicals are used in the production of food crops. I would agree that a problem exists where cash crops are produced. For example, I know that in the Philippines an exaggerated quantity of nitrogen fertilizers is used to produce rice.

TOLBA

I don't know why my dear friend Odhiambo is silent. It is not his nature. I am not sure that the problem of agricultural production is only in the developing countries. I think we are coming very close to a situation where the developed countries are facing a major problem. I just came yesterday from an official visit to Bonn. Both the Minister of the Environment and the Minister of Development Cooperation were telling me that they are starting to face the problem of what they are going to do with the land that has to be put aside because of the agricultural surplus that they have to cut down, within the scope of the Economic Community. Consequently, it's not a matter of speaking of developing countries particularly; it is a global problem that has got to be resolved somehow: cash crops versus food crops. Nobody would support you more than myself on that; but I would very much like to know how is Brazil going to pay the 70 billion dollar debt if it goes into food crops and not cash crops? How is Egypt going to pay the 17 billion debt, if they don't produce cotton to sell and pay the debt? It's the chicken and egg. They are being pushed in the Third World, via the debt, to produce cash crops in order not to be in default with commercial banks or with governments. Governments will probably accept some default on their loans, but the governments do not control the commercial banks, which have more than 80% of the loans of these developing countries. These people are scared of being in default, because then they won't have any further loans, and that might mean that they cannot buy food for their people in one year or the next year. This is the complexity of the situation. I am afraid, Mr. Chairman, that we feel that we are in a very embarrassing situation with the environment, that we cannot discuss environment in isolation. It is so intricately connected with we have to discuss population growth. We have to discuss all these elements everything else in the world, that we have to discuss trade, we have to discuss the debt, we have to discuss health, we have to discuss food productivity, we have to discuss population growth. We have to discuss all these elements, because all of them relate to the environment, and that's what's making our life difficult. The more the scientific community really comes to help by a multifaceted approach, that is, scientists, geneticists with economists, with demographers, with development planners, sitting together and studying how they can deal, for example, with the agricultural problems, then we can begin to see that there are ways and means of ensuring that agricultural development can be in harmony with the environment. But we are deprived of this because of decisions outside the scope of environment and outside the scope of agriculture. How could we get this? I think that probably more than 10 or 12 scientific disciplines must cooperate together. What one would very much like to see is a prestigious Institution like this to address one of these colossal issues.

MARINI-BETTÒLO

What you said now is very important. The environment is a very complex system. Its problems are not only scientific but also social and economic. We must therefore look at the problems from a new perspective. The question of the foreign debts is not easy to solve, but it should be solved. How? I don't know. Perhaps we should set up what in the past was called a new economic order. I am not an economist, but it is not right that developing countries produce only to pay off their foreign debts. We must find a way to avoid that the natural resources of a country be in alarge measure exported.

I will now give the floor to an economist, Dr. Maler.

MALER

I would like to support whole heartedly what Dr. Tolba said. In some sense, I do believe that the formulation of agricultural policy in Europe, in North America and in the developing world, is more important for the global environment than the formulation of environmental policies. To some extent we have neglected that aspect, although Peter Raven yesterday was discussing new schemes for agriculture.

If I could refer to my own country, Sweden, there are conflicting objectives. We have the problems of runoff from agricultural production into the sea on our west coast and into the Baltic, and that runoff has created very serious problems. Some bays on the west coast of Sweden are biologically almost dead because of this runoff, and the Baltic is under heavy pressure from eutrophication because of agricultural policies.

At the same time, agriculture is part of our history and agriculture has contributed to the Swedish landscape. A change in domestic agricultural policies, would change the landscape, perhaps. I say, perhaps, because I do think there are means of meeting different objectives, but there is an apparent conflict between, on the one hand, the problems of runoffs from agriculture, pollution from agriculture, and, on the other hand, the problems of keeping the landscape open.

Thirdly, we are, through our agricultural policy in Sweden subsidizing agricultural activities. The price level of agricultural foodstuffs is much higher than for the same items on the world market, mainly from the Third World. We are subsidising our agriculture which means that we are voluntarily accepting an economic burden which at the same time creates environmental problems in the Baltics and in inland lakes on the west coast, and at the same time means that we do not accept the surpluses of the developing countries.

I do believe that a radical change in our own agricultural policy could be introduced to achieve both a better environment, keeping the landscape open, and reducing the cost of the surplus we have in our own agriculture, by using other tools in agricultural policies, for instance, increase the tax on the use of commercial fertilizers in Sweden, decrease the tax on using manure as a fertilizer, introduce a subsidy not on the production in agriculture, but on the land cultivated. I do think that by looking on that issue as an incentive problem, it would be possible to find ways of reformulating agricultural policies which would reduce domestic surpluses and pollution problems from agricultural.

I do think that the agricultural surplus in Europe is, in a way, economic madness. It would be very interesting from a political and a scientific point of view to look at the mechanisms by which certain groups in our economies in Europe and North America are able to promote their own interest in such a way as to create these surpluses.

However, I don't think it's only the European and North American world that's to be blamed, because I share Peter Raven's views namely, that the agricultural policies in many developing countries, and particularly the pricing schemes which in a way exploit farmers and rural areas in order to subsidize urban areas, really ruin the incentives to preserve and develop domestic agricultural policies. I would very much welcome discussions on how to change agricultural policies in such a way as to promote economic and environmental objectives.

Scarascia Mugnozza

I agree with you on the globality of the problem. It needs to be discussed not only in reference to the protection but mainly to the rearrangement of all agriculture and of the management of agricultural assets. Research on new economic uses of biomasses, which are renewable resources, and on renewable resources of energy, especially if locally available, must be conducted. Agroforestry deserves high priority from an ecological and also an economical point of view. Among these agricultural assets, we should consider also the role of labour and of capital, and the importance of knowledge in some cases, which can become a substitute for capital. The extension systems, the credit systems, the needs of small farmers have to be taken into consideration in any of the research and development programmes for technological development and training.

Last year I organized in Italy the so-called Rome Forum, in which we discussed all these problems, from economy to credit, to sociology, to research in different fields. Therefore, I completely agree with you on the dimensions and the globality of the problem.

My report was on a specific problem: the relation between agriculture and the environment, considering globally the situations in the developed as well as in the developing world. I have demonstrated with some data the programme in equatorial Africa.

Di Castri

On the first day, I started the discussion, taking a global approach. Nevertheless, I want to stress that problems and the analysis of their solution should not always be envisaged on a global scale. This has been illustrated through the discussion of different ecosystem types, where issues have been "deglobalized". In other terms, global driving forces may produce different local effects and should imply different solutions. In the discussion on economy, emphasis has been put on the fact that the main current driving forces for environmental changes are related to the interdependence of market economies, indebtedness of many developing countries, employment crises and agricultural policies, such as that of the Common Market. These are all global forces, and global climatic change should also be considered, in addition to them,

One can wonder if it is possible to prevent these global phenomena or if it is pragmatically more realistic to try to adapt to them. Of course, both possibilities have to be taken into account, and brought to interact. However, I admit that it is easier for me to approach the issue of "adaptation", because solving the international economic disorder, or preventing the industrial emissions leading to climatic change, would require a political understanding and a will that is hardly conceivable within the present context.

Furthermore, the complexity of the problem is such that the number of interactions and combinations would increase in a geometric progression. This would be very difficult, even using such a useful tool as the game theory, as proposed by Dr. Maler. Accordingly, my main plea is that, even in the solution of local specific problems, one should not disregard the international scenery, otherwise, the response will be too naive to be applicable in a real world. As a matter of fact, one of the shortcomings of the "ecological approach" is that it has taken too narrow a perspective, focussing only on the specificity of a local problem.

Scarascia Mugnozza

I would like to say that, according to my experience, agricultural productivity is a problem for advanced countries. Much research must be done to maintain the present level of productivity. This problem has to be considered on a deglobalized scale because of local conditions: soil, moisture, climate, adaptation of animals and plants, and social needs. Solutions can be found only after agricultural productivity and the welfare of rural families are improved. Perhaps, more than the increase in productivity, the improvement of the welfare of rural families should be a priority. Only after these local issues are solved can a global solution be attempted by scientists, economists, sociologists and politicians. This is my experience, based on my work for several years in developing countries.

MARINI-BETTÒLO

I read recently about a proposal to transform the debt of developing countries into a loan for the betterment of the environment in debtor countries. It's an interesting suggestion. Private banks may not be interested in the proposal, but other institutions, for example, those working for development, might help.

STRATEGIES FOR THE PROTECTION OF THE ENVIRONMENT IN URBAN AREAS

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The "Sensitivity Model". An Instrument for Environmental Planning

The problems of agglomerations are well-known and must not be mentioned in detail. Whether it concerns Mexico City, Djakarta or Peking, population growth has caused serious damages in the ecosystem. The ecosystem, consisting of man and the biosphere, and especially the urban ecosystem, have to be understood and developed in their complexity. Tbis is more, must be more than environmental protection. Development includes environmental alteration, alteration of the system with the aspect of *system* viability, not of an individual component. Therefore, it is necessary to see the individual component as a part of the overall system and to cross-link the own specialist research sphere with other research spheres. Furthermore, the role of the own research within the system complexity must be considered (Fig. 1).

The urban ecosystem necessitates research in the original sense of the word ecology.

In the last few years, "ecology" has become one of the most misused words of our time. Those who use it most often for ideological reasons understand in the least.

"Thinking ecologically" means the avoidance of any ideology. It means more than that, however; it means that the ecological thinker must place his own objectives within an overall perspective and examine them on this basis.

"Acting ecologically" assumes flexibility in endeavour with regard to the viability of the system — our environment.

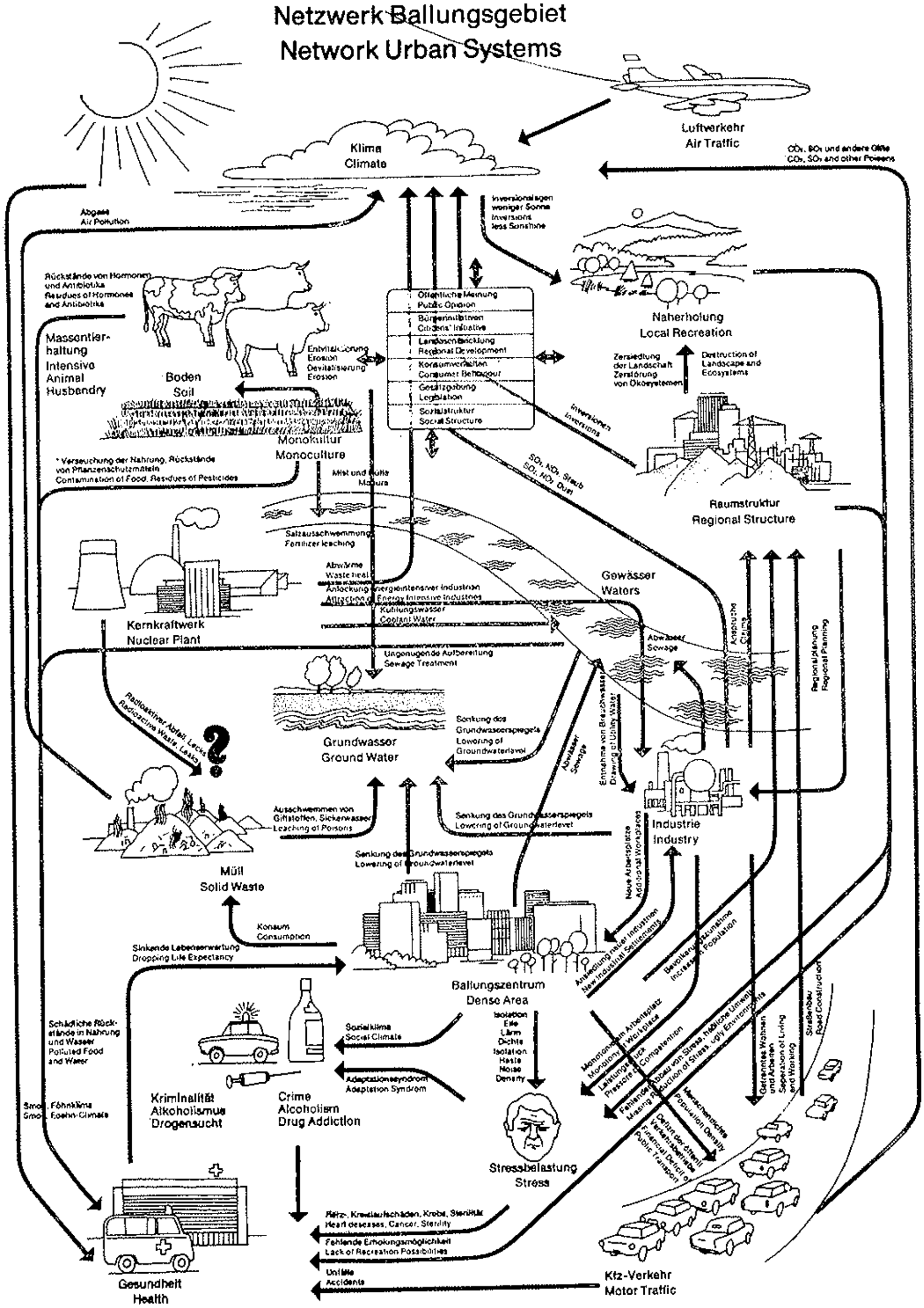
Netzwerk Ballungsgebiet
Network Urban Systems
Luftverkehr
Air Traffic
Klima
Climate
Abgase
Air Pollution
Inversionslagen
weniger Sonne
Inversions
less Sunshine
Naherholung
Local Recreation
Massentierhaltung
Intensive Animal Husbandry
Boden
Soil
Monokultur
Monoculture
Öffentliche Meinung
Public Opinion
Landesentwicklung
Regional Development
Konsumverhalten
Consumer Behaviour
Gesetzgebung
Legislation
Sozialstruktur
Social Structure
Zersiedlung der Landschaft
Zerstörung von Ökosystemen
Destruction of Landscape and Ecosystems
Raumstruktur
Regional Structure
Kernkraftwerk
Nuclear Plant
Gewässer
Waters
Kühlungswasser
Coolant Water
Ungenügende Aufbereitung
Sewage Treatment
Abwasser
Sewage
Grundwasser
Ground Water
Regionalplanung
Regional Planning
Industrie
Industry
Müll
Solid Waste
Konsum
Consumption
Sinkende Lebenserwartung
Dropping Life Expectancy
Ballungszentrum
Dense Area
Sozialklima
Social Climate
Adaptationssyndrom
Adaptation Syndrom
Kriminalität
Alkoholismus
Drogensucht
Crime
Alcoholism
Drug Addiction
Stressbelastung
Stress
Gesundheit
Health
Fehlende Erholungsmöglichkeit
Lack of Recreation Possibilities
Unfälle
Accidents
Kfz-Verkehr
Motor Traffic

FIG. 1.

1. *Ecology*: Protection *of Nature and the Environment?*

The zoologist Ernst Haeckel defined the expression *ecology* as "the science of the economy of organisms which has the task of investigating the relationships between the living creature and both inorganic and organic nature". In 1909, the biologist Jakob von Uexküll introduced the concept of *environment* into ecology as "the external world surrounding a living creature, to the extent that it is experienced by the sense and activity organs of animals and causes them to behave in a certain manner".

So those concepts were born which in the recent past have assumed an unequalled socio-political dimension. For a century, they were reserved, with their accurate definitions, to the natural sciences. In view of the confusing multiplicity of uses, a return to their origins may prove useful. A simplification, and simultaneous extension, of the two concepts may be permitted in order to make the intentions of the planner clear — it is a matter of relationships between living organisms and their environment.

The point of interest is the "relationships" (Fig. 2), the mutual interactions between individual creatures — not the individual — the pattern of interactions, the *ecosystem*. The biologists have now become accustomed to the fact that their conceptual world has been profanely invaded. On this point, J. Illies wrote in 1973: "In fact, the ecologists now know that only comprehensive consideration of all the natural phenomena and, in addition, of all the phenomena of civilization can provide a correct understanding of the conditions necessary for the existence of organisms in an environment". "Certain environments (biotopes) are the background to, and to a certain extent, the container for quite definite contents in each case, i.e., the two together — the container and its living contents — form an ecosystem for the particular living community (biocoenosis)".

It is necessary to reject the contradistinction between "natural" and "artificial" ecosystems because there is no longer any spot on the Earth which is not affected in some way by man. It is sometimes just possible to refer to ecosystems "approaching nature". It is, however, quite certain that the "urban ecosystem" in which man is dominant is the "most artificial" ecosystem which can be envisaged. Even in this case, however, the important problem is the relationships within this community of living creatures; these relationships guarantee their life and their "viability".

In present-day political discussions the concept of "ecology" is restricted to what can be referred to generally as the "protection of nature".

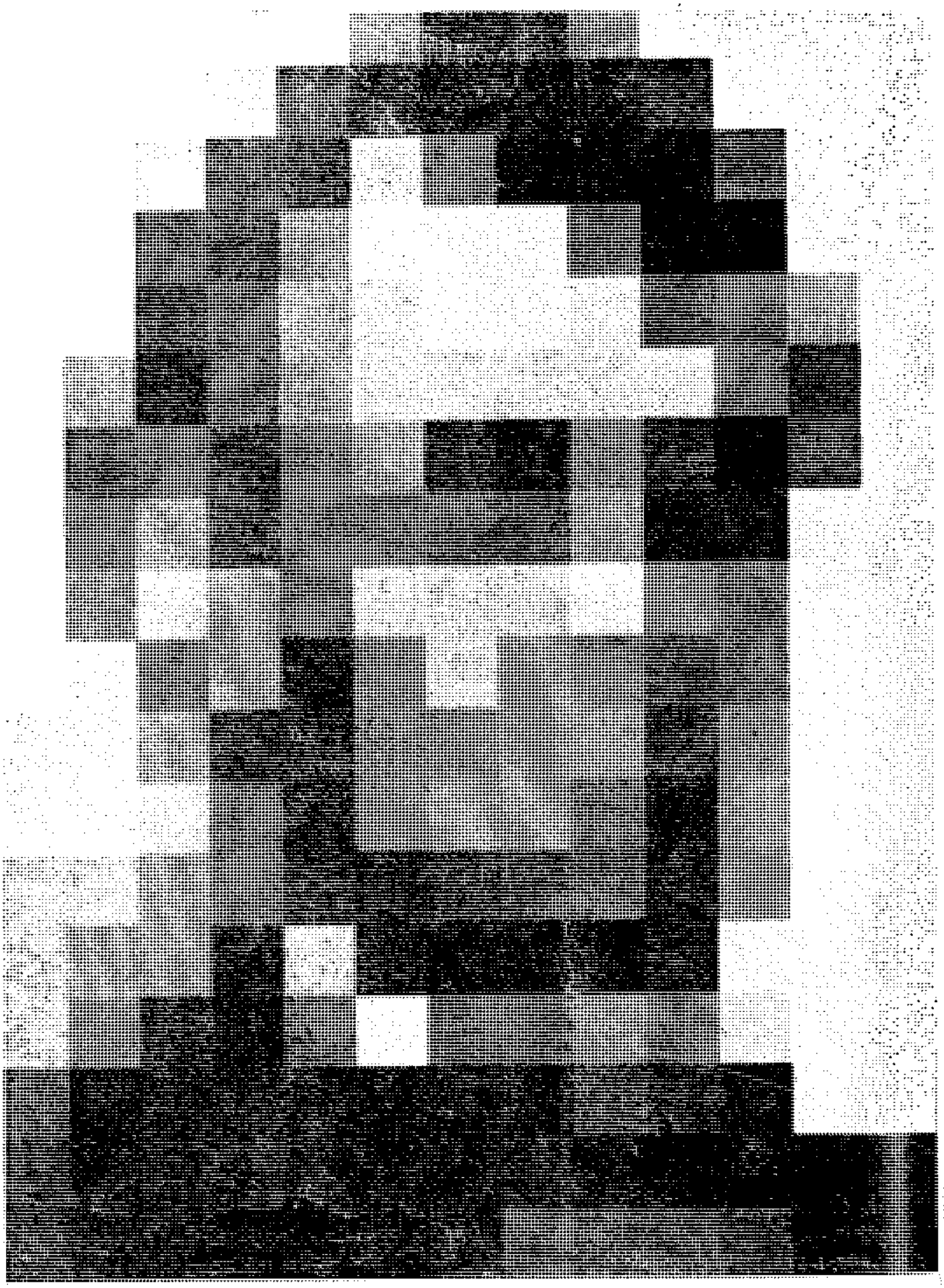

Fig. 2. The Complex Unity and the Details. To experience the statement of the overall pattern of these squares, they must be put in the background by looking from a longer distance or as blurred (e.g., without glasses) at the picture. Thus the relations **between** the squares stand out in relief and uncover a portrait of Abraham Lincoln.

The protection of nature, initiated by E. Rudorff and H. Conwentz in Germany around 1900 and extended internationally by the Swiss P. Sarasin in 1913, includes "the endeavours and measures taken for maintaining the residue of the original landscape with its plants and animals *as locations for edification, recreation and research into rural area.* Based on regional investigations and planning, it is intended to make the native home harmonious, purposeful and worthy of the national culture and to keep the constitution of its landscape healthy".

In Germany the legal foundation of the protection of nature was provided by the "Law for Protection of Nature" of June 26, 1935. It was replaced by the "Federal Law for the Protection of Nature" of December 20, 1976. Here too, the protection and the "development" of the bases of life are mentioned as well as the securing of recreational areas. The Laws for the Protection of Landscape by the individual German states repeat the same theme: maintenance, care and development of the natural bases of life and the multiplicity and beauty of nature and the landscape and the *securing of and access to recreation areas* in the open countryside.

In contrast to the widespread "conservation ideology", all the laws contain the idea of development and the "right" to enter nature. Attention to the objectives of "Area and Regional Planning" is mentioned. To this extent, there are no contradictions between regional and town planning on the one hand and the protection of nature on the other; there is no doubt that the protection and development of nature as the bases of life was always the objective of planning.

2. *Ecology and Decision Making*

Land Use Planning today only represents the possible condition of a system at a certain time and this only in part, i.e., to the extent that this condition is reflected in area documentation (Fig. 3).

These plans can be fulfilled but do not have to be fulfilled. This depends on the general development and on the decisions of people, politicians, entrepreneurs and employees. Many forces become active in this respect, some linear and some non-linear. High density continuously causes conflicts but, nevertheless, the system is viable. In fact, the solution of such limited conflicts at an early stage leads to a type of stability or, to put it better, to a flowing equilibrium because the system is also continuously changed in the process of overcoming the conflict.

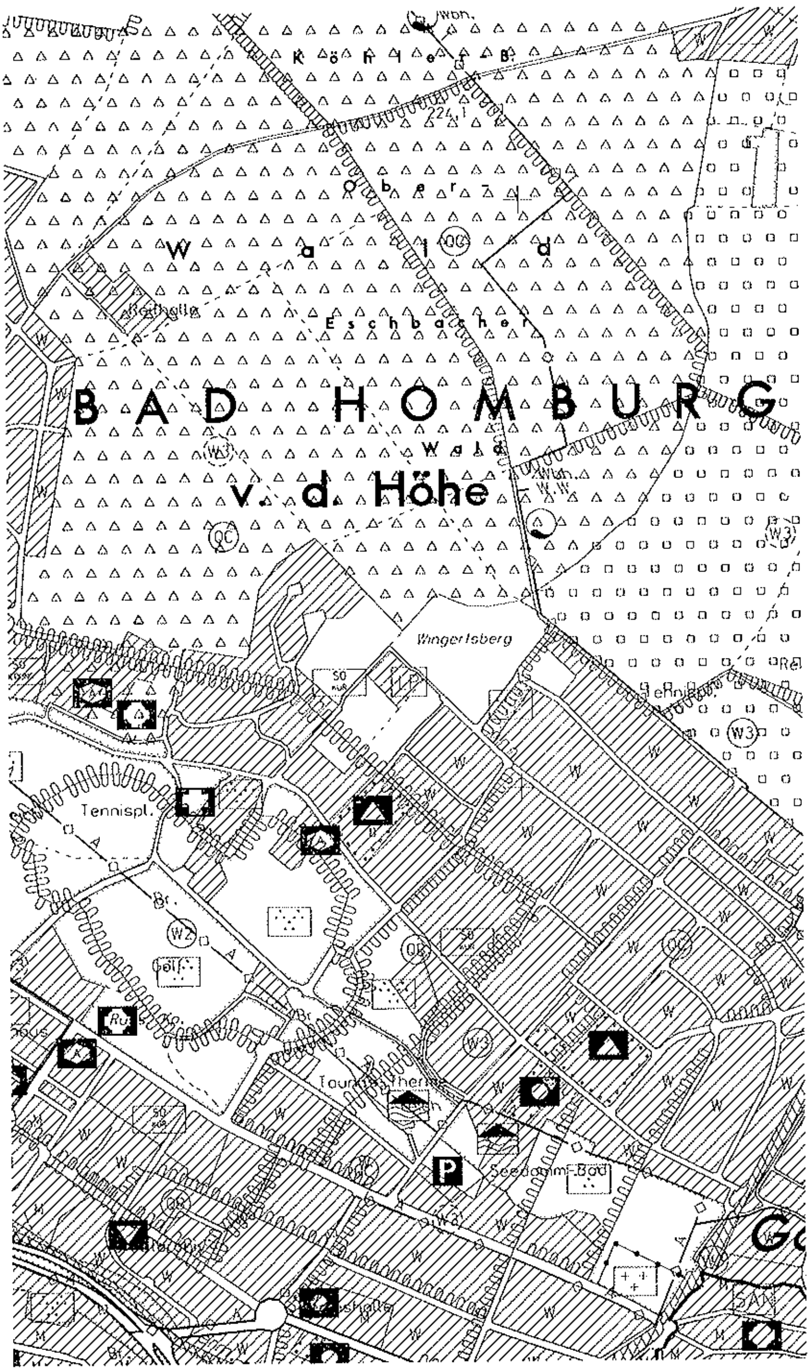

FIG. 3. Section of the Land Use Plan, scale 2:10.000.

The instantaneous direction of development, i.e., whether the system is growing or shrinking, does not matter in this type of self-regulation. The system is, in fact, in much greater danger when the amount of self-regulation, i.e., the freely acting forces, becomes too small. The less self-regulation is available, the more interference is required in the system, and this interference, because the functioning of the system is not understood, usually leads to further interference in order to compensate for the negative effects still present.

The extent to which the fields of decision of industry, politics and administration are interrelated is often not realised. Generally speaking, furthermore, the way in which the forces in a system are distributed is unknown. This can differ completely from system to system. If the mode of interaction of a system is unknown, however, it is impossible to draw many conclusions about the development of the system in the space/time reference plane.

The realisation of and also the modification to the plans, however, depends on this play of forces, the observation of which becomes more and more fascinating as the individual forces become less calculable. The "institution" of *citizens' initiative*, for example, has produced completely new standards in this sphere. Their effects are mainly felt in the duration of a decision process. This can, in turn, lead to planning becoming obsolete because of changes in the state of the system in the meantime; it can even mean that carrying out the plan would damage the system.

A parliament is in general not very well suited for understanding such considerations. Because of the political groupings, decisions are generally taken by the majority against the opposition. This means that these decisions, although usually based on specialist knowledge, are politically coloured and therefore stubbornly defended at a later date. This is quite understandable because the opposition cheerfully accuses the majority of incompetence if the latter departs from the original decision. Modifications to a step once decided are therefore extremely difficult for a parliament.

The role which the election periods play with respect to both the making of decisions and on decisions which only have an effect in the long term has long been known. This effect is reinforced by the change of the people responsible in parliament and also by changes of the majorities.

This even complicates the difficult task, which is difficult enough anyway, of making processes of continually increasing complexity comprehensible to the decision-makers. The specialist basis for making decisions is already very small because of the necessary distribution of parliamentary tasks among committees. During the vote, the groupings have to depend on the opinion provided by their committee members. These, in turn, often rely on the opinion of one colleague who has the appropriate specialist knowledge or has at least studied the material.

The description of this decision-making procedure explains the extent to which decisions often depend on one person or a very small group, and on their background. This is sometimes underestimated and always causes friction when the opinion of the trend-setting group is very different from that of the parliamentary group. In particular case, this can mean that the consciousness of parliament's necessity of a certain mode of behaviour can be brought to nought because the trend-setting group or personality has a different opinion. It is not a matter for fundamental complaint, but it should be realised that this factor does play a role in the decision process.

The planning administration, in particular, should consider this fact and, correspondingly, take care of its task: the preparation of decision-making. Unfortunately, however, the administration has its own problems. From the point of view of system planning, the greatest problem is the distribution of *one* task among various authorities. This usually produces impenetrable barriers which paralyse system-thinking.

3. *Thinking in Systems*

Are we capable of thinking in systems?

"Is it possible for us to deal with the flood of information which pours over us every day? Although it is necessary for our society to produce more information about itself, the question remains as to whether we can recognise the *vital* information from among the flood. There is increasing danger of incurable polarisation. *Generally speaking, we do not accept the information which we ought to but only that which we want to.* Information which we find comfortable and which confirms our opinion is given priority. Does this really help our orientation?" so writes Peter Atteslander (a sociologist) in the book "The Technical Revolution".

Thinking in systems means ordering and allocating information, separating the important from the unimportant and deciding on effects. This makes it possihle to extract the information which is important to decision-making. The desire to learn this mode of thinking, however, means that the people concerned — planners and legislators — have to climb out of their own little conceptual world, drop well-loved prejudices, examine themselves critically and make their own opinions available for discussion. This certainly does not correspond with our natural instincts. For the planner, this also means climbing out of a two-dimensional world into the three-dimensional world of patterns of interactions, escaping from a fixed time *horizon* and considering the *course* of time.

Planners, politicians, entrepreneurs and, by no means last and least, the citizens, should recognise that it is possible to gain from a cross-linked way of looking at things. In "Urban Systems in Crisis", Frederic Vester writes:

> "Only this approach [the interrelational way of considering problems] can help us to form our environment with less force and energy and thus in a more elegant way, so that many things will move in the right direction of their own accord. The more technocratic, the less combined, isolated, technically specific — in short, the less cross-linked a solution is — the more susceptible to external influences it will be. Only when we accept the fact that, even in our civilisation, not only factories are cross-linked with each other, not only rivers with each other, not only the vegetable and animal worlds with each other, but also river systems with factories, factories with consumer behaviour, consumer behaviour with tax law, and this via national development planning with the location of factories, this with a change in traffic volume, which in turn is cross-linked with human settlement structure, and this perhaps with criminality and drug abuse, can we begin to hope to make the right decisions and thus find the right solutions. Today, 'right' can only mean: in the direction of a system with long-term viability".

Our linear, causal/logical mode of thinking must enter into a symbiosis with feedback-cycle thinking. This learning process is not simple and not only contradicts our usual mode of thinking but also interferes with the spontaneity of political argument. It demands of the politician that he should consider the compatibility of his action with the system before he presents it to the public. How would the "Green" party look if they had to consider how their demands could be converted into reality without subsequently damaging the system? This learning process can, however, be achieved with good will.

Another condition is that our universities should be more willing to accept this subject. There are undoubtedly some approaches in this direction but they are certainly not sufficient to prepare the future generations of planners for the substantially more complex problems which they will have to solve and for problems which will differ in principle from the earlier ones.

Therefore, in a new project coordinated by the Umlandverband Frankfurt, thinking in interrelationships is demanded from the very beginning by a cooperation scheme for the work of the scientists involved.

Thinking in systems must be started in our universities. The Umlandverband Frankfurt has illustrated the meaning of system thinking in an urban ecosystem with the aid of a cooperation scheme for the project "Urban Ecosystems". None of the scientists involved in this project can work in his sphere without engaging himself with the other spheres. The natural scientist must deal not only with natural science, but also with legal science, medicine and politics. He must be able to estimate his location in the system and his role in the project and he must be willing to insert his work into the system. It also means that his research approach must be inspired by the requirements of the system development. This is not easy with the traditional education methods but it is a prerequisite to the accomplishment of our tasks (Fig. 4).

4. *Development or Development Step?*

Can we still extrapolate from the past and, by this means, plan for the future? Doubts occur because of the large number of changed parameters. "We are currently experiencing such a fundamental change that we have to go back a very long way in order to find a parallel. The only era which is really comparable is the change which led from the old stone age to the young stone age" (Sir Herbert Road). However, let us leave this comparison and consider some facts.

Alvin Toffler writes: "90% of all the scientists whom the world has ever produced are now living; new scientific discoveries are made every day and the new inventions and discoveries will be more rapidly assessed in practice and used than ever before".

"The relationship between tbe gaining of knowledge and the rate of change has altered dramatically. The novelty is continually forcing its way into our life to an incredible extent".

"Because of the acceleration of change, the ratio between the new and the known is radically modified. Endurance is replaced by inconstancy.

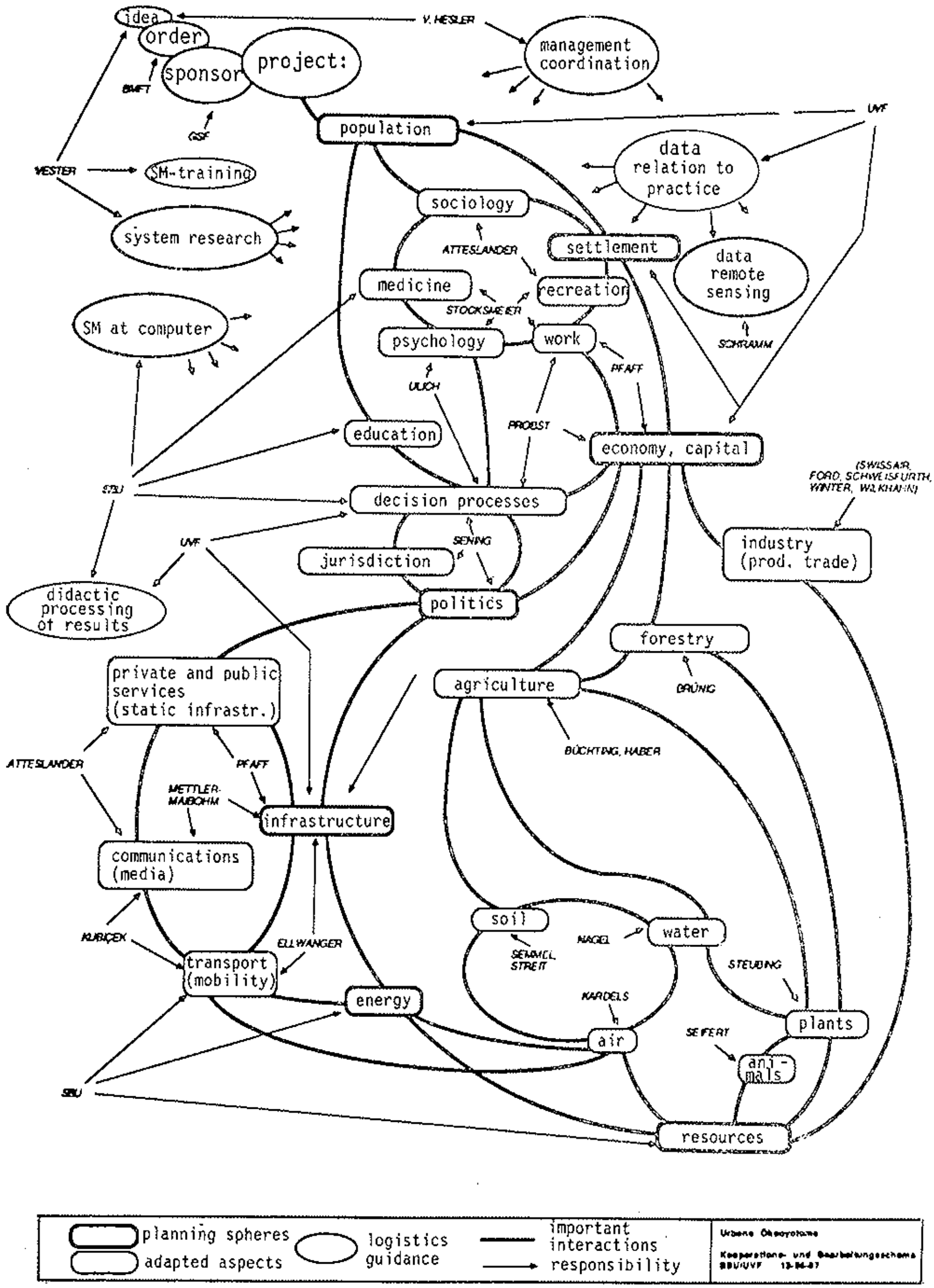

FIG. 4. Urban Ecosystems Cooperation and Processing Diagram.

Large fluctuations between the organisations, never-ending internal reorganisation and the continuous creation and breaking up of new working groups take place. The importance of hierarchies becomes limited".

The degree of cross-linkage over the whole earth, and with it the degree of world-wide mutual dependence, have taken on a dimension which is still incomprehensible to many people. The incredible development of information technology has had the effect that local events can be propagated practically without delay throughout the world and lead to reactions. A political disagreement in South Africa leads to immediate reactions in Europe and these occur in the most varied social fields, even including economic policy.

There is no national economy on earth which is still independent. Information and transport technology have made the exchange possibilities between the nations and the continents boundless, in the true sense of the word. The national economies depend on exports and imports and must therefore align their production to international markets. The discussions in the European Economic Community, particularly with respect to the agricultural market, show the extent of this interdependence.

The change in our society from an industrial society to a service and information society marches on constantly. "The transition periods between economic eras are the ones in which the entrepreneurial spirit blossoms. We are now in such a period". There is nothing that illustrates this better than the current technology discussion. The entrepreneurial spirit leads to new employment structures and, in the process, influences not only the labour market and the social structure but also the utilisation of the available residential areas.

Another interesting feature is the change from the careless growth society to the sensitive "environmental society". The environment discussion has become subject No. 1 within a few years, independent of party. No one should expect that having the subject discussed will lead to short-term possibilities of solution. The conversion of the whole of the economy, however, is in full swing, and it is going forward much more rapidly than might have been expected, in view of the human capacity for inertia. The change from the industrial to the information society is also effective in this respect. This change becomes obvious in the "industrial and trade zones" and also in the fact that by far the major proportion of jobs is no longer located in these zones but in the city centre and mixed areas.

The change is even clearer in the matter of dealing with nature and resources. The discussion involves not only the general demand to be economical in the use of areas but also includes the multiplicity of popular activities within nature — such as sport, leisure and recreation. The danger to the drinking water reserves, the pollution of the waters and ground water by industry and agriculture have, together with the damage to the forests, become some of the most important subjects of debate in our time.

The fact that we are at the beginning of a change in almost all spheres of life and that the change — and the time dimension plays an outstanding role here — means that short-term planning directed towards individual objectives must be replaced by long-term planning taking account of the whole system. Control mechanisms in systems do not act from one day to the next but require a certain period of time to bring about changes appropriate to the system with feed-back into the component systems. This applies particularly to us human beings. On this point, another quotation from A. Toffler is appropriate.

> "In a world that changes more rapidly than ever before in the history of mankind, we know lamentably little about how this creature — man — can deal with the change. Psychologists and politicians are continually astonished that many people and groups oppose changes for apparently irrational reasons. The manager of a company who wishes to reorganise a department, the teacher who wishes to introduce a new teaching method, the American mayor who is attempting to achieve peaceful race integration in his community — they all experience this blind resistance at some time. In fact, we know practically nothing about its causes. And why do many people hunger for change and try to bring it about with all their power whereas others try to escape from it?".

5. *Ecological Planning - The Sensitivity Model*

As little planning as possible, as much planning as necessary. This old planning rule corresponds exactly to the maxim for the viability of systems — the maximum amount of self-regulation.

All our activities have always had negative effects somewhere. In order to remove such unfortunate circumstances, a control mechanism has gradually arisen; this inevitably leads to other unfortunate consequences — but at a different place and possibly in another field. These are then removed again by further rules. The resulting regulation density, however. is the opposite of the highest possible level of self-regulation. One of the most important tasks of the future will therefore be to determine which regulations — laws, rules, decrees, DIN standards, guidelines — are unnecessary or even damage the system. It will also be necessary to investigate the extent to which these regulations neutralise one another. However, an "urban ecosystem" will not be able to manage without regulations even in the future.

Requirements of the type quoted above cannot be put into effect by using conventional planning methods. They will, like many similar requirements from earlier planning studies, remain empty formulae if they are not included in a model which illustrates the cross-linkages and effects of these requirements. In a system whose main centres of interest change, the effects which are particularly interesting are those which lead to new network constellations. The more important part of future Land Use Planning is therefore an instrument by means of which the actual effects of the activities in an agglomeration can be modelled visually and mathematically (Fig. 5).

In the model, effects are simulated over a period of time, in contrast to earlier models in which a condition was represented at one particular moment. The model also provides clarity with respect to the intermediate states, which are not currently considered at all but which play a decisive role in the quality of life of the citizens in the case of building projects, which often go on for years. In view of population development and the continually increasing times required for planning and decision (road construction, for example), the question of whether a measure will still be sensible at the time when it can actually be achieved becomes more and more important.

Finally, only by simulation of the system behaviour can the interrelation between the activities of people and the reaction of the environment be illustrated as well as a statement on the viability of a region be made.

These characteristics of the sensitivity model become obvious during a short study of the most important steps. In each area of application, which has to be defined from case to case, only those data are used which are available for the area. New data are only collected if they are of special significance for the area. The "Specific List of the Variables" illustrates the type of data in question.

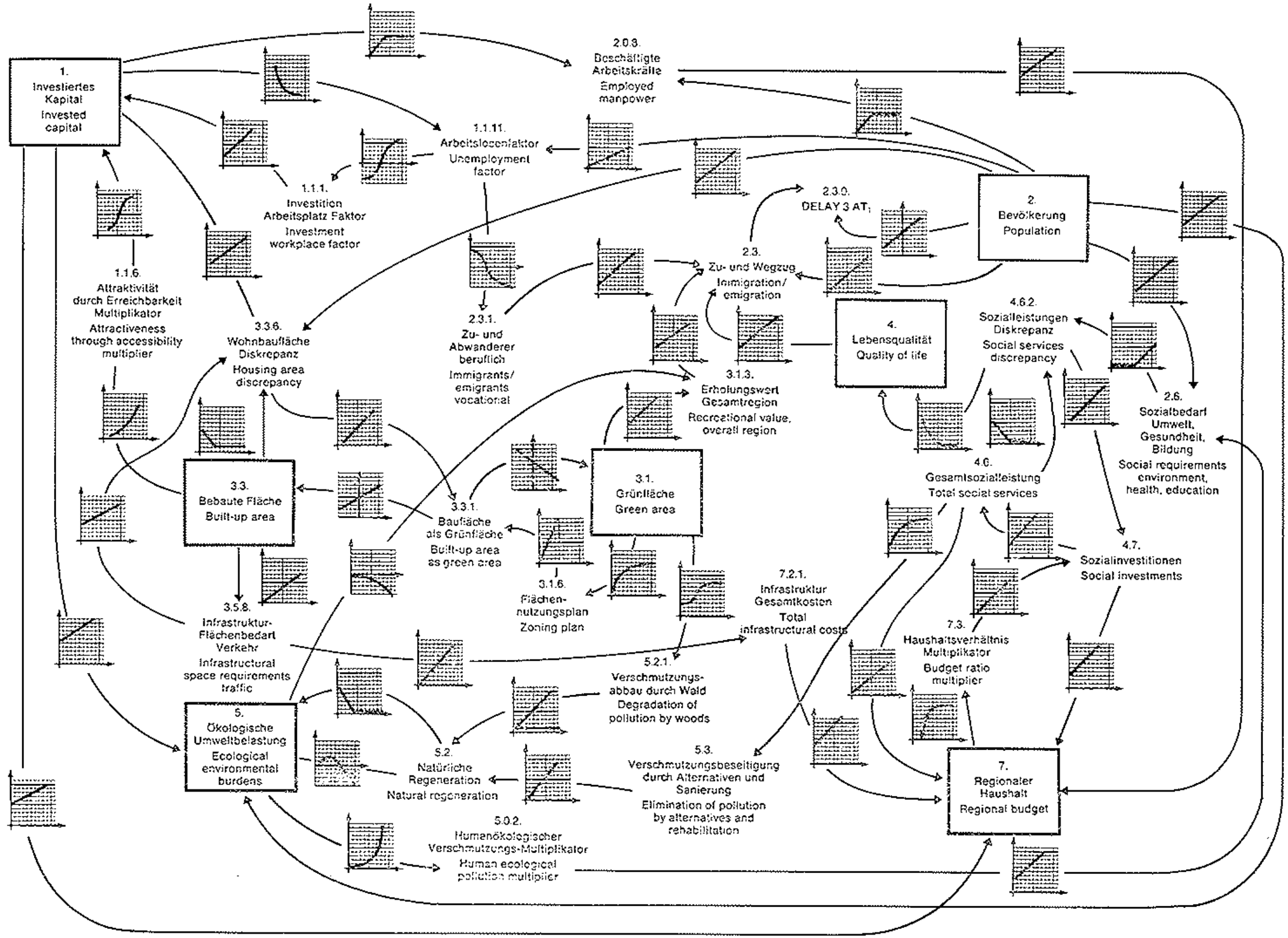

FIG. 5. Visual Simulation Model with Functions.

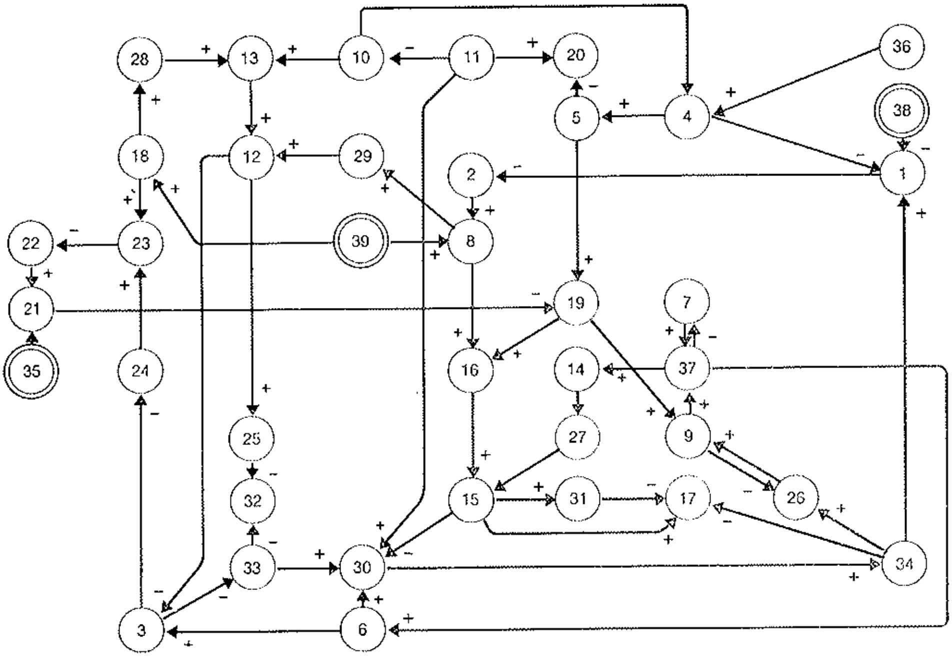

FIG. 6. Example of a Heuristic Pattern of Interactions.

1. Workplaces.
2. Unemployment.
3. Small spacedness.
4. Rationalisation of agriculture.
5. Yields from green areas.
6. Diversity of population.
7. Family size.
8. Commuters.
9. Life expectancy.
10. Convertibility of fallow land.
11. Convertibility of woods into building areas.
12. Road area.
13. Destroyed land use.
14. Land prices, rents.
15. Inadequate soc. quality of life.
16. Inadequate psych. quality of life.
17. Consecutive social costs.
18. Refuse.
19. Reduced air hygiene.
20. Water balance.
21. Diversity of green areas.
22. Quality of water.
23. Ecological burdens.
24. Power consumption.
25. Tourism.
26. Medical services.
27. Shopping facilities.
28. Communications (telephone).
29. Communications (roads, rail).
30. Citizens' activity.
31. Police stations.
32. Reduced ability for activity.
33. Trade taxes.
34. Educational facilities.
35. Topography.
36. Soil quality.
37. Population density.
38. Technology.
39. Wage level.

Wirkung von ↓ auf / Effect from ↓ on →		A	B	C	D	E	F		AS	Q
Stadtplanung / City Planning	A	●						A		
Grünflächen / Green Areas	B		●					B		
Luftverschmutzung / Air Pollution	C			●				C		
Gesundheit / Health	D				●			D		
Individualverkehr / Individual Traffic	E					●		E		
öffentliche Meinung / Public Opinion	F						●	F		
		A	B	C	D	E	F		AS	Q
	PS							PS		
	P							P		

Wirkung von ↓ auf / Effect from ↓ on →		A	B	C	D	E	F		AS	Q
Stadtplanung / City Planning	A	●	3	2	2	2	1	A	10	1,25
Grünflächen / Green Areas	B	0	●	2	2	1	1	B	6	1,2
Luftverschmutzung / Air Pollution	C	2	1	●	3	0	2	C	8	1,14
Gesundheit / Health	D	2	0	0	●	1	1	D	4	0,4
Individualverkehr / Individual Traffic	E	2	1	3	2	●	1	E	9	1,28
öffentliche Meinung / Public Opinion	F	2	0	0	1	3	●	F	6	1,0
		A	B	C	D	E	F		AS	Q
	PS	8	5	7	10	7	6	PS		
	P	80	30	56	40	63	36	P		

In the paper computer, the elements are arranged from top to bottom (influence of) and from the left to the right (influence on). The sequence is immaterial. As the elements in our schema cannot influence themselves, all boxes in which an element comes up against itself are simply marked with a dot. We can immediately begin to assess the several interactions. For example, by inserting the figures 0-3 in the boxes as shown above.

0 = no influence
1 = slight influence
2 = medium influence
3 = strong influence

These entries are made after simply assessing the relative effects. A finely-graduated classification only makes sense if one has sufficient reliable values available and if the cross-linking is continued to a corresponding degree.

When we have answered the question of how strongly each element influences each of the others and have filled out all the boxes, the following simple calculations will already provide answers to the above questions: Adding all the figures next to one of the elements, moving from left to right, produces the so-called active sum (AS) of the element; adding all the figures under a letter, proceeding from top to bottom, produces the passive sum (PS). The element which influences the others most strongly (regardless of how it is influenced itself) will then have the greatest active sum. The element that is most influenced will have the greatest passive sum. To determine the above-mentioned four particular elements, one proceeds as follows:

We divide the active sum of each element by its passive sum (AS : PS = quotient Q). The element with the highest Q value is then the active element, whilst that with the lowest Q will be the passive element. In the next step, we multiply the active sum of an element by its passive sum (AS × PS = product P). The element with the highest P value is then the critical element, the buffer element being that with the lowest P value.

For the six elements used in our schema (city planning, green areas, air pollution, health, individual traffic and public opinion), the "effect values" shown in the specimen would lead to the following assessments:

Active element (highest Q value: E = 1,28) = individual traffic
Buffer element (lowest P value: B = 30) = health
Critical element (highest P value: A = 80) = city planning
Passive element (lowest Q value: D = 0,4) = green areas

Specific List of Variables:

1. *Economy.* Industry, agriculture and forestry, raw materials and energy, services, capital, workplaces.

2. *Population.* Birth and death rates, structure, dynamics and migration, manpower.

3. *Land use.* Fallow land, agricultural and forestry areas, marsh areas, special biotopes, settlements, trade, industry, traffic areas.

4. *Human ecology.* Quality of life, well-being, self-realisation, communal life, security, welfare, education, information.

5. *Natural balance.* Air/water/soil/living world, ecology, output.

6. *Infrastructure.* Traffic, tourism, communications, media, supplies, waste disposal.

7. *Communal life.* Regional and communal budget, taxes, public measures and services, decrees.

These variables are analysed for their significance in the system with the aid of a "Criteria Matrix", and with the same matrix the amount of data will be reduced. Usually, the data set can be diminished from approximately 500 variables to 50.

With these 50 data a "Heuristic Pattern of Interactions" (Fig. 6) can be produced which shows the interrelations between the variables.

Simultaneously, a "Paper Computer" examines for the first time whether the variable plays an active, passive, critical or buffering role within the system.

With the aid of the heuristic pattern of interactions representative persons or groups of the population involved are interviewed in order to check the plausibility of the system interrelationships obtained by the scientists and planners.

This examination results in a "Corrected Pattern of Interactions" (Fig. 7) out of which the simulation model (shown in Fig. 5) can be developed.

The structure of this model leads the user to "his" variables, "his" region and thus to "his" problems. One is not obliged to make use of generalised data, guide values, regulations or standards. On the contrary, the model demands that the user correctly collates the system-relevant

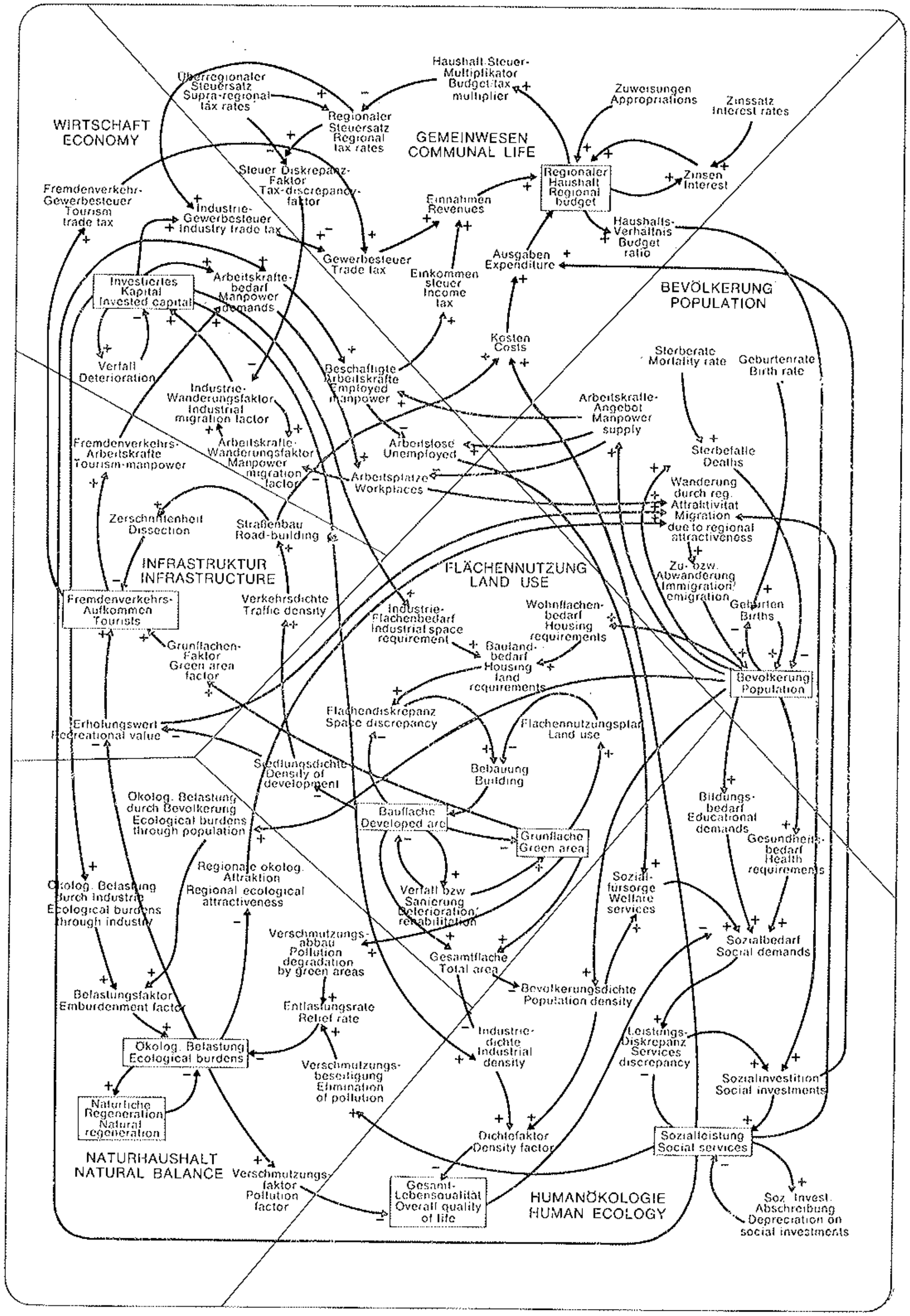

FIG. 7. Corrected Pattern of Interactions.

variables to apply for his region and recognises the typical interactions in the cybernetic sense.

The most important spheres of application for this instrument are:

— demarcation and representation of any type of system;
— determination of the most important factors of influence;
— simulation and development of the system;
— simulation of effects of interference in the system;
— representation of alternative modes of procedure;
— education for interdisciplinary work;
— improvement of decision bases.

With the sensitivity model, which has been outlined here briefly, an instrument was developed which teaches man to *understand* the environment. Only with this understanding the environment can be developed and protected.

In such a model, man can recognise his own location, he can appreciate better his role in the system, he can recognise the reasons for his actions and for those of his opponents and, finally, he can generally decide between several routes to achieve his goal and thus minimise the negative effects in other spheres.

DISCUSSION

BOURDEAU

The methodology you have presented should be applied to concrete projects. You have this table of the possible impact of the project and you come out with the decision of whether to do it or not, or how to modify it. Could you just give us an example, a concrete example, of the application of this methodology?

VON HESLER

We think that first it's very, very important to know what is going on in urban systems. You really don't know where the great impacts on the system are, and, therefore, it's necessary, first, to use the model, only to get an imagination from the system itself, without any impacts. Second, it's possible to see which way it would be possible to go to improve the system. There are more, not only one way, to go. It's possible, there are more ways to go also in political aspects. It's necessary to have some different ways to improve the system, and it's possible to find that out by using the computerized part of the model, to show what is going on in the system over the next ten or fifteen years, in which direction it will develop, without any impact of man or with different impacts. You can also simulate where, on which parts, which areas, if you have done something, you will have some changing patterns. Therefore, I think it's also useful to have this instrument in a developing country. You have to find out what you have to do first. You can then use this model and see what is going on if you change, if you improve on one part of the urban system.

TOLBA

Somewhere in his presentation, Professor Von Hesler said that one of the aims is to check whether the planning — this theory which has been developed some fifty years ago — still retains its validity. Is it urban planning, regional planning, or are you talking of economic development planning?

Von Hesler

Can we include regional and town planning? We have regional and town planning from about seventy years ago, from the beginning of the century. We first did regional planning, then town planning, and, finally, we are into city planning. Let me say that we have excellent land use planning. I was in China recently where I saw a lot of very good land use plans, based on methods developed all over the world some 30, 40 or 50 years ago.

Tolba

I think that my question was probably trivial. Your last comment leads me to think that you are getting into a sort of comparative exercise with China. I cannot see how regional, or urban planning, in the Chinese system and in all the centrally oriented or centrally planned economy countries, which fit into the overall picture of the development planning exercise, could compare with a country which is free in terms of economic development planning and only looks at urban development planning without any constraints. I can't see how the comparison is going to go. I just want some clarification for my own understanding.

Von Hesler

It's not a matter of making comparisons with Chinese planning or with United States models. It's only interesting for us, that — it would be the first time — in any other country with absolutely different conditions, these tools were used to get an impression of a large town. I think that some of the facts, some of the variables we have, are not interesting to the Chinese, or it is politically not possible to discuss them. Nevertheless, the structure of the model will make it possible also to get an idea of such a system in China. Also, you can get decision proposals using the model. It's interesting for us that they use it and we want to know what has to be changed in such a country.

Tolba

I know that our colleague was talking about the situation in Germany where the natural environment is equivalent to nature, and nobody takes into account what you call the artificial system. I think what you call it, in our own jargon, is the built ecosystem or the man-made ecosystem, rather than an artificial system. It's an ecosystem, but it's man-made. I think Dr. di Castri could correct me: we have been working together with UNESCO for almost ten years on what we term human settlements as ecological systems. If in the Federal Republic of Germany they didn't recognize it, it has been recognized, probably internationally, for the last ten years.

Von Hesler

I did this work with di Castri for 15 years. One of the first meetings we had in the UNESCO-MAB programme, Number 11, was in Germany, about nine miles from Frankfurt, and I mentioned it earlier.

THE ROAD TO MONTREAL - AND BEYOND

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As a scientist I am honoured to be invited to address this prestigious body — the Pontifical Academy of Sciences.

As an environmentalist I am encouraged that the Academy has decided to devote a study week to environmental issues during the European Year of the Environment.

As a moslem to address you here in the Vatican on the birthday of our prophet is another example of the ecumenical approach we all take to environmental issues.

As one who tries to use and recruit the most modern methods in the assessment and solution of environmental problems I am delighted that the theme of your study week is "A Modern Approach to the Protection of the Environment".

And as the Executive Director of the United Nations Environment Programme I am pleased to speak on the subject you have requested: "The role of UNEP in the global protection of the Environment".

There could be no more appropriate moment than the present for a study week on the environment by a prestigious scientific institute. There could be no more appropriate moment than the present for me to submit for your consideration a statement on the environment with the emphasis on "*modern*" and "*global*".

On this occasion I shall not present a catalogue of UNEP's activities in protecting the environment. These are, of course, numerous and varied. They embrace every constituent of the physical and natural environment, from the stratosphere to the ocean depths, and include deserts, forests, rivers, wildlife, lakes, soils, genetic diversity, and the environmental impact of chemicals and other substances which modern man produces and disperses.

I should stress that UNEP is not an operational agency. We do not oversee the implementation of projects in the field in the way that, say, FAO does. In a sense, our mandate is more demanding in that we are a catalytic organisation charged with encouraging others to respect the environment.

I note that many of the subjects we deal with are listed on your programme and doubtless other speakers have or will address them. I note also there is a discussion period. So I will take as my main subject today two examples of UNEP in action, examples of UNEP's role in global protection of the environment. This will not be a scientific presentation in the sense my fellow scientists around the table accept. It is rather a presentation actually taking up the point of my colleague Prof. Ives: the tremendous importance of coupling good science with good development planning and good policy making if we are to achieve conservation of our global environment. There are several areas of UNEP activities which I will not mention. I shall be happy to respond to questions on these and other points.

In Montreal, Canada, six weeks ago UNEP had the duty and privilege to convene a meeting of the world's industrialized and developing nations, including the EEC and its Member States, to make an agreement on protection of the global environment against threats arising from the dangerous depletion of the ozone layer. As you all know, the ozone layer shields the planet from excessive ultraviolet radiation from the sun.

The Montreal conference made the historic decision to protect the ozone layer, and thus protect the earth, by limiting the emissions of the CFC family of chemicals and of the Halons which are damaging the ozone layer.

That decision was historic for three reasons:

— It was the first truly global agreement on protection of the environment.

— It was the first global pre-emptive environmental agreement — it looks ahead to face a distant threat and enables action to be taken now to prevent grave damage in the future; and

— It sets a precedent for further global action against global dangers to the environment.

These achievements required a decade of gradually intensifying work by scientists, diplomats, lawyers, and politicians. UNEP was involved in the entire process and since I was engaged at every stage, from the earliest preliminary and exploratory meetings to the final words of the Montreal Protocol, I am able to describe it for you. As scientists I think you will be interested because the contribution of science and scientists was crucial. This was, I believe, a classic example of UNEP applying its catalytic mandate and a classic example of the positive contribution of science to political action. As scientists we can be proud of this work by our fellow scientists.

The story of the Road to Montreal has its earliest beginnings in 1929 at Oxford. There Dr. G. M. B. Dobson began basic studies on atmospheric ozone. Ozone concentrations at ground level are normally very low — fortunately, because ozone is extremely poisonous. However, above the earth ozone is a blessing. Nearly all the atmosphere's ozone is contained in the stratosphere between 10 and 50 kilometres up, with the highest concentrations at 25 to 40 kilometres. Even there it is only about ten parts per million by volume. But life on earth depends on this thin veil because ozone has the ability to absorb ultraviolet radiation from the sun up to wavelengths of about 320 nanometers. Ultraviolet wavelengths of 200 to 280 nanometers, known as UV-C, are lethal but are almost totally absorbed by atmospheric ozone.

Between 280 and 320 nanometers, the spectral band known as UV-B, ozone absorbs most but not all the incoming radiation. Ozone thus acts as a kind of sponge, shielding tbe earth from most harmful radiation. But even at the low levels now reaching the Earth the UV-B radiation causes skin cancer and eye damage. If more radiation penetrates, the impacts on human health, agriculture, plants, marine life, and climate could be very great. Hence the importance of preserving the ozone layer.

In the 1950s, British scientists began studies of the ozone layer using instruments taken into the atmosphere by balloons from bases in the Antarctic.

In the 1960s, this research was continued and extended by American satellite observations. Some years later it was concluded, in retrospect, that the satellite-based instruments had, in fact, measured depletion of the ozone layer, but the measurements were, at first, rejected by the analysing computers. They had been programmed to detect small variations from the norm and therefore dismissed, as faulty, data which indicated large variations. Thus the first evidence of ozone depletion was slow to reach human analysts. But they did pick it up and the search began for the causes — were they natural or were they caused by some activity of man?

The photochemistry of the atmosphere is complicated, but there were rapid advances in knowledge of it in the 1970s and 1980s.

In 1974 two American scientists, Sherwood Rowland and Mario Molina, working at the University of California, advanced the hypothesis that the chlorofluorocarbons (CFCs), commonly used for many domestic and industrial purposes, rise to the stratosphere and cause a catalytic reaction which destroys ozone. This suggestion set alarm bells ringing. They certainly rang at UNEP which had been established by the United Nations two years previously with a mandate to catalyse and coordinate actions to protect the environment. In 1976 the Governing Council of UNEP, the committee of governments which sets our broad policies, directed that this possible threat to the global environment be dealt with.

Early in 1977 UNEP convened a meeting of experts. It adopted a 21-point World Plan of Action on the Ozone Layer and gave UNEP the role and responsibility of collating, disseminating, and encouraging research. A Coordinating Committe on the Ozone Layer was established by UNEP to assist it in coordinating the increasing international research programme and information on the issue, and the carrying out of regular assessments of ozone layer modification and its impacts based on the research results. At that stage there was then no prima facie case against CFCs. But already some governments were very anxious. In 1976 Canada had announced it would order the progressive elimination of CFC-11 and CFC-12 and prohibit their use in non-essential aerosols (spraycans).

In 1978 the United States government prohibited the use of CFCs as propellants in aerosol containers.

And at this time some large chemical companies began research to develop safe substitutes for CFCs.

The worldwide investigation of the extent, composition, and photochemistry of the ozone layer continued and accelerated.

Data were collected from ground stations, from balloons, from rockets, from satellites, and from spaceships carrying instruments and scientists.

The data gradually became more precise as instruments improved. Over the last ten years, sensitive, solid-state high-resolution infra-red detectors, the interferometers, have been developed for recording the flux of solar radiation at the absorption frequency of ozone. Between

1977 and 1985 UNEP, working through the Coordinating Committe on the Ozone Layer, was able to publish seven separate assessments of the severity of the threat to the ozone layer in the light of developing knowledge of atmospheric processes and the trends in the release of chemicals into the atmosphere. Then in 1984/85 there came a scientific bombshell.

On the basis of measurements taken in the Antarctic spring (September-October) of 1984, and on the basis of historical records compiled from the Antarctic since the 1950s, Dr. Farman, a scientist at the British Antarctic Survey, published startling findings. He found that the ozone layer over the Antarctic had been declining sharply since the late 1970s, with recurrent annual depletion of the layer of some 40 percent since 1957 during each southern hemisphere spring.

In effect there was a "hole" over the Antarctic in the ozone layer as big as the United States, and as deep as Everest is high, spreading northwards into the latitude of 40 south. Latest observations from the Antarctic, a few weeks ago, confirm the existence of the deepest hole ever, some 15% additional depletion from 1985.

Why this should happen over the Antarctic was not known then and is not perfectly understood now. But we are getting nearer to knowing.

It had been postulated that the Antarctic ozone depletion is a natural phenomenon linked to the solar cycle, the ozone reduction being caused by enhanced levels of nitrogen oxides produced as a result of increased solar activity. However, the most recent analyses (*Nature*, Sept. 1987) show a striking correlation between low concentrations of Antarctic ozone and high concentrations of halogen compounds. While this is not absolute proof of a cause and effect relationship between halogenated source gases and the Antarctic springtime ozone depletion, it seems to be consistent with such hypotheses. The latest observations, made in September from United States aircraft over the Antarctic, tend to confirm these hypotheses. However, the fact that there was a reduction of the ozone layer of up to 10 percent in one day indicates that there must be an important factor of the climate in the equation.

Against this background of confirmation of depletion of the ozone layer, albeit in a specific area and albeit at least partially by chemical agents produced by man, UNEP convened the Vienna Conference of March 1985. The conference had before it the reports and recommendations of a working group of scientific and legal experts which had been working since 1981, under UNEP auspices, to prepare a treaty for the protection of the ozone layer. The Vienna Conference adopted a convention, which has now been signed by 30 countries, which committed the governments to, and I quote, "take appropriate measures to protect human health and the environment" from adverse effects of human activities which are likely to modify the ozone layer.

In other words, the community of nations decided, on the basis of scientific observations and warnings, to take action against a distant threat, to act in advance and not to wait for incontrovertible proof — proof of cause and effect that might come too late to avoid irreparable harm.

So at Vienna in 1985 the nations decided to do something. It has taken the last two years for them to decide what to do, what first actions to take. In 1986 the National Space and Aeronautics Administration of the United States — whose satellites had produced the spectacular infrared MAPS of the Antarctic "hole" — estimated that an increase of emission rates of the CFC chemicals of 3% could deplete the ozone layer by about ten percent by the middle of the next century. And in the same year the U.S. Environmental Protection Agency said that if CFC emissions continued at recent rates, their damage to the ozone layer would be such as to permit ultraviolet radiation to reach the earth at levels which could cause 40 million more skin cancers and 12 million more eye cataracts over the next century in the United States alone.

At about the same time, Swiss scientists reported evidence of a "hole" in the Arctic ozone layer centred over Spitzbergen, with the ozone layer becoming thinner as far south as Switzerland. At this time also the Coordinating Committe on the Ozone Layer, meeting at the UNEP headquarters in Nairobi, reported that production of the common CFCs had increased by 7% in 1983/84, despite the limitations on some of their uses in North America and Europe.

Clearly, the distant threat was coming nearer. The pressures for global regulations and limitations to reduce emissions of CFCs were also growing. There was also resistance. Some governments thought action was premature. One adviser to a European government was quoted as saying "There is no scientific evidence that suggests we should panic now".

Mr. Chairman, distinguished colleagues, no one was talking about panic. We were talking about prudence. We were talking about caution. We were not talking about a conclusive conviction of CFCs as a culprit. We were talking about a prima facie case. We were talking about *NOT* gambling with the composition of the atmosphere. We were talking about *NOT* gambling with the future of the planet.

And fortunately most governments, most scientists, and most manufacturers were talking with us. I have paid tribute to the contribution of scientists. The governments can properly congratulate themselves. I would like to add a word of commendation for many chemical companies. The Chemical Manufacturers Association, which reperesents most of the chemical industry firms, has acted in a most responsible and supportive way, providing valuable data and analyses. This is significant because great commercial interests are involved. Global production of CFCs is worth over $US 2 billion a year. And they form the base for major industries: refrigeration, air conditioning, electronics, foams, aerosols, fire extinguishers, worth billions more. But research is underway to produce safe substitutes. Again scientists will contribute.

So we came to the year 1987. All those involved in negotiating and drafting regulation of CFCs will long remember the process vividly. We all developed an infinite capacity for taking planes as we travelled from meeting to meeting across Europe. A crucial scientific meeting came at Wurtzburg, West Germany, last April. There UNEP gathered scientists from Europe and the United States, the modellers of the impacts on the ozone layer of nine different scenarios of CFC production control, ranging from moderate limitations to severe restrictions. As you can imagine, it was a difficult problem of mathematics and chemistry.

I think you will be interested in the conclusions of those scientists, for their conclusions were the basis of the Montreal agreement.

First, the modellers from both sides of the Atlantic agreed that, under given assumptions for emissions, all feasible regulations will still result in some degree of ozone depletion. Ozone depletion is here. Legislation, there will be some degree of ozone modification. The central question is how great that depletion will be.

Second, the modellers agreed that regulatory action covering only CFCs 11 and 12 would fail to address the problem of ozone depletion in its entirety. Models showed, for instance, that CFC 113 will play a significant role in the ozone equation, as will Halons, particularly 1211 and 1301. Regulations that failed to take into account these substances would not be adequate.

Third, the modellers agreed that even if ozone depletion is held to minimum levels, changes in the ozone column — changes in the vertical distribution of ozone — will occur. Even without any ozone depletion at all, we may face chemical changes which could alter the face of the earth. Even if the total amount of ozone remains unchanged, its accumulation in the lower levels, the troposphere, could contribute to a global warming.

The fourth finding was perhaps the most significant. Modellers agreed that the rate of ozone depletion depends on the control strategy. They agreed that with no control the ozone layer may be modified to an extent which will certainly increase human cancers, and will probably affect agricultural production, atmospheric pollution, and climate change. And on the other hand, regulations will certainly reduce those risks.

Those scientific conclusions had a crucial impact on the vital, final political and legal negotiations, from April to August 1987, that preceded the meeting, and the agreement, in Montreal.

That agreement was of course ultimately a reflection of the art of the possible. It will mean a reduction by 50% in the consumption of the damaging chemicals by 1999 — twelve years from now. There may be a case to be made for stricter regulation sooner. The agreement is flexible enough to permit further limitations if there is scientific evidence for them. I suspect that evidence will be forthcoming. I expect there will be renegotiation of the regulations to reflect that evidence. A few days after the Montreal signing ceremony, a leading British scientist gave the opinion that there is enough evidence to justify an 85 percent reduction. He said he will be presenting this evidence to UNEP. We retain all the machinery to consider it and will welcome the opportunity. The Montreal Agreement obliges UNEP to continue its role on the issue of the protection of the ozone layer.

The working title I gave to my remarks today is "The Road to Montreal — and Beyond", for what the ozone accord has done is to open the way for a global response to another distant threat: the potentially disastrous modification of the climate. There is an old saying that everybody talks about the weather but nobody does anything about it! The same is true with climate. Even worse, as you know from the scientific literature of the past decade, mankind has, usually unwittingly, been doing a great deal that, apparently, affects climate. In the two centuries or so that encompass the agricultural and industrial revolutions, man has begun to replace nature as the engine of climatic change. And the process seems to be accelerating. I refer here again to what is commonly called the global warming or greenhouse effect. In essence the issue is this: there is no doubt that atmospheric concentrations of CO_2 and other "greenhouse gases" have been increasing and are likely to continue doing so for the next several decades at least. Climate models predict that this will lead to a significant rise in world temperatures, particularly in polar regions, during the next 50 to 100 years. The questions that arise from this process — which, indeed, seems to have started already — have been intensively studied over the last decade. UNEP, in collaboration with the International Council of Scientific Unions and the World Meteorological Organisation, has been assessing the role of carbon dioxide and other greenhouse gases in climate variations since 1980. There seem to be four main points common to all the studies:

— The impacts will vary but all countries are potentially affected;

— The environmental changes related to global warming will take place over decades, maybe centuries;

— The possible causes and effects of global warming are linked to energy, agriculture, population and environment; and

— Uncertainty dominates most aspects of the global warming debate.

These and other fundamentals, and many more debatable matters, will receive intensive scrutiny at two major meetings now being planned with the assistance of UNEP: in 1988, in Toronto, a conference on "The Changing Atmosphere — Implications for Global Security", and in 1990, the WMO World Climate Conference.

Science and scientists are very well aware of the issues. An enormous amount of work has been done, and intensive research continues.

This research generally agrees on some basics:

— Levels of carbon dioxide, the most significant greenhouse gas, are expected to increase 30 percent in the next 50 years;

— This build-up of gases may increase the Earth's global average surface temperature by between 1.5 degrees Celcius and 4.5 degrees by the year 2030 — 42 years from now.

— That would be sufficient to have a major effect on climate — apparently small changes in average temperatures have great impact — for instance during the last Ice age, some 18,000 years ago, the Earth's average temperature was only about 5 degrees centigrade less than it is now.

— In a world warmer by 1.5 to 4.5 degrees, in the northern latitudes winters would he shorter and wetter, the summers would be longer and drier. The sub-tropical regions might become drier than they are now. And tropical zones could become even wetter.

A distinguished American scientist (Francis Bretherton) said recently that the issues involved in the changing of our climate present scientists with a profound challenge. An eminent oceanographer, Roger Revelle, wrote recently that forecasting the temperature and rainfall anticipated from the greenhouse effects is the most intellectually challenging problem now before the international scientific community.

Certainly the research needed, particularly to predict man-made and natural changes, may take decades and involve numerous disciplines. Already the work involves meteorologists, oceanographers, geologists, chemists, botanists, biologists, glaciologists, and paleoclimatologists.

To give one example of the difficulty of the research, it has recently been reported that the 70 million observations recorded during the last 100 years are proving inadequate to distinguish the rise in global sea-surface temperature that is assumed to have already occurred because of the known increases in atmospheric carbon dioxide, which is the principal warming agent.

Another example: an ambitious international research programme is about to be launched (late 1987) known as the World Ocean Circulation Experiment. This has been described as the most complex experiment in the history of oceanography. It will last eight years. By 1995 it should provide the first comprehensive global survey of the physical properties of the oceans, information vitally needed to understand glohal climate dynamics.

However, the difficulty and duration of the scientific tasks set by the greenhouse phenomena do give time to consider the policy options and needs that flow from them. We have an early warning of a later warming. The international action to protect the ozone layer has set an encouraging precedent of the ability of statesmen and scientists to face a distant environmental threat.

But even with precedent to help and guide us, it must be recognised and stated that the policy options to combat or cope with global warming are far more difficult to implement than solutions to ozone depletion. It has been difficult enough to obtain agreement to reduce consumption and production of ozone-damaging substances. Some of those substances have inessential uses which can be discarded. Others are essential in some industries but safer substitutes can be found.

But reducing the build-up of carbon dioxide, and other greenhouse gases such as methane and nitrous oxide, involves decisions much more profound.

There are five possible approaches:

— Reduce the use of the fossil fuels, notably coal and oil, which produce CO_2;

— Reduce activities which produce other greenhouse gases;

— Filter out the greenhouse gases during industrial production and dispose of them, possibly in the oceans;

— Recover greenhouse gases already in the atmosphere and dispose of them elsewhere;

— Accept the changing climate and environment of greater heat, dryer soils, greater rainfall and rising seas and adapt to this evolution.

Clearly action — or a combination of actions — on this global problem cannot be taken by any individual government or group of nations.

The process by which international action could be agreed upon and implemented raises political and diplomatic problems far greater than the legislation to protect the ozone layer and even the nuclear arms control.

But I think it is clear that global warming is on the agenda. It is an unavoidable issue.

I have focused today on just two environmental issues. Each illustrates well the complexity of the tasks facing UNEP, and the scientific and political uncertainty accompanying them.

We face similar problems across the broad spectrum of environmental problems for which there are no quick-fixes, no instant solutions.

I believe that in framing a response to the threat from ozone depletion, UNEP has shown itself equal to complexity. Our every action was rooted in sound science and eventually we got the public and the politicians to listen and take action.

What we saw at Montreal, I believe, was the beginning of a new era of environmental statesmanship, one that takes into account the complexities, the uncertainties and the differences in economic interest that in the past have frustrated concerted action by nations.

Our challenge now is to bring a similar measure of environmental statesmanship to bear on other pressing problems: deforestation, marine pollution, desertification, which threaten this planet's web of life.

The road beyond Montreal is a long one, but at least we have a much better idea now of which direction we are travelling in.

DISCUSSION

Bourdeau

I think that the accomplishments of UNEP's involvement in the ozone layer protection is really a momentous event in the history of the consciousness of environmental issues. It's absolutely remarkable that such an accomplishment was achieved and I think it's an omen for relative optimism in the management of the planet. As Dr. Tolba said, it was relatively simple in relation to future problems like that of climate change, where the difficulties are absolutely fantastic.

In respect to the latter point, as Dr. Tolba undoubtedly knows, there is a group which had a meeting recently to reassess the results of the Villach conference of '85 on climate change, etc., and this group has a second meeting, I think, next week in order to prepare the Toronto conference. The accent seems to be put on the fact of policy approach that would sort of delimit the rate of changes of climate rather than try to resist any change, because the latter seems to be difficult to achieve. Thus, to fix some rates of climate change might be more or less acceptable, and then determine the measures that ought to be taken to constrain the changes within those limits, changes in climate, changes in sea level, changes in other phenomena that are affected by the greenhouse gas circulation. I want to ask Dr. Tolba how he reacts to that sort of approach.

Marini-Bettòlo

Dr. Tolba, you have been speaking about fluorocarbons and their importance in the depletion of the ozone layer. I have heard recently, but I don't have any evidence, that not only fluorocarbons are responsible but also methane and other hydrocarbons. I should also like to know if you have any data on the presence of these hydrocarbons which may give rise together with fluorocarbons to the photochemical reactions which deplete the ozone layer.

Tolba

Concerning the first question, I am aware of the work of the climate group. I think I would be the first one to be extremely supportive and happy if there is a possibility of putting in the way you stated the case, and of course identifying the level of the change that we are experiencing. I take that to mean that the first step would be to try to limit the amount of change in temperature which is assumed to be the main cause of the change in the weather pattern or the climatic changes that are going to happen as well as the increase in sea level temperature and, again, the rise in temperature. This is not going to change the pattern of what we are trying to do in addition to their study, and that is the issue of adjustment or adaptation to actual situations. As an individual responsible to the world community a whole, I cannot abandon them, without flagging the seriousness of the problem because there may not be any way of controlling it. In that case, the only solution is to try to adapt, and to try to adapt early. So, while we are doing this most appreciated exercise of trying to constrain the impacts themselves, we have to work hand in hand to find out what other options are available. That is why I feel that there is too much being placed on the shoulders of the scientific community, and I think the meeting of Montreal, as you kindly mentioned, did not only show that something could be done, but in fact showed that if the scientists get together and make their position clear, then there is no way that governments are going to hide behind what is always said: scientists differ. So we need to get together more regularly and more often, when there are issues that are considered by governments as scientific differences which permit them to take no action.

As to your question, Mr. Chairman, we have presently five chlorofluorocarbons which are controlled: CFC 11, 12 and 113, 114 and 115. All the scientific evidence shows that the five or six other chlorofluorocarbons which are being produced singly or as a mixture of the 115, and additional hydrocarbons, have very little, if any, ozone-depleting capacity. So they are not controlled. There is another family, which is the bromohydrocarbons, called halons. Two of them are more dangerous than the five chlorofluorocarbons that we have controlled. Three of the CFCs have a depletion potential of one unit. One of them has a depletion potential of 0.6, and a fifth has a depletion potential of 0.8 units. Each of the halons has a depletion capacity of no less than 10 units, i.e., 10 times any of the dangerous CFCs, and these are already controlled. In fact, I learned from some of the scientists, at the final phase of the negotiations in Montreal, of a third halon, bromine hydrocarbon, which is equally dangerous, and it is already produced and used in the Soviet Union and Italy. In the informal consultations, it was confirmed that it exists. Consequently, at the last minute, the day before the conclusion of the protocol, we included it in the list of substances which are controlled.

BOURDEAU

I don't want to monopolize the floor, but permit me to add to your question the form of methane. Methane is a hydrocarbon after all, and its concentration seems to increase in the atmosphere due to many phenomena, and this may also play a role, I think, in the warming. It's a greenhouse gas.

TOLBA

Yes, chlorofluorocarbons are globally influential in the warming process. Methane and nitrous oxide are definitely in the warming exercise. I think, if I'm not mistaken, the Chairman was asking about the other ozone-depleting substances and whether they are controlled or not.

MARINI-BETTÒLO

I knew about the properties of the greenhouses gases, but I was wondering if methane could enter into this chemical reaction, together with other compounds, to cause the ozone depletion.

TOLBA

Well, not to my knowledge, Mr. Chairman. Last April, in the meeting of the technical and scientific and technical and legal groups, we had a full scientific group of scientists deal with the ozone layer, to identify the potentially damaging gases and the depletion capacity of each one of them. Methane was never mentioned in any of the discussions by any representative from any country.

PUPPI

Dr. Tolba, I have a very difficult question. I am not asking you to give an aswer but to make some comments. We know that, if the earth is going to warm, there will be a great geographical distribution of precipitations, winds, soil moisture and so on. How is it possible to organize a worldwide response?

TOLBA

We are not organizing a worldwide response at all, because we know clearly that what is missing entirely in the scientific community is an analysis of where the impacts are going to be. Which one of them is going to produce a drought. Is it true that the high latitudes will be a little warmer towards the poles and what the tropical areas will be more wet? We don't know. These are just basic speculations now, and that is why we picked as an example the Southeast Asian point, just one region to which to apply all the scientific knowledge on what is likely to happen as a result of the increase of temperature. What is likely to happen in that particular region if the global increase in temperature goes between one degree and another? And if these are the impacts, what then are the socio-economic responses that the governments of this region should start considering now to adjust to the change if it happens? Otherwise we could have had a global response; but we are fully aware that there is no global response whatsoever, and we have to take it piece by piece. The cake is too big for anybody to take as a whole.

Lundberg

I would like to emphasize what Dr. Tolba has just said. I think that we may get the real proof in a ten-year period or so, but I think we have to run a lot of regional studies to look at their possible impacts. But we cannot sit and wait until the models are detailed: we can use the regional climatic patterns. We have already undertaken a study of Scandinavia, looking into the impact on forestry, agriculture and conservation of the natural ecosystems. What would be the scenario if the temperature rose between 1.5 or 4 degrees, which seems to be the maximum? Joint collaboration between European countries has also been undertaken, and we are looking to doing regional studies on the Alps and the Mediterranean. But I think it's very important to look now into other regions. As Dr. Likens said before, some of the species have a closed adaptive niche. A change in temperature by one degree, as a minimum, might mean that some of the main species, maybe some of the coniferous species, will be threatened, because of the temperature of some of the critical periods during the year, or could be more or less extinct. That would change completely the whole ecosystem in large areas. Consequently I think we have no time to wait and we should start, even if we are uncertain, because we know there is going to be a change, but we don't know when and how.

Tolba

Well, I couldn't agree more with what has been said. I wish we collectively thought so, and, on our own, would have enough resources to supervise three or four regions. I know that the Netherlands is taking a tremendous interest because whatever happeens could wipe out the Netherlands.

GOLTERMAN

Dr. Tolba you have been very tactful, very kind, towards the chemical industry. My national experience is quite different. As late as 1979, I think, the Dutch chemical industry, which, as you know, is responsible for an important part of the growth of fluorinated carbons, refused, or even vetoed, a motion in the National Council for Environmental Protection to reduce the usage of these compounds.

The second example comes from the problem of eutrophication. The industry is still trying to produce some evidence that phosphates are not important in the problem of eutrophication. That brings me to the problem which is not on our agenda unfortunately: the responsibility of industry. Now, it has been said, governments do what we want them to do, because we have been voting for them, and the chemical industry is producing what we want to buy. But how will it be possible to get a great influence on what the chemical industry is producing, because apparently we are buying what they are producing.

I don't think that economic arguments are so important. I am quite sure that industry will discover another product which will probably be more expensive, and it will not be any worse off economically by marketing that product. What I would like to see is some kind of control over what the chemical industry can produce and what kind of advice they can spread out to the news media about the harmlessness of their products, because they have been very misleading in the past.

TOLBA

How did the change occur? I am glad that you mentioned the position in 1979, because in '79, '80, '82 and '83 they were still as negative about UNEP as they were in any response to anything at the international level. The change probably came when we started talking. I personally started talking to the chief executives of industry. Instead of entrenching in positions against governments, non-governmental organizations and scientists I encouraged them to meet together. Somehow they felt that this was a general approach, but they agreed to meet and to be in a minority, in a minority which they themselves financed. The industry financed a meeting which cost more than three quarters of a million dollars, and they constituted no more than 35% of the participants, the rest being governments, non-governmental organizations and the scientific community. To have these chief executives sit down and talk in Versailles, near Paris, for three days in November '84 was a definite breakthrough. They started to acquire a sort of credibility. That is one point.

The second point: they will continue today and tomorrow, the next year and the year after, to say no in the Environmental Council and anywhere else, that this is a matter of competitiveness on the external market, and that you people are asking them to do something which others are not doing and therefore they will lose their competitiveness. This is a matter of trade. It's not a matter of doing it for the love of the environment. They will act like this whenever they see that a treaty possesses loopholes, or whenever they feel that someone is going to play a trade game behind the back of someone else, or when someone else is going to jump into the market of the Dutch, or the French, or the Americans. When they see that such action is solidly blocked, then it is possible to undertake global action country of the Community could sell to others outside the Community was a stumbling block. The country that produces more can sell outside the Community. This is what trade is about and industry does not want to lose in the game. I did ask them before the treaty, what is your realistic approach? How long would it take to get substitutes?

The second point: they will continue today and tomorrow and next year and the year after to tell you no in the Environmental Council and anywhere, to tell the government no; that this is a matter of competitiveness on the external market and you people are asking them to do something which others are not doing and therefore they lose their competitiveness. This is a matter of trade. It's not a matter of doing it for the love of the environment. They will act like this whenever they see that a treaty possesses loopholes, or whenever they fell that someone is going to play a trade game behind the back of someone else, or when someone else is going to jump into the market of the Dutch, or the French, or the Americans. When they see that such action is solidly blocked, then it is possible to undertake global action. If we reach that stage with anything else, nothing is going to be preventing them from responding and they will be very open, provided again that we talk with them. I did ask them before the treaty, what is your realistic approach? How long would it take to really get substitutes? They said, at the highest level, between 4 and 5 years. How long does it take to change the technology to make the new substitutes or the new chemicals? Another 4 or 5 years. That is where we worked out the 8 to 10 years. In return, they gave me all the confidential, classified documents of their estimates of the total consumption by each country in the world. These documents are in their own computers and nobody else has them. I have them and that is what put me in a strong position when I went to negotiate with governments. I knew probably more than what they knew, because of the credibility I had with industry.

We must play the whole game and not only the environmental game. The environment is related to trade, custom harriers, competition, and employment. All of these had to be negotiated for 7 or 8 days in Montreal, as if we were in an UNCTAD or GATT meeting. It was a trade agreement, but nobody argued that the environment was going to be damaged. Can the European Community with its 12 countries become one unit and then play games in between, one party increasing while another decreasing? The fact that each country of the Community could sell to others outside the Community was a stumbling block. The country that produces more can sell outside the Community. This is what trade is about and industry does not want to lose in the game.

III.

SYSTEM-WIDE APPROACH TO THE PROBLEMS OF THE PROTECTION OF THE ENVIRONMENT

PERSPECTIVES OF AIR POLLUTION IN EUROPE

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Introduction

Large parts of Europe are today facing serious environmental problems due to pollutant emissions. The synergetic effects caused by a great variety of pollutants interacting make the problem very complex. Today it is impossible to make predictions of the future impact by using single factors. In the early 70s sulfur dioxide (SO_2) was thought to be the main factor responsible for the forest decline. Since then several hypotheses have been evolved besides the direct effect by SO_2 (Fig. 1):

— ozone injury, aluminium toxicity
— loss of base cations (e.g., magnesium leading to nutrient losses
— nitrogen stress
— organic substances
— heavy metals and natural stress, abiotic and biotic.

The acidification of forest soils leads to a higher mobility of aluminium and toxic heavy metals and thereby has a direct effect on the soil nutrient cycling. Furthermore it has an inhibited effect on soil microorganism, especially fungi and bacteria. The mobility of aluminium species into watersystems, lakes and streams gives a direct impact on fish populations (Hinrichsen, 1986).

The impact by global warming due to increasing CO_2 and other trace gases ("the greenhouse effect") has to be taken into consideration. Within a decade we may have clear evidence of a temperature rise. Different climate scenarios indicate a change by 1.5-4°C by the year 2040 (Bach, 1987). Winds and precipitation patterns may be altered. A temperature

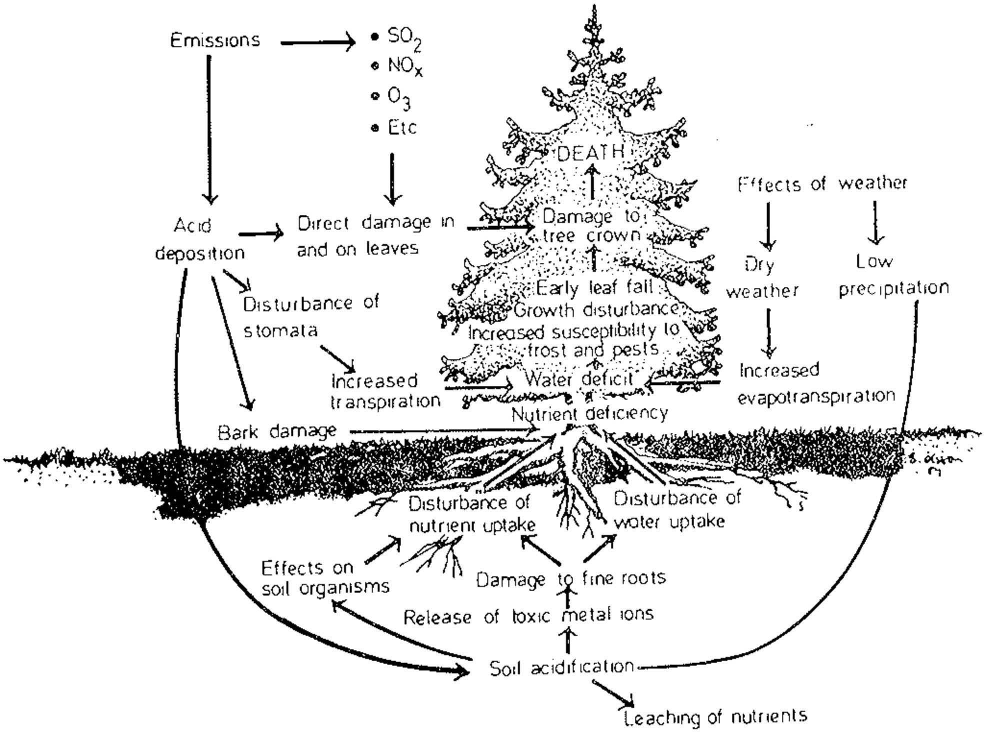

FIG. 1

Source: Report from an expert group appointed by the research board of the faculty of forestry 1984. (The Swedish University of Agricultural Sciences).

rise will probably have an accelerating effect on air pollutants in different ecosystems. The severe impacts made by airpollution in limnic and terrestrial ecosystems are well documented in Europe. Sweden was one of the first countries recognizing the problem due to the impact on lakes. The widespread forest decline in Europe has been recorded from most of the countries (Table 1) and is accelerating especially in the eastern European countries. In order to get an overview assessment of the present situation in Europe and to get reliable predictions for the future, many models have been developed especially on national basis. Two main models for Europe have been developed. IIASA (Institute for Applied System Analysis) has a model which is called RAINS (Regional Acidification Information and Simulation). The second model is called BICRAM (Beijer Institute for

TABLE 1 - *Estimated Forest Damage in Europe, 1985.*

Country	Total Forest Area (thousands	Estimated Area Damaged of hectares)	Portion of Total Forest Damaged (per cent)
Austria	3,754	910	24
Belgium	616	111	18
Czechoslovakia	4,600	1,250	27
East Germany	2,900	350	12
France	15,075	—[1]	—[1]
Hungary	1,600	176	11
Italy	6,363	400	6
Luxembourg	82	42	51
Netherlands	309	138	45
Norway	8,330	400	5
Poland	8,677	600	7
Sweden	26,500	1,000	4
Switzerland	1,200	408	34
West Germany	7,371	3,824	52
Yugoslavia	9,500	1,000	11
Other	39,087	—	—
Total	135,964	10,609	8

Source: Postel, 1986.

Resource Assessment and Management) made by the Beijer Institute of the Royal Swedish Academy of Sciences (Alcamo *et al.*, 1987; Beijer, interim report 1987). The two models use present and future trends of energy consumption linked with different abatement scenarios (e.g., 30% reduction of sulphur) in order to predict possible costs and control strategies. These models are based on submodels of environmental sensitivity, e.g., forests and lakes (Fig. 2).

The different future energy pathways taken by the European countries are crucial questions when forecasting future environmental impacts. Even though technical solutions are available, e.g., flue-gas desulfurization, many countries in eastern Europe are unable to meet the costs in the near future.

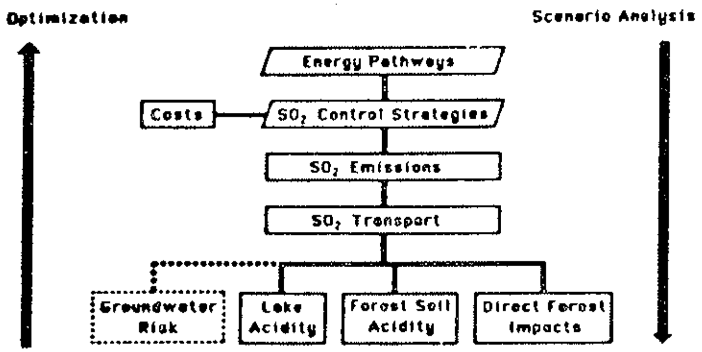

FIG. 2

Source: Alcamo *et al.*, 1987.

ECOSYSTEM IMPACTS

Lakes and streams in Scandinavia are very sensitive to acidification due to the geology. The Scandinavian shield consists mainly of acid igneous rocks (granite, gneiss), and the weathering capacity is slow leading to a low buffering capacity of the forest soils (Fig. 4). The lakes surrounded by thin podzolic soils are especially vulnerable to acidification due to a quick runoff from the catchments areas. Today Sweden has 15,000 acid lakes and 1,500 are seriously affected. Acidified lakes are found in central Europe (the Carpathians) and in the Scottish Highland.

In large parts of southern Scandinavia the soils have become gradually more acid. Reinvestigation of sampled pH measurements from 1927 revealed a general decrease by as much as one pH unit (10 times more acid) in southern Sweden (Hallbäcken and Tamm, 1986) (Fig. 3).

Broadleaved deciduous forests have in general a higher buffering capacity than coniferous forests. The spruce forest is the most sensitive one to air pollutants. Even arable land is becoming more acidified by the intensive use of nitrogen fertilizers and the use of monocultures over large areas in Europe.

The BICRAM report has utilized detailed soil and geological maps as well as vegetation types in order to construct the most vulnerable regions in Europe (Fig. 4). By using detailed submodels, critical levels can be estimated. In the IIASA model different parameters have been used in the soil acidification models, such as, cation-exchange capacity, silicate weathering rate, hydrogen-ion concentration, aluminium-ion concentration.

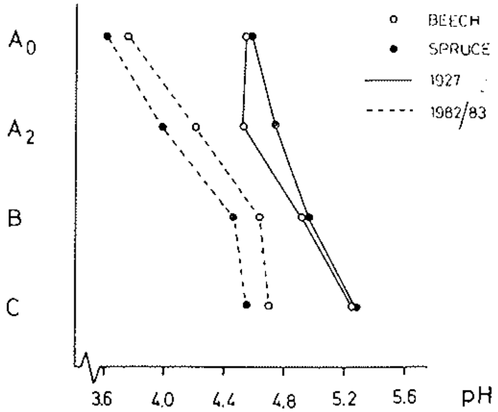

FIG. 3

Source: Hallbäcken and Tamm, 1986.

When constructing ground water models, the following parameters are used: soil base cation contents, soil depth, soil texture, recharge, aquifer size, mineral composition, sensitivity of ground water deposition of sulfur, etc. Even if these submodels are detailed, they lead to very large approximations due to the great variation and complex conditions in the ecosystems.

A lot of data exist about critical levels of different toxic compounds on different plants. Concentrations of SO_2 exceeding 25 microgram/m^3 annually cause direct damage on spruce (*Picea abies*). Ozone and other oxidants, such as peroxyacetyl nitrate (PAN), and hydrogen peroxide are formed by light dependent reactions. These compounds are formed by combustion of fossil fuels. Some examples are given in Table 2 (Skärby and Sellden, 1984).

Using the EMEP model (co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe) the transport of sulfur dioxide over Europe can be established (Fig. 5).

When exceedingly high rates of sulphur deposition and ecological damages appear, the term critical load can be used. The definition could be expressed as "the highest load that will not lead to harmful effects on biological systems in the long term (within 50 years)" (Nilsson, 1986). It is difficult to define and quantify dose-response relationships, but the relative sensitivities of an ecosystem could be assigned. The critical load has been estimated at 0.5 gs/m^2/year in low-buffered surface waters. Large regions in Europe receive 1-5 gs/m^2/year. In this perspective the 30% reduction of sulfur negotiated by many European countries (Table 3) is far from enough to meet the critical sustainability of many ecosystems. It is likely that a reduction of sulfur emissions by 80% is needed. There will only be a very limited recovery of the forest soils in the lowest pH-classes in central Europe if only the 30% reduction is undertaken. The situation will be very much the same for the most acidified lakes. The present and future consumption of different kinds of energy is essential when constructing and predicting models. Data of the use today is avail-

Fig. 4

Source: An interim report - Beijer Institute, Stockholm, Sweden, 1987.

able from, e.g., UN-ECE (United Nations Economic Commission for Europe) and IEA (International Energy Agency) (Table 4).

Coal is expected to be the most important source of energy in the near future (2050) in Europe (Chadwick, Highton and Lindman, 1987). Especially in the eastern European countries the future use of coal with very high sulfur contents (2-5%) will have drastic effects on the ecosystems.

TABLE 2 - *Examples of ozone concentrations resulting in acute and chronic injury, background levels of ozone, and limit values of ozone.*

Concentration µg/m³	ppb	Duration hours	Effect	Note	Reference
100-120	50-60	2-3	Acute	Necrotic flecks on tobacco leaves	(5)
120-160	60-80	1-2	Acute	Necrotic flecks on spinach leaves	(40)
500	250	4	Acute	Necrotic injury on Virginia pine needles	(56)
100	50	6/day for 133 days	Chronic	Reduced seed yield in soybean	(57)
300	150	9/day for 10 days	Chronic	Reduced photosynthesis in Ponderosa pine needles	(58)
300	150	8/day 5 days/week for 6 weeks	Chronic	50% reduced shoot, leaf and root dry-weight of sweet corn	(59)
30-80	15-40			Background levels of ozone	(44)
120	60	1		Limit value, Japan	(44)
120	60	1		Limit value, WHO	(44)
60	30	8		Limit value, WHO	(44)
240	120	1		Limit value, USA	(44)
120	60	1		Suggested limit value, Sweden	(60)

Source: Skärby and Sellden, 1984.

Two Examples: Poland and Czechoslovakia

The environmental situation in eastern Europe due to air-pollutants has become very serious and some regions are at an ecological risk. A triangular area limited by a triangle with its peak in Thüringerwald (East Germany) and the base between Cracow (Poland) and Brno (Czechoslo-

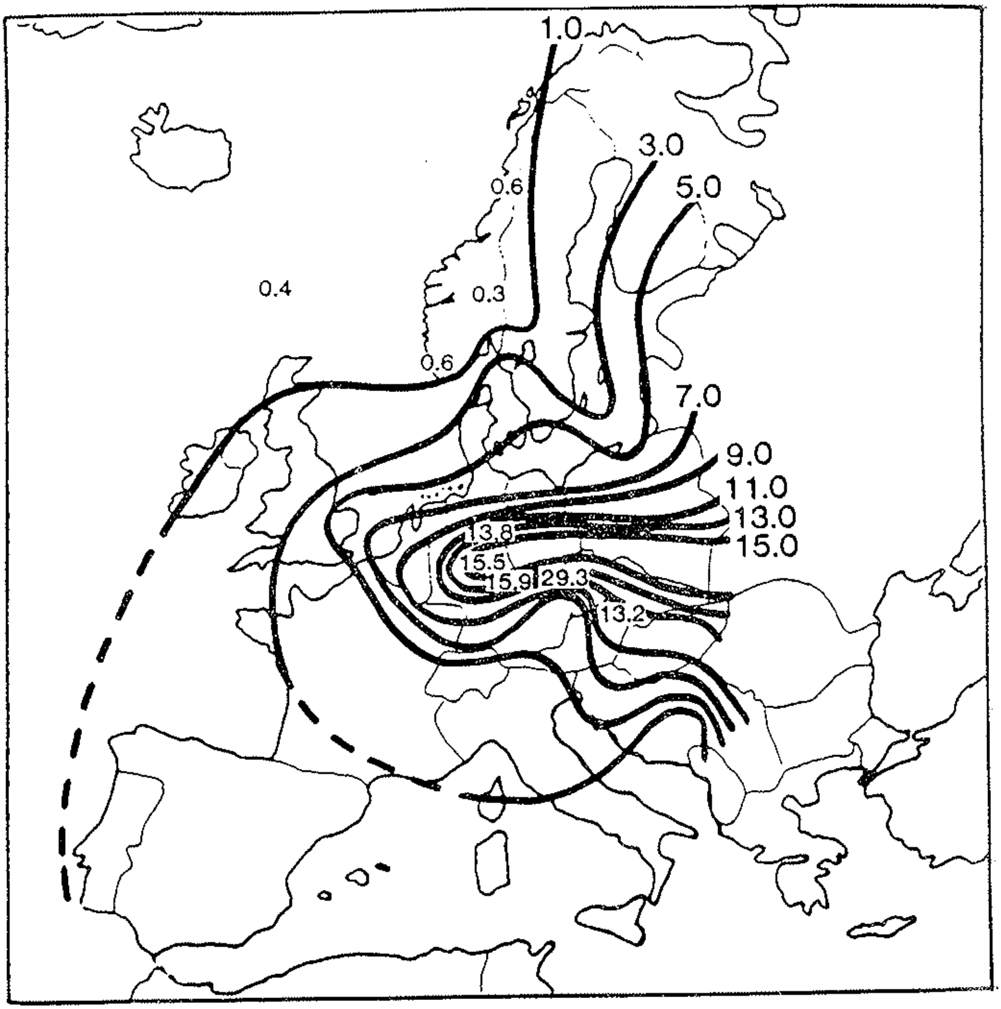

Fig. 5. Annual mean concentrations of sulfur dioxide 1985 ($\mu gS/m^3$).

Source: EMEP CCC - Report 3/87.

TABLE 3 - *Figures based on EMEP's sulfur budget for Europe for 1984.*

Country	Ratio export/import	Import * (%)	Promised reductions **
United Kingdom	10.9	19	30% by 1999
Italy	6.7	22	30% by 1993
Spain	6.7	24	—
D.D.R.	5.9	32	30% by 1993
Hungary	4.8	36	30% by 1993
Czechoslovakia	4.1	42	30% by 1993
U.S.S.R.	3.7	32	30% by 1993
Belgium	3.5	53	50% by 1995
Poland	2.9	42	—
F.R.G.	2.0	53	65% by 1993
Denmark	1.8	69	50% by 1995
Luxembourg	1.7	78	58% by 1990
Ireland	1.4	69	—
France	1.3	60	50% by 1990
Netherlands	1.2	74	50% by 1995
Finland	0.7	74	50% by 1993
Austria	0.6	81	70% by 1995
Sweden	0.4	84	68% by 1995
Switzerland	0.4	89	57% by 1995
Norway	0.2	93	50% by 1994

Figures based on EMEP's sulfur budget for Europe for 1984.

* The import figures show the percentage of the sulfur deposition not originating in the country itself.

** Reductions are from emissions in 1980.

vakia) may be classified among the most industrialized and polluted regions in Europe. Today it is possible to get access to the most accurate data from Poland. There it has been officially recognized that four main areas inhabited by 30% of the population are seriously damaged by pollution. The term eco-catastrophe might be relevant for these areas (Schlesien, Cracow-Katowice, Gdansk, Legnica-Glogow). Another 23 areas are under risk.

Poland derives some 80% of its energy from domestic coal. The wide use of coal and thousands of industries with low or no reduction of emis-

TABLE 4 - *Consumption of commercial sources of primary energy in the Region: 1972, 1982, 1992 and 2002.* (In millions of tons of coal equivalent).

	1972				1982				1992				2002			
	Coal	Fuel oil[1]	Other[2]	Total	Coal	Fuel oil[1]	Other[2]	Total	Coal	Fuel oil[1]	Other[2]	Total	Coal	Fuel oil[1]	Other[2]	Total
Austria	5	12	12	29	5	14	13	32	9	19	16	44	13	15	25	53
Belgium	16	29	21	66	15	25	25	65	18	28	31	77	21	32	37	90
Bulgaria	16	8	6	30	18	15	13	46	28	23	23	74	39	29	34	102
Czechoslovakia	56	14	24	94	63	19	34	116	71	21	46	138	79	22	59	160
Denmark	2	24	2	28	6	17	7	30	11	16	8	35	16	14	9	39
FRG	124	143	102	369	113	126	147	386	148	98	196	442	182	70	246	498
Finland	3	15	4	22	5	15	5	25	9	12	6	27	14	8	6	28
France	50	112	66	228	46	100	93	239	53	68	156	277	60	36	219	315
GDR	80	14	12	106	81	17	26	124	86	17	33	136	90	17	41	148
Greece	2	8	5	15	5	12	3	20	10	16	9	35	15	19	16	50
Hungary	13	8	7	28	12	12	14	38	14	13	18	45	16	14	23	53
Ireland	3	5	4	12	2	5	6	13	4	8	11	23	5	12	16	33
Italy	11	99	70	180	13	92	84	189	18	89	133	240	23	85	183	291
Luxembourg	3	2	2	7	2	2	1	5	3	2	1	6	3	2	1	6
Netherlands	4	22	49	75	5	22	54	81	8	25	66	99	12	27	78	117
Norway	1	8	15	24	1	8	16	25	2	9	20	31	2	10	26	38
Poland	110	8	25	143	161	14	26	201	180	14	40	234	199	14	54	267
Portugal	1	3	2	6	1	5	3	9	2	7	6	15	3	10	8	21
Rumania	12	10	40	62	18	17	54	89	25	21	77	123	32	25	101	158
Spain	14	32	22	68	20	46	28	94	35	52	61	148	50	58	94	202
Sweden	2	36	12	50	2	29	21	52	7	23	24	54	13	15	28	56
Switzerland	1	15	7	23	0	14	9	23	1	16	12	29	1	19	15	35
Turkey	6	14	9	31	7	17	11	35	14	49	42	105	22	80	72	174
USSR	287	253	597	1137	403	330	759	1492	485	371	1180	2036	568	411	1602	2581
UK	118	110	125	353	116	48	140	304	132	51	148	331	149	53	157	359
Yugoslavia	17	10	8	35	20	15	12	47	37	19	22	78	54	22	33	109
Total	957	1033	1248	3219	1140	1036	1604	3780	1410	1087	2385	4882	1681	1119	3183	5983

[1] Includes gas oil. [2] Includes nuclear, hydro, wood, natural gas, petrol and other light petroleum products.

Source: Highton and Chadwick, 1982.

sions at all have caused the serious environmental situation. The average emissions of sulfur dioxide are more than 20 microgram/m^3/year, and large areas get more than 60 microgram/m^3/year (the limit for direct health effects). During extreme episodes, as much as 1,000 microgram/m^3/year have been recorded. These extremes are to be found in the Schlesien-region. In Cracow the deposition of dust is 134,000 tons. The deposition of gases is 570,000 tons, including 102,000 tons of sulfur dioxide, 7 tons of cadmium, 170 tons of lead; 470 tons of zinc and 18,000 tons of iron. The emitters are mainly steelworks, copper industries, refineries, and chemical industries.

In relation to these enormous emissions, direct health effects appear. In the Katowice region 35% of the children and young people have symptoms of lead poisoning. Furthermore, there are 30% more cases of cancer and 47% higher rates of respiratory diseases compared to the whole country. The infant mortality is high. To grow vegetables in the region is under risk. Lettuce has been observed to contain 230 mg Pb/kg while the norm is 3 mg Pb/kg. Approximately 20% of the arable land is not suitable for growing vegetables. Ecosystem studies (Grodzinski, Weiner and Maycock, 1984) made in the region indicate high accumulation of heavy metals in herbivores and carnivores (Table 5).

It is likely that more than 50% of the forests (4.3 million hectares) will be damaged during the coming 10 years. The forest damage in Poland is 7% according to official figures, but in upper Schlesien the figure is as high as 60% (Starzewska, 1986).

TABLE 5 - *Energy and Matter Flow Through Consumers in the Niepolomice Forest Ecosystem. Amounts of heavy metals in biomass of some homeotherm consumer populations in the Niepolomice Forest.*

	Average concentration in body				Biomass standing crop	Total amounts (mg ha^{-1})			
	Cd	Pb	Zn	Fe	g ha^{-1}	Cd	Pb	Zn	Fe
Small birds	0.57	14.8	107.9	355.1	262	0.05	1.27	9.2	30.2
Rodents	1.06	15.6	99.5	264.6	184	0.08	1.1	7.1	19.0
Roe deer	0.20	9.7	103.7	358.8	5.000	0.36	17.3	185.1	640.5
Fox	0.05	21.5	150.1	144.7	65	0.00	0.56	3.9	3.8

Source: Grodzinski, Weiner and Maycock, 1984.

The official strategy for the time up to the year 1990 is to reach a stabilization of emissions by 1995 and then start a decrease. The plan of action emphasizes the following issues:

— conversion into processes dealing with coal enrichment

— desulfurization of exhaust fumes in 200 megawatt generators and district heating plants

— burying of coal in fluidized beds.

For each of these processes at least one construction will be built during the coming 5 years. Poland has also undertaken a nuclear plant program and two reactors are under construction.

* * *

Czechoslovakia is characterized by a high concentration of heavy metallurgical industry, dense urbanisation and intense local and transit transport. As in Poland and East Germany the rapid post-war development of these sources of pollution has lead to a very serious impact on the environment (Binek *et al.*, 1986). The official figure of sulfur dioxide deposition is 3.5 million tons, but the real figure is probably much higher. The fuel sources consist mainly of brown coal with sulfur contents of 1.5-4%. According to prognoses the coal will last until 2060. The emissions of sulfur will gradually increase until the year 2000. One-third of the energy production is going to be replaced by nuclear power by the year 1990 (Table 6).

The most affected areas are to be found in the north-western part of the country (Most-region). Emissions of 155 kg sulphur/ha/year have been recorded. 30% of the forests are seriously damaged and the future scenario is similar to that of Poland with a possible damage of 50% within a ten-year-period. The total loss of forest production in Bohemia is 1.6 million tons m^3/year and it is assumed that these losses will increase to 3.5 million m^3 by the year 1990. The health problems are very much the same in these regions as in similar regions in Poland.

The basic strategy is to reduce the sulfur dioxide emissions according to the 30% commitments, a task which will probably be difficult. Other actions that will be undertaken are

— reducing the total emissions of nitrogen oxide in proportion to the reduction of sulfur dioxide,

— the reduction of total solid emissions below 1 million tons per year,

— to achieve, by the year 2000, a return of sulfur dioxide as well as other polluting substances to the levels existing at the end of the sixties.

TABLE 6 - *Forecast of coal and lignite exploitation and electricity production.*

Year	Coal & lignite (mil. t)		Electricity exploration (TWh)	Nuclear power plants (TWh)
	ČSSR	ČSR		
1965	72,3	48,9	34,2	
1970	81,1	56,2	45,4	
1975	89,0	63,2	59,1	
1980	95,5	69,5	75,3	
1985	100,2	74,7	94,1	
1990	102,8	78,6	115,2	40,0
1995	103,2	80,9	138,2	53,1
2000	101,2	81,4	162,4	69,1
2005	97,1	80,0	186,9	88,1
2010	91,0	77,0	210,8	110,1
2015	83,4	72,4	232,8	134,8
2020	74,7	66,5	251,8	161,6
2025	65,4	59,7	266,6	189,9
2030	55,9	52,4	276,5	218,6
2035	46,7	44,9	280,8	246,5
2040	38,1	37,6	287,6	272,3
2045	35,0	35,0	294,5	294,5
2050	35,0	35,0	311,9	311,9
2055	35,0	35,0	323,4	323,4
2060	35,0	35,0	328,4	328,4

Source: Binck *et al.*, 1986.

FUTURE PERSPECTIVES

The two examples given above (Poland and Czechoslovakia) emphasize the serious situation for large parts of Europe. By using different kinds of models and submodels it is possible to give guidelines for future impacts. By using the data from EMEP (Fig. 5) general transport models of sulfur dioxide can be calculated to give the regional patterns of distribution. Today's data, together with the future use of fuel in individual countries, give the basis for estimating emissions. The general ecosystem sensitivity (Fig. 4) can be based upon submodels for ecosystems (lakes and forests). In order to achieve different abatement strategies, the cost must be included in the models. Tbe BICRAM-model has calculated different cost abate-

TABLE 7 - *Current emissions and depositions of SO_2 by country.* (Thousands of metric tons per annum).

Receivers \ Emitters	Austria	Belgium	Bulgaria	Czechoslovakia	Denmark	FRG	Finland	France	GDR	Greece *	Hungary	Ireland *	Italy	Luxembourg *	Netherlands	Norway	Poland	Portugal *	Rumania	Spain	Sweden	Switzerland	Turkey	USSR *	UK	Yugoslavia *	Unidentified +other areas	Total
Austria	151	9	—	92	—	66	—	39	54	—	33	—	96	—	5	—	23	—	—	6	—	7	—	—	18	19	72	690
Belgium	—	198	—	—	—	50	—	55	5	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—	41	—	21	380
Bulgaria	—	—	270	21	—	9	—	4	14	10	29	—	14	—	—	—	13	—	98	—	—	—	6	79	5	25	70	667
Czechoslovakia	64	30	4	1266	6	223	—	88	438	—	157	—	67	—	18	—	170	—	41	13	—	5	—	89	73	29	218	2999
Denmark	—	—	—	8	109	23	—	6	28	—	—	—	—	—	—	—	7	—	—	—	—	—	—	—	25	—	26	232
FRG	23	110	—	126	12	1160	—	211	265	—	14	—	41	7	57	—	32	—	—	19	—	14	—	18	165	8	192	2474
Finland	—	6	—	22	8	31	260	10	43	—	7	—	4	—	5	6	27	—	6	—	37	—	—	270	32	2	132	908
France	—	97	—	21	—	203	—	1232	45	—	—	11	70	6	30	—	7	—	—	201	—	18	—	—	226	3	398	2568
GDR	—	25	—	146	8	176	—	41	1117	—	10	—	6	—	16	—	41	—	—	—	—	—	—	18	51	3	62	1720
Greece	—	—	60	90	12	6	—	6	7	137	12	—	24	—	—	—	4	—	23	6	—	—	9	24	—	15	84	519
Hungary	25	—	—	120	—	27	—	14	40	—	448	—	46	—	—	—	37	—	45	—	—	—	—	24	7	42	48	923
Ireland	—	—	—	—	—	—	—	4	—	—	—	96	—	—	—	—	—	—	—	—	—	—	—	—	28	—	62	190
Italy	17	6	—	32	—	46	—	104	24	—	25	—	1357	—	—	—	10	—	8	52	—	16	—	13	20	36	223	1989
Luxembourg	—	—	—	—	—	4	—	6	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	14
Netherlands	—	47	—	5	—	93	—	29	13	—	—	—	—	—	99	—	—	—	—	—	—	—	—	—	62	—	26	374
Norway	—	12	—	21	16	41	7	21	50	—	5	—	—	—	7	61	18	—	—	—	26	—	—	50	92	1	178	606
Poland	20	21	5	356	22	165	—	51	478	—	99	—	31	—	17	—	1012	—	37	6	10	—	—	215	73	22	185	2825
Portugal	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72	—	52	—	—	—	—	—	—	70	194
Rumania	10	—	53	97	—	33	—	14	58	6	164	—	46	—	—	—	68	—	822	—	—	—	9	301	13	64	144	1902
Spain	—	6	—	—	—	41	—	74	9	—	—	—	4	—	7	—	—	35	—	1121	—	—	—	—	34	—	266	1597
Sweden	—	15	—	47	44	72	34	29	95	—	12	—	7	—	12	24	55	—	8	—	218	—	—	152	80	4	271	1179
Switzerland	—	—	—	5	—	27	—	45	7	—	—	—	81	—	—	—	—	—	—	6	—	32	—	—	11	2	41	257
Turkey	—	—	49	13	—	10	—	6	13	29	16	—	22	—	—	—	9	—	35	9	—	—	360	107	—	12	190	880
USSR	41	53	122	496	69	393	168	131	636	32	367	11	161	4	57	15	691	—	587	31	100	7	92	22674	236	115	264	27553
UK	—	20	—	11	—	43	—	53	24	—	—	36	4	—	12	—	4	—	—	11	—	—	—	—	1545	—	173	1936
Yugoslavia	41	6	57	99	—	46	—	39	56	9	166	—	224	—	5	—	37	—	74	20	—	—	—	50	15	308	209	1461
Other areas	38	149	150	276	144	522	101	578	481	117	156	106	765	9	133	34	235	33	216	537	119	21	174	1416	1398	120	281	8309
Total	430	810	770	3370	450	3510	570	2890	4000	340	1720	260	3070	30	490	140	2500	140	2000	2090	510	120	650	25500	4250	830	3906	65346

Source: Highton and Chadwick, 1982.

ment strategies. An all-European 80% reduction of sulfur emissions would amount to approximately 300 billion U.S. dollars, the environmental benefits can also be calculated in terms of cost. Still nitrogen oxides are not included in these models and there is no general commitment to reduce them in Europe. At least a reduction by 60% will be necessary to meet the environmental problems. All the synergistic effects of pollutants, e.g., heavy metals and toxic organics, must be included. Also the possible linkages to global impact of climate by the combustion of fossil fuels.

New Strategies

The ultimate strategy is to keep the emissions at levels to maintain the sustainability of ecosystems by using the best available cleaning techniques, e.g., fluidized bed technology, in coal combustion. By using this technology it is possible to reduce the emissions of sulfur to 0.03-0.05 g per Mega Joule. Furthermore, it is needed to:

— use low sulfur fuels
— introduce natural gas on a wider scale
— use energy much more efficiently (savings)
— develop renewable energy sources, e.g., bioenergy, solar energy, windpower, wave energy, etc.

The transboundary air pollution pattern of Europe clearly demonstrates the further need of an intense cooperation between the European countries to find abatement strategies in all fields of environmental problems. The export and import of sulfur dioxide is shown in Table 7.

International agreements are needed for other kinds of air pollutants, hydrocarbons, fluorgases, etc.

The environmental problems are becoming more complex due to synergetic effects, and much more research is needed. Large regions in central and eastern Europe have already passed the limit of ecological tolerance. Today many countries have great difficulties in solving the problems on their own. The ethical aspects of the use of our environment must be an overall assessment. Therefore, it is essential to reach a close European cooperation in all aspects: research, technology, handling of natural resources, etc. It is an impossible task for individual countries to undertake to solve the immense environmental problems.

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DISCUSSION

RAVEN

The problem of acid precipitation, which so clearly requires collective, international action, is paralleled by that of the destruction of tropical forests, by the greenhouse effect, and by the problem of world hunger, among many others. Therefore, the kind of useful analysis that Dr. Lundberg has provided affords us a good model for devising the means of dealing with many of our common environmental problems.

In addition, and specifically, global changes in the atmosphere are progressively limiting our ability to preserve biological diversity. Thus Professor Andrey Molski of the Main Botanical Garden in Warsaw, Poland, has pointed out that none of the botanical gardens of his country may exist in a region unpolluted enough to allow the survival of the more sensitive, threatened, plants that occur in Poland naturally. In a single, concrete example, Dr. Molski's work illustrates the problems that confront us as we strive to preserve the Earth's biological diversity.

JEFFERS

Mr. President, I wonder whether Dr. Lundberg would like to comment on some of the historical perspectives which were involved in air pollution, because I think we should remind ourselves that a large part of today's problems actually arose from attempts we made to improve the environmental situation. I can remember that 30 years ago we had fogs in London in which you could scarcely see even two or three feet in front of you. We no longer have those London fogs although they are still a joke amongst the European Community. I also remember 30 years ago doing research on trying to grow trees in very dirty atmospheres which were really only a few miles from where the smoke was actually being created. We thought we had solved that problem by raising the height of the smoke-stacks which pushed this pollution much higher up into the atmosphere and exported it to a number of other places, including Scandinavia. It's something that isn't often mentioned nowadays: air pollution is a problem which we created to a large extent by taking the heavy particles out of the domestic and industrial emissions through Clean Air Acts and by raising the height of the smoke-stacks to move the pollution higher into the atmosphere. When we export some of our technologies from the north to the south, we must be careful that, in trying to improve economic or environmental conditions, we don't actually worsen the situation by actions for which we haven't predicted the consequences. I wonder whether Dr. Lundberg would like to comment on this need for an historical perception.

TOLBA

Thank you very much Mr. Chairman. I just want to add my voice to that of Dr. Raven on the issue of the globality of the problem. I was also struck by what Dr. Lundberg said in a very strong, graphic, way: nothing can be solved at a single national level because the problems are global. I would like to see this scientific group stress the global aspect and the need for international cooperation.

What surprises me is the concentration on European problems, especially on the poor people in Poland and Czechoslovakia who need help to deal with their environmental problems. For the last ten years, we have been screaming like wolves in the wild that 6 million hectares of land are annually lost to the desert, and that loss is occurring in the Third World. A special account, in the sum of 100,000 dollars, exists for the latter problem. Now, I can foresee scientists gathering to insist that a pan-European fund be established to deal with European environmental problems. How will that be received in developing countries?

I would like to raise another point. The Poles, for example, are arguing very strongly in the international forum that their problem is not financial but technological. They maintain that political decisions impede their access to certain technologies, some of which cannot be exported from European countries or from the United States for fear that they be used militarily. Last June, the Poles fought for a decision in the Governing Council of UNEP to obtain a very fluid formula which allows the free flow of information and technologies pertaining to the protection of the environment. A week ago, that same delegation at the General Assembly told me that it hasn't got any difficulty in obtaining financing, but it simply cannot buy the necessary technologies. How does one solve this kind of problem?

MARINI-BETTÒLO

Thank you Dr. Tolba. Dr. Lundberg, would you please answer the various speakers up to now.

LUNDBERG

I would first like to reply to what Dr. Tolba said. I completely agree with you. My message here was to describe the situation of the European problem. If you compare this problem to the global ones in the Third World, I completely agree with your observations. If you set it in a global perspective, you can also talk about acidification in the tropics, as Dr. di Castri did.

Dr. Raven raised the extinction of species. If you compare the extinction of species due to acidification in Europe, which is important, as you realize from the data from Poland, and we can see changes in the flora in other parts of Europe as well, then I think it might be one of the real threats for many of the plants in the future. If you put that in a global perspective, we are facing the same problem. It's probably more important to deal with the tropical rainforests. But I think it's very difficult to weigh them against each other.

Dr. Jeffers spoke about the historical background of acidification. We know very well that we have had similar situations and events of smog before, and a lot of the history has been recalculated through sediment studies we know fairly well. What is more interesting is what might be the cooperation now being set up. We had a programme running between northern Sweden and the UK which was sponsored by the Central Electricity Generating Board and the National Coal Board. It divided completely the scientific community, and for us it was debatable whether we should get into this cooperation. I think we did the right thing by participating, because we had some impact and the problem was at last recognized.

RAVERA

Your lecture was extremely interesting and I have many questions to ask. I shall limit myself to three. Do you know some cose studies on the combined effects of acidification and eutrophication in Scandinavian lakes? Second, according to Henriksen, the mortality of fish in acidified lakes is principally due to aluminium ions. If I well remember, he carried out laboratory experiments on the combined effects of pH and aluminium. Don't you think that in natural environments, in addition to the aluminium, other causes may be important? For example, the elimination of invertebrates, food for fish, has been demonstrated hy Okland and his wife in several Norwegian lakes. The third question is related to cadmium toxicity to soil microorganisms. We have carried out some experiments on the effects of cadmium on phytoplankton and bacteria. From the results of these experiments it was evident that phytoplankton was less resistant than bacteria; for example, lake phytoplankton declined at concentration of cadmium of some micrograms per litre, while bacterial growth was abolished by some milligrams.

LUNDBERG

I cant's answer all the questions, but I'll try. First, let us face the question about the relationship between the acidification and eutrophication of lakes. There are some studies being conducted into phosphorous cycles, because there seems to be some sort of release of phosphorous due to acidification, but it's still very much uncertain how this cycle works.

Aluminium toxicity in relation to fish is, of course, the crucial problem, as Dr. Ravera mentioned. Especially in the United Kingdom, many experimental studies — lab tests on aluminium — have been done on the episodes. Similar tests have been done in flowing water to collect data to understand the episodes in streams. In these studies, the release of aluminium has been measured. Cages with fish have been located downstream to study dose-response to aluminium. These studies have been conducted in short periods, that is, during the snow melting period. It is obvious that the episode and the aluminium species are most toxic especially to young populations of fish.

I don't know too much about cadmium and plankton and about the relationships of bacteria in lower sediments. As far as I know no studies are being conducted in Scandinavia in these areas, although many studies are being undertaken into heavy metals such as cadmium. In the latter case, fungi and microorganism activity outside smelters has been studied. The significant decrease in soil microorganism activity has been demonstrated by Taylor and his group.

CHEMICALS IN THE ENVIRONMENT

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ABSTRACT — We live, and always have lived, in a chemical environment, but human activities have altered considerably the chemical "climate" by increasing the mobilization of chemical elements and natural substances and by releasing into the environment a large number of synthetic chemicals.

Examples are given of the size of the problem: particulate material, metals, SO_x, NO_x, O_3, CO_2 in the atmosphere; production, use and release of some 60,000 marketed chemicals; major chemical accidents.

Chemicals present a risk to living organisms and may also create global problems such as climatic change. Risk assessment entails the study of sources, pathways and chemical transformations in the various compartments of the environment. Exposure of living targets must be estimated and effects to human health and to the ecosystems studied.

Once a risk is characterized, it should be managed. Appropriate measures may aim at emission reduction through standard setting for effluent streams, development of "clean technologies", testing of new chemicals prior to marketing, restriction of exports of hazardous chemicals, waste minimization and waste detoxification, prevention and mitigation of chemical accidents, etc.

The implementation of these measures should result in reduced exposure of critical organisms to toxicants, which can be checked by sound monitoring programmes. Such environmental regulation should be under constant review in order to address new emerging problems and to keep pace with technological progress.

While a totally wasteless and pollution-free economy appears impossible, the release of potentially dangerous chemicals should be minimized, and kept under well established levels in order to preserve human health and the environmental balance.

INTRODUCTION

Man and the biosphere have always been affected by the presence of toxic or hazardous chemicals in the environment. Thus, volcanoes are emitting large amounts of SO_2 in the atmosphere, bacteria produce extremely powerful toxins (e.g., botulin), some of the most potent carcinogens are synthesized by fungi (e.g., the aflatoxins). Natural chemical accidents may occur which kill thousands of individuals, such as the 1986 massive release of CO_2 from a lake in Cameroon.

Yet, the "chemical climate" (Wybenga and Hutzinger, 1984) has changed drastically as a result of human activities. Man has, on the one hand, greatly increased the flows of natural chemicals in the environment and, on the other, created a very large number of synthetic chemicals, of which many are marketed in sizeable quantities. The whole biosphere is affected by anthropogenic emissions of chemicals and has become part of the technosphere or noosphere (*sensu* Vernadski) (Duvigneaud, 1974).

Consequences have been dire, and in some instances catastrophic. Public and official concern about these "environmental chemicals" is now widespread, and not only in industrial countries. A survey conducted in 63 developing countries showed that problems related to chemicals (pesticides and fertilizers, industrial and toxic waste disposal, oil pollution, vehicular and industrial air pollution) ranked high among all environmental protection issues (Figure 1).

The subject of environmental chemicals is a very broad one. In this short presentation only a brief overview of the whole problem can be given, covering the main scientific and policy aspects.[1]

A modern approach to environmental protection, as far as chemicals are concerned, may be considered as consisting in a risk management operation, based on a scientific assessment of this risk (Figure 2).

The Size of the Problem

Through his multifarious activities, his increasing numbers and economic development, man has become a powerful geochemical agent. By mining, burning fossil fuels, cutting down forests, cultivating the land, draining, irrigating, etc., he has accelerated in many instances the geological sedimentary cycle. In some cases the quantities of materials he has mobilized approach or exceed those of natural phenomena.

Thus, estimates of anthropogenic emissions of particulates in the atmosphere, due to various activities, average 396 million tons per year (Table 1), or 13% of natural emissions. The combustion of fossil fuels alone releases as much mercury as natural weathering of rock (Table 2).

[1] Radionuclides are not considered specifically in the following discussion.

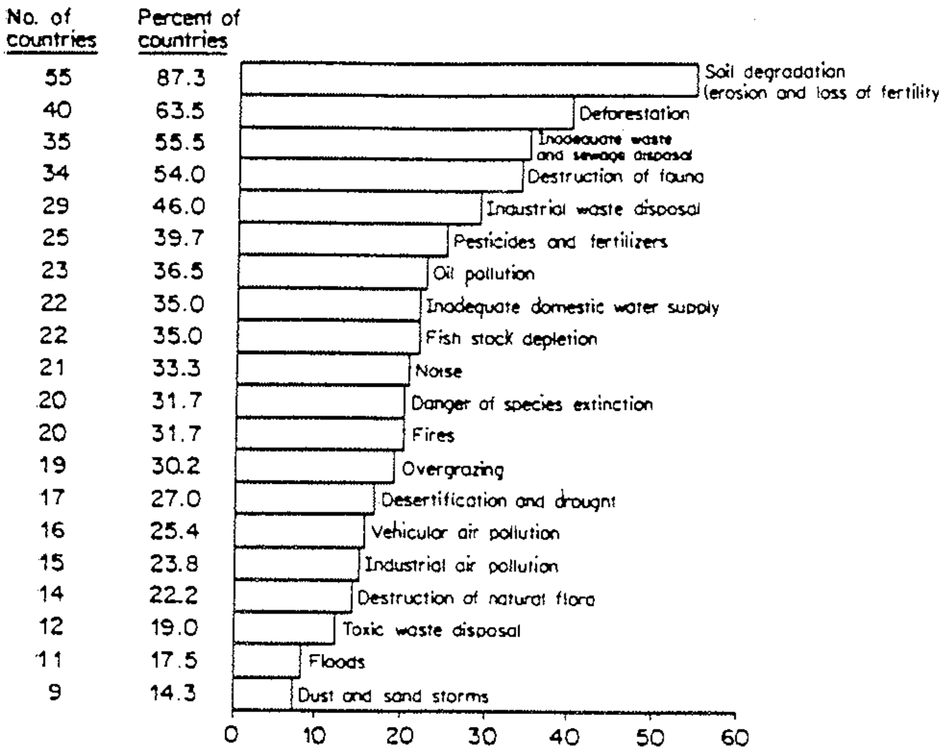

FIG. 1. The 20 most frequently reported causes of environmental risk in 63 developing countries (after Goss and Wyzga, 1982).

It also entails the emission of large quantities of sulfur and nitrogen oxides resulting in acid rain, which may mobilize toxic ions (e.g., of aluminium) in water and soils, and the production of photochemical oxidants.

Fossil fuel burning produces enormous amounts of carbon dioxide (estimated at 5 gigatonnes per year, Figure 3) which, together with other "greenhouse gases" (methane, chlorofluorocarbons, nitrous oxide, etc.), accumulating in the atmosphere, may bring about modifications of global climate which would put entire regions at risk, either through unfavourable climate changes or rising sea level.

Man-made releases of non-ferrous metals (cadmium, copper, nickel, lead, zinc) greatly exceed natural emissions (Table 3) (Nriagu, 1979).

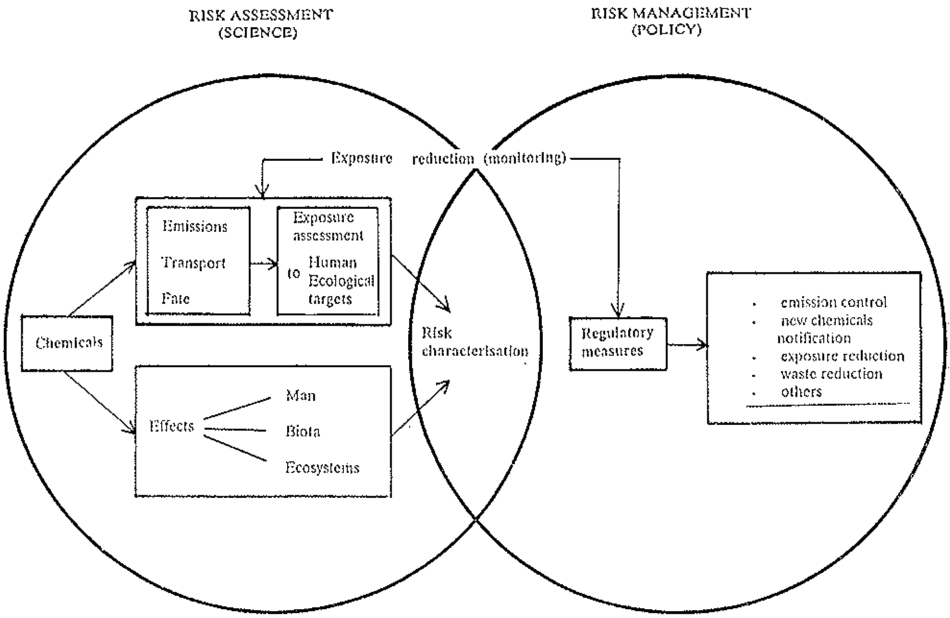

FIG. 2. The relation between environmental protection research (risk assessment) and policy (risk management).

Estimated ratios of anthropogenic to natural sources of various atmospheric gases and other compounds are given in Table 4. They range from 0.6% for ammonia to 88% for sulfur dioxide.

Fertilizers are used in ever increasing quantities (Table 5). Not only do they provide excess plant nutrients which cause eutrophication in water bodies, they also carry impurities which may be harmful to man and other living organisms. Phosphate fertilizers, in particular, may contain hundreds of parts per million of cadmium and uranium which are accumulated in soils, taken up by crop plants and transported along the food chain.

Oil is transported in very large amounts and is spilled accidentally or deliberately in the marine environment.

Asbestos has been used extensively as a heat insulator in buildings, ships and appliances before its carcinogenic properties were discovered.

Of the several million synthetic chemicals in existence, over 100,000 are marketed in sizeable amounts and several hundreds are added each

TABLE 1 - *Estimates of anthropogenic emissions of primary particulates* (adapted from Ellsaesser, 1975).

	Million tons per year
Stationary Combustion	24
Transportation	3
Industrial	50
Solid Wastes	2
Agricultural Burning	22
Slash Burning	5
Miscellaneous	25
Total	131
Secondary Emissions	
Sulfate	160
Nitrate	35
Ammonium	60
Hydrocarbons	10
Total	396

TABLE 2 - *Mobilization of some elements during fossil fuel combustion and during weathering processes* (1000 T per year) (adapted from Goldberg, 1975).

	Fossil fuel combustion	Weathering
Ti	70	108-9000
V	12	32-280
Pb	3.6	21-110
Hg	1.6	1.0-2.5

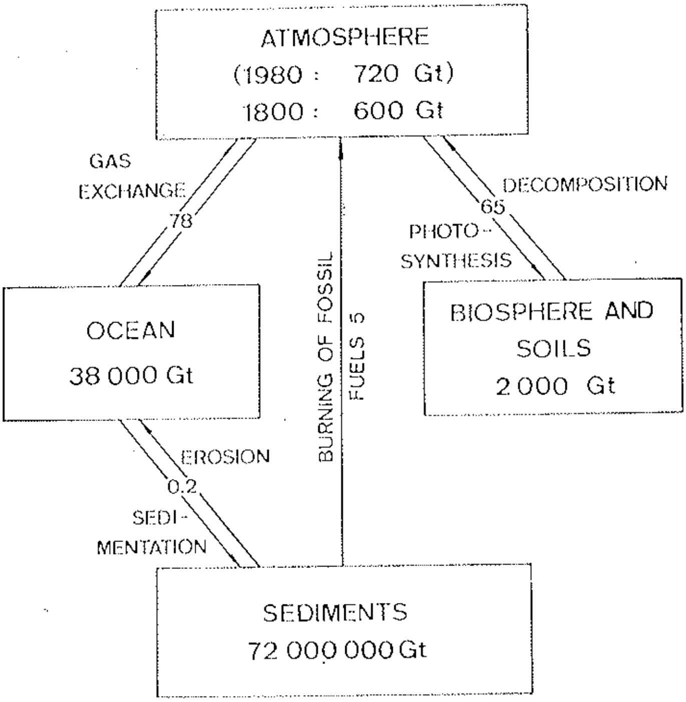

FIG. 3. The carbon cycle. Fluxes and stores in compartments (after Oeschger, in press).

year, not to speak of intermediate compounds and numerous impurities. The volume of base chemicals produced has increased dramatically during the last 30 years to reach over 90 million tons in 1980 (Figure 4). The production of the main organic chemicals in the European Community is given in Table 6.

Thousands of synthetic pesticides are sold in increasing amounts in industrialized and less developed countries (Table 7), and deliberately released into the environment for controlling agricultural pests and infectious agent vectors. The persistence of some of these molecules, particularly the chlorinated hydrocarbons, has led to worldwide dispersion of these chemicals and their degradation products. Impurities such as dioxins in the herbicide 2,4,5, T may present even greater risk.

Industrial chemicals also find their way into the environment, either through emissions from manufacturing plants, during transport and use, or through ultimate disposal as solid or liquid waste. The case of the persistent

TABLE 3 - *Estimated natural and anthropogenic emissions of non-ferrous metals* (adapted from Nriagu, 1979).

	Natural emissions 1000 T per year	Anthropogenic emissions 1000 T per year	*Main Sources*
Cd	0.83	7.3	Cu - Zn production Waste incineration
Cu	18.5	56	Cu production Wood combustion Waste incineration
Ni	26.0	47	Oil combustion Ni production
Pb	24.5	449	Gasoline combustion Iron and steel Cu - Pb production
Zn	43.5	314	Zn production Wood combustion Waste incineration Iron and steel

TABLE 4 - *Global emissions from natural sources and human activities* (from Korte *et al.*, 1987).

	Natural mio T per year	Anthropogenic mio T per year	% of Total
CO_2	600,000	22,000	3,5
CO	3,800	550	13
Aerosols	3,700	246	6
Hydrocarbons[a]	2,600	90	3
CH_4	1,600	110	6
NH_3	1,200	7	0,6
NO, NO_2[b]	770	53	6,5
S-Compounds[c]	304	150	33
SO_2	20	150	88
N_2O	145	4	3

[a] without CH_4
[b] calculated as NO_2
[c] calculated as SO_2

TABLE 5 - *Total quantity of fertilisers used in EEC countries in 1982 in 1000 T.* (adapted from Cooke, 1985).

	N	P	K
The World	60,443	134	19,862
Western Europe	9,760	2,315	4,350
Belgium/Luxembourg	197	41	116
Denmark	376	46	113
France	2,193	732	1,411
Germany	1,323	329	876
Greece	335	68	28
Ireland	275	62	146
Italy	981	303	292
Netherlands	477	35	88
UK	1,386	194	390

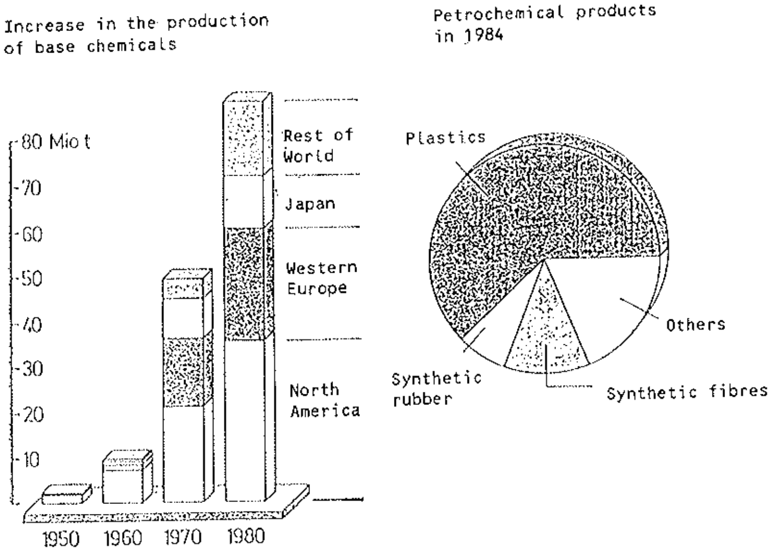

FIG. 4. Production of petrochemicals (after Korte *et al.*, 1987).

TABLE 6 - *Production of various organic chemicals in the European Community, 1979* (adapted from Korte *et al.*, 1987).

Chemical	Tons per year
Chloroform	80,000
1, 1-Dichloroethane	10-20,000
1, 2-Dichloroethane	5,290,000
1, 1-Dichloroethene	3,500
Dichloromethane	245,000
Epichlorohydrin	120-130,000
Hexachloroethane	6,000
Hexachlorobutadiene	
Tetrachloroethene	286,000
Carbon tetrachloride	400-450,000
1, 1, 1-Trichloroethane	123,000
1, 1, 2-Trichloroethane	70,000
Trichloroethene	244,000
Trichloroacetic acid	< 1,000
Vinyl chloride	3,500,000

TABLE 7 - *Consumption of agricultural pesticides in selected Asiatic countries and in Australia* (in Tonnes active ingredient) (adapted from Korte *et al.*, 1987).

Country	Insecticides	Fungicides	Herbicides	Total
Australia	2,306	1,441	6,031	9,778
China	111,950	11,050	70,075	133,075
India	23,954	2,571	723	27,248
Indonesia	4,845	906	833	6,584
Japan	35,245	30,956	15,257	81,458
Pakistan	948	117	36	1,101
Philippines	1,615	832	1,062	3,509
South Korea	6,358	5,502	3,374	15,234
Thailand	3,749	1,780	4,257	9,786

polychlorinated biphenyls (PCBs), used i.a. as heat transfer medium in electrical transformers is well documented.

Disposal of waste in landfill or through incineration is another source of environmental contamination. Materials which are not toxic or exhibit low toxicity may give rise to hazardous compounds such as the dioxins and dibenzofurans, through imperfect combustion.

Some chemically stable consumer products, the chlorofluorinated carbons (CFCs), deprived of any toxicity to man or other organisms, have proved to enhance the decomposition of ozone in the stratosphere, which could dangerously increase the level of ionizing ultraviolet radiation at the earth's surface.

Chemicals may contaminate the environment in three main ways: point spills, chronic local releases and widespread releases (Miller, 1984). Chronic local releases, from point sources or diffuse sources, are probably the most numerous. They are more or less continuous or recurring in time, and affect a fairly large region through air or water contamination. Widespread releases affect the whole or most of the globe. Contamination with DDT, PCB's, radioactive fallout from bomb tests, CFC's and CO_2 belong to this category.

Major chemical accidents (Seveso, Mexico City, Bhopal, Amoco Cadiz, Sandoz at Basel, etc.), the frequency of which has increased recently because of several factors (increasing plant size and transported quantities, proximity of large populations, etc.) may release large quantities of toxic chemicals (or small amounts of highly toxic compounds) into the atmosphere or water bodies, thereby causing death and illness to people, or severe perturbation in ecosystems.

Consequences of Anthropogenic Emissions of Chemicals

Contamination of the Environment

As a result of human activities, many chemicals have been widely disseminated in all compartments of the environment. Their presence as contaminants has been ascertained in lower and lower concentrations due to the remarkable progress achieved in analytical chemistry. Techniques such as atomic absorption spectroscopy, gas chromatography, high pressure liquid chromatography, mass spectrometry, resonance ionization spectroscopy, and combinations thereof, make it possible to detect very small amounts of material (nanogramme or less). In that respect, one of the first and most startling discoveries in the late sixties was that of DDT and its degradation compounds in Antarctic penguins, followed by the identification of PCB's in numerous biological samples in the northern hemisphere.

Chemical Risk Assessment

The very presence of a chemical does not necessarily imply, however, that undesirable effects will be produced either on human health or on non-human biota and ecosystems in general. For this to occur, the biological targets must be effectively exposed to the chemical, and at doses that are toxic.

Thus, an assessment must be made of the risk, i.e., the probability of damage, resulting from the presence of a chemical in the environment. The methodology of chemical risk assessment, outlined in Figure 2, is the object of the recently developed discipline of ecotoxicology. As defined by SCOPE (Scientific Committee on Problems of the Environment), it is "concerned with the toxic effects of chemical and physical agents on living organisms, especially on populations and communities within defined ecosystems; it includes the transfer pathways of those agents and their interactions with the environment" (Butler, 1978).

Chemicals are released either in the atmosphere, the hydrosphere or in the soil or subsoil (Figure 5). Within an environmental compartment

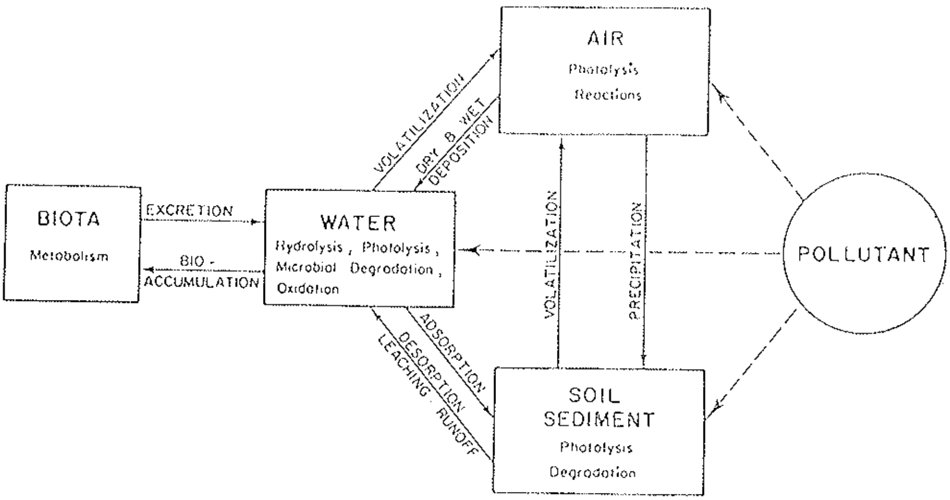

FIG. 5. Transport and transformation processes for pollutants (from Connell and Miller, 1984).

such as air, soil, and water, the movement of a chemical is mostly determined by the principal transfer processes in that compartment. Thus, the transportation of chemicals in the atmosphere may be predicted to a certain extent by using diffusion models combined with meteorological data. Chemicals in the sea are mostly transported by currents, either in the dissolved state or adsorbed on suspended particulates.

If the environment is considered as a system comprised of several compartments, chemicals are transferred across interfaces until equilibrium is achieved. Of course, they continue to cross the interface in both directions but the net movement is equal to zero. Much work has been done to calculate transfer coefficients on the basis of such parameters as fugacity, and the activity coefficient of the chemicals and their concentration. Between two immiscible phases a chemical distributes itself at equilibrium according to a partition coefficient, which depends on the solubility in each phase, and is independent of the quantity of the dissolved fraction. Partition coefficients have been calculated for many organic chemicals, for instance, between water and n-octanol, and this has great value for predicting the behaviour of chemicals in aquatic systems.

The transfer from the liquid or solid phase to the atmosphere is a function of vapour pressure. Co-distillation phenomena may be important and, for instance, enhance the volatilisation of relatively insoluble and low water vapour compounds such as DDT. Once in the atmosphere, pollutants may return to the soil and water compartments through the phenomena of wet and dry deposition.

The pollutant may be transferred through abiotic or biotic processes (see Figure 5). Normally at relatively low concentrations the rate of reaction for a specific process is linearly related to the concentration. Similarly, loss from a compartment can usually be described with the same first order kinetics. A useful parameter is the half-life constant which characterises the persistence of a pollutant in a certain compartment. Complicating matters is the fact that, in reality, discharges of pollutants are often irregular or discontinuous.

In soils, chemicals may be adsorbed onto colloidal particles. Quantitative relationships can be obtained on the basis of Langmuir or Freundlich isotherms. Movement within soils may be through diffusion in the gas/liquid phase or downward transport with water (leaching), which may lead to groundwater contamination.

Polar species are more mobile, thus mobility of organic compounds adsorbed in soil increases in the following order: hydrocarbons, ether, esters, alcohols, acids (Korte, 1987).

Chemicals may undergo transformation processes (Figure 5). These are mostly hydrolysis, photolysis, oxidation, reduction and the various biodegradation processes. Hydrolysis is affected by temperature and pH. Photolysis depends on the intensity of solar radiation in the short wavelengths. It may occur in the atmosphere, on soil surfaces, or in water. It is particularly important for aromatic and saturated compounds. Redox potential may affect the solubility of chemicals, especially metals. This is important, for instance, in rice fields. Metal speciation is in fact an important factor in the mobility and bioavailability of these elements.

Biotic processes involve basically hydrolysis, oxidation, reduction and transformation but occurring in living organisms, particularly microorganisms. An example would be the methylation of mercury by bacteria in river sediments. The biotransformation of organic chemicals may be predicted to a certain extent (Table 8) on the basis of their molecular structure.

Uptake occurs through direct contact (skin, gill, etc.) inhalation, or ingestion. Passive diffusion and active phenomena are involved. After uptake the chemical may be retained, transformed and eventually excreted. The balance often results in a higher concentration of the chemical in organisms. Several terms are used in this respect: bioaccumulation, which is the uptake and retention through any mechanism; bioconcentration, which results from uptake directly from water; and biomagnification wich is the process of accumulation from one trophic level to another (Connell and Miller, 1984).

The quantitative relationships of uptake, retention and excretion have been worked out using compartment analysis, usually not exceeding three compartments, but many uncertainties remain. Bioaccumulation may be predicted with some success on the basis of the n-octanol/water partition coefficient. This is based on the fact that many persistent synthetic chemicals are hydrophobic and liposoluble and that solubility in n-octanol approximates liposolubility. In this way potential bioaccumulation of a chemical may be estimated.

Biomagnification has been invoked to explain the high concentration of persistent pollutants in organisms at the end of the food chain. Thus there would be a selective retention through each passage in the food chain. However, the situation is not that simple and it is more reasonable to say with Moriarty (1983), that the retention of pollutants by organisms

TABLE 8 - *Predictability of biotransformation of chemicals with certain structural characteristics in the soil-plant system* (from Klein and Scheunert, 1985).

Structure Characteristic	Predicted biotransformation products
$-C{=}C-$	$-C-C-$ (bridged by O); $-C(OH)-C(OH)-$; $-COOH/COOH$; unextractable residues
$-C(=O)-O-$	$-COOH$; unextractable residues
Aromatic rings	Phenols; phenylmethylethers
$-OH$ (aromatic)	OCH_3; unextractable residues
$-NH_2$ (aromatic)	$NHCHO$; $NHCOCH_3$; $-NO$; $-NO_2$; $-N{=}N-$; unextractable residues
$-N-C(=O)-N-$ (aromatic)	$-NH_2$ (as intermediate) and resulting secondary products; unextractable residues
$-Cl$ (general)	Decreasing biotransformation with increasing substitution
$-Cl$ (aromatic)	Reductive dechlorination products; decreasing biotransformation with increasing substitution

depends more on differing rates of metabolism and excretion than on the position of these organisms in the food chain or food web.

Toxic effects on the organisms are obviously a function of the absorbed dose and the latter is determined by the intensity and duration of exposure. Toxic effects may be classified as acute, which result rapidly in death or serious physiological disturbances; sub-acute, in the sense that a significant proportion of the population may survive although all individuals present clinical symptoms; and long-term toxicity through cumulative effects and which may lead to long-term serious consequences such as cancer induction or the appearance of mutants in the offspring. In this case, generally, these effects are produced by chronic exposure to fairly low doses.

There is an essential difference in assessing the impact of toxic compounds on man and on ecosystems. In the first case, the obvious concern is the survival and well-being of the individual, whereas, in the second, it is the welfare of the population of a given species and of the community of populations. Consequently, what is in one case an intolerable level of exposure, may be of no great consequence in the other. Of course, sensitivity of plants and animals to a toxic substance may be either lower or higher than that of man. An example of the latter is the response of plants to SO_2 in the atmosphere.

Many examples of the toxic effects of environmental chemicals can be given. As far as human health is concerned, they have been responsible for the death and illness of many individuals, be it mercury poisoning in Minamata (Japan), lead intoxication in slum-dwelling children in the USA, massive killing by methylisocyanate in the Bhopal accident, respiratory diseases induced by high SO_2 and suspended particulates in the air, etc. The epidemiological approach is of primary importance in establishing dose-effect relationship in these cases.

Massive ecological damage has been caused by air pollution (acid deposition and photochemical oxidants) in forests, crops and lakes. Water bodies become eutrophic as they receive excess nitrogen and phosphorous from agricultural land and sewerage.

Pesticides have caused fish kills in rivers flowing in areas treated for insect damage (Mitchell and Roberts, 1984); DDT has caused a decline in predatory bird populations, i.e., by reducing egg shell thickness.

It is noteworthy that chemical stress often acts synergistically with other natural stress (drought, cold, etc.) in damaging ecosystems. In general, the result is not only a reduced productivity of the system but also a loss of biological (species) diversity.

In ecosystems, the fairly rapid effects of chemical pollution on individuals of a given species (biochemical, behavioural, physiological and morphological responses) lead later to an impact on the population of the same species (reduced abundance, altered distribution, change in age structure, altered gene pool). The aggregate effects on the different populations of a given ecosystem result in modifications of the structure and dynamics of the ecosystem (population extinction, dominance switches, reduction in abundance of biomass) and finally on ecosystem function (reduced organic decomposition, alteration of cycles of essential nutrients, reduced primary productivity, alteration of food web and of the functional regulation of ecosystem processes) (Sheehan, 1984).

An example is given in Table 9 which shows that pollution of a forest with cadmium, lead and zinc is associated with an accumulation of litter, probably due to toxic effects on the soil microfauna, which blocks

TABLE 9 - *Litter mass and metal concentrations* (μgg^{-1} dry weight) *at woodlands various distances from the Avonmouth smelter* (from Hutton, 1984).

Wood	Litter mass (gm^{-2})	Distance from smelter (km)	Metal content of litter		
			Cadmium	Lead	Zinc
Moorgrove	8,345 ± 2,131	2.5	23	1,052	764
Blaise	13,160 ± 1,411	2.9	32	721	1,844
Hallen	8,343 ± 598	2.9	62	2,179	2,469
Haw	7,910 ± 640	3.1	98	1,545	2,814
Leigh	1,784 ± 157	6.8	7.2	191	169
Wetmoor	913 ± 100	23.0	1.5	44	80
Midger	3,104 ± 268	28.5	5.7	103	202

the recycling of essential nutrients and eventually the productivity of the system.

Chemicals in the environment also affect non-living targets, such as materials and buildings, thereby causing considerable financial loss (estimated at about 14 billion US dollars for the European Community [ERL, 1983]), as well as irreversible damage to the cultural heritage.

Finally, as already mentioned, the "greenhouse gases" may cause climate changes of still uncertain magnitude and impact.

Risk Management

As mentioned before, environmental protection is a matter of risk management. This is particularly true of chemical risks. Once these are characterized (Figure 2) through multidisciplinary ecotoxicological research, involving chemistry, ecology, meteorology, oceanography, toxicology, probabilistic risk evaluation, etc., decisions must be made as to their acceptability.

Judgements of this kind must weigh the importance of the damage that has happened or could happen against the economic and social cost of reducing its probability of occurrence. Cost-benefit analyses are called for, but as they are limited to monetary terms, they often are unable to evaluate properly the health or ecological damage of environmental alteration. Ethical considerations must be taken into account. In the end most decisions of this kind are political.

A variety of policy measures are available to manage chemical risk, i.e., to maintain it below a prescribed level. Environmental quality objectives set the concentrations of chemicals that should not be exceeded in a given part of the environment, taking account of the use to which it is put. These can be achieved by limiting the introduction of the hazardous chemicals into the environment. Hence the establishment of emission standards and product norms.

The first apply to effluent releases in the air or water. To the second are related the measures applicable to marketed chemicals. Whereas regulations on pesticides, food additives and drugs have long been extant, it is relatively recently that other industrial chemicals have been subjected to pre-market control. Various forms of notification procedures have been introduced in the US (Toxic Substances Control Act), Japan, the European Community ("Sixth Amendment"), and other countries, which illustrate the prevention principle which should ideally apply to all environmental protection problems. Prevention is indeed better, and usually cheaper, than cure.

Under these regulations, manufacturers or importers of a new chemical must notify the authorities in advance and submit the proof of the acceptability of their product with regard to hazard to human health and the environment. The basic set of relevant data pertains to the physico-chemical properties of the chemical, its persistence in environmental media and its toxicity to different groups of organisms, as determined from simple tests. More elaborate data may be required if doubts remain on the relative innocuity of the product. Much research is carried out on improving methods to estimate the toxicity of chemicals. One approach is based on quantitative structure-activity relationships (QSAR).

Existing chemicals marketed prior to the establishment of these regulations are not submitted to them, and a recent inventory performed by the EC placed their number at around 100,000. Most are probably not hazardous but there still remain a sizeable number which have to be studied in depth. How to set priorities for the review of these chemicals is currently an important concern of environmental protection authorities.

A problem which has arisen recently is that of the export to developing countries of chemicals which have been banned in some industrialized countries. International conventions are prepared to regulate this trade. They are based on the principle of "informed consent" of the receiving country's authorities.

Wastes, and in particular hazardous wastes, are produced in ever larger amounts, and possibilities for disposing of them are shrinking. Potential landfill sites are getting scarcer, dumping in the sea is less and less tolerable. Hazardous waste must be recycled, destroyed or detoxified, without producing even more dangerous substances, as may occur in incineration. The ideal solution would be not to generate them. This is impossible, but the amount of waste produced can be minimized through the introduction of "clean" technologies substituting classical industrial processes.

In the last few years trade in toxic waste has become a lively, and lucrative, activity. Here again international agreements must be concluded to control such trade and prevent the transfer of hazardous materials to those countries which are not in a position to enforce stringent regulations.

Concerted action is also needed to deal with the risk of large chemical accidents through preventive (siting, process modification, training of personnel) and mitigating measures (emergency planning, physical loss reduction).

Of special concern are chemical problems which have emerged recently, namely, the threat to the stratospheric ozone layer and the accumulation of greenhouse gases in the atmosphere. Managing the ensuing risks can be achieved only on a global scale. It has been very encouraging that the world nations have agreed to the Vienna Convention on the protection of the ozone layer and signed recently the Montreal protocol on the limitations of CFC's production. This may be considered as a very significant achievement in the management of the global "commons".

Work must be started now on the much more difficult issue of greenhouse gases and climate change.

Conclusions

Chemicals introduced by man into the environment cause a broad range of problems. They may threaten human health, food production systems, ecosystem stability and induce climate modification. Their total banning is inconceivable if the Earth is to sustain its current level of population.

Chemicals must be carefully managed to control the damage they may cause. Constant vigilance must be exercised to detect any emerging problem, which must then be thoroughly researched.

The approach should be preventive rather than curative, and in most instances, international.

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SYSTEM-WIDE APPROACH TO THE PROBLEMS OF THE PROTECTION OF THE ENVIRONMENT: THE MEDITERRANEAN

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When in the 1960s it became fashionable to be concerned with the fate of our environment, the first prophets of environmental catastrophe saw the Mediterranean as a vivid example for things to come. The post-war economic recovery, the rapid increase of tourism, and the ill-conceived coastal developmental schemes were rapidly changing the arcadian tranquillity and serene beauty of the Mediterranean shores and its transparent waters. The changes were too frequent, too obvious and too fast. You did not need to be an especially keen observer to notice them. It was generally accepted that the situation was going from bad to worse and that something had to be done to halt the decline.

The scientists, the public, the media, even the Governments called for action. However, nobody was aware at that time how long and difficult is the road from aroused environmental consciousness to environmental action. Solutions seemed simple and yet the situation was getting worse every year.

In the early 1970s the chances looked very slim for a successful action. The Mediterranean Sea and its shores, this cradle and common heritage of several great civilizations, going back to 5,000 years from the present, seemed in an advanced state of decline.

The once beautiful shores were systematically destroyed by poorly planned development. The proud cities, which meant so much as architectural and cultural monuments, were fast growing into impersonal and unpleasant urban conglomerates. The rich forests covering the islands and the shorelines were rapidly disappearing. The crystal clear sea, which inspired generations of poets, was turning in too many places into murky and smelly bays. The fish and shellfish, so important as a source of proteins for coastal inhabitants, were becoming scarce and unsafe as food. The very air over some parts of the Mediterranean changed from transparent blue into semi-permanent smog, choking people, vegetation and wildlife.

At the time of the Stockholm Conference on Human Environment in 1972, it became obvious that only well planned international action, based on good insight into the problem and supported by political commitment at the highest level and, last but not least, by considerable financial resources, could lead to a solution.

In spite, or maybe just because of the grim picture of the Mediterranean's future and in spite of many pessimistic views about the will and ability of the Mediterranean Governments to find remedies to the common problems of their people, in the climate created by the Stockholm conference, the United Nations Environment Programme (UNEP) selected the Mediterranean region as its first large-scale test ground for the principles endorsed at Stockholm.

The first step taken by UNEP was to convince the Mediterranean Governments that in the interest of the Mediterranean's future they should act before it is too late. And they did, to the surprise of the prophets of doom.

The Mediterranean Action Plan

After considerable preparatory work, in early 1975, sixteen Governments of the Mediterranean States, setting aside their political differences and recognizing the sovereign right of their people to different socio-economic development, adopted an Action Plan for the Protection of the Mediterranean Sea. The Action Plan was a remarkable political document which outlined a complex and comprehensive framework in which the Governments agreed to co-operate on safeguarding the quality of the Mediterranean Basin.

The Action Plan consists of several major interconnected and mutually reinforcing chapters.

A continuing process of *environmental assessment* was expected to provide the diagnosis of the Mediterranean's health, of the causes, sources and magnitude of its deterioration, and to serve as the scientific basis for remedial actions.

The *environmental management* chapter of the Action Plan was designed as a response mechanism to the problems identified through the assessment process.

A wide range of *supporting measures* was also adopted to provide the necessary institutional and financial basis for the Action Plan.

The Barcelona Convention and Its Protocols

The adoption of the Action Plan was followed, within a year (1976), by the adoption of the Barcelona Convention for the Protection of the Mediterranean Sea Against Pollution, accompanied by two protocols, one on control of pollution from dumping, the other on co-operation in cases of pollution from maritime accidents and emergencies. The signing of the Convention and its entry into force in less than two years (1978) was a clear indication that in spite of their different political systems, in spite of their different socio-economic goals and in spite of their different levels of development, the Governments were ready to set aside their differences in order to safeguard their shared environment now and for the benefit of future generations. Later, two additional protocols were added to the Convention, one on the protection of the Mediterranean from land-based sources of pollution (1980) and another on Mediterranean specially protected areas (1981).

The negotiation of the protocol on land-based sources of pollution was particularly difficult as it was estimated that its application may cost the Mediterranean Governments about 15 billion US dollars in the forthcoming years. Today the Convention and its four protocols are in force and serve as the legal basis for the Action Plan. Preparations are well advanced to negotiate an additional protocol on control of pollution from off-shore exploration and exploitation.

The European Economic Community (EEC) joined the Governments of the Mediterranean States as signatory to these international legal agreements and as partner in the Action Plan. Albania remains the only Mediterranean country which does not actively take part in the Action Plan.

The Results

A vast network of national institutions, more than eighty from all Mediterranean States, was organized and engaged in a systematic pollution monitoring and research programme, commonly known as *MED POL*. Its goal is to identify the sources, levels and effects of pollution entering the Mediterranean. The common methodology used by these institutions enabled UNEP, as the secretariat of the Action Plan, to provide a reliable picture of the present state of health of the Mediterranean and to make reasonable recommendations about the measures to be taken in order to remedy the present problems.

The results obtained in the first phase of the pollution research and monitoring programme, which ended in 1981, revealed that the Mediterranean Sea is not a dead sea, that it is not a dying sea, but that it is a sick sea.

It was revealed that the most important sources of pollution are located in the northwestern part of the European coast and along the big rivers flowing into the Mediterranean, although significant point-sources can be found in many other parts of the Mediterranean too. Every year about 120,000 tons of mineral oils, 12,000 tons of phenols, 60,000 tons of detergents, 100 tons of mercury, 3,800 tons of lead, 2,400 tons of chromium, 21,000 tons of zinc, 320,000 tons of phosphorus and 800,000 tons of nitrogen are introduced into the sea from man's activities. The amount of pollutants reaching the sea are very considerable, exceeding in many cases the natural inputs of these substances into the sea. Their concentration in the sea-water, sediments and marine life is often significantly increased. The coastline of the Mediterranean Sea is evidently quite polluted by oil and its derivatives. Eutrophication is evident in some coastal zones and recreational use of previously safe areas is becoming a risky venture. Levels of pesticides and metals in marine organisms have risen.

About eighty percent of the sewage from some one hundred and twenty coastal cities reaches the Mediterranean inadequately treated. Viral hepatitis and dysentery are endemic in the region and there are periodic outbreaks of cholera. Twenty four percent of Mediterranean beaches surveyed through MED POL were not safe for bathing. Only four percent of surveyed shellfish-growing areas were producing seafood safe for human consumption.

The second, long-term phase of the pollution research and monitoring programme, continues the work of the first phase with certain modifications, taking into account the changing needs of the Action Plan.

The results of MED POL are of very practical value. They are used:

(a) for the identification of the most urgent measures which would have to be taken in order to improve the present situation;

(b) for setting common Mediterranean standards for the quality of the environment; and

(c) as an indication for the effectiveness of the measures taken through the Action Plan to curb the inputs of pollutants into the sea.

As concrete practical results of data and analyses obtained through MED POL, the parties to the Barcelona Convention adopted common Mediterranean standards for the microbiological quality of bathing waters and shellfish, as well as for mercury in edible marine organisms. These are just a few examples demonstrating the use of MED POL's results in the context of the Action Plan.

Scientific research, fact finding and critical evaluation are the sound foundations on which the Action Plan rests. However, from the very beginning it was clear that the Action Plan will become fully meaningful only if it is action oriented in terms of problem-solving. Therefore, a great emphasis is laid on activities, on national and regional level, which contribute to this goal.

In order to ensure solutions which are along the line of long-term interest of the Mediterranean Basin, a study popularly known as the *Blue Plan* was launched to explore the interaction between the development and environment in the Mediterranean region. The study consists of in-depth analysis of the present situation and past trends, and of scenarios built for the most likely future developments. The main factors which were analyzed include fresh water resources, industrial growth, industrialization strategies, energy, population movements, urbanization, rural development, tourism and intra-Mediterranean influences.

According to the still incomplete results of the Blue Plan, unless the tendencies of the last 20-30 years are not modified, by the year 2025 the major part (ninety-five per cent) of the Mediterranean coast may be urbanized and may have to support more than 500 million inhabitants, 200 million tourists and 150 million cars. The energy requirements of these will be equivalent to about 1,000 million tons of oil. Several Mediterranean and national scenarios are being developed in order to get a better grasp on these facts and their implications.

Without waiting for the final results of the Blue Plan, a parallel set of activities, called the *Priority Actions Programme*, was initiated in the late 1970s to promote sound environmental management through practical and direct attack on existing problems. They include preparation and testing of guidelines for environment impact assessment and for integrated planning and management of coastal zones, projects on aquaculture development, case studies on rehabilitation and reconstruction of historic centres, and a number of workshops and seminars on subjects relevant to interaction of development with the quality of the coast and marine environment. A target was set to identify and to put under protection, by the year 1995, one hundred coastal historic sites of common Mediterranean interest.

Recognizing that the release of sewage into the coastal waters poses one of the most serious problems for the general public and tourists, the Governments agreed to build sewage treatment plants for all Mediterranean cities with more than 100,000 inhabitants and appropriate outfalls or treatment plans for all cities with more than 10,000 inhabitants before 1995. Likewise, the Governments agreed to establish in their harbours, by the same year, reception facilities for dirty ballast waters and other oily residues from tankers and ships.

Particular attention is given to halting the further destruction and to restoring the damaged coastal ecosystems and to protect the endangered species of animals and plants, almost one hundred of them unique to the Mediterranean. A firm decision was taken to add, by the year 1995, at least fifty new marine and coastal sites or reserves to areas under special protection and to protect species such as the Mediterranean monk seal and turtle from extinction.

Supporting Measures

The institutional support to the Action Plan is provided by its secretariat, the Co-ordinating Unit for the Mediterranean Action Plan, established and operated by UNEP in Athens. The secretariat co-ordinates all activities of the Plan on the basis of decisions taken by regular meetings of the Contracting Parties to the Barcelona Convention, which are the highest and ultimate authority of the Action Plan and the Barcelona Convention. The Parties to the Convention review the progress of the Action Plan, determine its future development and decide about its budget.

The secretariat is assisted in the implementation of the Action Plan by a number of regional and national centres, some of them with a distinctive regional role, as well as by a vast network of national institutions participating in various aspects of the Action Plan. The major regional centres are:

(a) Regional Oil Combating Centre in Malta, operated by the International Maritime Organization (IMO);

(b) Blue Plan Regional Activity Centre in Sophia Antipolis, operated by the Government of France;

(c) Priority Actions Programme Regional Activity Centre in Split, operated by the Government of Yugoslavia; and

(d) Specially Protected Areas Programme Activity Centre in Tunis, operated by the Government of Tunisia with the assistance of the International Union for the Conservation of Nature and Natural Resources (IUCN).

UNEP succeeded to mobilize considerable support to the Action Plan from a number of international organizations, notably from the Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO), United Nations Educational, Scientific and Cultural Organization (UNESCO), International Oceanographic Commission (IOC), United Nations Industrial Development Organization (UNIDO), International Atomic Energy Agency (IAEA), IMO and IUCN.

More than 9 million US dollars have been contributed by UNEP to the development of the Action Plan. UNEP's contributions were gradually decreasing and today the Action Plan is practically self-supporting through contributions of the Parties to the Barcelona Convention to a special trust fund set up by them. The approved budget of the Action Plan, for the biennium 1988-1989, is slightly above 9 million US dollars

Critical Evaluation and Future Prospects

The Action Plan is today a mature and well established programme of co-operation which served as a model for eight additional similar programmes sponsored by UNEP in the framework of its Regional Seas Programme worldwide.

The objectives of the Action Plan are clearly defined and centered on sustainable development of the resources of the Mediterranean Basin, to which correspond specific obligations arising from the Barcelona Convention and its related protocols. During the fourth meeting of Contracting Parties in Genoa (1985), a Declaration was unanimously adopted which went a long way in selecting specific, well defined targets, and established a ten-year limit for them to be achieved.

In spite of this, it is felt that the Action Plan still lacks a clear long-term strategy on how to achieve its main goals and that, as a result, it may be spreading its resources and activities in too many directions and without concentrating on issues crucial for the protection of the Mediterranean. This hampers the Action Plan from becoming the main instrument of a joint co-ordinated policy of the Mediterranean Governments in matters dealing with the environmental protection of the Mediterranean Sea and of the coast of the Mediterranean Basin.

The workplans and timetables adopted for MED POL, for the implementation of the land-based sources protocol and the Genoa Declaration, for the activities of the Split, Tunis and Malta regional activity centres and for the follow-up on the Blue Plan exercise, do not reinforce each other adequately, lack a well-defined common focus, and may fail to achieve the Action Plan's overall objectives even if fully applied under ideal circumstances.

The links between some activities are frequently missing and some of them are developing in a centrifugal way, without providing mutual reinforcement for the main issues on which the Action Plan was expected to concentrate. In addition, most of the activities are mainly oriented towards assessment of the region's environmental problems and only some of them contribute directly to the solution of these problems through management action.

For these reasons the Executive Director of UNEP proposed to the fifth meeting of the Contracting Parties (1987) that the Action Plan should be re-focused on environmentally sound integrated planning and management of the Mediterranean Basin, which was declared as the central objective and the cornerstone of the Action Plan at its adoption in 1975. The proposed re-focusing of the Action Plan would take full advantage of the past achievements of the Action Plan as well as of ongoing activities and structures which could be easily adapted and streamlined to meet the central goal of the Action Plan.

The Contracting Parties noted the proposal of the Executive Director about the refocusing of the Action Plan and instructed their Bureau to analyze its implications.

Conclusions

Today, twelve years since the Action Plan was adopted, the Mediterranean States and the European Economic Community are rightly proud of their achievements. From its modest start twelve years ago the Mediterranean Action Plan blossomed into a full-scale complex programme.

It is true that the Mediterranean is today not clearer than it was twelve years ago, but it is much cleaner than it would have been without the Action Plan. And the time is in sight, 5-10 years from now, when the trend of further deterioration will be generally reversed and the improvements become visible and convincing even for the worst pessimists. Without the full and sincere co-operation of the Contracting Parties to the Barcelona Convention it could not have been achieved.

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DISCUSSION

MARINI-BETTÒLO

Dr. Bourdeau, how have you envisaged the monitoring of trace substances not only in the Community but all over the world?

BOURDEAU

I did not have much of a chance to talk about it yesterday because of the late hour. Obviously some monitoring must be maintained. Monitoring is expensive and it has to be done well to have any meaning. We do think that — at least this is the EEC position — it is essentially a national or local responsibility and that the effort at the international level should be one of making the measurements comparable and ensuring some standards, some quality, in the measurements. Monitoring of gross pollutants, such as SO_2 and particulates in the air, has been going on for many years and even there the measurements are not exactly comparable. The simplest sort of thing can create large difficulties when it comes to ensuring long-term repeated measurements which are reliable. It's a continuous effort which is needed.

Perhaps one should turn more and more to a synoptic type of monitoring with remote sensing devices, either ground-based or satellite-based, because thus you get many more measurements finally for a lower unit cost. It's a very complicated issue. When it comes down to trace at a very, very low level of substances, such as the organic, I'm not sure that a constant monitoring system is really feasible. One should strive, it seems to me, to reduce or prevent emissions at the source.

MARINI-BETTÒLO

The Mediterranean is a very interesting example of the difficulties and the possibilities offered by a closed basin. The Mediterranean has become a great challenge for all countries. Dr. Keckes has underlined the difficulties we encounter when we get out of the phase of assessment of particular interests and costs. I think that the Mediterranean Sea is a very important model and that we must help in implementing the Blue Plan because it is essential to the people along the shore. Dr. Keckes has quoted some figures which are important. I may add that each summer there is a migration every year of about 100-120 million persons to the shores of the Mediterranean. If you compare these figures with those of the barbarian invasions, they represent quite a revolutionary data. As far as health is concerned, there are a lot of diseases that are common to the Mediterranean basin.

GOLTERMAN

As you know I am interested in studies of nutrients and lakes, and I have been making some quick calculations on phosphorus and nitrogen budgets. If the Mediterranean is a sick sea, I would say it is greatly undernourished, although the total input of phosphorus is higher than mentioned in the paper. When I take the data from the Rhone, I have already 10% of the total input, and if I add the Po, I have already 25% of the 320 tons of phosphorus.

I think that one of the major problems in the Mediterranean is that what you get in a certain place stays there. I have been suggesting that it should be possible to maintain the input of nutrients if they are spread out. There is no doubt that fish production in the Mediterranean could be increased greatly; it seems to be a very low productive system. I would like to ask a specific question: How are these phosphorus and nitrogen estimates being made? Is there a suggestion that they should be reduced, or is there a suggestion that they can be spread out more evenly?

KECKES

The Mediterranean Sea is almost a dead sea in a certain sense, that is why it is so blue and transparent. It has very little life. It is a desert because of the low nutrient concentration. On the other hand, the anthropogenic input of nutrients is one of the major problems of the Mediterranean. Not because tbe Mediterranean could not absorb tremendous amounts of nutrients without harm, but because these nutrients are introduced into the Mediterranean in tbe wrong place and in the wrong concentrations. It is nice what you are say about engineering, hut do you know how much a ten-kilometer pipeline costs? For example, in Alexandria, the disposal of sewage is one of the major problems. Three and half million people are there without an adequate sewage disposal system. The cheapest solution to their problem is sewage disposal through a 10-kilometer pipeline into the sea. It costs 1.5 billion US dollars. The question is: Where do you find this money?

While I agree with you that the Mediterranean Sea has tremendous capacity for receiving nutrients, the question is how to utilize this capacity. We are aware of that. The problem is that in many instances the engineering approach failed. The Adriatic coast of Italy, the Adriatic coast of Yugoslavia and in many other places, during the summer, suffers from plankton bloom, through chronic depletion of oxygen and rotting of fish due to well-meant but ill-conceived engineering actions.

GOLTERMAN

In Holland we have been fighting against pipelines going out two or three kilometers into the sea, which were built because they were cheaper than treating the sewage.

MARINI-BETTÒLO

I would like to ask Dr. Keckes another question. Do you have any data about population on the Mediterranean? What is the range from the coast that you assume for considering people as belonging to the Mediterranean basin? Is it linked to rivers which go into the Mediterranean or is there an average range from the coast?

Second point: I think that, beyond all the general scenarios for the Mediterranean, we also have the problem of the Adriatic. The Adriatic is not a deep sea and has a lot of pollution problems every summer. Could you give us some more details about it?

KECKES

The problem was how to define the Mediterranean basin. Geographers and some other specialists tried to help us, but they confused the issue tremendously with semantics. Finally the governments decided that they must be very pragmatic about it; they defined the Mediterranean basin as the sea and the adjacent coast influenced by the sea or influencing the sea. This is obviously a very flexible definition: in the case of France it goes up the Rhone Valley; in the case of the Yugoslav coast it sometimes extends only 100 meters because of the steep mountains.

On the basin of this definition, we consider that today we have permanently around the Mediterranean about 220 million people. The Blue Plan scenario shows that by the year 2025, we can expect 500 million people as permanent inhabitants on the same territory. We expect also that in the same territory, which is now visited by about 100-120 million tourists, we are going to have about 200 million tourists annually, if the the trend remains the same. We can also expect to have in the same area 150 million cars. The energy requirements of these people and of these cars will be equivalent to one billion tons of oil, i.e. one thousand million tons of oil.

We are the secretariat of the Mediterranean Action Plan, but we are not a, supranational police force which could tell somebody what to do. We are now trying to concentrate, for instance, the whole Mediterranean Action Plan on a coastal zone management plan for the Mediterranean.

MARINI-BETTÒLO

The oil mentioned by Dr. Keckes is not only petrol but mainly the exausted oil lubricant. If you now consider that there are 60 million cars at present, and each uses an average of four kilograms of oil, which is changed almost twice a year, you get figures that are enormous, about 500.000 tons per year. I think we should prevent, with some enforcement, that this oil be simply put into the sewage rather but, it should be recycled in order to avoid the pollution of the seas.

RAVERA

Thank you very much, Dr. Keckes, for this very clear exposition about the up-to-date situation in the Mediterranean. Do you think that there is adequate information on the pollutant concentration in marine organisms in order to compare past and present concentrations in marine organisms? The Mediterranean, like all lakes, is not homogeneous? What does it mean then to say that the Mediterranean received a certain load of phosphorus? For instance, in the Adriatic Sea near the coast, we have a very high concentration of phosphorus, that is of the same order of magnitude as the eutrophicated lakes, but in the open Adriatic Sea, especially in the eastern part, we have a concentration of phosphorus quite the same as the ocean, for instance, a few milligrams per cubic meter. Another factor is related to cities. For instance, the Yugoslav coast is very well known for its clean water, but the Bay of Split is very much eutrophicated. The coast of Greece is very well known for the same reason, for tourism, but the Gulf of Salonika concentrates a lot of pollutants, especially heavy metals. The Bay of Kastela is heavily polluted by oil, and so on. It is possible to consider as a unit this variegated mosaic?

KECKES

Professor Ravera is right. I was giving average figures to give you some sort of feeling about the total amount of pollutants, but it is quite clear that this pollution load is not distributed evenly in the Mediterranean. That is the whole problem. The pollution load on the coastal waters is unacceptable in many parts of the Mediterranean and Professor Ravera has referred particularly to two of them, the Kastela Bay and the Gulf of Salonika. Along the coast around Genoa, Marseille, and Barcelona, it is also bad. We are fully aware of that and therefore we are concentrating on action to reduce the pollution input from coastal sources. It's the only way you can solve the problem. The spread of pollutants from coastal sources, once they are released into the sea, is relatively slow and in most cases, affects only the coastal waters of the Mediterranean. There are only a few pollutants that can be measured as increased in the open waters of the Mediterranean, for instance, lead. Generally speaking, if you are two miles from the coast of the Mediterranean, you have to measure very carefully the level of pollutants to say that the Mediterranean is polluted.

Reliable measurements of pollutants in the Mediterranean date back to the late 60s. We started to measure mercury in the Mediterranean in the late 60s. We got high figures and we didn't dare to talk much about them until we found out that everybody had high figures, and that the museum samples also demonstrated high figures. Then we realized that nothing is wrong with our measurements, but something is wrong with our basic assumptions.

I agree with Professor Ravera that historic data is very slim. Therefore we are trying to compare the levels of contaminants or pollutants in the Mediterranean with the levels in other seas. Obviously the Mediterranean is different from the Atlantic. It is a closed sea. It probably always had a higher mercury concentration than the Atlantic, and probably some other metal anomalies have also been present in the Mediterranean from prehistoric times. As I said, we do not have a good series of measurements over a long time period.

Professor Marini-Bettòlo, you have mentioned the problem of oil. This is much more complicated than we believed at the beginning. The release of used lubrificating oils into the sea is much more dangerous than the release of raw, crude oil. But what can we do with it? Recycle it? When we looked into that matter, we were not sure whether recycling is better than releasing it into the sea. Recycling usually means burning it, putting into the air all those elements contained in used lubrificating oil, starting with vanadium chromium, mercury and so on. Ultimately they all end up in the sea. Any other technology for recycling or using used lubrificating oil is too expensive. The Mediterranean basin is using a large amount of coal and a large amount of oil. The burning of both is putting into the atmosphere quite a large amount of various atmospheric pollutants that end up not only in the sea but also on the coastline. By recycling the used lubrificating oil, we would just add a considerable amount to these pollutants.

MARINI-BETTÒLO

Thank you, Dr. Keckes. I think we shall now go on to Professor Puppi's paper. Professor Puppi is Professor of Physics at the University of Bologna. He was engaged last years in organizing at the Academy a very important Study week on the global climate change in the environment. He will present the results of that meeting. So far we have considered only the aspects of limited area programmes; now we are going to have a look at a system wide approach to the problem of global empact mainly on the climate.

GLOBAL CLIMATE CHANGE AND ENVIRONMENT

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A) The Global Climate System Can Be Understood as Follows

I) The system is a *thermodynamical "Closed" one,*

maintained approximately in equilibrium by virtue of an average balance between the fraction of incoming solar radiation absorbed and the amount of infrared radiation emitted in outer space (Fig. 1). This global equilibrium can be expressed in terms of *the constancy of* the mean temperature of the surface of the earth $T_\odot = T(\lambda, \varphi, t)$.

Taking into account albedo (α) and greenhouse (ε) effects, the zero-dimensional balance model can be written as

A1) $$\frac{S_0}{4}(1-\alpha) = (1-\varepsilon)\,\sigma T^4_\odot$$

where S_0 is the "solar constant", and the physical system is assimilated to a simple black body, at Kelvin temperature $T_\odot$.

The main use of this model is for sensitivity analysis of global variations

A2) $$\frac{d\,T_\odot}{T_\odot} = \frac{1}{4}\left[\frac{d\,S_0}{S_0} - \frac{d\alpha}{1-\alpha} + \frac{d\varepsilon}{1-\varepsilon}\right]$$

A variation of 1°K in $T_\odot$ can be produced by variation of $\sim 1\%$ in the governing parameters S_0 α, ε.

	TW
Incoming solar radiation	178.000
Conversion into heat	76.000
Reflected solar radiation	62.000
Water cycle	40.000
Conversion into mechanical energy (Winds, waves, convection and marine currents)	370
Photosynthesis	40
Geothermal flux	32
Anthropic	8
Tidal phenomena	3
Volcanos - hot sources, earth quakes	.3

1 tw = 10^3; gw = 10^6; mw = 10^9; kw = 10^{12}w

FIG. 1. Power flow balance.

The balance between solar energy absorbed and infrared energy emitted, true on a planetary scale, is not true as a function of latitude, the energy absorbed being greater than the energy emitted at low latitudes and vice versa at high latitudes, causing a heat transfer from the equator to the poles.

A one-dimensional balance model should contain this term of transport of heat $\tau(\lambda)$ and be written as, averaged over φ and t:

$$\text{A3)} \qquad \frac{S_0(\lambda)}{4} [1 - \alpha(\lambda)] = I(\lambda) + \tau(\lambda)$$

where $I(\lambda)$ represents infrared emitted radiation.

Both $I(\lambda)$ and $\tau(\lambda)$ depend on the local temperature T_λ and can be expressed consequently.

Now the thermal history of the earth in the last million years shows variation in $T_\odot \sim$ a few % around the actual value of 288° K so that the right-hand side of equation A3 can be approximated by a linear function in T(λ) [1].

A4) $$\frac{S_0(\lambda)}{4}[1-\alpha(\lambda)] = [a + b\,T(\lambda)] + \beta\,[T(\lambda) - T_0]$$

This dependence on T(λ) can justify the Milankovich theory, in which variations in the thermal regime of the earth are primarily due to variations of incoming solar energy as a function of latitude, due to the various changes in the characteristics of the earth orbiting around the sun (precession, axis inclination, eccentricity).

The time scale of these periodic phenomena being in the range ($10^4 \div 10^5$) years, it should be possible to understand the sequence of glacial and interglacial periods in the last million years and it turns out to be apparently so.

In fact, all three fundamental periodicities of orbital motion [20,000, 40,000, 100,000 years] are clearly present in the thermal history of the earth, but the amplitude of the signal cannot be so simply related, as in equation A4, to the amplitude of the forcing, due to the non-linear intrinsic nature of the climatic system.

Upgrading of balance models is possible along the following lines [2]:

i) the surface temperature $T(\vec{r}, t)$ is a function of geographic position ($\vec{r}$) and time (t)

ii) incoming solar radiation as $S_0(\lambda, t)$ and emitted infrared radiation as a function of "local" temperature $T(\vec{r}, t)$

iii) different absorption of solar radiation in different points of the earth's surface (plus atmosphere) represented by a function $C(\vec{r})$, a "heat capacity" which has quite a different value over ocean, land, criosphere [60:9:1] and enters in the balance equation via a new term

$$C(\vec{r})\frac{\partial}{\partial t}T(\vec{r}, t)$$

The model is now able to reproduce seasonal effects not only at present but also in the past with a different geographical distribution of continents [plate tectonics].

It is able also to inspect future possible scenarios with hypothetical changes (for example, changes in greenhouse effect).

It is not able, because of its nature of "balance model", to *predict* the future behaviour of climate.

II) *The System is Physically Composed of Various Subsystems* (Fig. 2)

These sub-systems exchange among them not only heat but also matter; each of them is therefore an open system interacting with the others and exchanging heat and matter with various time constants and various intensities; they participate in the overall instantaneous balance of the global system with contributions related to their instantaneous thermal condition.

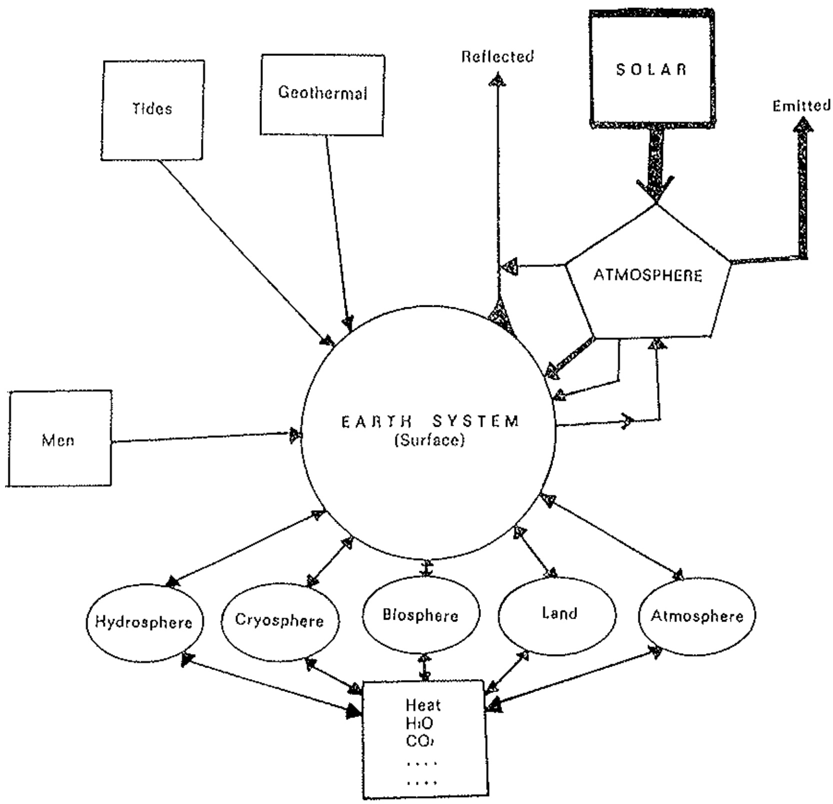


FIG. 2. Sub-system of Earth System.

III) *The System is Only Partially a "Prompt" One*

Energy can in part be stored and released with a great variety of "lifetimes" of the responsible process.

These lifetimes range from very short ones (mostly in connection with day-night asymmetry or in connection with atmospheric dynamics) to intermediate ones typical of seasonal effects (on the biota or the snow cover, for example), or to very long ones related to the behaviour of hydrosphere and criosphere (like deep ocean currents or criosphere-litosphere dynamics).

The "non-prompt" part of the energy balance may be responsible for irregularities in responses in time, and therefore in a non-complete steadiness of the equilibrium in many time scales not related to the external mean forcing.

IV) *The System is a "Complex" One*

This is for two reasons: the first is because it contains feed-backs due to the coupling among the various sub-systems or components of them; the second is because it contains fundamental non-linearities, connected with the behaviour of the two fluid sub-systems: atmosphere and oceans.

Due to this built-in complexity we can expect non-linear responses to variations in the input from external or internal forcing processes in terms of enhanced or damped oscillations or fluctuations. This behaviour sometimes makes it difficult to establish a firm effect versus cause link.

V) *Weather and Climate*

Climate, although related to the mean properties of weather and, in terms of these mean properties of weather originally defined, it has basically a different nature.

As a matter of facts, weather is definitely an intransitive system, (in relation to the definition introduced by Lorenz) as a consequence of the fact that it is a system whose evolution is strongly dependent on the exact specification of initial conditions [3].

This situation, first described by Poincaré, has a great influence on the problem of forecasting future weather evolution. Two slightly different initial states can have an evolution quite different as far as we proceed toward the future. It is possible to affirm that, after a week or so, the evolution of any two weather states, which at the beginning were very near one to the other in terms of initial values of the relevant parameters, show no more similarity than any possible couple of weather states randomly selected; the memory of an *almost* identical initial state is completely lost by the system during its evolution in time.

This type of asymptotic behaviour of weather is qualitatively independent from the precision by which the nearly identical initial states are defined. Therefore there is an *impossibility of principle* for weather forecast beyond a certain time lapse; this is due again to the non-linearity and complexity of the weather system.

For *climate*, where we speak in terms of quantities averaged over long time intervals, much longer than the above quoted "memory" of the weather system, there should be a restoration of some kind of "deterministic" behaviour, at least in terms of response of the climatic system to external forcings, although not generally in a linear form.

The reason for this type of behaviour is that, for time intervals which are large compared with those typical of "weather loss of memory", what is relevant are the statistical properties of a kind of "Gibbs ensemble" of weather states, representing a climate state with their most probable configuration. The idea is that this "most probable configuration" follows deterministically any kind of external, slowly varying small forcing.

B) Changes in the Global Climate System

I) *Natural Changes*

The climate system responds to a modification in the external forcing amplitude with a modification of what we can call, in terms of the previous discussion, representative climatic "state".

The response need not be proportional to the forcing modification due to the non-linear behaviour of the climatic system: but a qualitative coherence between input and output is expected.

External forcings due to solar input work on any time scale from the shortest ones, like variation in solar activity due to sunspot cycles and its amplitude modulation on time scale of the century, to the longest ones related with geological phenomena.

Sunspot cycle and its amplitude modulation can trigger climate modifications on time scale of decades or centuries and those modifications are most probably responsible for the behaviour of the climate in recent times, including the so-called "little ice age".

Modifications in solar forcing amplitude due to the different kinds of motions of the earth on its orbit around the sun (precession, inclination of the axis, eccentricity) are the only possible factors responsible for the sequence of "ice ages" during the last million years as we have already discussed.

Going further backward in time, on the order of tens of million of years, plate tectonics seems to be the candidate for climate modification, like the initiation of glaciations in Antarctica ($\sim$ 30 million years ago) due to the establishment of the circum Antarctica current; or the warm period during the Cretaceous era ($\sim$ 100 million years ago and more), thanks to enhanced heat transport in the Pacific Ocean from equator to the poles (due to the confinement of continents in a reduced range of longitudes).

In the range of billion years, the role of leader in forcing's variation is probably due to changes in composition of the atmosphere mostly in terms of CO_2 content.

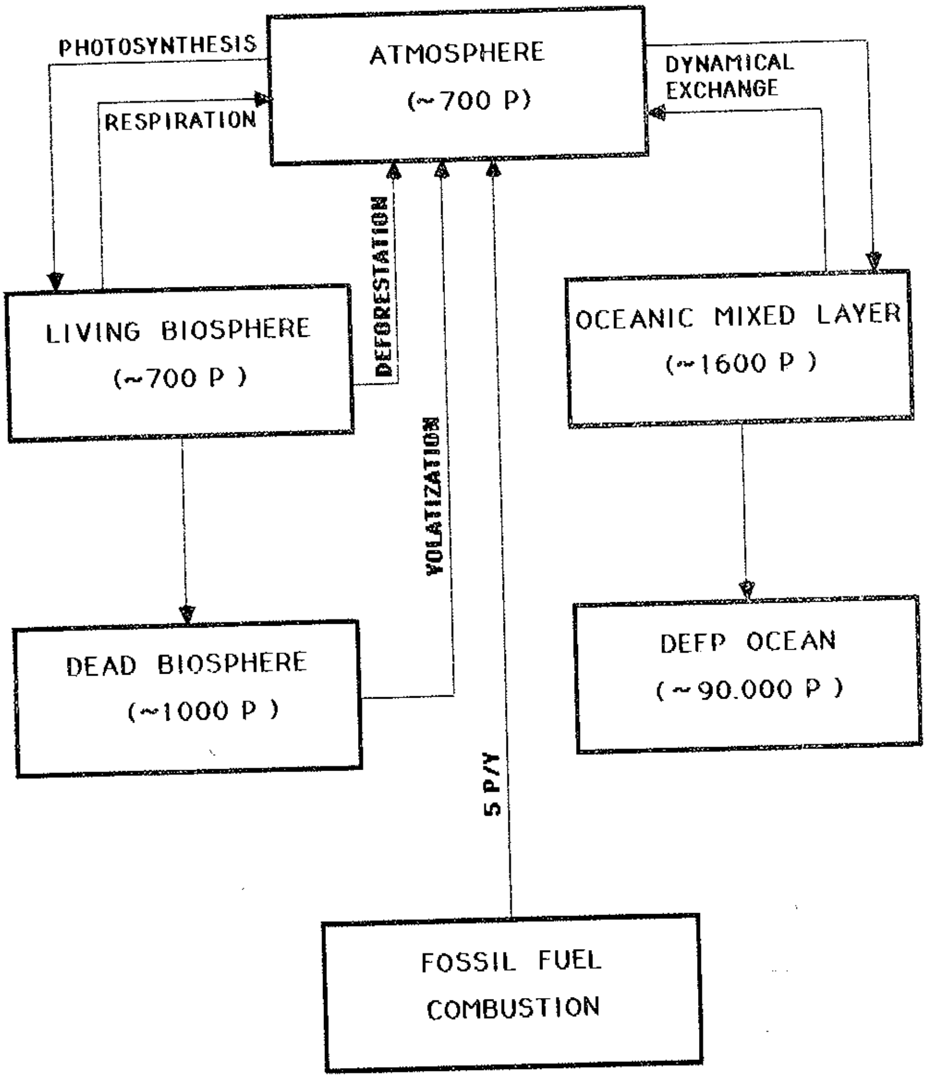
Coming back to the present time, with the exception of some transient effects due to vulcanic explosions, the only "*natural*" external forcing able to produce modifications on time scales interesting to human life seems to be the variation in solar radiation input S_0.

II) *Man-made Changes*

Quite recently man's activities have introduced a new kind of external forcing on the climatic system by increasing the CO_2 content of the atmosphere, and breaking natural equilibrium in the exchange of CO_2 between atmospbere, oceans and the biota [4].

The disequilibrium comes mostly from the inability of the oceans to incorporate in time all the excess of CO_2 injected into the atmosphere by combustion and, on a minor scale, by deforestation.

This new kind of external forcing has a well-defined consequence of increasing the "greenhouse effect" and, finally, "*all other factors being constant*", of increasing the mean temperature of the earth, and a more conspicuous consequence of decreasing tbe temperature gradient between the equator and the poles, where the maximum effect will be noted. Nobody doubts the qualitative partial effect of this new forcing. The problem is when and how a signal related to this forcing will emerge on top of the natural fluctuations of this complex system. (Fig. 3 shows the role of subsystems in exchanging CO_2.)



1 P = 10^9 t of carbon

FIG. 3. Sub-systems containing and exchanging CO_2.

It is important to mention that CO_2 immission into the atmosphere, by fossil fuel burning and deforestation, is not the only cause of alteration of the properties of the atmosphere by man.

Injection of nitrogen oxides, chlorofluorocarbons, methane and other gases also produces consequences similar to CO_2 with regard to the "greenhouse effect"; but there are from some of these gases, and in particular from those containing chlorine, other kinds of alterations of the chemical composition of the atmosphere. It has been recently advocated that CFC immission can substantially contribute to the destruction of the protective ozone layer.

In the past, man was considered a negligible perturbation on the global ecosystem, and the responsibility of alteration was almost completely due to natural phenomena like vulcanic explosions, forest burning, and extraordinary events like the impact of a large meteorite or a comet with our globe. Today man's activities rank, in terms of power produced and dissipated, quite impressively as shown in Fig. 1.

But the energy itself produced by man is not important enough to influence the global energy balance; the real problems are the by-products of his activities, like the CO_2 and other gases mentioned above.

C) Predicting Climatic Changes

There are substantially two ways which correspond to quite different philosophical approaches and have different purposes:

a) *Stochastic-dynamical models*, whose purpose is to inspect the dynamical behaviour of the system in highly idealized situations and in a very simple and transparent mathematical framework, in which the importance of a few crucial feedbacks is checked in order to reproduce a long-term intrinsic behaviour of the system, like the alteration of glaciations in the last million years.

An example: the earth's surface covered by water and sea ice near the poles as an idealized physical situation, and characterized in the interaction with the atmosphere by two feedbacks [effect of thermal insulation of the ice on the body of water below, and the dependence of the exchange of CO_2 between water and atmosphere on the temperature of water], shows indeed a periodic behaviour for the latitudinal extension of sea ice, in terms of a "limit cycle" [5].

The simple addition of a stochastic perturbation to the system produces irregularities in the form of the limit cycle, in terms of location of trajectories and residence time in different parts of phase space. These are common characteristics to many non-linear complex systems of different nature (mechanical, electric, chemical, etc.).

Due to the high idealization of such models in comparison with the reality of the climate system, it seems not worthwhile to upgrade these models: the lesson we learn from them is interesting enough.

b) *General Circulation Models* (G.C.M.), introduced originally for weather forecast in the atmosphere, which, if written in terms of a coupled atmosphere-ocean-land model, represent the most complete and ambitious approach to climate modelling.

The fundamental idea is to treat the evolution of every phenomenon known in the system through the basic equations governing them.

Because the task of representing every phenomenon through its basic equations is an impossible one, a comprimise is normally adopted between basic equation parametrization and degree of completeness.

The most important information about climatic changes for alteration of external forcing in the future is provided by these models.

We are still far from having completely satisfactory models of coupled sub-systems and true tridimensionality, but the idea is that any further improvement in climate prediction is bound to an improvement in this kind of models, not necessarily in terms of improvement of details.

In particular, regarding the effect of CO_2 increase in the atmosphere, the predictions of such kind of models for doubling of the CO_2 content is of an increase of mean surface temperature of the order of a few degrees $(2 \div 4)°$ C and of $\sim 10°$ C for Arctic regions, enough to present a problem in the next century.

D) Toward the Future: Climate and Man

Predicting future climate by General Circulation Models is a task which is based on continuous improvement of our knowledge of the processes which take place in all sub-systems and their mutual interactions, as well as the possible improvement in the formulation of the numerical model toward completeness and resolution in space and time: an endless effort as it is seen today.

Completeness is necessary for the reliability of the predictions, but resolution in space and time is especially important for man.

As a matter of fact, any changes in global climate will have quite different repercussions on mankind's situation in different parts of the globe, as a few reconstructions of past changes have shown. Change in surface temperatures, precipitations and winds, with their immediate consequence on local climates, food production, transportation, etc., will not be geographically uniform and there will be, in comparison with the actual situation, winners and losers.

From one item we know — the possible doubling of CO_2 content in the atmosphere — it can be foreseen in an interval of time that is not well defined (because of the difficulty to design future scenarios for possible fuel consumption and deforestation); but the order of magnitude of this time period, extrapolating from the actual situation, can be estimated at around half a century.

In this span of time the only other external forcing which can compete with the CO_2 forcing is a variation in solar activity like that experienced during the last "little in age", with change in the mean earth surface temperature of the order of 1° C. Oscillations of the climate system can produce variations of the same magnitude but probably smaller and in both directions. Tbe effect of the coupling between the two is difficult to assess.

It is a little difficult for me to conceive that these contributions in the long range can compete with a non-directional cause, like the increase of CO_2 and other gases in the atmosphere.

It is therefore reasonable to assume that if the greenhouse effect is going to increase steadily, the qualitative result will be an increase in the earth's temperature.

The next problem is: Will it be possible to detect this effect, in addition to the continuous spontaneous oscillations presented by the climatic system on a time scale of the order of ten-year periods, which is the time scale of interest to us? When detected, worldwide measures would be necessary for at least a mitigation of this effect: by stopping fossil fuel combustion, by increasing forestation, by modification of land use, and so on.

There is no point yet for panic or for early measures, but the problem must be followed most accurately by scientists.

The international program of "early warning" seems to be a must, starting at once in order to have a better definition of the global climate situation and to test the improved accuracy of the models.

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DISCUSSION

BOURDEAU

Thank you, Mr. Chairman. It is becoming trivial, I suppose, to say that this is the most important and vital issue. Climate change is something of such importance, and, as you have justly pointed out, there are uncertainties of all kinds as to where and how and when it is occurring. It is absolutely mind-boggling. At the present stage, most scientists will probably tell you that we need more research and this is not so. They tend not to do anything really. But we are more and more under pressure from some politicians — at least in the system I'm involved in — to advocate some measure that could be taken, or that at least should be prepared now. Hence the numerous meetings, conferences on a worldwide or regional basis on the subject of climate change.

It is difficult enough to improve the general circulation models and to forecast the local climatic changes that may occur. It becomes even more difficult to do the impact studies. The European Community has a fairly large climate research programme going on, which is conducted in close cooperation with the equivalent U.S. programme run by the Department of Energy, and it's all inscribed within the world climate programme which WMO, UNEP and ICSU are running.

Well, tbe impact is difficult to estimate, and when we ask scientists for ideas for such projects on impacts, these tend to be very trivial. « You know, » somebody will say, « let's calculate the effect of an increase in temperature of 3 degrees on the growth of grass and what happens to plant growth if the CO_2 concentration goes up by 20%. » We seem to be stuck there on what we can do in really sound impact research, and, if you have any ideas, I would be very interested in hearing them.

PUPPI

Answering the main question posed by Professor Bourdeau, on what could be done, and possibly initiated now, I do not see much more than, on the one hand, to organize a worldwide watch system of climatic anomalies, and on the other hand, to improve the performance of General Circulation Models formulated in such a way that they can be used as some kind of "climatic models".

What seems to me important is to formulate them with the purpose of interpreting regional effects on temperature and precipitation changes. I believe that from the analysis of this kind of changes there is the possibility to have an early warning of climatic evolution.

DI CASTRI

During the last four years, I have been involved in the launching of the ICSU International Geosphere-Biosphere Programme (IGBP), the so-called Global Change Programme. This programme is now well established, and its Secretariat is located at the Swedish Academy of Science.

The process of climatic change could be debated at length. I would only like to stress that CO_2 accounts for only about 50% of all trace gases that are provoking the greenhouse effect. The rest is composed of other gases like methane.

Let us consider one issue in research and one in management.

As regards research, we need to improve the predictive capacity of Global Circulation Models. The grid of GCMs is about 100 kilometers square. This scale is almost incompatible with our current biological research that is at the scale of a few kilometers square, or — more often — much less than that. To solve this problem, research is being undertaken on the "scaling up and down" issues. The objective of such research is to understand the approaches of biological research of the ground, on the one side, and of remote sensing, on the other side. The challenge is to define ways and means to shift from one scale to another, from leaves to regions, and from remote sensing to ground phenomena. Another aspect of IGBP is to try to predict some of the present changes in the light of past changes, revealed by the analysis of ice cores, dendrological analysis, etc. As regards prediction of climatic change, reliability is higher for temperatures than for precipitations. By all means, the precision of such prediction is still very low.

Accordingly, the only point where I see that there should be already some managerial action is to adapt to the rise of the sea level. First of all, very large engineering works are being carried out along the coasts. Secondly, the life span of an engineering work has to be of some 35 to 70 years; at that time, it is very likely that the sea level will be considerably higher. Therefore, it will be almost irresponsible to plan now some very large engineering works on the coasts without taking into account effects of global change. Three countries are particularly vulnerable in this respect. The first one is the Netherlands, and this explains the fact that this country is the most concerned about this issue. The second one is Egypt, because the rise of the sea level would imply waterlogging and salinization of the Nile delta, where most of the Egyptian lands suitable for agriculture are located. The third country is Bangladesh, where one could expect also an increased frequency of floods. Moreover, many small and flat island countries could be strongly threatened by an even small rise of sea level. Besides, most littoral zones might be more vulnerable to coastal erosion and dune destabilization.

For the rest of the emerged lands, one could predict a change in vegetation, comparing "maps of the future" with "maps of the past"; however, the reliability of such prediction is very low. Equally difficult is to predict what the reaction of different species of plants to the increase of CO_2 will be. In principle, there should be an increase of the photosynthesis rate, but this would also depend largely on the balance of nitrogen and phosphorus in soil, and on many other factors.

In conclusion, tbe greatest emphasis in research should be addressed to increasing the reliability of Global Circulation Models, through studies zooming up and down from remote sensing to ground experimental research. From the managing and planning points of view, first consideration should be given to coastal zones.

Ives

First I would like to thank Professor Puppi for a very valuable presentation of a vital problem. I can only speak, however, as somebody far removed from being an expert in this area, although I can claim to have been a student of Professor F. Kenneth Hare and to have spent the first half of my career in the eastern Canadian Arctic in an attempt to answer the questions: Why did the Pleistocene Laurentide Ice Sheet grow, and why did it disappear so rapidly. Attempts to answer these questions have divided the involved scholars into two schools of thought concerning glacial conditions that prevailed 18,000 years ago. One school believes in a super-large ice sheet whereby the North American and Euro-Asian ice sheets were virtually joined; and the other school, to which I belong, believes in a much smaller extent of glaciation. We have not been able to resolve these two hypotheses. I think we must be aware that there are still a few climatologists in the world who think that we may conceivably be moving into the beginnings of new glaciation rather than a period of warming. On a very limited scale — and I am very wary about even saying this — I visited Iceland last summer to repeat observations on glaciers done 33 years previously; most of the glaciers in Iceland are advancing. I think here we have a very different problem from that of the ozone layer. It seems, going back to Professor Puppi's question about what shall we do and the very interesting ideas that Professor di Castri put forward, that we must be rather cautious and strive to obtain more data and better models before we make firm predictions. With the ozone layer, it seems that a very critical, urgent, practical response has been taken, and appropriately so.

If we start responding to a possible rise of sea level and find that an actual fall in sea level occurs, there will be a serious loss in scientific credibility, to say the least. If it is considered that the largest of the northern hemisphere Pleistocene ice sheets, the Laurentide Ice Sheet, originated in a rather cold and dry region, it can be argued, but not proven, that warmer winters, in providing heavier precipitation, could be a trigger for renewed glaciation, rather than the reverse. Present studies on the so-called "greenhouse effect" have not yet succeeded in achieving a satisfactory linkage between temperature and precipitation changes, and the ratio of solid to liquid precipitation on world and local scales. I most certainly do not wish to leave the impression that climatic research is not vitally important; it certainly is. However, the climatologists are still far from being able to make reliable predictions. I am always afraid of the tendency to overdramatise and to promise too much as a strategy for raising more research funds. Here science policy becomes a matter of ethics, and proper communication a vital process.

JEFFERS

I have a very simple question for Professor Puppi. I too share his enthusiasm for the general circulation model, mainly because the mathematics is elegant and interesting; but my feeling is that the model has not been widely successful in predicting even relatively short-term events. My question is this: Why then should we trust it in predicting longer term events?

PUPPI

I share the opinion of Professor di Castri that if some measure has to be anticipated, or at least planned, it must deal with possible variations of the sea level. Vegetation can be displaced, but the organization of human life is more difficult and very costly to move.

He is right of course in reminding us that contributions to the greenhouse effect from other molecules besides water vapor and carbon dioxide, like methane, nitrogen oxides, CFC's, have reached the same order of magnitude as carbon dioxide.

The questions of Professor Ives and Professor Jeffers do offer me the possibility to recall what I have said about *weather* and *climate* predictions. Weather prediction is treated with a purely deterministic approach to the evolution of a system, through the basic equations governing the various phenomena. Because the system is a complex one with lots of feedbacks and non-linearities, its evolution in time is strongly dependent on specification of initial conditions. Better specification means better predictions and better time spans for them, but the problem remains.

The problem of prediction of future climates is different because the purpose is to foresee the statistical behavior of the system in terms of the more important physical variables in relation to changes in external forcing or in internal physical state. This has proved to be successful in the reconstruction of past climates. Therefore, with all the caution needed in relation to possible autovariations of the system, I am still convinced that in the long term there will be a *coherence* between the response of the system and the variation in external forcing (solar mostly, as Milankovich proposed) or the variation in the internal physical state (like composition of the atmosphere).

For what concerns the growth of ice sheets in Canada and Greenland during the peak of the last glaciation, my understanding is that in those geographical regions most of the water evaporated from the sea to accumulate as ice sheets.

DEVELOPMENT AND PROTECTION OF THE ENVIRONMENT IN THE TROPICS

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One of the enduring perspectives regarding the recent famine and drought in Africa during the 1983-1986 crisis is the realization that the recurring hunger in this region is overlaid by three principal factors: poverty, the deterioration of the environment, and drought and its associated phenomena. Indeed, it can be said that poverty is closely linked to hunger, as it is equally closely linked with the factors of environment. The late Prime Minister of India, Mrs. Indira Gandhi, expressed this relationship unambiguously in her presentation to the United Nations Conference on the Human Environment, held in 1972 in Stockholm, in these powerful words:

> "How can we speak to those who live in the villages and in the slums about keeping the oceans, the rivers, and the air clean when their own lives are contaminated? Are not the poverty of the poor and the greed of the rich the greatest polluters?"

The key to the debate on the environment in its long-term developmental aspects is the issue of *sustainability*. Perhaps the clearest statement we have of what we actually mean by this concept was first made by the World Commission on Environment and Development. In its final report, entitled *Our Common Future*, the Commission describes sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. From such a perspective, the notion of environmental management has taken root, as a mechanism of ensuring that a functional methodology for the proper management of the environment for the benefit of present and future generations is assured. Consequently, environmental management is taken as "a set of activities and procedures, properly seen as integral elements of the development process, aimed at ensuring that development activities affecting the environment:

— provide net benefits to society,
— are sustainable,
— allow for the continuation of valuable non-consumptive uses of ecosystems" [2].

Such management functions through a two-part system: firstly, a system of environmental impact assessment for each development project, a practice that is beginning to permeate most regional and international projects from medium to large-scale size [3]; and, secondly, a system of monitoring of such projects, once the development process has begun. This latter practice, for the purpose of systematic auditing of these development projects as well as providing a basis for improving future planning and management of similar development projects, is rarely implemented [2]. We cannot afford to do without this audit process, as the African enduring environment-linked development crisis seems to suggest.

Fragile African Ecology

Tropical ecosystems, for all their apparent profusion, which makes them much more complex than the ecosystems in the temperate zones, are poorly understood — and vastly more fragile. Indeed, in this respect, we can state that African soils and the vegetation they support are exceptionally fragile, and are highly susceptible to long-term damage. Let us take the example of Burkina Faso, in the Sahelian zone of West Africa [4]. Its soils are very poor in nutrient elements, such that their organic content is usually less than 1-2%, its total nitrogen content is less than 0.06%, and extremely poor in phosphorus and exchangeable potassium. Similarly, the vegetative cover consists mostly of savannah and sparse woodlands. In spite of this situation, crop production (millet, sorghum, groundnut, cotton, etc.) is the dominant economic activity in the country, and is dependent on the availability and timing of rainfall. The farming practices based on these agro-ecological factors are of great significance to the question of sustainable development. For instance, the practice of clearing land for cultivation by burning bushes succeeds in preparing the soil for wind erosion during the dry season and water erosion at the start of the rainy season, which normally comes in downpours [4]. Again, stock-raising, which is undertaken largely in the sparsely populated areas of the semi-arid and arid North and East of the country, is carried out in areas showing exceptional fragility, where transhumance was the general practice under traditional livestock production systems, and therefore avoided the use of this fragile area all the year round. Increasing the cultivated area of the more amenable arable lands has constricted this possibility of livestock mobility; and the consequences are great:

> "One of the crucial problems of livestock production is that livestock is concentrated in the areas with the lowest ecological potential. Availability of natural bush-grass fodder, the dominant feed for cattle during most of the year, is often limited in the arid zones. As more and more land is used for cropping in the semi-arid areas, livestock are excluded from the year-round grazing" [4].

It can be seen that in this one example, which illustrates the conclusion in many other tropical countries as well, the effects of environmental degradation fall most heavily on the poor (Table 1), sometimes leading them to engage in "unsound farming, grazing, and fishing or to settle on ecologically fragile, marginal lands" [3].

We have already referred to the general nutrient-poverty of Africa's soils, derived as they are from ancient weathered rocks, which are highly leached, and with a low clay content — and therefore poor in fertility and having low water-holding capacity. The consequences of this soil resource

TABLE 1 - *Cost of combating desertification, 1983.*

Type of land use	Area Desertified ('000 ha)	Cost of improvement Per hectare (U.S.$)	Total (Billion U.S.$)
Irrigated cropland	27,100	750	20.3
Rainfed cropland	173,100	250	42.2
Rangeland	3,071,600	25	77.5

Source: World Resources Institute (1987).

TABLE 2 - *Extent of desertification in Africa's drylands, 1980's.*

Region	Total productive drylands	
	Area (millions ha)	% Desertified
Sudan-Sahelian Africa	473	88
Mediterranean Africa	101	83
Southern Africa	304	80

Source: World Resources Institute (1987), modified.

circumstance include the fact that the drylands of Africa are prone to desertification (Table 2), soil erosion, and drainage problems.

Soil erosion has steadily become a threat to ecological sustainability of much of the drylands of Africa. Ethiopia's croplands suffer erosion loss of approximately 42 metric tons of soil per hectare each year; Lesotho, a largely semi-arid country in the south, loses 7 metric tons per hectare each year from its grazing and croplands; and the Congo River carries about 65 metric tons of soil down to the Atlantic Ocean each year [5]. Some of the traditional agricultural practices in Africa had evolved to deal with soil erosion through leaf litter, mulch and continuous canopy cover [6]. For instance, the practice of agroforestry, long an established traditional African farming practice, recently rediscovered by modern agronomic practitioners, can be rationalized in terms of alley cropping. This practice leads to tremendous reduction in run-off and soil erosion, without any significant reduction in the net yield of the crops planted in such alleys of trees and shrubs (Table 3). Similarly, the practice of mulching adds plant nutrients to the soil, and it also improves the soil's physical properties, such as total porosity, the water-conservation potentials of the soil, infiltration properties, and the reduction of soil splash [6]. Therefore, it is not surprising to find experimentally that mulching manifestly reduces run-off and soil erosion (Table 4).

The point about mulching, as well as irrigation and other systems for regulating water supply, and its utilization by crops and trees, is that plants normally store very little water in relation to their daily water requirements, which can amount to approximately 6 litres of water per square metre (or about 60 cubic metres of water for each hectare of crop-

TABLE 3 - *Effects of alley cropping on run-off and soil erosion under maize-cowpea rotation, at Ibadan (Nigeria), 1984.*

Treatment	Run-off (mm)	Soil erosion (ton/ha/yr)	Crop production (ton/ha) Maize	Cowpea
Ploughed	232	14.9	4.2	0.5
Zero cultivation	6	0.03	4.3	1.1
Leucaena alley cropping	10	0.2	3.9	0.6
Gliricidia alley cropping	20	1.7	4.0	0.7

Source: Lal (1987), modified.

land) [7]. It is for this reason that the factor of water-storage capacity of soil is so important, especially in our consideration of sustainable development of the drylands of tropical Africa (and other tropical regions of the world). It is in these circumstances that the farmer must seek ways of making full use of this water-storage capacity of the fragile dryland soils. For instance, the practice of mulching is an option having excellent rational scientific reasons why it functions so well, by reduction of evapotranspiration through reduced insolation of the soil surface, and through water infiltration control; similarly, deep root development allows the tapping of the soil-stored water [7]. Yet, we find that aluminium toxicity

TABLE 4 - *Mulching effects on soil and water loss at Ibadan (Nigeria), 1981.*

Slope (%)	Run-off (mm) Mulch	No mulch	Soil erosion (ton/ha) Mulch	No mulch
1	0	412	0	9
5	11	483	0.2	134
10	21	303	0.2	137
15	20	375	0.7	96

Source: Lal (1987), modified.

is highly deleterious because the release of aluminium in acid subsoils prevents the roots from getting down to the water horizons; or, if the soil is already moist, it prevents the roots from effectively taking up water.

Forest, including streamside forest and forested areas of the watershed, are therefore especially vulnerable aspects of the savannah and dryland areas of Africa. The relatively rapid depletion of forest resources in Africa and Asia, without adequate compensatory afforestation schemes, is therefore a serious matter for stream management, and eventually that of the desertification potentials (Table 5).

Stream management in Zimbabwe should provide an illustration of the serious unsustainable consequences of woodland destruction on the streamside. Rainfall is the most vital climatic and economic factor in the agriculture of East and Southern Africa [8]. Much of the region has too little rain to undertake settled agriculture, and the rain is concentrated into definite seasons, with a sharply delimited dry season in-between. The so-called inter-tropical convergence zone (ITCZ) is the zone of convergence between the North-East and South-East trade winds, which transport moist air masses from the equatorial rain-forest to the surrounding savannah zones of the region, has an annual mean position of 5°N but shifts with the seasons. The ITCZ is responsible for much of the annual rainfall of the region.

The transportation of moist air by the ITCZ is assisted by evapotranspiration from woodlands "which act as secondary pumps to lift moisture into the atmosphere" [9]. This uplifted rain is then "cascaded"

TABLE 5 - *Forest resources, 1981-1985.*

Region	Changes in closed forests ('000 hectares per year)	
	Deforestation	Reforestation
Africa	1,268	212
North and Central America	—	2,539
South America	3,186	580
Asia	1,762	5,679
Europe	—	1,031

Source: World Resources Institute (1987), modified.

to the dry savannah of Zimbabwe by the ITCZ. The concern, therefore, stems from practices which lead to the clearing of the equatorial rain-forest of the Zaire Basin and coastal West Africa, as it very likely will have a long-lasting impact on the savannah rainfall regime. This is because savannah streams usually originate in the wetlands; woodland destruction from the headlands therefore leads to siltation of the lowland stream bed, and eventually results in the removal of the transition zone between the stream itself and the surrounding dryland, "creating a sharp edge-effect between these two habitats which are characterized by unstable erodable river banks" [9]. The loss of this transition zone transforms the stream to a mere drainage ditch. The termination of stream-flow, and the decrease of groundwater recharge during each rainy season — recharge which acts as a dry-season reserve — may follow, as a result of the removal of the woodland shade, which then leads to increased evaporative water loss, and at the same time may lead to the rapid growth of filamentous algae and other aquatic plants, which might consequently choke stream-flow [9]. The terminal result may be the transformation of a once perennial stream into a seasonal one, as is presently happening in Zimbabwe and in many other parts of the region.

But water bodies are not always a boon in tropical Africa (and other tropical regions of the world).

Health in the Tropics

Bilharzia is a common problem in water projects; malaria is a great development constraint in Sri Lanka, Nepal, Mexico and large parts of Africa; and river blindness, caused by the filarial parasitic worm (*Onchocerca volvulus*) transmitted by the blackflies (*Simulium damnosum sensu lato* group of species), keeps vast, seemingly fertile areas of West Africa from socio-economic development [10]. Yet, the dimensions of such environmental issues cannot be fully accounted for by the usual yardsticks of the market forces; nor are they adequately accounted for by the conventional economic criterion of cost/benefit analysis or even of social cost/benefit analysis [3]. Nevertheless, there is a manifest perception that health is vital for sustainable development in the tropics; and the World Bank has, for example, undertaken direct lending for health projects approximating a total of U.S. $1.01 billion for 35 projects during the five-year period, 1981-1986, including such projects as malaria control in São Paulo, Brazil [10].

But perhaps the largest single tropical health project ever undertaken in the world is the Onchocerciasis Control Programme (OCP), started as a long-term project in 1974, and run jointly by the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the World Bank. The programme encompasses the river basins of the Volta, Niger, Sassandra, Bandama and Comoe rivers, covering over 25,000 km of running waters [9]. The manner in which the control of river blindness in this vast area has been planned, implemented and monitored through systematic research and development activities, has provided a powerful model for future control campaigns of this sort. Because of the absence of a safe curative or immunological measure against the filarial parasite, an early decision was made to control the menace by controlling the larval stages of the *Simulium* [11]. A candidate larvicide, temephos ("Abate"), was selected because of its larvicidal effectiveness while having no acute effects on non-target invertebrate and fish species; having no significant impact on species disappearance on a regional basis or the alteration of animal cycles in the river waters; and with no demonstrable accumulation along the food chain [11]. By 1979, larval resistance to temephos had emerged, and another organophosphorus insecticide (chlorphoxim) was introduced to take its place. Other control measures are now being utilized as additional control components (for example, *Bacillus thuriengiensis* serotype H-4); and the monitoring schedule continues [11]. Onchocerciasis is now practically under control in the original control programme area (mostly in Burkina Faso, Côte d'Ivoire, Guinea and parts of Ghana, Togo, Benin, Niger and Mali) — and that is when we begin to ask developmental questions.

It has become clear that the control of the disease has created a need to know how best to utilize the liberated lands — even though they have been conventionally treated as large, fertile, riverine areas ready for the influx of human development activities. There is an undertone running through many plans to keep the liberated areas free of human disturbance, firstly because there is as yet no safe prophylactic drug for the treatment against the filarial parasite itself; and, secondly, because of the perception that the areas so liberated are, in fact, very fragile ecologically. In this respect, it is pointed out that maps of these river basins made in precolonial times "show a pattern of villages set well back from the rivers" [9]. It is not uncommon to encounter somewhat similar views expressed regarding the question of what to do with areas liberated from other tropical African scourges such as tsetse-transmitted trypanosomiasis. Such views evidently call for a thorough study of the savannah ecosystem, so as to gain a better perspective of the productive capacities of such agro-ecological zones, and their sustainability under changed circumstances of effective disease control whose absence had previously kept these areas from normal human economic activity.

In many of these cases of disease control, vast quantities of insecticides have been used — in tsetse eradication campaigns, tick control schemes, and malaria control — to name a few prominent cases with a long history in tropical Africa.

Pesticide Management

Twenty-five years since Rachel Carson's epoch-making book, *Silent Spring*, the main thread of her argumentation for a more discrete pesticide management practice still remains fresh and current [12]:

> "The whole process of spraying seems caught up in an endless spiral. Since DDT was released for civilian use, a process of escalation has been going on in which ever more toxic materials must be found. This has happened because insects, in a triumphant vindication of Darwin's principle of the survival of the fittest, have evolved super races immune to the particular insecticide used, hence a deadlier one has always to be developed — and then a deadlier one than that. It has happened also because... destructive insects often undergo a 'flare-back', or resurgence, after spraying, in numbers greater than before. Thus the chemical war is never won... Along with the possibility of the extinction of mankind by nuclear war, the central problem of our times has therefore become the contamination of man's total environment with such substances of incredible harm... All this has been risked — for what?... How could intelligent beings seek to control a few unwanted species by a method that contaminated the entire environment and brought the threat of disease and death even to their own kind?"

Notwithstanding this passionate plea, some authorities consider that, for the foreseeable future of pest control, there will continue to be a strong reliance on pesticides [13]. The tropical developing regions are not excluded from such a determined view. From a low level of pesticide usage in 1982, the developing countries now utilize 22% of all pesticides used globally [13, 14]. In the ASEAN countries alone, pesticides put at a value of U.S. $211 million were used in 1984 (Table 6); and India, the largest manufacturer and consumer of pesticides in Asia, had 30 manufacturing plants, producing a total of 40,000 tons a year of 50 different technical-grade pesticide products, including DDT (15%), butachlor (12%), malathion (11%), BHC (8%) and endosulphan (5%) [14]. Because of the spectacular success of high-input crop production systems in North America, Europe and of the Green Revolution, at least for the medium term, it has become axiomatic to rate the level of modernization and potential productivity of agriculture in terms of the intensity of pesticide usage [13]. Thus, using such categorization, the tropical developing regions, showing a decidedly low level of pesticide usage, are considered to have a low level of crop productivity [13], and Africa has the lowest (Table 7).

The insect-borne tropical diseases to which we have already referred, added to the several migrant pests (locusts, armyworms, quelea birds, etc.), mean that vast quantities of pesticides are sprayed in the tropical regions, often in those fragile ecosystems, such as the dryland savannah areas, we have commented upon in another context. Because of the emergency nature of many such migrant pest outbreaks, large-scale aerial treatment of these areas is considered necessary, even though it is possible that serious long-term impact may ensue. However, it is generally hypothesized that the higher temperatures found in the tropics, together with the more intense ultraviolet radiation prevalent there, may well degrade persistent pesticides much more rapidly compared to the situation appertaining to

TABLE 6 - *Volume and value of pesticides used in ASEAN countries (Indonesia, Malaysia, The Philippines and Thailand), 1984.*

Type	Volume (Metric tons, '000)	Value (U.S.$, millions)
Insecticides	41	84
Herbicides	29	97
Fungicides	7.8	30

Source: Delp (1986), modified.

TABLE 7 - *Comparative usage of pesticides in farming in monetary terms, 1978.*

Region	Usage in arable and Cultivated land (U.S.$/ha)	Per capita usage (U.S.$)
North America	13.0	12.4
Western Europe	21.9	5.7
Eastern Europe and USSR	3.9	3.0
Latin America	5.6	2.3
Far East	4.9	1.1
Africa and Middle East	1.5	0.7

Source: Brader (1956), modified.

the temperate zones. But against such a perception is the fact that, after intensive pesticide treatment in the tropics, new pests have frequently emerged. A dramatic instance is the emergence in the Sudan of the cotton whitefly (*Bemisia tabaci*), previously a minor pest of cotton, to becoming its most serious pest as a result of regular intensive insecticide spraying of cotton in the 1970's.

Many pest control specialists in the tropics are now turning to the practical possibilities of integrated pest management (IPM) strategies as a more cost-effective, sustainable approach to the large pest management problem in the tropics. We have a resoundingly successful IPM of the rhinoceros beetle in coconut plantations in Western Samoa [15], where a combination of cultural methods, biological control, trapping, and selective use of insecticides has brought about a continuing control of this pest beetle to a sub-economic level over at least a decade now (Table 8). The International Centre of Insect Physiology and Ecology, based in Nairobi, Kenya, has gone a considerable way to developing similar IPM strategies for the major crop borers of cereals and grain legumes.

The econometric study of the cost performance of successful IPM programmes is still in its early stages. But in at least one case, that of the control of cotton pests in Central America, carefully reported by

TABLE 8 - *Integrated pest management (IPM) of the coconut rhinoceros beetle in Western Samoa: Range of components utilized.*

1. REDUCTION OF POTENTIAL BREEDING SITES
   — environmental sanitation
   — use of cover crops
2. COCONUT PLANTATION IMPROVEMENT
   — creation of large, uniform plantations without open areas
3. MISCELLANEOUS
   — trapping of adult beetles
4. BIOLOGICAL CONTROL AGENTS
   — *Baculovirus*
   — *Metarhizium anisopliae*
   — parasitoids (*Scolia* wasps)
   — predators (larvae of elaterid beetles)
5. INSECTICIDES
   — to protect living palms against adult beetles
   — to prevent breeding in rotting logs

Source: Pertzsch (1984), modified.

TABLE 9 - *Budget information from field tests of a cotton integrated insect pest management (IPM) programme in Central America, 1974-1975.*

Budget Item	Type of strategy IPM	Conventional
A. Output		
(1) Yield (kg/ha seed cotton)	2,975	2,764
(2) Gross returns (at U.S.$ 0.331/kg)	985	915
B. Insect control		
(3) Number of insecticide treatments per hectare	14.3	21.0
(4) Costs of insect control in U.S.$/ha, include labour, equipment and insecticides	232	302
C. Other variable costs		
(5) Cost (U.S.$/ha) of all other production inputs	502	527
D. Total variable cost (U.S.$/ha)	734	829
E. Profit/ha (gross returns less total variable costs) in U.S.$	251	86
F. Relative profit (profit/cost)	0.34	0.10

Source: Bottrell (1987), modified.

Bottrell (1987) [16], the cost-effectiveness of IPM vis-a-vis the conventional insecticidal approach, abundantly demonstrates the superiority of the former (Table 9). In this light, the modern definition of IPM sounds apposite: it is "the farmers' best mix of control tactics, based on criteria of crop yield, profit and safety".

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DISCUSSION

Marini-Bettòlo

Thank you Professor Odhiambo. With your important contribution you have focused on the main points of the protection of the environment in Africa. The I.C.I.P.E. is an example of what can be done in this field .

Ayyad

I appreciated very much Dr. Odhiambo's presentation, particularly the part on the agricultural systems and the promotion of the rationalization of traditional practices. As you mentioned, Dr. Odhiambo, the prime objective for development of these rural ecosystems or life support systems is to promote their sustainability and perhaps to create an equilibrium between a subsistence economy and a market economy. One of the ways you have mentioned to do that is by increasing the capacity of the system for crop production by different traditional practices. Perhaps another way of doing it is to support local small-scale cottage industries. Let me give you an example from the village where I was raised in the Nile delta. When I was young, it was a very common scene to see the farmers' children going to the fields at the end of the cotton crop season, picking the remains of the cotton from the crop and then using primitive, but efficient, spinning instruments to make their own material for manufacturing their dresses, sweaters and head covers, and perhaps to sell the rest of it for cash. I can give you more about that, but this is just an example of how we had turned a self-sustained ecosystem with local small-scale cottage industries into a consumer society. This scene is no longer occurring in the Nile villages. Most of the people now go to the cities to buy their dresses and clothes. Do you want to elaborate more on the issue of the cottage industries and their role in the rural communities of the Tropics?

Bourdeau

I was most impressed by the situation which develops when you have gone through a whole programme of trying to wipe out the simulides and onchocercosis and then don't know what to do with the area you have liberated.

It is really very striking. Another comment I want to make is the following: in a recent scope project, we looked at what happens with chemicals introduced into the environment in non-temperate areas, because most of the literature is based on what happens in temperate conditions. We tried to see whether you could really extrapolate from one to the other, either to warm or to very cold places, and we found out that one just couldn't do that, as you yourself pointed out. One does not know too much about the fate of chemicals introduced into, among other things, the moist and dry tropical environments. One thing that struck us very much was the extreme paucity of data pertaining to that, so that one can almost argue that pesticide residue, for instance, will disappear more rapidly because it is warm and you have more UV radiation. On the other hand, one might say that you may have less bacterial activity where it's dry, etc. etc. The point I want to make is that one should really encourage the study of the fate and effects of introduced chemicals in environments such as the wet and dry tropical ones.

ODHIAMBO

Well, I am pleased to respond to these really major questions which have been posed. To start with the second one, as Professor Bourdeau has indicated, there are very few studies systematically undertaken over a period of time. There have been a few studies which have taken not more than one month, and sometimes done under conditions in which one is not sure that the technology being used would answer those questions critically, and often, as you have indicated, based on very simple assumptions that, because of high temperature, the breakdown of products will be much sooner, which of course one should assume.

The problem here is that very few scientists have actually systematically followed what happens within the tropical environment. I think the only attempt I know that went to some extent to do this was in the case of DDT in the Lake Mature environs; but the study was done under conditions from which it is difficult to make any judgements as to what was really happening. I agree with you that this is a matter that should be followed very closely, because, as I said, this insecticidal or pesticidal load in much of the Tropics is now very high. In Asia, particularly with rice production, it is extremely high. We know there are some effects now on algae. Some people say that blue green algae is not blooming as much as it used to under rice field conditions because of very high pesticidal loads, but one does not know. There may be other reasons why this is not happening. In the case of Africa, in some semi-arid regions, there must be a very large load now. I agree with you that we need some very carefully planned experiments to follow through the fate and environmental destination of insecticides and pesticides in general.

Coming back to the question of developmental projects related to liberation of areas, you'll find in many conferences on this topic that this is always stated as a major recommendation, but there are few examples of successful accomplishment of this goal, in such a way that you can say, « When we liberate this area, this is what we are going to do. » I would say the pressure is very high; and political decision-makers will make decisions as to do, without the wisdom of scientists behind their decisions.

Ayyad's question is really a profound one. Those of you who have been involved in development planning know that the question of small-scale or informal industry is a very major one. There are few people, including governments, willing to put credit in such schemes; but there is no doubt that our economic development plans are in many ways distorted. In many countries in the developing world export-led development is now the word. Korea and Singapore, have succeeded in developing their countries because of export-led strategy. But in fact, when you consider it, for large populations such as Nigeria and India and Brazil, maybe stimulation of their own market, their own needs within the country, is a major part of what should be their development strategy. In the case of Africa, intercountry trade is or should be, a very major part of their own development strategy. We know that 300 years ago that was the major way in which Africa was developing. All the trade routes demonstrate it. All the stories of travellers show that the inter-African trade was very large indeed. At the moment, only 15% of trade in Africa is between countries of Africa. Among the developing regions, only 22% to 26% is between areas of the developing regions; 73% of trade now is between the south and the north. It is completely distorted. In Europe, 85% of trade is within or between Europe and North America. In other words, the developed regions of the world know what they are doing. They are actually trading among themselves. International trade for them is between European and American countries. It is between developed regions of the world, or within the developed regions of the world.

I don't think it is going too far to suggest that within Africa there should be much greater trade internal to the continent. Within Asia, there should be much more trade between Asian countries; and, indeed, in the Asian region already 20% of world trade is within the Asian region. They are beginning to make an impact; but not so in Latin America. In Latin America only 13% of trade is within that subcontinent. Consequently, I agree with your general thesis. There is a very large market which can be satisfied by the so-called informal sector, or what you called cottage industries. One of the items for such industries is cotton. But let me say that food crops that we have been discussing are not just food crops; many food crops are actually trade commodities. The greatest trade in these commodities emanates from the United States, followed by Canada and Australia. This is an important one as part of our strategy for development, and obviously it has got a very large impact on the environment.

Scarascia Mugnozza

Professor Odhiambo, in all agricultural systems, the loss of crops after harvesting in terms of quantity and nutritional value, mainly due to insect attack and formation of toxic substances, is rather high. In the temperate zones, it may be around 15-25%, you say. Now, large is this loss in the tropics? I don't think that there are very good data up to now on this subject, which is, nevertheless, very important, I think. It's very important to know the situation and the measures which have been taken or were taken.

Odhiambo

As Professor Scarascia has said, there are not many studies on post-harvest losses and, certainly, there are very few good ones. Most of the figures on agricultural losses that you see quoted were figures which were summarized in the early 1970s by looking at the whole of the world literature and then extrapolating what is probably happening in the tropics. That position has actually not changed. My own institute, the I.C.I.P.E., together with the United Nations Economic Commission for Africa, held a study workshop only three weeks ago in Nairobi, to examine this question of post-harvest losses in the tropics, and there are very few critical studies going on in this prohlem area. I think we should look at this problem in greater detail, and much more systematically over a longer period of time, and take into consideration specifically the food reserves at the household level because, in much of Africa and the other developing tropical regions, much of the food reserves are not placed in the strategic reserves at national level. They exist at the domestic level, and there are very few studies that have examined this situation and the losses at that time. The studies that you will see quoted were taken in warehouses, particularly at the shipping stage, and therefore do not fully reflect what actually is happening in much of the country. We have better statistics when it comes to afflatoxin, particularly in relation to groundnut. Those figures are good, and they are available. WHO has done a good job in collecting them; and I believe that the losses are very high in groundnut; in other cereals they are lower, but nevertheless very serious.

IVES

I would like to thank Professor Odhiambo for bringing to our attention some very critical and important points. I would like to make a comment at this juncture. All of the proposed approaches — reducing post-harvest loss; reducing the reliance on pesticides; increasing efficiency of agricultural production, particularly for local consumption — are all vital and necessary actions. The topic of the rapid growth in world population has been touched on throughout the last four days, but we have not faced it head on.

All of these measures, one has the impression, are really serving only to give us a little more time. In fact, we may be still losing. I doubt that we have the data. If we do not know what the post-harvest losses are, we cannot calculate the actual effects of reducing sucb losses nor can we be sure that predicted increases in local food production can keep pace with increasing demands, both from population growth and the needs to increase the existing standards of thing. Population growth and approaches to the control of that growth become central points to any discussion on global environmental deterioration and how to reverse it.

In making this stipulation, I am not advocating any particular type of birth control programme. Rather I am urging that steps be taken to achieve a better understanding of why population is growing so rapidly in various parts of the world, and especially in the Third World. Scholars and environmentalists, as well as aid agencies and government ministries, have been too ready to claim that rapid population growth is the major *cause* of environmental deterioration in Third World countries. It can be argued that it is rather a *symptom* of poverty, which in turn is tied to unequal access to natural resources. As an example, the very extensive birth control programme of the government of Nepal has recently been recognized as a failure. Some individual village studies by anthropologists seem to demonstrate that a large family is a risk-reducing strategy, and practically all the children born were wanted in a situation where marginal subsistence agriculture is forced into an ever more labor-intensive occupation.

The subsistence farmer has so often been a convenient scapegoat and treated as part of the problem rather than potentially as a major part of the solution, as I am sure Professor Odhiambo will agree. What I am proposing, therefore, is that, while all possible efforts must continue to be made to increase production and the availability of food produced locally, *at the same time* a much more serious attempt must be made to understand the relations between poverty, population growth, and unequal access to resources. Similarly, more effort is required to bring the local farmer — men and women (we must understand that in many developing countries women do most of the farm work) — into the process of identifying local needs, the policy formulation in response to this identification, and its implementation.

MARINI-BETTÒLO

Humanity has to face the need to settle adequately in the next 50 years a population which will double our present 5 billion, and this requires not only accurate planning and scientific and technical research, but also a new approach of the whole behaviour of man and of all humankind to the environment. I think the figures show that we will rapidly reach 10 billion, but that after that point there will be a certain stabilization and an increase of wealth. I think we should make every effort to give food and an acceptable standard of life to all these people.

PRZEWOZNY

The presentation by Dr. Odhiambo raises quite a number of questions and I don't think this is the place to discuss them all. I don't think we have the professional people to help us face issues such as what do we mean by progress and how are we to evaluate the cultural consequences, for certain regions, of rational and scientific methods in increasing food production. Certainly, food production must be increased; but the methods used to achieve this may cause culture shock. I remember reading in René Dubos' book, *A God Within*, that a future generation may be shocked by the fact that some introduced the outhouse into their homes. In other words, for some it may not be the best cultural solution. In certain areas, a simple change such as that may not be a sign of real progress. This, then, would be my first comment: we are not prepared here to discuss the philosophical, cultural, ethical and moral issues of what we intend by progress.

In commenting on what Professor Ives has just finished saying about demographic expansion, I'd like to say that we don't have to be afraid that we can't say anything about it. I attended two meetings in which it was raised at the level of a religious discussion. Demographic expansion, however, should not be isolated as the sole factor, because the global question also includes ageing in some parts of the world. Furthermore, we would have to address the question of the distribution of the population. Some of the practical aspects of distribution are being solved rather spontaneously, if you wish, and at times illegally, as you all know. A country may have more than a hundred East Indians disembarked on its shores and it must solve that issues in as humanitarian a way as possible, with all the immigration problems it involves. I remember seeing the figures somewhere that a belt in Canada of about 150 kilometers, along the American border from the Atlantic to the Pacific, could sustain a population of 300 million. The population of Canada at the moment barely reaches 26 million. What are we, to do about distribution? Are we to invite 200 million Chinese and 100 million Indians to Canada? Of course, cultural, social and other issues would have to be solved.

Consequently, if we are going to face the issue of demographic expansion and if we are going to discuss it, then we should try to formulate it in a way that would keep in mind ageing and distribution.

RAVEN

I of course give, as we all do, many speeches that involve the interrelationship between these topics, and I tried to treat the subject of population rather carefully in the paper that I presented here. Normally, when I finish giving a talk like this in the United States on any one of these subjects, someone will say: « Obviously the only problem involved at all is population, and if population growth will only slow down, everything will be all right again. » The problem is that it's just not so, as can be illustrated very easily. If population growth were to cease tomorrow, all of the negative consequences that I outlined in my paper and virtually all of the negative consequences that we've been discussing for the last four days would go on unabated. The tropical forests, with no further population growth, would all be destroyed in a 30-year period — roughly some quicker, some slower. A quarter of the biological diversity in the world would be lost within the next 15 or 20 years. Despite a lack of population growth, some 400 million people would still continue to be hungry, and the sustainable productivity of the world would be just as surely destroyed whether one additional person were added or one additional person were not added. Furthermore, objectively, as Professor Marini-Bettòlo has just brought out, demographers generally agree that the world population will stabilize, according to present trends, in the second half of the next century at a level somewhere around 10 billion people. We don't have any idea whether the world can provide a sustainable home for 10 billion people, and we certainly are not taking steps to discover how. We don't even know whether the world can provide a sustainable home for 5 billion people on the long term. The imperfect distribution of resources between nations and within nations, which creates severe gradients in wealth, has given us a world in which very large numbers of people live in conditions that are entirely unacceptable for life. Partly in consequence of this, we are clearly destroying the overall productive capacity of the earth and its ability to support us. In fact, population is that single aspect of the problem which is being addressed most effectively and about which there is the greatest consciousness.

Consequently and paradoxically, although I would subscribe to the principle that absolute numbers of people are the underlying cause of environmental destruction they are not as difficult to solve as many other aspects of the problem that are receiving very little, if any, attention, and are much more difficult to solve. The nations of the world are dealing with population growth in their own ways, but there are many other important problems that demand our attention also.

De Giorgi

I should like to know — if possible — how much we should spend to obtain, in a reasonable time, the control of pests in Africa, without damaging the environment. Are there any figures about it?

Keckes

I have no figure on that, but I want to say something else on another subject later.

Marini-Bettòlo

We should include in the conclusions this item about pest control.

Keckes

I wanted to say something about the relative magnitude of the various problems which are affecting or may affect the environment. We discussed the problem of population pressure and it was highlighted that it is not as simple as some people manage to think, but I think that we forgot the major environment problem. We agreed that the population is exerting a pressure on natural resources and that something has to be done about it. We agreed that we are destroying tropical forests and arable land. We agreed that we are using pesticides excessively. But what about the real major threat? Is it so big and so monstruous that it escapes our attention? What about planning for nuclear war? All the other problems will pale in significance compared with the environmental consequences of nuclear war, and we didn't mention it at all. If we knew that one of us is planning to stab his colleague here or kill him, we would call the police or at least put the tentative killer in an asylum. But nothing is done about those who are using the most modern science and technology to prepare the mass murder of millions of people and a thorough destruction of our environment.

Odhiambo

Yes, but I'd like to go back to the question that Professor De Giorgi raised, which I think is a very important question. To paraphrase it, when people talk of pest control, they assume that they are going to eradicate pests. I want to say, as a biologist, that it is unlikely that you will be able to do so. If you do so, you will probably he bringing down other insects which may not be pestiferous and so should be in the environment as part of our species diversity. In thinking about pest eradication, we are really talking probably about chemical control, because the other control measures normally will not end up in eradication. To me, and a number of other people, we are concerned with bringing about a management of pests, so that they become sub-economic, that they do not interfere with our lives, but not that we should eradicate them, because that is very difficult, and you would probably be doing more harm than good. Biological control, or control measures associated with it, is expensive at the level of research. The management of such measures is fairly cheap, and I think that this makes biological control the future for the resource-poor rural community, should the State and the international community take responsibility for mobilizing resources, both human and capital, to undertake the necessary research and development to come out with effective methods for biological control. If you calculate what R and D costs went into the control of the coffee mealybug in Africa to become effective, the total sum is about only 3 million dollars. We are not talking about a vast amount of money. Biological control requires sophisticated research, but in the end its implementahle results will be cheaper for humanity.

IV.

INSTRUMENTS

ECOSYSTEM MANAGEMENT: SOME INSTITUTIONAL CONSTRAINTS

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SUMMARY. — Our environmental situation continues to decline faster than ever. This is demonstrated by the growing spread of pollution of water and atmospheric systems, erosion of topsoil, tropical deforestation, desertification, mass extinction of species, depletion of the ozone layer, and climatic dislocations. Why should our environmental situation continue to decline, despite a remarkable outburst of awareness on the part of the general public and its political leaders since the time of the Stockholm Conference on the Human Environment? The problem does not lie with inadequate effort, but rather with misdirected effort: we persist in tackling symptoms of problems, rather than problems themselves, let alone the sources of problems. We should broach these issues within a context of fast-growing interdependence among the community of nations, both economic and ecological interdependence — which presents yet more problems, but also raises many opportunities for creative action.

At the time of the Stockholm Conference on the Human Environment in 1972, fewer than 10 governments had environmental agencies. Today the total is around 140. In other ways too the past fifteen years have seen a remarkable outburst of awareness of environmental issues, on the part of both the general public and its political leaders. Yet our environmental situation has continued to decline. Why should this be so? And what should we do about it — that is, how differently should we try to do a better job with our environment?

This paper tackles these two questions. Moreover it broaches them within a context of interdependence among the community of nations — not only economic but ecological interdependence. This factor of interdependence is of salient significance to the environmental cause, presenting both problems and opportunities.

OUR ENVIRONMENTAL PREDICAMENT

A World of Accelerating Change

We are not only imposing ever-more profound impacts on our biosphere, we are doing so at ever-increasing rates. We have been injecting pollutants into the environment at such progressive speed during the past few decades that certain parts of the pollutant burden would leave their mark for many more decades to come even if we were to halt the process forthwith. The recent spread of deserts can mostly not be repaired for centuries. Tropical deforestation has worked up such momentum within the past few decades that the damage can surely not be made good for millennia. Climatic dislocations from recent human activities may well persist for tens of thousands of years. The current extinction spasm will leave our natural world so impoverished that evolution will not restore the biotic injury in less than millions of years. We are imposing all these mega-scale changes on our planetary ecosystem within the space of a single century at most — the twinkling of a geologic eye.

There are also superscale changes afoot in our economic and political situation. The population explosion (or to give it its correct name in a world of finite resources, the population implosion) has not only added more people to the human community since 1950 than in all the previous history of mankind, but the main phase of population growth is still to come during the course of the next few decades. Associated with the population phenomenon, there is an unprecedented amount of absolute poverty in the Third World.

This means we must seek, during just the next few decades, to build several new human worlds on top of the one we have already built — bearing in mind that the environmental foundations, and hence the economic basis, of the present one are all too shaky. To cater for twice as many people, we shall need three times as much in the way of food, fibre and buildings if we are to catch up with quality as well as quantity of need (Myers, 1987). We must also generate three to four times as much energy. We have recently reached a $13-trillion global economy, or well over 20 times as large in real terms as at the start of this century; and during the next half century it needs to expand a further five times if we are to meet all-round aspirations — with all the additional pressures that economic expansion will impose on our natural-resource base.

This economic and environmental background serves to introduce an equally significant change: the growing interdependence that characterizes our global community. Until quite recently, nations and even entire regions could more or less go their own way. What a difference today, when we are evermore locked into each other's affairs. Interdependence is now an established fact of life, as witness patterns of trade, commerce, finance, investment, communications, energy, transportation, migration, and technology transfer. And just as we can export inflation and unemployment, so we can export pollution, desertification, climatic disruptions, and a host of other environmental problems. We are learning that joint problems warrant joint answers, and that we can best become prosperous by becoming prosperous together. So too we shall manage to live better with nature as we learn to live better with each other; and vice versa. Our prospect is as simple, and difficult, as that.

In short, we face a situation of one form of mega-change superimposed on another and another, each reinforcing the rest. We also face a fast-growing gap — a gap between our capacity to impose changes on the world we live in, and our capacity to manage our basically changed world. Far from closing that gap, we are watching it grow bigger. We still have time to close the gap: but only just enough time.

All this means that as the global economy becomes evermore integrated, and as we make ever greater demands on our natural-resource base, we face two major sets of institutional challenges. The first is with respect to our national systems of government, and the second our modes of international cooperation. We shall consider the first of these in this opening section, the second later in the paper.

Integration of Environment and Economics

A prime task is to integrate two sets of values, those of environment and of economics. When we make use of man-made assets, such as equipment and buildings, we write off our use as depreciation. But we haven't learned to evaluate our environment as productive capital, even though we utilize it as such. When we cut down forests, overwork croplands until the soil erodes, and utilize our skies as a free garbage can and our rivers as costless sewers, our income as revealed through GNP indices actually registers an increase. Yet we eventually have to pay, often more heavily than if we had acknowledged the cost in the first place. (For some exploratory analysis along these lines, see Leipert, 1986; Peskin, 1987; and Repetto, 1986a).

An obvious illustration is the case of acid rain. In Europe, some 200,000 sq. kms. of forest, or an area almost the size of Britain, are injured if not dying (Environmental Resources Ltd., 1985; Mandelbaum, 1985; Nilsson, 1986; Pearce, 1987). In the worst-hit country, West Germany, the costs to the timber industry are conservatively estimated at $1 billion a year, and the overall costs to the economy at $2.8 billion a year (Federal

Ministry of Food, Agriculture and Forestry, Government of Federal Republic of Germany, 1985; Wicke, 1986). In addition, the European Community believes that acid-rain damage to community-wide forests, crops, lake fisheries, buildings and human health amounts to at least $13 billion a year (Mandelbaum, 1985; Pearce F., 1987).

The acid-rain problem is spreading, widely and fast. There are signs of it in China, Malaysia and Brazil (McCormick, 1985) — even of an acid haze over the Arctic (Harte, 1985). These all demonstrate that the problem of pollution externalities is endemic to economic systems West and East, North and South. There could hardly be more vivid evidence that we need to integrate the values of environment and economics until a unified system of accounting reflects the world outside the window, a seamless world that does not recognize man-made divisions of reckoning.

Let us look forward, then, to the day when we shall hear of a nation where a minister presents a regular "total picture" accounting of his nation's economy *and* of its natural-resource base, each ranking as equally important with the other. The key point — little recognized though it may be — is that much of our economic activity is grounded in the natural-resource base that ultimately sustains us all.

For an instance of the economic penalties of environmental mismanagement in a developing country, consider Ethiopia. The country's forests, which covered 25 percent of the country as recently as 1940, have declined to only 3 percent today (Lamb and Milas, 1983). The result has been widespread soil erosion from the traditional farming areas in the country's highlands. It can be roughly reckoned that this loss of soil with its plant nutrients cuts Ethiopia's agricultural output by at least one million tons of food per year (Newcombe, 1984) — equivalent to two-thirds of all relief food shipped to the country in 1985. Moreover, as trees disappear and sources of fuelwood go too, people take to burning cattle dung and crop residues. So much of these materials are now being used as fuel instead of fertilizer that there is further agricultural output foregone, worth some $600 million a year, or no less than 30 percent of recorded value added in the entire agricultural sector in Ethiopia (Pearce, 1986). To restore tree cover and to safeguard topsoil would, according to a United Nations estimate (Tolba, 1986), have cost some $50 million a year if undertaken in due time during the 1960s. Yet in 1985 the outside world spent almost $500 million on relief food alone for Ethiopia.

An End to Business as Usual

This clash between our systems of economic accounting and environmental management points to a basic conclusion. The future will not be a simple extension of the past. If we try to pursue a path of business as usual, we shall encounter some altogether unusual consequences.

In essence, we are consuming our environmental capital rather than the income from that capital. Latest calculations from West Germany reveal that pollution of all kinds is levying sizeable costs on the economy, no less than 103 billion Marks ($57 billion) per year, equivalent to 8.3 percent of GDP (Wicke, 1986). In developing countries, the spread of deserts was imposing agriculture-loss costs on 80 million aridland-dwelling people to the extent of at least $26 billion in 1975, a figure that in the absence of ameliorative measures is projected to double by the end of the century (Dregne, 1985; Mabbutt, 1984) — and a figure that puts perspective on the proposed budget for the U.N. Anti-Desertification Campaign of less than $5 billion per year.

We must beware, then, of those who assert that we can somehow "get by" until we have restored full economic growth, whereupon we shall possess the discretionary funds to deal with environmental problems. This view suggests that environmental problems are sideline affairs that can wait until we have the luxury of wealth to spare. But if economic growth is based on mis-use and over-use of environmental capital (as is too often the case), then we shall find we are undercutting the very capacity of our economies to keep on growing. The question to ask about environmental protection is not "Can we afford to do it eventually?" It is "Can we afford not to do it immediately?".

Let us also beware of those who suggest that we can do the job through a few incremental changes in the way we manage our natural-resource base. The order-of-magnitude changes sweeping over us and our biosphere demand quantum changes in our perceptions and practices, as in our policy responses. Incremental changes must be accompanied by radical reform. Alternatively stated, we must face the fact — the fact, not a theory — that however much we may engage in fine tuning of the engine, this will not suffice unless we re-design certain basic parts of the engine itself. Or, to use another "automobile metaphor", as long as we suppose that the future will be a case of "the same as before, only more so", we shall be heading into the future with an image from the rearview mirror.

Some Policy Responses at National Level

In face of these radical problems, what sort of radical response shall we envisage? We have tried environmental impact assessments, technological fixes and a host of other such measures. Helpful as they are, they are plainly not enough, since our environmental situation is deteriorating faster than ever. So we need to take a long look at our environmental policies — or rather the lack of them.

Simply stated, the current approach amounts to an "add on" approach (World Commission on Environment and Development, 1987). It reflects the notion that environmental values are an add-on technologically, an add-on economically, an add-on institutionally, and (worst of all) an add-on politically. In other words, essentially reactivist: we engage in *re*forestation, *re*habilitating watersheds, *re*storing wildlife habitats and *re*claiming desertified lands. Of those 140 governments with their environmental agencies, hardly one has accorded to its agency the institutional capacity — that is, the professional expertise, the funding, and above all the "political profile" — to promote its cause within inter-agency councils, i.e., at highest levels of government, where it runs up against counter-pressures from industry, agriculture, energy, trade and other major sectors. All too often it remains a Cinderella agency; and whatever its ecologically-minded technocrats may know about flows of energy through ecosystems, they are less expert about pathways of influence through corridors of power.

Instead of a react-and-cure response, then, we need an anticipate-and-prevent response (Warford, 1987; World Commission on Environment and Development, 1987). Or to put it another way, we should replace the add-on response with a build-in response. And not just for projects and even programmes, but especially for policies. Nothing less will do to match up to the complex syndromes of inter-locking environmental problems that characterize many development sectors.

Ironically we find that whereas there are all too few policy-level measures to support the environment, there are all too many policies in other development sectors that actively, albeit unwittingly, undermine the environment. Whether in economic sectors such as finance, investment and trade, or in resource-based sectors such as agriculture, forestry, energy and human settlements, there are policies that serve to induce and reinforce patterns and practices of development that are anything but sustainable — because they ignore, in fact they degrade, the environmental-resource base.

A notable example is agriculture, and especially with respect to certain policies of developed nations. While pursuing an immediate goal of stimulating productivity and profitability, the policies throw up long-term problems in that they over-reward farmers for over-production of food at cost of environmental values (Barnaby, 1986; Conservation Foundation, 1986; Repetto, 1986b). For instance, they encourage farmers to over-apply pesticides, with the environmental contamination that is becoming pervasive. They prompt farmers to over-apply nitrogenous fertilizers, to the extent that water bodies in several European countries now feature nitrates above the health limits set by EEC and WHO They lead farmers to make careless use of scarce water for irrigation. They induce farmers to open up new land by clearing woodlands and forests, even at the loss of environmental services such as watershed functions. In the United States soil erosion imposes on-site costs of $2.5 billion a year, and off-site costs of $6 billion (Runge, 1986).

As for more distant parts of the world, there is a plethora of policy inducements to fell tropical forests. In Central America, if a man owns a patch of forest and does not do anything with it, he is taxed because he fails to "improve" it (Myers, 1984). If he decides to log it, clear-cut it or slash-and-burn it, he is deemed to have served a socially useful function, so he gets a tax break. In Indonesia there are so many hidden subsidies to foster over-cutting of the rainforests that whereas a conventional accounting asserts that timber-exports add $2 billion to GNP each year, a more rigourous appraisal (Repetto, 1986b) reveals they impose a net loss of $1.6 billion. Overlogging is a problem in many tropical forest countries. Export revenues are now worth more than $7 billion a year, yet they are projected to fall to only $2 billion by the year 2000, when a majority of present timber exporters are expected to become net importers (World Resources Institute and World Bank, 1985). As for non-logging types of exploitation, cattle ranchers and small-scale farmers in Brazil, Colombia, Peru and Ecuador are actively encouraged through fiscal and tax incentives to establish enterprises in Amazonia, at cost to the rainforest.

Especially in the field of energy we find a host of concealed subsidies that emphasize the role of fossil fuels in modern societies, for instance by offering support for extraction of fossil fuels and by offering tax-and-trade support for large vehicles (Repetto and Kosmo, 1986). Conversely there is ample scope to foster greater efficiency of use — which not only has obvious advantages for national economies, but assists the international need to curb atmospheric pollution, whether in the form of acid rain or carbon dioxide buildup. The energy content of economic expansion in industrialized countries, as measured by units of growth in GNP, has fallen in the past decade from an average of 1.2 to 0.5 units (Chandler, 1986). Yet this breakthrough represents only a small part of the scope to increase energy-use efficiency. We could make much more use of the energy source that is cheaper, more widely available and less exploited than any other, and that is conservation, worth perhaps 25 percent of all energy consumed (International Energy Agency, 1987). In Britain alone the savings could amount to £3.3 billion a year, or almost three times more than 1986 revenues from North Sea oil; while in developed nations as a whole, the total could reach $94 billion a year, or three-quarters as much as the value of all commercial energy consumed in the Third World each year.

Were national governments to mobilize a full array of measures to increase energy efficiency, the result would be not only a steady gain in economic productivity, but a steady reduction in forms of pollution that are among the most significant worldwide. From a policy standpoint, then, it is not enough to focus on problems' effects (fossil-fuel pollution, such as acid rain and carbon dioxide) as a prelude to corrective action. Rather we need to shift from a "problem effects agenda" to a "problem source agenda".

Policy Implications

Scope for Initiative: a Conceptual Framework

Plainly the new era of interdependence represents a basic departure in international relations generally, and with respect to environment in particular. An array of issues that have traditionally been treated as primarily domestic — forestry, agriculture, water stocks, pollution, population — are coming to be seen as issues with growing international ramifications. To this extent, they deserve to be broached through cooperative response among all nations involved. This places a premium on a much larger measure of concerted action among the international community than has been the case hitherto.

An example of these issues is acid rain, manifested in several sectors of the world. Another is climatic dislocation, emerging on a global scale as a result of carbon dioxide buildup. Each of these two issues has profound implications for energy policies in all nations, especially as concerns fossil fuels. In particular the second is a problem to which all nations contribute, albeit some more than others; by which all will be affected, albeit in different ways and to different degrees; against which no nation can insulate itself, or deploy worthwhile measures on its own; and to which all nations need to respond through joint endeavour. It is a problem of major dimensions and intrinsic complexity. Fortunately it is also an issue that political leaders with a sense of vision can view as a chance to exercise creative collaboration on an unprecedented scale.

To this degree, the new issues should make it easier for the global community to assert itself in support of its common heritage in environmental resources. It is scarcely realistic any longer to proclaim that a tract of tropical forest, or a watershed, or an exceptional concentration of species with their genetic resources, exists within the territory of an individual nation — and that they should therefore constitute natural resources over which the nation exercises sovereign rights of absolute and exclusive sort. (Something similar applies to non-living resources, such as coal deposits: the United States, the Soviet Union and China possess two-thirds of known commercial reserves of coal — and thus possess exceptional capacity to affect the entire biosphere). The world hardly works in such black-and-white terms any more. Were the community of nations to express an interest in what happens to crucial resources within the jurisdiction of a single nation need not be construed as unjustified interference. It is no more an "encroachment on sovereignty" than are international measures to regulate trade patterns, investment flows, inflation, contagious diseases and international transportation.

Within this conceptual framework for policy initiatives, let us now review some scope for specific measures.

1. *Recognition of Opportunity*

First and foremost, there is need for political leaders to take explicit cognizance of the nature and scope of interdependence, and its import for environmental issues. They will thus acknowledge the new "objective reality" — which need not be perceived as a constrictive constraint on established patterns of activity, rather it can be seen as creative incentive to constructive initiative.

2. *Expanded Potential for Policy Changes*

We no longer enjoy the option of a world without interdependence. We face only the option of ways to live with interdependence, i.e., to manage it. This postulates a quantum advance in international cooperation, to reflect the qualitative shift in international relations. An approach of "the same as before, only more so and better so" will no longer suffice. An unprecedented degree of cooperation is becoming an imperative. Equally to the point, it is becoming an opportunity, too, for expanded policy initiatives that reflect an environmental situation where we shall all win together or we shall all lose together.

3. *New Perceptions of the Nation-State System*

Arising from the above, we need to acknowledge that our affairs still tend to be run for the most part by intrinsically national institutions that derive from the nation-state system — a system that is traditionally competitive rather than cooperative. Fortunately, a growing number of nations are starting to swap certain images of independence for the benefits of interdependence, at least in the economic arena (albeit in rather laissez-faire manner). But in the environmental arena, the process remains largely unplanned, undirected, uncoordinated — unmanaged in general.

We have noted the need to recognize that decisions about our welfare are increasingly made, in part at least, in places other than the established centres of power within their national purview. By virtue of the cross-impact relationships of an integrative global economy and a unitary biosphere, the domain of a government's decision-making increasingly extends to include other governments, plus additional actors such as international corporations.

But while we face an expansion of interdependence among nations, this need *not* imply any diminution in the role of the nation-state. Rather it will require a basic shift in mode of operations — often with an increase in the "positive profile" of the nation-state. Collective action of the sort envisaged need not downplay sovereignty. On the contrary, it should serve to emphasize sovereignty as a functional rather than an idealized concept. Management of the common biosphere, as of the global economic system, will require a large measure of decentralized planning and activity. What better body to undertake this than the nation-state that exercises competence within its own sphere, while upholding broader responsibilities among the community at large? As an established administrative unit, the nation-state will surely find its role enhanced as it undertakes the task of "thinking globally while acting locally".

4. *Need for New Institutions*

To reiterate a central point, the decision-making nexus, still centred on national governments, is more and more limited for decision-making on international concerns. Alternatively stated, certain of our institutions are not mature enough to meet the new challenges. This is hardly surprising when we remember that they were not designed for international cooperation of scope and scale to match up with today's demands.

But what about those institutions that do reflect interdependence and foster international cooperation? Will it be enough to refine and reinforce them? Or do we need to devise new institutions? We have already made some preliminary efforts to articulate common-heritage concepts through, e.g., the Law of the Sea Treaty, the World Heritage Trust, Islands for Science, and similar initiatives. But due to lack of political support, these measures work only moderately well: there are substantial debars that prevent them and their spirit from gaining greater currency. Worse, they are essentially reactivist in nature — a limited attempt to repair damage after the event, rather than a purposeful strategy to take expansive action ahead of time. We are far from having a sufficiently grounded "basis of experience" to serve as a springboard from which to launch further and more far-reaching efforts.

5. *Costs of Action — and of Inaction*

Finally the question of costs. To undertake environmental measures of sufficient scope, the costs will be substantial, totalling tens of billions of dollars per year. But to put them in perspective, we should consider the concealed costs of inaction. We bave noted that in 1980 desertification was imposing costs on communities affected to an extent of at least $26 billion a year — a figure that throws light on the budget for the Anti-Desertification Action Plan of $4.8 billion a year. In the Sahel, measures to meet food needs during 1984-87 were expected to cost a total of $1390 million. Yet a concurrent four-year effort to stem further desertification (reforestation, anti-soil-erosion measures, etc.) was scheduled to cost only $102 million — and if undertaken 10 years ago, the effort would bave markedly reduced the scale of the recent famine-relief operations (World Bank, 1985). So too with fuelwood deficits in Nepal, where diversion of cattle dung and crop residues from farmlands to domestic hearths means a decline in food-growing capacity. By the year 2000 this will lead to food production foregone on a scale to match Nepal's entire crop output in 1970 (Myers, 1986).

So we should be able to mobilize the motivation and political will through a pragmatic appeal to enlightened self-interest. Moreover, the developed nations, which may have to undertake a good part of the financial outlays in question, should not look upon the prospect as merely more foreign aid, to be dispensed out of a spirit of charity. They should rather view it as a form of self-serving investment, in order to avoid a world where the more disadvantaged nations of tbe Third World degenerate into a state of increasing turmoil — with all that implies for general stability among the community of nations.

By far the greatest costs of inaction appear to lie with delay in developing energy policies to cater for threats of a greenhouse-affected world. This applies especially to our inefficient use of fossil fuels, which generate carbon dioxide among other greenhouse gases. Suppose we were to exploit, immediately and fully, the various forms of energy-efficient technologies available to us already; and suppose we were to supplement them with measures to internalize the non-greenhouse effects of coal and shale-oil burning (effects that include acid rain among other forms of pollution). According to this scenario, and if we assume that our reliance on fossil fuels will continue roughly as at present, we find that an aggressive commitment to energy efficiency could hold power-plant emissions of carbon dioxide to 7 billion tons a year worldwide; but if efficiency levels remain at levels of the mid-1970s, annual emissions would rise to 17 billion tons by the year 2050 (Cheng *et al.*, 1986). Alternatively calculated, carbon dioxide buildup by the year 2050 could be limited to not much more than 400 ppm (Goldemberg *et al.*, 1985; U.S. Department of Energy, 1986) — or little above the present level of 345 ppm, and way below the anticipated level of 550 ppm that will ensue without such interventions.

What would be some costs associated with a greenhouse affected world? In the field of irrigation alone, we find that plans for new installations of dams, canal networks and the like, projected to cost $200 billion by the year 2000, are posited on the assumption that climatic conditions will not change significantly. In a planet with higher temperatures (let alone with shifts in precipitation patterns), many of these installations will prove pointless; and many more will be needed to compensate for climatic changes. The cost for adaptive measures in just 15 percent of irrigated lands could be as much as a further $200 billion (Brown *et al.*, 1987). When we add in the need for extra flood-control measures, new crop varieties and other agricultural responses, the total cost could soar to $450 billion.

Regrettahly the momentum that has generated energy-efficiency gains of as much as 2 percent per year during recent years is now threatened by what may be termed the "third oil crisis". The return of cheap oil means we could quickly lose our recent momentum in efforts to increase energy efficiency. If we were to sustain the rate of increase over the next half century (and there is plenty of reason why we could, without harming economic growth rates), we could halve carbon dioxide emissions worldwide.

Unfortunately we do not work well with fifty-year time horizons. We tackle mere ten-year problems with five-year plans, staffed by two-year personnel working with one-year budgets. What counts as "urgent" is what lies right under our eyes. Yet if the urgent drives out the important today, the important can become the imperative tomorrow — when we shall surely bave far less scope to confront it.

Conclusion

The thoughts presented in this paper are not an idealist vision. Rather they are the acceptance of scientific facts. From this premise, a crucial two-fold challenge arises. First, how to shift from a largely scientific understanding to a political perception? And second, how to express the new concepts via policy measures and institutional initiatives? We have plenty of mechanisms to uphold and further the interests of nation-states. We have all too few to promote tbe interests of nation-states working together, in a community where collective welfare is often greater than the sum of the parts. Yet what is perceived today as a desirable but "impractical" prospect will come to be seen tomorrow as a political imperative — though by tomorrow our room for manoeuvre may be severely constrained if we remain enmeshed in conventional strategies that reflect a by-gone world.

Let us not underestimate, of course, the size of the challenge ahead.

It will represent one of the greatest changes ever to confront nations since the emergence of the nation-state as an established concept. It will probably prove to be a greater change than those precipitated in the past by widespread wars. Let us also remember, however, that the change is already in the making, albeit very little and very late. Nations already cede slivers of sovereignty to international bodies such as the United Nations and the Organization for Economic Cooperation and Development; they cede significant slices of sovereignty to regional groupings such as the North Atlantic Treaty Organization and the Association of Southeast Asian Nations, and to trade organizations such as OPEC; and they cede considerable chunks of sovereignty to integrative units such as the European Economic Community. So a start has been made.

This enables us to assert that the new approaches, radical as they may appear, are not only desirable, but feasible as well. Who would have thought at the time of the Stockholm Conference in 1972 that a Mediterranean Action Plan would become practicable, involving several parties who are long-standing antagonists (Israel and Syria, Greece and Turkey, Egypt and Libya, etc.)? How much more difficult and costly would an Action Plan be to formulate today? As we face the daunting challenges ahead, we can take heart from the ground-breaking precedent of this endeavour in international cooperation that *works*. The key component is this: pressing environmental needs have served to foster a sense of creative interdependence among the Mediterranean nations. Economic wellbeing and political stability have come to be recognized as indivisible — as indivisible as is the common environment.

To this extent, environmentalism helps to articulate the shared interests of nations: confrontation gives way to cooperation. By promoting a consciousness of the biosphere's unity, as of society's unity, the environmental cause may even encourage governments to adopt a more constructive approach toward problems of other sorts — notably the manifold questions of sustainable development within a safeguarded biosphere.

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TRANSFER OF KNOWLEDGE AND OF NEW INNOVATIVE TECHNOLOGIES

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"An nescis, mi fili, quantilla prudentia regitur orbis?"
Count Oxenstierna, 1648

Introduction

In a world which is becoming increasingly technologically oriented and in which the choice of the appropriate action to combat environmental problems is both difficult and complex, the transfer of knowledge has become an important issue. The different actors on the world stage are divided by language, by interest, by motivation, and by function. Even between scientists of the same discipline, communication is often difficult because of differences in the scientific traditions of individual countries, and communication of technical information between scientists of widely different disciplines is notoriously unreliable. It comes as no surprise, therefore, that communication between scientists or technologists and the resource managers, administrators, and politicians who might be able to use the results of their research is slow, often confused, and liable to misinterpretation.

The difficulties are increased rather than reduced by the necessarily differing perceptions of the actors about the nature of the problems they face. For research scientists, the principal objective is to do, and to continue to do, research. All other activities are secondary, and by definition unsatisfactory, if necessary, adjuncts to that research. For the scientist, the essential communication is with his peers. The resource manager, on the other hand, has to concern himself with day-to-day management, and with the formation of policies which will guide future management and influence the practical outcome of competition between agencies for common resources like land, water, manpower, and finance. While he may he aware that research might help him in these tasks, to-day's problems have an immediacy which often overrides any possibility of considering those problems which lie in the future, and which are likely to be solved by research initiated now. He needs access to such information and advice as currently exists, and in terms in which he can both understand and apply that information. Managers in industry and commerce are in a similar position to those of the resource agencies, except that their end-products are the goods and services characteristic of their particular concerns. Industrial and commercial economics also demand that each company make sufficient profit to satisfy its investors and to plough back for future investment.

Administration, or the management of public affairs in central, regional, and local government, has a similar set of objectives, but with particular emphasis on the development of policies to govern the conduct of future management, especially where there is likely to be conflict, and hence disagreement. Much of the success, or failure, of administration lies in selective support for a limited number of policies which do not foreclose future options (Walters, 1975). The requirements of all of these actors, and of many others, including politicians, teachers, land-owners, taxpayers, etc., for scientific and technical information are analysed in more detail in Jeffers (1984).

This paper, however, examines the conventional methods for the dissemination of scientific and technical information against a background of rapidly developing new technologies. It considers the special requirements of environmental issues, where there may be a particular need for the resolution of conflict between the many agencies and concerns involved in these issues. The use of knowledge-based systems which combine a data base with problem-solving heuristics is described, together with some suggestions of priorities for the creation of such systems. The importance of systems which aid the resolution of conflict is emphasised.

Conventional Publication of Scientific Results

As has been emphasised above, research is a self-motivating activity with its own carefully structured end-products, designed to ensure that research scientists have access to the informal communication which takes place between scientists accepted by their peers. Without research, they would have no outlet for their expertise and for their creativity. The publication of research results in the formal journals of their respective disciplines represents a necessary condition for their belonging to the scientific community. Communication of research results to a wider audience may be a necessary chore for the obtaining of support for new research, but itself uses the scarce resources of time and energy which might otherwise be spent on what the research worker does best, i.e., research. As a result, therefore, publication of research results in scientific journals is principally intended to gain and keep the acceptance of other scientists. These papers follow a very special set of rules and conventions, are subjected to careful scrutiny by editors and referees, and are seldom intended to convey information to a wider readership. There is also usually a long delay between the submission of a paper and its publication, sometimes as much as 2 or 3 years.

This formal mode of publication, which is so essential to the active scientist and technologist, is often supplemented by the publication of research reports, conference proceedings and books. Research reports are also intended to summarise research results, but usually at some stage before the completion of the research. They, too, are submitted to critical review by the director or senior staff of the research organisation producing the report, but the delays in publication will often be shorter. Such reports also have less value to the research scientist in furthering his career, and hence his ability to do more research. In addition, the policy of the research organisation may place constraints about what can be said in the report, or the whole report may be classified as "Confidential". More seriously, there is no mechanism for the distribution of such reports, so that their existence may remain unknown. Indeed, one of the disadvantages of the methods of contract research which have been introduced into many countries is that they lead to the production of a sub-literature of research reports which are not readily available to other scientists or to decision makers.

The publication of the proceedings of scientific conferences is also intended to reduce the delays in formal publication by scientific journals, but the proceedings will usually still be refereed and edited. The increasing emphasis on speed of publication, and the consequent demand that participants in conferences write their paper before the conference, often results in the published paper being very different from what was actually presented at the conference. The whole purpose of a conference is to stimulate an interaction between the participants, and publication of what each participant thought before the interaction took place frequently misrepresents the results of this process.

Many scientists do write books, principally collecting together research results obtained over several years. With rapidly increasing costs of book publishing, however, the royalties to the authors scarcely repay the effort needed to write the book unless the sales are likely to be extensive. Highly specialised topics are thus less likely to be published than the more general textbooks because of their limited sale.

As pressure on space in libraries mounts, as well as the cost of traditional publishing methods, some results of scientific research now appear on microfilm. A limited amount of material appears in this form alone, but microfilm readers are not popular with anyone except librarians, and the logical development of this more condensed form of information presentation has been slow. In contrast, the publication of scientific abstracts has become extremely popular, enabling readers to scan a large number of papers very rapidly through their titles and short abstracts of their contents. It has sometimes been suggested that only the abstracts should be published in future, and that anyone interested in reading the complete paper should then write to the author for a copy. This form of publication would not meet the requirements of the peer review demanded by scientists, however, and is unlikely to be adopted. The same reason has inhibited the production of on-demand reports, although short reports of this kind may be produced as a result of requests for advice.

Finally, where the participants can be brought together, in reasonably small numbers, the communication of information can be made face-to-face. When one person gives a talk and the rest listen, the use of lectures can be effective, provided the transfer of up-to-date information is in terms which are understandable to the audience. However, genuine discussion is often limited in traditional scientific conferences and symposia, principally because of lack of discipline in keeping speakers to their allotted times and the consequent erosion of the limited times allowed for the discussion. During the last two decades, more interactive "workshops" have become popular, enabling relatively small numbers of people to communicate effectively. Rotational Group Workshop systems have shown themselves to be particularly successful in generating interactive participation between members of even the most diverse groups (Wynn, 1981).

Some Practical Alternatives

With the development of the modern computer, many alternative methods of disseminating information have become possible, and it is clear that science, resource management, administration, industry and commerce have not yet begun to realise the full possibilities of computerised systems. There has, for example, been much talk about the setting up of data bases, organised collections of information which may be consulted hy authorised enquirers, either directly or through remote terminals. Valuable library reference systems providing access to abstracts of scientific papers already exist in this form, but data bases for other kinds of environmental information have proved to be more difficult to organise. One of the problems is that data collected in the field are less easy to index and access, particularly where it is necessary to qualify those data with information on how they were collected and with constraints on how they may be used. Nevertheless, despite the problems, many potentially useful data bases are now being compiled and will provide access to the kinds of information which simply have not been available to decision makers in the past.

An even more direct way of using the computer as a means of information exchange is through computer programs or algorithms. The need to write complete and unambiguous instructions to enable the computer to do anything at all has provided us with the unexpected benefit of being able to transfer the same information to other scientists through computer algorithms — systematic mathematical or logical procedures enabling a problem to be solved in a finite number of steps expressed in one or more of the internationally accepted computer languages. This method of transferring information is further extended in the use of mathematical models as simulations of complex processes or of solutions to practical problems through the means of computer programs. Such simulations can also be used by resource managers and administrators, although few decision makers are willing to use computer models without some understanding of the underlying mathematics. The sad fact that many people who consider themselves educated often boast that they know no mathematics severely limits the use of simulation models.

Also dependent on computers is the rapidly expanding development of word-processing. Initially often based on special function machines, word-processing is now most frequently done on micro-processors provided with special programming facilities to make them particularly adapted to the easy handling of text, tables and figures. Linked together, word-processors also act as a communication system, enabling the scientist, administrator, or resource manager to consult, edit or update material which has been prepared by others, perhaps long distances away. Viewdata systems which link computers and word-processors by telephone lines or by satellite already offer interactive access to large amounts of data, computer programs or graphical presentations. The use of videodiscs for storing extensive mixtures of data, programs, visual images and sound is currently being explored and has been demonstrated recently by the British Broadcasting Corporation's Doomsday Discs. So far, even the scientific community seems barely aware of the possibilities offered by these methods of communication.

Special Requirements of Environmental Issues

Wise management of our environment obviously requires access to information about past trends, about land use, about planned policies and management practices, and about the economic, social and ecological systems which determine the consequences of our actions. The information that is required, therefore, is complex and multifaceted. It is not easily interpreted, even where it is available, as is evidenced by man's past record of environmental disasters. The northern desert ecosystems of Africa were the vineyards of the civilised world at the time of Christ, but the agricultural land was destroyed by methods of land use which, though traditional, failed to accommodate to the changes taking place in the environment as a result of its exploitation. The use of pesticides like DDT were hailed as a triumph in the battle against pests and organism-borne diseases, but underestimated the persistence of the chemicals and their transfer and accumulation in organisms at the end of the food chain. It also underestimated the ability of pest organisms to develop resistance to specific chemicals. The building of expensive dams, while miracles of technology, is often the cause of ecological disasters, as in the effect of the Aswan High Dam on the lower reaches of the Nile.

Management of ecological systems, in particular, needs to take account of the complex interactions between the organisms found in such systems, and of the interactions between these organisms and their environment, itself a definition of ecology. The paradigm of the ecosystem as that system resulting from the integration of all living and non-living factors of the environment demands a holistic approach to ecological research and management. Although much progress has been made with such research (McIntosh, 1985), the expression of ecosystem theory is necessarily complex and essentially mathematical, so that much of this theory is inaccessible to those who most need to use it. The multivariate and non-linear nature of the relationships between organisms, and between organisms and their environment, and the often complex feedback loops between cause and effect, make common-sense unreliable as a guideline for action or for the formation of future policies. The same is almost certainly true of the less well-developed sciences of economics and sociology.

Knowledge-Based-Systems

Fortunately, there now seems to be some hope of a solution to the problem of making the complex mathematical theory which underlies ecology, and perhaps also economics and sociology, accessible to the resource managers, administrators, and politicians who need a more informed base for their decision making. This solution lies in the current development of expert or knowledge-based systems, defined as computer systems capable of giving intelligent advice and of justifying the basis for that advice. The characteristics of such systems are that they can solve difficult problems as well as, or better than, human experts and can justify their own conclusions. They reason heuristically and interact easily with human users. They manipulate symbolic descriptions, such as mathematical models and algorithms, and can function with data which contain errors, using uncertain judgmental rules. They can contemplate multiple and competing hypotheses simultaneously, and can explain why they are asking a question (Waterman, 1986).

Knowledge-based systems differ from previous forms of computer programs by incorporating the heuristic methods used by human experts with the information provided by a data base or mathematical model, often with the aid of new programming languages such as LISP or PROLOG (Hayes-Roth, 1983). Building such systems is helped by the possibility of creating expert system shells which are capable of holding a wide variety of different kinds of expertise, but which nevertheless use the same programming methods. The difficulty in creating expert systems, therefore, usually lies in extracting the expertise from the heads of human experts rather than in programming the computer, but, even here, new computer-based methods are often helpful in codifying and classifying the constructs used by the experts (Olson and Rueter, 1987).

It is too soon to say just what the impact of these knowledge-based systems will be on environmental management and research. Prototype expert systems have been built for making assessments of environmental impact, and for providing advice on taking land out of productive agriculture in the European Community. Well-developed systems exist for predicting vegetation succession following fire or some other ecosystem disturbance, and for diagnosing pests and pathogens of forests and agricultural crops. Expert systems for the determination of the objectives of National Parks and other conservation areas have been developed and are currently being tested in the field. Many other applications are under consideration, but have not yet reached a stage at which they can be tested or verified.

Conflict Resolution

Perhaps one of the most exciting developments of knowledge-based systems is in the design of computer programs for the resolution of conflicts. Almost all environmental problems result from conflict between the policies or management practices of one or more agencies. Some of these conflicts are so complex and depend on so many variables that it is almost impossible to make effective decisions or to find an optimal solution without the aid of a modelling program. The meta-game algorithm devised by Fraser and Hipel (1984) provides a tool that a decision maker can use to analyse any problem involving two or more participants, each with separate goals, whose actions affect one another. The algorithm enables the user to predict the likely consequences of a particular strategy, and determine the best course for a given participant. It also enables him to gain valuable insight into the dynamics of the conflict and facilitates communication about the conflict to others.

What is important about this approach to conflict resolution is not that such a program gives a major advantage to the user over the other participants in the conflict but that it generates a wider range of practical options than would otherwise be considered and relates these options to the likely outcomes of the conflict. Some options may be mutually exclusive, or there may be some other reason that the resulting outcomes are not logical, and these can be identified and removed from the model. The overall stability of every outcome is determined on the basis of the participants' options and preferences. An outcome that is stable for all the decision makers is likely to persist in the real world, and thus will constitute a possible resolution to the conflict. Identifying the exact reason for an unstable outcome also helps to guide participants towards a logical solution. Inspection of the forecasted result may also suggest modifications of the preferences of one or more of the decision makers. Adjustment of these preferences and re-analysis of the model provides the kind of sensitivity analysis which is lacking from more traditional methods of decision making and compromise.

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THE NEED FOR PROFESSIONAL TRAINING OF EXPERTS IN THE ENVIRONMENT AND IN ENVIRONMENTAL EDUCATION

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Cultural change

Consideration of the professional training and education necessary for the programming, management and control of the environment must take into account cultural and historical characteristics and even more the degree of interest in environmental issues.

There have been long periods in history in which the cultural frame of reference of people and groups has remained substantially unchanged. At birth, the member of one generation would find, in his own community, a set of values and behavior which, for the duration of his life, he helped perpetuate. The past was delineated on the generation which was aging and gradually left the field, while the present and the future were delivered into the hands of the younger generation. However, the fundamental (cultural) picture remained essentially intact.

Such periods have been followed by periods of transition in which the cultural references dissolved more or less radically, while a new plan was being started with choices and behaviors corresponding to a human environment which was being constructed on a new basis.

Consider what happened in the western world after the fall of the Roman Empire. After six, seven centuries of elaboration, often hidden but always very active, there emerged the stupendous civilization of the 13th century.

In that period:

— agriculture, which remained the driving economic force, was accompanied by the development of the handicrafts and commerce,

— nobility, which had its strangholds disseminated in strategic points, ceded power to a dynamic middle-class which shifted the centre of political and economic power to the city, which became once more the centre of cultural elaboration,

— institutions such as universities, on the one hand, and spontaneous forces and strong personalities, on the other (remember Francis of Assisi), formulated a new project regarding the relationship man-natural environment-human environment.

The model remained essentially unchanged in its fundamental structure up to the beginning of the second half of the 20th century. In the years that followed the last World War (1939-1945) the model was superseded mainly as a consequence of three facts:

— the intense scientific development that has heen the basis for technological and industrial development;

— tbe distorted use of the instruments and technologies in which the industrial society abounded;

— the grave problems posed by the human population: numerical growth, migration, and, in the western world, aging.

A completely new picture emerged, which side by side with very positive prospects, involved serious risks for man, for his relationship with the environment, for his own identity, both as a person and as a member of the community.

Essentially, in respect to the environment, there has been a transition:

— from a close relationship with the environment to a behavior in which man feels himself, both existentially and operatively, above and out of nature;

— from a global, even if prescientific, view of the environment to a reductive view of the same, which is regarded as the sum of several factors, processes and subsystems;

— from an economy based on recycling to the adoption, as a praxis, of the logic of consumption and waste;

— from methods based on intervention to methods limited to the correction of effects that leave the causes intact.

Nature itself has been degraded into a mere source of materials available for an economic project of unlimited economic growth which, despite the enormous price it has cost the natural and human environment, has not solved the fundamental problems it had proposed to solve.

This "culture" of what is quantitative and of consumption has cut transversely all aspects of our present industrial society. It has made a bonfire of traditions, subordinate cultures, natural and cultural resources.

Think of the past, set in a new dimension, which has been overtaken in one generation and now represents a different epoch. An epochal gap exists between the culture of the generation which started its course before the war (which today is living across two cultures) and the younger generation.

The dramas which in twenty years this approach has caused in the industrialized world and consequently in the emerging countries are, by now, part of everyone's experience.

The first reaction took place in the 60s and 70s and must be credited to the environmental movements. It has contributed in a determinative way to the rediscovery of the environment as a unitary reality, living, complex and fragile, with which every person feels by now directly involved.

Environmental problems have soon brought under scrutiny the public administrations, which had to lay down appropriate norms on water, air, waste, and nature conservation.

The attitude towards the environment on the part of productive forces (industry, agriculture and the tertiary) has changed profoundly. Their first reaction had been completely negative and did not exclude accusing the environmental associations and the scientific community (engaged in ecological research) of wanting to block economic growth, start the spiral of inflation, and cause unemployment.

In the second half of the 70s this attitude was followed by a more critical approach. The norms regulating the quality of the environment had been accepted, and interventions were made in order to repair the negative effects of polluting technological processes.

Recently the more advanced sectors of the industrial world have matured to the point of seeing the greater economy offered by the use of clean technologies (and thus of prevention) and have verified the appearance on the market of new environment-related productive sectors. The trade unions, too, have discovered an interest in the environment, both because they had to face the problems posed by the diminished health of the workers (due to hazardous industrial processes) and because they registered the emergence, in the labor market, of many new professions closely related to the management of the environment.

The preceding picture, although obviously simplified, shows the extent of the change in traditional models and approaches to land management that have been produced by the development of an environmental perception among citizens.

Contents and agencies of environmental education

In the Middle Ages cultural change was introduced by monasteries, universities, and by spontaneous forces. Today, at least as far as the perception of the environment and the analysis of its problems and needs is concerned, the relationship appears substantially overturned.

In the 60s and 70s interest in the environment, as we have seen, has been aroused by spontaneous associations. In many countries the scientific community was taken aback by an overwhelming demand (and often in dramatic conditions) for knowledge, methods and techniques, on the one hand, and for graduates and technicians, on the other. The reason was that ecology, the discipline that deals with the processes of the functioning of the environment and with the systems analyzed in their globality, was still relatively young.

In contrast with chemistry and other disciplines, ecology did not have a consolidated scientific identity. Still today it is difficult for the systems approach to obtain recognition. Scientific and methodological reductionism is quite widespread in schools, in the programming of environmental action, in social life, and in many cases in the very world of scientific research on the environment.

In fact, ecological factors and processes are studied separately from one another by the chemist, the zoologist, the botanist, etc., without taking into consideration their interactions, their side effects and the systemic frame in which they are inserted. Research in fundamental ecology is insufficiently developed, and even less so are interdisciplinary projects merging the naturalistic, legal, economic and social components necessarily involved in the programming and management of human environments.

Scientific and professional training presents the same expectations and suffers from the same limits.

The development of a culturally advanced educational system for the environment is one of the most urgent challenges to the scientific world (within and outside university settings), to public administrations and private (training) agencies.

An effective training of technicians and researchers constitutes the keystone for the building of a realistically better relation between man and his environment.

Environmental education: demand and offer

In the industrialized world as well as in emerging nations a strong demand for environmental education has developed in the last ten years. The proponents of it are public administrations, schools of every kind and grade, naturalist associations, the industrial, agricultural and tertiary sectors, trade unions, political, economic and legal spheres, and countries as a whole. The demand has received an organic response, on a worldwide scale, from two activities undertaken by UNESCO:

— the intergovernmental Conference on Environmental Education in Tbilissi (Georgia, USSR, October 1976), and

— the MAB (Man and Biosphere) Program.

At a regional level, National Centres for Environmental Education have elaborated *ad hoc* programs and organize conferences with the aim of verification and making proposals. The European Economic Community has made the theme of Environmental Education one of the focal points of the European Year of the Environment (21st May 1987-20th March 1988).

The reflection upon environmental education made by the international scientific community in the 70s has led to the formulation of a first definition of it:

— "Environmental education is the transmission of a *system of knowledge, methods, experiences* by means of which *a person who is part of a group*, and the group itself, *become conscious of the reality of the natural and human environment in which they live* and consequently assume a *correct and responsible behavior* in the programming and management of the systems and of the natural and cultural resources of human environments".

Thus environmental education is not the teaching of ecology or of the natural sciences, nor a specialistic pedagogic methodology. Instead, environmental education, drawing significant inputs from the knowledge elaborated both by scientific research and the human sciences (such as pedagogy, psychology, sociology, economy, law, etc.) and through the use of interdisciplinary methodology, deals specifically with the development of a correct environmental perception that is to be taken as the basis of a balanced behavior towards nature and towards the city.

Environmental education as a scientific discipline and as a point of view

Environmental education can be considered in two different perspectives: as a discipline and as a point of view.

Environmental education as a scientific discipline

The identity of environmental education is born of the integration of the contents and methods of naturalistic ecology, on the one hand, and the human sciences (pedagogy, psychology, economy, ethics, law, etc.) on the other.

The analysis of the research work carried out in environmental education by several groups shows that there exists today a good basis for systematizing it as an autonomous discipline.

As a discipline, environmental education will be involved in professional courses for trainers and operators. In these cases, environmental education becomes a *professional discipline*, and the objective of this teaching is the promotion of a specific professionality.

Environmental education as a point of view

A second objective of environmental education concerns the education of citizens of all ages and social classes about a correct behavior towards the environment.

In the schools environmental education has one of its most significant, but not exclusive, fields of action. It extends, in fact, to the spheres of public administrations, of production and work, mass media, environmental associations, and the political, legal, economic, and religious world. Environmental education assumes, as a consequence, a key role in a cultural process which will render irreversible the interest in the environment, saving it from recurring economic, political and social fluctuations.

Consider, for example, the need for a widespread dissemination of environmental education in order to undertake in a coherent way the reading of studies on environmental impact by the community. If one considers the school, in particular, environmental education is a *point of view* which runs across all disciplines, both experimental and humanistic. Every discipline (history, geography, languages, sciences, technical education, etc.) must "read the environment" according to its own cultural interest and so interrelate with other disciplines and, thanks to the interdisciplinary methodological approach, to the elaboration of a human environments. The objective is that of forming mental attitudes and human environments. The objective is that of forming mentalities and behaviors carefully directed at the realization of relationships and capable of organizing environmental factors in the processes that characterize environmental dynamics in order to be able to operate in a complex and changing system. To this end, one must remember that no man is an island; but rather each man realizes himself as a mature and balanced personality through a daily measuring of himself with the natural environment and the human community.

One must therefore outgrow the attitude "of remaining on the outside" in a daily life without a future, and acquire the consciousness that in this way he will never make history, nor promote a reality that will require planning, participation and mediation.

Environmental education seen in this light becomes one of the most important components of a new culture, directed at the development of a correct relationship between man and his environment.

Actions for the promotion of environmental education

The complex of objectives, concepts, methods and plans for action, which environmental education today proposes to develop, is very mixed. A qualified answer to the demand for environmental education, which comes from the industrialized world and from emerging nations, requires two actions: research on the contents of environmental ecology and the training of experts.

Research on the contents of environmental education by the natural sciences and the human sciences

The research on the crucial themes that give man's behavior towards the environment its characteristics and that dictate modes of management, acquire a strategic meaning for the development of environmental education.

Consider the relationship between *economy and ecology* that calls for the necessary overcoming of the model of unlimited economic growth and for the adoption of a model of development which confers equal dignity to the quantitative and the qualitative aspects of life, taking into account great emerging problems such as energy, human environment, food, etc.

Consider the relationship between *progress, technology, and ecology*, the relationship between *nature conservation and quality of the environment*.

Consider the relationship between *historical memory* (represented by the patrimony of cultural heritage and by traditions), *the present and the attention to the future* (a component that carries a strategic significance in a culture in rapid transition such as the present one, rich with means, but poor in objectives and in ethical projects).

Facing the increasingly pressing demand for environmental education, the scientific community and spontaneous groups began, in the 70s, an effort to formulate a coherent answer. Since then problems have increased, become more complex and the answer has gradually become more critical and complex. Today one has the sensation of being at a turning point at which an answer will be found only through a strong professionality capable of transferring its objectives and contents to schools, to social, political, economic, intellectual, religious and other forces.

In the university system, the training of researchers in environmental education can be carried out with Ph D courses in Environmental Education, operating preferably in interfaculty and interdepartmental centres.

The training of trainers for schools and for environmental education programs for different social categories and the public at large can be carried out in postgraduate professional schools.

The forces that operate in voluntary service must find by themselves qualified opportunities for training.

Conclusion

It is becoming more and more evident that the present drive towards scientific and technological innovation is destined to successfully promote the quality of life only if two essential conditions are satisfied:

— the development of a true consciousness of the role of man in his natural and human context,

— a sincere will to act for a management of the environment where development means a harmonic balance between quantity and quality, progress and conservation, economy and ecology, scientific and humanistic cultures, and will produce a real quality of the natural environment and of the city, the systems of which every person is, at the same time, parent and child.

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DISCUSSION

BOURDEAU

Dr. Myers said many things, but one item that I think could be useful for the conclusion is what some people call teleconnections in meteorology, what he called the "hamburger connection", as an example. A point worth considering is the following: to show the interlocking of relationships with regard to environmental problems, that something we do here has an effect a long distance away, and vice versa.

MYERS

I really have nothing to add to that, except to thank you for your comments.

TANDBERG

When we are discussing the possibilities of scientific environmental cooperation, we should not overlook the importance of the legal forces of governmental resolutions which make it possible to reach the goal. You gave some interesting suggestions, and I think that legal cooperation between the states is a necessity in order to solve the questions on pollution or degradation of the environment, as we heard when you described the problems concerning the Mediterranean. It is important to study how the different steps are taken and how legal procedures have to be followed before a binding convention between the states becomes a reality. I think the scientific community should be made aware that here we have an important tool which could be most useful. We must learn how to use the legal help in order to reach our common goal: a better environment.

KECKES

The comments made by Professor Tandberg are most welcome, because even the best recommendations and resolutions will not help the environment. Unfortunately, scientists are deluding themselves if they feel that good science alone will solve environmental problems. Good science is an essential element for the solution of the problem, but good science in itself is not enough. Action is needed, and this action consists of several components. Action must be based on sound science, otherwise it will backfire sooner or later.

Action must be supported also by political commitment on the highest possible level. No political commitment is coming forward unless you can support the recommendations of scientists with economic arguments. Let's face it, the world is run by money, not by good ideas only. Action should be formalized and there is no better way of formalizing an action than by a legal framework, as Dr. Tandberg has said. It is essential, because otherwise the action just fizzles out sooner or later. With a long-term commitment on the highest possible political level, such as an international convention, you have an instrument in your hands which can be used effectively. You can put the government in an embarrassing position if it does not follow it up. It is still not a guarantee that things will be done; naturally, because no international agreement is law unless it is really transferred into national legislation, but that is the safest road which leads to certain long-term solutions of the problem.

MARINI-BETTÒLO

Are there any other comments now? Well, if there are no more comments, I would like to ask Professor Jeffers to make his presentation about the transfer of knowledge and of new innovative technologies.

TANDBERG

I wish to congratulate Mr. Jeffers for a thought-provoking and interesting lecture, where he informs us about one of the important instruments in the modern approach to the protection of the environment.

We are in the middle of a tremendous information explosion, a sort of elepbantiasis of knowledge, because huge mountains of information are overwhelming us. In the tremendous ocean of information from experts, it is sometimes very hard to pick out the relevant information you really need. As the Foreign Secretary of the Royal Swedish Academy of Sciences, I am personally very much involved with this process of selecting the right information at the right time. I am representing my academy as National Member of the General Committee of ICSU (the International Council of Scientific Unions), an organization which coordinates the non-governmental scientific community. The ICSU Press was established in 1983 in order to assist tbe Members of the ICSU family, which consist of National Members, mainly academies, international scientific unions and scientific associates. One aspect of the ICSU Press, where I personally am heavily involved, is to follow and report on publications and communication technologies such as the video discs and compact discs described by Dr. Jeffers, when he informed us about the Doomsday Project carried out in England by the BBC and Philips Electronics, where 300 thick volumes are digested into two video discs — indeed, a very important tool.

I would like to come back to the matters we discussed this morning. When you have the tool, you must then try to translate the information you have received and make it understandable to the legal experts so that they can provide the legal base which makes the scientific cooperation between states binding and meaningful. If you try to establish an international convention, it is important that you choose the right tool so that the relevant information can be digested and understood. Mathematics is a wonderful way of communicating, regardless whether your alphabet is Latin, Greek or Cyrillic, the mathematical symbols are the same. But you must try to express the mathematical formula so that it is understood by the people who make the drafts of the real tool you need: the final text of the international conventions. In my opinion, Dr. J.N.R. Jeffers has shown us some wonderful possibilities and also great dangers in his expert system with a conflict analysis. One of the smaller risks is that the system is so effective that there will be no time left for coffee breaks, which are so important for providing informal discussions and exchange of information to the participants before a final decision is reached.

JEFFERS

I have very little to say except that I agree. I think it's true that the systems might be dangerous, and not simply because they limit the coffee breaks. Maybe they will actually increase the coffee breaks in the sense that, if we can transfer the information more efficiently, we can spend more time communicating in the informal way which is so important for us.

I think there may well be dangers in the use of expert systems, particularly if they are used uncritically. They could be dangerous also if they are constructed uncritically or maliciously. There is an other problem. A number of people have said to me, "What relevance has this got to problems in the Third World, which doesn't have access to computers?" Well, we work with a number of Third World countries and they do now have access to computers, but need guidance on how best to use them. It's important that they get the right kind of guidance, that they get the right kind of expert systems, as it were. But giving them that advice, as if it was from a human expert, may be the most valuable way of actually providing practical help, rather than trying to train large numbers of people to have specialist expertise which then can't be brought together very easily. The only danger about conflict analysis, in my view, is that it gives a very great advantage to the person who uses it. Therefore, I would like to see the existence of this particular type of system more widely advertized so that those who might use it will know about it. There is a danger that conflict analysis gives an enormous advantage to somebody who knows how to use such a system, because he can always select the optimum strategy.

BOURDEAU

I would like to come down to a more mundane level, after having heard these very exciting things about expert systems and other means of communication. I have learnt from my experience in trying to communicate with decision-makers, parliamentarians and so forth, that one medium that is very important is a high quality press, scientific journalism. For instance, some large German newspapers have very well written scientific pages and these are read by politicians. I think enhancing the quality of what is published in the field of environment might be quite useful.

GOLTERMAN

I would like to come back to the basic preliminary statement: humanity has to face the need to settle adequately in the next fifty years the population expansion which will double our present 5 billions? I have heard several times that we more or less accept automatically that the world's population will be ten billion in about fifty years. I think it's very clear that, if this is happening, we will be very quickly proceeding to a nuclear war, and after the nuclear war there will be no need of environmental protection because there will be no environment. I think that this meeting, here, has greatly neglected the possibility to emphasize the need for controlled population growth; and I think we are failing in our task if we do not consider this as one of the most important things for environmental protection.

MARINI-BETTÒLO

There is no doubt that planning of the growth of the population should be envisaged in the coming years; although the betterment of the quality of life of many populations will itself act in the direction of reducing the growth rate. But we should make clear how this should be realized.

CONCLUSIONS AND FINAL CONSIDERATIONS

After Professor Moroni's presentation, the Chairman asked Professor Odhiambo to prepare, together with Professor Ives, Dr. Lundberg, Professor Raven and Professor Ravera, a document on the conclusions of the meeting, and recommendations for future action.

In the following session, Professor Odhiambo read the draft of the document, entitled Final Considerations and Conclusions, *which consists of a preamble and the analysis of four principal items on which it is necessary to focus the attention of governments and of international institutions.*

The four points mentioned by Prof. Odhiambo were the following:

1) *the conservation, of all species;*

2) *the incorporation of the indigenous knowledge, to be derived from cultural diversity, into project planning, implementation, monitoring and evaluation;*

3) *effective and continuous attention should be given to transboundry problems;*

4) *the establishment of an international network for the management of mountain resources.*

An additional point was raised about the ethics of environmental management.

Professor Ives, as well as Professor Raven, pointed out the significance of the recommendations. A discussion followed, in which Professors Chagas, Marini-Bettòlo, Bourdeau, Przewozny, Likens, Golterman, Ayyad, Keckes, Ravera, Rodrigues, Maler, Lundberg and Jeffers participated. It was agreed to introduce in the Conclusions additional items, e.g., global environmental problems, trace substances and social and educational aspects related to the environment.

The final document of the participants was submitted to the attention *of the components of the panel which drafted the first document. It was approved and appeared in* Documenta Pontificia Academia Scientiarum 26, 1-24, (1988) *after accurate editing by Father Bernard Przewozny and now in this volume.*

* * *

The world and humanity are at risk; alarming signals of this danger reach us from all directions. But an all-embracing institutional structure capable of dealing with the crisis — to ensure the correct identification of its causes and to implement effective remedies — does not yet exist. Difficulties inherent in the very analysis of the risk are further exacerbated by its complexity and by the widespread uncertainty about its precise nature.

Environmental problems pervade all facets of human activity and should be treated as an integral part of all national and international policies. Indeed, this Study Week was called to address what is, in a certain but very real sense, one of the all-encompassing and, therefore, ultimate problems that humankind must face and solve.

The purpose of our meeting was to examine damage to the natural environment caused primarily by the undisciplined activities of humans. It was considered that, to face the needs of an increasing population, the limited resources of the earth and the management of the environment require rational and accurate planning, based not only on demographic and economic factors, but also on ethical, cultural and social considerations. Thus, while it is generally assumed that poverty, population growth and mismanagement of the environment are not independent of each other in exerting large but unequal pressures on available resources, there are no simple solutions to the perceived interdependence of these factors as causative of the risk.

In order to formulate suggestions and proposals for guidelines to ensure the protection of the environment, we considered separately those problems which give rise to worldwide or global changes and those which, being related to particular geographic regions or to meteorological-climatic processes, modify the single ecosystems.

The first group of problems may in great part be attributed to modifications in the atmosphere caused by anthropogenic activities and the subsequent changes in climate due to increasing concentrations of CO_2, trace gases, particulates, depletion of the stratospheric ozone layer, and to acid depositions and photochemical oxidants. These problems were examined by the Academy in 1983 (cf. Scripta Varia, 56, *Chemical Events in the Atmosphere and Their Impact on the Environment*, Pontificia Academia Scientiarum, 1985). Aware of the conclusions of that Study Week, we take into consideration here only the most recent advances in the field.

We examined other aspects of the protection and sustainable uses of the environment and of the biosphere, principally the biological, such as deforestation, mountain ecosystem, desertification, etc., as well as some social dimensions of human development, for example, poverty.

Finally, some of the aspects covered during our Study Week included the management of the global commons such as tropical and temperate forests, mountain environments and climatic change, together with regional issues such as the pollution of soil, water and vegetation ecosystem, and of international rivers and seas. Also considered were institutional strengths and weaknesses, and ethical issues involved in the conflict between perceptions on the part of societies and on the part of individual human beings. In reviewing these problems, the breakdown of incentives for the management of environmental resources was examined and possible remedies were proposed.

These problems were the object of our considerations and discussions. The proposed solutions take into account not only theories of profit but also ethical principles. We believe that adeguate solutions to the problems of the environment can be found if, beyond economic considerations, principles of ethics are applied to development and progress.

We recognized the dangerous tendency for institutions and the scientific community to oversimplify environmental problems and, consequently, to propose simplistic or self-serving solutions. It is necessary to take into account all the dimensions — natural and cultural, economic and political — of a complex problem, if any realistic formulation of a commitment to long-term solutions is to be achieved. This approach will require a carefully conceived structure for global and regional monitoring, linked to the decision-making process. In particular, simulation models and knowledge-based systems are proving to be exceptionally efficient in making scientific expertise available to resource mangers, administrators and politicians. We also identified the need for immediate action, based on the best available information at any given time, with allowances for foreseeable short-term adjustments, as a response to the ever-growing clarity with which an environmental problem must be addressed. This kind of intervention ought to ensure flexibility and the utilization of newly acquired knowledge. Furthermore, it should apply to many of the major global problems as perceived today, problems which include climate change, depletion of the ozone layer, the degradation of the life-support base, and the threat of nuclear destruction.

1. Regional Issues

Today, many countries experience great difficulty in solving environmental problems on their own. This difficulty is partly due to the transboundary nature of many problems, such as acid rain, the mismanagement of international river systems, the pollution of the seas, etc.

Individual countries have little or no control over contaminants that are, or will be, transferred to their territories through the atmosphere or international waters. Nevertheless, their forests, surface and ground waters, soil, and even the health of their populations are thus exposed to grave risks. Furthermore, countries may not have the incentives to act in a manner conversant with the general good of an entire region. Therefore, it is essential to create close regional cooperation in all areas of protection and management of the environment, including the buildup of an appropriate, regional, institutional framework.

We are greatly encouraged by success in pollution control achieved through certain regional arrangements, such as the Mediterranean Action Plan. Established within the framework of the political realities of the countries bordering on the Mediterranean Basin and funded by them, the Action Plan demonstrates the feasibility of action based on sound scientific research and responds to the needs of the countries, as defined by their highest political authorities.

We therefore recommend the use of bilateral and multilateral arrangements, supported with adequate funding, so that effective, solutions to transboundary pollution problems may be found and implemented.

2. Global Aspects

Beyond the problems posed by the rising concentrations of CO_2 and atmospheric particulates and by the depletion of the ozone layer, it is the very pollution of the environment by chemical substances that causes serious concern. Chemicals present a risk to living organisms and may create global, as well as regional and local, problems such as climate change.

Risk assessment entails the study of sources, pathway and chemical transformations in the various compartments of the environment. Exposure of living targets and of entire ecosystems must be estimated, including the effects on human health.

Once a risk is characterized, it should be managed. Appropriate measures may aim at emission reduction through setting of standards for effluent streams, development of *"clean technologies"*, testing of new chemicals prior to marketing, restriction of exports of hazardous chemicals, waste minimization and waste detoxification, prevention and mitigation of chemical accidents, etc.

The problem is manageable if appropriate action is taken.

We therefore recommend that the impact of chemicals introduced into the environment be kept track of and evaluated, and, through international agreements, trade in potentially toxic chemicals, as well as in hazardous waste products, be strictly controlled.

3. Biological Diversity

The unsustainable and destructive use of the land and other common resources is driving a high proportion of the world's species of plants, animals and microorganisms into extinction. Since human societies are based almost entirely on their ability to utilize other species for their own benefit, the loss during the next 15 to 20 years of perhaps a million or more species — possibly amounting to a quarter of the earth's biological diversity — is extremely serious.

Since most of these species will be lost in the tropics, this represents a great loss from economic, aesthetic, moral and scientific points of view, and will greatly limit future human potential.

We believe that immediate steps must be taken to catalogue the remaining biological diversity to understand its properties, and to protect as many kinds of organisms as possible, but especially those of ascertained or potential importance to human beings. Moreover, since species function and survive in specific habitats, the preservation of biological diversity must be conceived as part of a larger effort to preserve those specific habitats. Effective preservation, however, can be implemented successfully only if other legitimate needs of human beings are also safeguarded.

We therefore recommend the conservation of all species and their respective habitats as an urgent issue for the international community, and also the provision by that same community of the financial resources necessary to undertake such a task.

4. Mountain Environments

Mountain lands can be characterized, both physically and culturally, as one of the most complex divisions of the world's land surface. For example, research into erosion of mountain lands, although conducted over several decades, has failed to produce an acceptable body of process theory because of the extreme variability both in time and space of the dynamic processes occurring in those lands. Despite this, and despite the even greater uncertainties introduced into research by cultural complexities, conservationists and development programmers persist in working with generalizations that are then used as bases for simplistic solutions to inadequately understood problems. Such is the case of the Himalaya. Thus, networks which would coordinate interdisciplinary research into mountain lands and the application of solutions to their complex environmental problems should be encouraged.

We therefore recommend the establishment of an effective international research network on environmental problems related to mountains in order to ensure a more realistic approach to the management of mountain resources. Such a network is conceived as one of a series; others should be set up whenever the necessity is demonstrated.

5. Poverty

According to the World Bank, some 1.2 billion of the world's 5 billion people live in absolute poverty. Of these, from 300 to 400 million receive less than 80% of the UN-recommended minimum number of calories. Of the approximately 55 million deaths in the world every year, at least one-third — 90% of them being children under four years of age — result from starvation or from conditions associated with it. International assistance programs rarely address the plight of these people directly, and national policies often favor the more affluent urban dwellers over the rural poor. It will be impossible, however, to implement stable land management systems unless a far greater proportion of poor people enjoy the benefits of *their own* societies and, through them, of the global economy. Greater equity in the distribution of resources and the development of appropriate technologies in forestry and agriculture, and greater equity in the social and economic conditions which make possible the adoption by poor rural people of suitable farming and forestry techniques, are essential if the global ecosystem is to be managed in a sustainable way.

We therefore recommend that the satisfaction of the needs of the rural poor, as a measure of critical importance in the sustainable management of the global ecosystem, receive priority attention in development schemes.

6. Cultural Diversity and the Preservation of Traditional Knowledge

We recognize the importance of preserving cultural diversity, not only because of our moral obligation to do so but also because of the accumulated knowledge that is transmitted through their particular forms of traditional inheritance. A recurring theme of our discussions was the importance of the careful study of traditional systems of agriculture and agroforestry, and of local adaptations of indigenous species to particular habitats. Such systems and practices merit comprehensive scientific study and understanding so that they can be rendered more systematic, upgraded and incorporated into modern agricultural procedures. Indeed, a critical interest in the accumulated knowledge base of how tropical societies have met the challenge of living in difficult environments can give an early and effective point of departure for the development of a productive and ecologically sound life-support system. A similar interest in the knowledge base of rural communities can be particularly important to their productivity and ecosystems.

We therefore recommend the development of guidelines for the incorporation of the knowledge derived from culturally diverse societies into project planning and implementation, monitoring and evaluation.

7. Ethical and Educational Considerations

Appropriate action for the use of our biological and cultural resources, for the preservation of the dignity of human life and for the advancement of living standards throughout the world requires a much fuller attention to the entire educational process. It demands more effective dissemination of knowledge, both traditional and recent, at every level of teaching and of communicating information. Such dissemination of knowledge is necessary to enable specific sectors of society and individuals themselves to participate more effectively in the decision-making process involved in the attainment of sustainable and meaninigful forms of living on our planet.

Religious concern for the protection of the environment, as evidenced in Papal documents and addresses and in study programs organized by the World Council of Churches, makes us bold to suggest that ecumenical, interreligious and interdisciplinary dialogue be encouraged and undertaken concerning the following: environmental problems, human life and the conservation of species, humankind's ethical and religious position in the biosphere, progress, and the purpose of scientific research and of its technological applications. Such dialogue could render an incalculable service to a modern approach to the protection of the environment.

* * *

We have in our conclusions stressed only a few aspects of the action required for the current management of the environment, aspects which in the past received less attention and emphasis but which today, in our judgement, are of great importance to a new approach to the complex problem of environmental protection.

SUBJECT INDEX

AUTHOR'S INDEX