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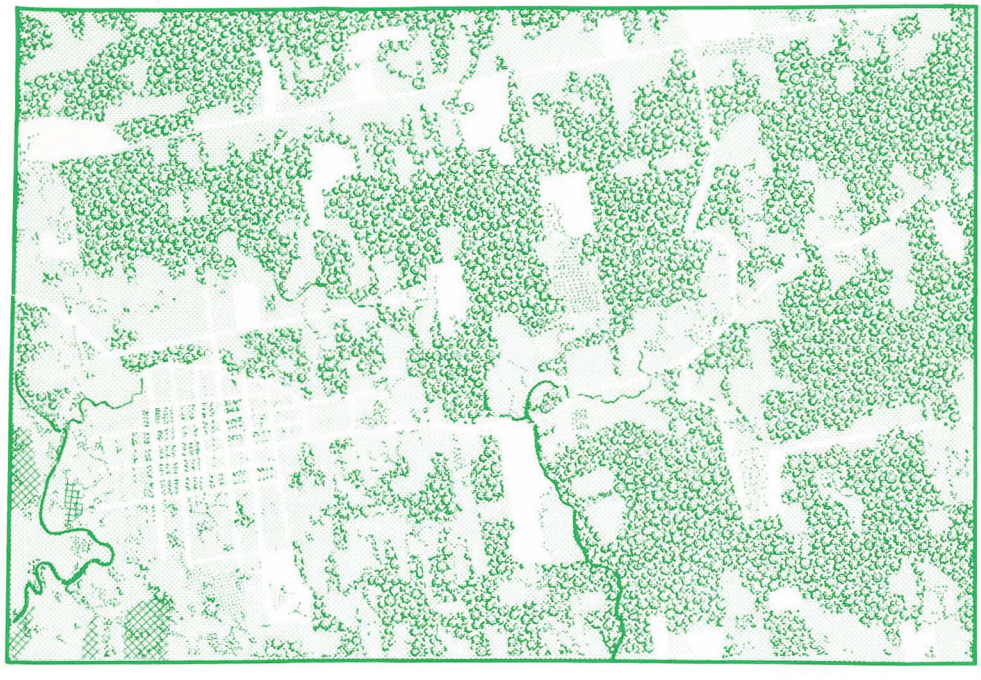

Relating Land Use and Global Land-Cover Change

HDP

HUMAN DIMENSIONS OF GLOBAL ENVIRONMENTAL CHANGE PROGRAMME
OF THE INTERNATIONAL SOCIAL SCIENCE COUNCIL

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Relating Land Use and Global Land-Cover Change: A Proposal for an IGBP-HDP Core Project

A Report from the IGBP/HDP Working Group on Land-Use/Land-Cover Change

Edited by B.L. Turner II, R.H. Moss, and D.L. Skole

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Preface

Gaining a better understanding of the ways that land cover and land-use practices are evolving is a priority concern of the global change research community. The characteristics of land cover have important impacts on climate, biogeochemistry, hydrology, and the diversity and abundance of terrestrial species. Hence being able to project future states of land cover is a requirement for making numerical predictions about other global changes.

Understanding the significance of land-cover changes for climate, biogeochemistry, or ecological complexity is not possible, however, without additional information on land *use.* This is because most land-cover change is now driven by human use and because land-use practices themselves also have major direct effects on environmental processes and systems.

Land-use is obviously determined by environmental factors such as soil characteristics, climate, topography, and vegetation, but it also reflects land's importance as a fundamental factor of production. Thus understanding past changes in land use and projecting future land-use trajectories requires understanding the interactions of the basic human forces that motivate production and consumption. High population growth or increasing consumer demand combine with varied land-tenure arrangements, degrees of access to financial capital, shifts in international trading patterns, and local inheritance laws and customs to produce unique land uses in different places and times. Research on how such human factors interact in driving land use will improve projections of land use and our comprehension of human responses to environmental changes. For the economic, social, and behavioral sciences, it will also provide an opportunity for basic research into the factors that shape individual and group behaviour.

Evaluating the causes and the consequences of changes in land use and land cover is becoming an urgent need for more than the academic research community. At the 1992 UN Conference on Environment and Development, a framework convention on climate change and a convention on biodiversity were signed, as was a declaration of principles on forests; while no formal action was taken on desertification, a broad agreement was reached to work toward a conference and a convention in the near future. Changes in land use and land cover are significant components of all the problems addressed by these agreements, yet we do not have enough knowledge about such phenomena to decide how these conventions should best be structured and which of their proposed elements are likely to be effective. At present, we are unable to answer even the most basic questions. For example: are the world's deserts really spreading, and if so, why? Are population pressures extending land uses, such as agriculture or settlement, to

areas that cannot sustain these uses? How are deforested areas of land used, and what are the implications of these different uses for the net emission of greenhouse gases?

Recognizing the importance of studies of changes in land use and land cover in developing our understanding of global environmental change, the International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP) formed an ad hoc working group in early 1991 to investigate the possibilities of a joint effort by natural and social scientists to study the issue. The members of the working group were:

Billie Lee Turner II - USA, cultural-ecologist and geographer, Chair
Lourdes Arizpe - Mexico, social anthropologist
Paul Cheung - Singapore, demographer
Dean Graetz - Australia, grassland ecologist
Pablo Gutman - Argentina, resource economist
Dennis Ojima - USA, ecologist with interest in trace gas emissions
William Reiners - USA, plant ecologist
David Skole - USA, modeller with interest in remote sensing.

The group met in New York City with the assistance of the Social Science Research Council in May 1991 and in Dalarö, Sweden in October 1991, with support from the Swedish Council for Planning and Coordination of Research (FRN). Carolyn Malmstrom represented the IGBP Secretariat at the New York meeting. Several additional individuals took part in the working group's second meeting: Vladimir Annenkov (Russia, geographer), Olga Bykova (Russia, geographer), Exequiel Ezcurra (Mexico, ecologist), Richard Moss (USA, political scientist, Programme Officer of the IGBP and HDP), Ing-Marie Andreasson Gren (Sweden, economist), Steven Sanderson (USA, political scientist), and Uno Svedin (Sweden, FRN).

The working group recommended that a joint IGBP-HDP Core Project Planning Committee be established to develop an interdisciplinary research programme involving social and natural scientists to project future states of land cover. This recommendation was based on the following conclusions of the working group:

- Understanding the past and future impacts of changes in land cover is central to the study of global environmental change and its human driving forces and impacts, including hydrology, the climate system, biogeochemical cycling, ecological complexity, and land degradation and its impacts for agriculture and human settlement.

- Land-cover modelling requires improved knowledge of land use; it is not possible to make projections of future states of land cover without knowledge of the factors that determine land use and land-use change.

- The major determinants of land use are demographic factors such as population size and density; technology; level of affluence; political structures; economic factors, such as systems of exchange or ownership; and attitudes and values.

- Additional basic research is required to understand how these factors interact to drive land cover change or how projections about them could be used to project future patterns of land use, future rates of land-cover change, and future states of land-cover.

- Categorization of land-cover changes and associated socio-political-economic conditions must be carried out in conjunction with coordinated case studies to further our understanding of changes in land use and their implications for the functioning of the Earth system.

- The knowledge gained through this categorization and the case studies will be crucial to developing regional and global models of land-use/land-cover change.

In light of the recommendation of the working group and the importance of the subject, the Scientific Committee of the IGBP and the Standing Committee of the HDP decided to establish a joint Core Project Planning Committee (CPPC), under the joint chairmanship of B L Turner and D L Skole, with responsibility to develop a detailed scientific plan for an IGBP-HDP project on changes in land use and land cover. The CPPC terms of reference are given on pages 62-63 of this report. It was further decided to hold an open scientific meeting to review the scientific plan that will be proposed by the CPPC. Assuming the subsequent establishment of the project, a Joint Scientific Steering Committee would then be formed to coordinate its implementation.

This report presents the main findings of the working group. It describes the research questions defined by the working group and identifies the next steps needed to address the human causes of global land-cover change and to understand its overall importance. The plan outlined by the working group calls for the development of a system to classify land-cover changes according to their socio-economic driving forces. Selected case studies will be carried out according to a common protocol and will provide detailed settings in which to refine the classification of socio-economic situations and land-cover changes. In the final step of the plan, the knowledge gained regarding the human determinants of land use and the driving forces of land-cover change will be used to develop a global land use and land-cover change model. The model will be designed to link to other global environmental models. In all of it activities, the CPPC will pay special attention to defining the data needed to support research on human forcing of land-cover change.

Drafts of this report were reviewed by the Scientific Committee of the IGBP in Rosenheim, Germany (March 1992) and Durham, New Hampshire (September 1992), and by the Standing Committee of the HDP in Madrid (October 1992).

For further information about this project, please contact: Land-Use/Cover Change Project Planning Office, Graduate School of Geography, Clark University, 950 Main Street, Worcester, MA 01610-1477, USA; Tel: +1 508 793 7336, Fax: +1 508 793 8881, E-mail: BTURNER@VAX.CLARKU.EDU (Internet), B.TURNER (Omnet).

1. Introduction and Definitions

Human-induced changes in land cover are as ancient as humankind itself. Society's demand for physical resources, and the expansion of its technological, managerial, and institutional capacity to produce, move, and consume such resources, have long altered land vegetation and other surface features (Thomas 1956; Wolman and Fournier 1987). Particularly since the middle of this century, however, land-cover change has become truly global in scale and is now occurring at rates that are unprecedented (Turner *et al.*, 1990a). Human uses of the land have affected most of the ice-free surface of the Earth, with consequent impacts on the very processes that sustain the interacting systems of the geosphere-biosphere.

While most land-cover changes are undertaken at the spatial scale of a field or a homestead, these discrete changes have attained global significance because they are repeated frequently. In this sense, local changes in land cover reach a global dimension by patchwork addition, in a process identified as *globally cumulative* (Turner *et al.* 1990b). Another example of such a cumulative change is the current magnitude and rate of loss in biodiversity.

Cumulative land-use and land-cover changes not only have considerable local and regional environmental significance in themselves, but they also have links to *globally systemic* environmental changes (e.g., climate change). For example, the increased use of irrigation and nitrogen fertilizers are both associated with increases of methane release. The relationship between deforestation and afforestation processes, and the role of the terrestrial biosphere as a source and sink of atmospheric CO_2, are not well understood - yet are of critical importance in modelling future changes in atmospheric composition. (Bouwman 1990a, 1990b; Houghton *et al.* 1987; Melillo *et al.* 1990)

A better understanding of the physical, biological, and chemical processes involved in changes in land use and land cover is therefore crucial to developing a predictive understanding of globally systemic changes. Changes in land cover cannot be understood, however, without a better knowledge of the land-use changes that drive them, and their links to human causes (Ojima *et al.* 1991).

Relating the human driving forces of land use to changes in land cover is difficult because of the complexity of the interactions between human and environmental factors, and the different ways that these interactions unfold in particular areas of the world. The complexity of these *situations* (here used to mean the interactions of causes in their spatial and temporal settings) makes it difficult to identify simple relationships between human driving forces and global environmental change, or between environmental changes and their impacts on society. Linking the human and the environmental, even

within the restricted field of land-use and land-cover change, requires a careful assessment of the variations of these situations as the key to understanding the general patterns of global change.

This report proposes a programme of research that will develop projections of land use and future states of land cover by linking the physical and human dimensions of this issue. The objective of this project is to improve our understanding of the human driving forces of land-use change, and hence changes in land cover.

In concentrating on the human causes of land-use and land-cover change, the project selects one subset of an integrated system of land-use/cover problems for detailed study (Fig. 1). Human driving forces operate together with natural forces to shape land uses and the associated land covers. The environmental consequences of changes in land use and cover include direct feedback effects on land cover as well as contributions to other global environmental changes. Any change in global conditions, such as projected climate warming, will in turn have impacts on the land uses and covers in question as well as on the driving forces. The "human dimensions" of the problem consist of two linked subsets: human driving forces that can cause change, and human responses to change.

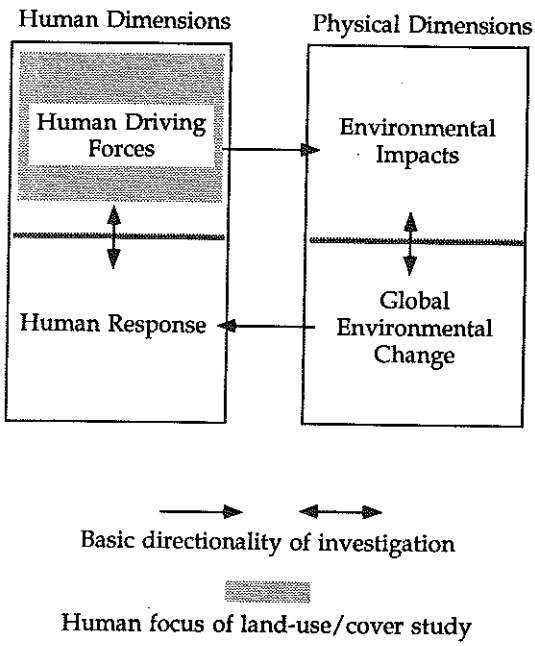

Fig. 1 Problem categories linking the human and physical dimensions of global environmental change (see text for explanation)

The proposed project concentrates on human driving forces for several reasons. The amount of research effort devoted to response, largely in the form of environmental or climate impact assessment, has to date been much larger than that focused on human cause. Impact assessments analyze the likely interactions of environmental change with existing social structures and processes. Because these structures and processes include the very driving forces that initially brought about the environmental change in question, a better understanding of driving forces would also improve the reliability of impact assessments.

Before presenting the rationale and structure for the proposed project in greater detail, a few definitions are needed to establish a common terminology.

- The term *land cover* refers to the attributes of a part of the Earth's land surface and immediate subsurface, including biota, soil, topography, surface and ground water, and human structures. Land cover can be classified according to numerous criteria, depending on the scientific purposes for which the classification is being developed. Examples of some broad categories of land covers include boreal forest, tropical savanna, temperate grasslands, croplands, wetlands, and settlements.

- The term *land-cover conversion* refers to the complete replacement of one cover type by another: tropical forest by pasture, for instance. Such land-cover conversions usually have large impacts on biogeochemistry and on water and energy balance. For example, the carbon content of the biomass in a mature tropical forest may be on the order of 180 metric tons carbon per hectare, while its conversion to pasture leaves only 5 - 10 metric tons per hectare (Houghton and Skole 1990). This particular land-cover conversion is therefore an important source of carbon dioxide to the atmosphere.

- *Land-cover modification,* in contrast, refers to more subtle changes that affect the character of the land cover without changing its overall classification. Modification typically results in degraded ecosystems, such as an overgrazed grassland or impoverished forest. The environmental impacts of modification are thought to be considerable, if not as well documented as for conversion (Houghton 1991). Forest thinning contributes to carbon emissions, cropland fertilization contributes to other trace gas releases, and overgrazing has been associated with desertification, though its global significance is a matter of controversy.

  The threshold between conversion and modification is necessarily arbitrary. Land-cover change involves the full spectrum of alteration from minor modification of the existing cover to complete conversion to a new cover type. In some instances, these alterations occur in patterned sequences moving from modification to conversion.

- *Land use* refers to the purposes for which humans exploit the land cover. Common land uses include agriculture, grazing, forestry, mineral extraction, and recreation. Several examples illustrate the difference between land cover and use. Cropland designates a land-cover type of soil, water, and cultivated plants. In contrast, agriculture, a land use, refers to a system of human inputs and management that sustains this land cover. Forest is a land cover dominated by woody species, which may be exploited for uses as varied as recreation, timber production, or wildlife conservation. Changes in human land use are frequent causes of land-cover conversion and modification.

The remainder of this report defines the research problem and lays out a plan that addresses the human causes of global land-cover change. This plan includes the development of a global land-cover and land-use model that can link to other global models central to the study of global environmental change. The report reviews the importance of modification and conversion of land cover to the functioning of the Earth system. It then discusses the relationship between human uses of the land and changes in land cover; reviews what is known about the human forces that determine land use; and proposes a conceptual system for relating these driving forces to changes in land cover. The complexity of the relationships between the human driving forces of land use and land cover is illustrated by briefly reviewing the results of a recent case study of the causes and consequences of land-cover changes in Amazonia. The last section of the report describes the three foci which provide the basic structure for the proposed programme of research.

2. Land Cover and the Global Environment

The characteristics of land cover have important impacts on climate, global biogeochemistry, and the abundance and composition of terrestrial species. The nature of the land surface - its roughness, albedo, and other properties affecting heat and water fluxes - modifies the basic patterns of ocean-driven atmospheric circulation and generate the regional and local intricacies of weather and climate. Different cover types have different ecosystem structures, community compositions, and biomass contents; they also take up and fix nutrients such as carbon and nitrogen at different rates, with important consequences for the distribution of these elements between soil, air, and water.

The magnitude, spatial scale, and pace of land-cover change have escalated, particularly over the last 300 years (Table 1). While estimates of human-induced changes in land cover vary according to the system of classification that is employed (e.g., whether a particular parcel of land is classified as "forest" or "shrub"), several examples illustrate the general scale of these changes. Over the past three centuries, human activities have resulted in:

- A net loss of approximately 6 million km^2 of forest (an area slightly smaller than Australia)

- A net gain in cropland of approximately 12 million km^2 (an area approximately the size of the USA and Mexico)

- A net loss of approximately 1.6 million km^2 in wetlands (an area approximately the size of Iran)

Recent research indicates that these human-induced conversions and modifications of land cover have significance for the functioning of the Earth system. The conversion of other land-cover types to cropland over the course of human history has contributed to the net release of CO_2 to the atmosphere (Houghton *et al.* 1985, 1987; Houghton and Skole 1990). The conversion of forests and savannas is frequently accompanied by biomass burning, which releases other radiatively important trace gases (Crutzen and Andreae 1990). When pasture or cropland is abandoned, the growth of secondary forest results in a net uptake of nutrients from the atmosphere. Land-cover change also has an important influence on regional climatology and hydrology (Shukla *et al.* 1990).

Land-Cover Changes and Impacts on Biogeochemistry, Climate, and Ecological Complexity

The consequences of land-cover change depend on such factors as the characteristics of the pre- and post-disturbance land cover, the specific conversion or modification process (e.g., whether deforestation is brought about by clear-cutting and removal, thinning, burning, decline, or die-back from deposition of atmospheric pollutants); its geographic location; its spatial and temporal distribution; and whether one is considering the impact of the change on biogeochemical cycling, on the climate system, or on species composition and abundance.

While the direct effects of land-cover changes on biogeochemical flows and global budgets are not adequately understood, it is generally accepted that:

- the conversion of natural to human-managed systems over the past 150 years has resulted in a net flux of CO_2 to the atmosphere approximately equal to the net release over the same period from fossil-fuel burning

- the current release of CO_2 from land-cover change is approximately 30 percent of that from fossil fuel combustion

- land-use/cover changes represent the largest human source of emissions of N_2O, which contributes to both greenhouse forcing and stratospheric ozone depletion.

While we are relatively confident of the general trends in land-use and land-cover change over the long term and at a global scale, the paucity and unreliability of much of the data frustrate attempts at more fine-tuned assessments of the biogeochemical implications of such changes. One major uncertainty in modelling the net flux of carbon between terrestrial ecosystems and the atmosphere lies in a lack of information on the types of ecosystems that have been cleared for agriculture. This knowledge is important because terrestrial ecosystems vary considerably in biomass, soil organic matter, moisture regimes, rates of recovery, and other characteristics. The conversion of high-biomass humid forest to cropland or grassland has consequences very different from those arising from the conversion of tropical dry savanna. Humid forests release much more CO_2 when cleared, and their burning results in greater releases of other gases such as carbon monoxide, nitrogen oxides, methane, and other hydrocarbons.

Attempts to develop global budgets of such radiatively important trace gases have suffered from the lack of spatial data. Regional extrapolation of trace gas fluxes has frequently been based on a very limited number of "representative" measurements. Matson *et al.* (1989) have argued that global budgets could be greatly improved by giving more attention to spatial and temporal variability. They argue for analyses based

Table 1. Human-Induced Conversions in Selected Land Covers*

Covers	Date	Area ($x10^6 km^2$)	Date	Area ($x10^6 km^2$)	% Change
Cropland**	1700	2.8	1980	15.0	+435
	1700	3.0	1980	14.8	+393
Irrigated Cropland	1800	0.08	1989	2.0	+2400
Closed Forest					
pre-agricultural		46.3	1983	39.3	-15.1
Forest and Woodland					
pre-agricultural		61.5	1983	52.4	-14.8
Grassland/Pasture***	1700	68.6	1980	67.9	-1
Drained Land			1985	1.6	
Settlement					
Urban			1990	2.5****	
Rural			1990	2.1	

Notes: * The variation in dates and significant digits reflects the various sources from which they were taken; ** Estimates given from two different sources; *** Includes some areas often classed separately as shrub and arid land; **** Includes substantial areas not built up. Summary based on Meyer and Turner (1992)

on spatial gradients, where functional relationships between fluxes and land cover, soils, climate, and disturbance could be derived.

The potential impacts of land-cover changes on climate can be only crudely assessed at present. Attention to date has focused on the effects of deforestation of large areas of tropical forest, with regional climate models predicting significant continental-scale consequences for surface air temperature, precipitation, and run-off. The spatial arrangement of land-cover change, particularly deforestation, influences the results of such model simulations: deforestation distributed as a few large blocks has a much greater influence on water and energy budgets than the same area distributed as many widely scattered small patches (Henderson-Sellers 1987; Henderson-Sellers and Gornitz 1984). Linkages between global climate conditions and land-cover changes are more speculative, since the grid size for the general circulation models (GCMs) is very large (mostly more than 10,000 km^2) and biospheric feedback effects have not yet been included in their formation.

Finally, land-cover changes in both tropical and temperate regions have important implications for species diversity and community composition, and have caused a dramatic increase in the rate of species extinction (Ehrlich and Wilson 1991). Effects on biodiversity depend on the severity of the habitat disturbance, among other factors. In the case of tropical deforestation, such additional factors include the biogeographical history of the locality, its previous exploitation, the total area of forest conversion, the amount of forest fragmentation, the conversion process, and the rate of conversion. Quantifying fragmentation requires an understanding of the spatial arrangement of cleared areas (Soule 1991; Wilson and Peter 1988).

The Need for Data on the Distribution and Patterns of Change

These few examples demonstrate the importance of knowing more than just areas of vegetation types or the magnitude of their change; we must investigate the coincident distribution, and detailed patterns in space and time, of land cover, land-cover attributes, and land-cover change. It is generally accepted that land-cover changes of a given magnitude will have the greatest influence on atmospheric behaviour, and ultimately on climate, if they occur in the tropics, where changes in land surface conditions exert a stronger influence on the behaviour of the atmosphere than elsewhere (Keller *et al.* 1991; Matson and Ojima 1990).

Additional data on land cover and land-cover change are therefore required. One of the highest priorities of the land-use and land-cover change communities is to acquire improved data and develop better means of monitoring on-going changes in land use and cover. Townshend (1992) outlines some of the characteristics of a land-cover data set that would meet a number of global change research requirements.

3. Land Use and Global Change

Even if reliable quantitative data on land-cover change were available, it would be impossible to assess the effects of changes in land cover on biogeochemistry, ecological complexity, and climate without additional information about land *use*.

In part, this is because most land-cover modification and conversion is now driven by human use, rather than natural change. In this sense, land-cover change is an immediate response to land-use changes, as all studies and modelling efforts demonstrate (e.g., Grainger 1990). The diversion of net primary production to meet human wants usually requires alterations of nature (e.g., Vitousek *et al.* 1986). The scale of land use for such appropriation is so great that nearly all land cover is likely to be intensively managed by the middle of the next century, other than in mountainous, polar, and desert regions. To understand human-induced change in land cover, therefore, requires an understanding of its underlying social causes (Houghton, Lefkowitz and Skole 1991; Lugo *et al.* 1987).

But land use practices also have major direct effects on other global environmental changes. Variations in agricultural practices, for example, have very large impacts on biogeochemistry. Adding organic matter to rice-paddy soils has been reported to result in an 22-fold increase in methane emission (Cicerone *et al.* 1992). Variation in the timing and frequency of flooding and drainage of rice paddies during the growing season has been demonstrated to increase methane emission 12 times (Sass *et al.* 1992). Thus variation in agricultural practices is a likely explanation for differences in the measurement of trace gas flux in different stands of the same crops. Accounting for the biogeochemical impacts of variations in land use will be important in establishing accurate global budgets for greenhouse gases.

This is especially true considering that most of the Earth's land is already managed, if only peripherally or haphazardly. Of the Earth's total land surface (around 130 million km^2), roughly 40 per cent of the land cover has been extensively modified or converted for production or habitation, while only 25 per cent remains in a near-natural condition.

Certain land uses have significant impacts out of proportion to their spatial extent. Settlements, for example, emit a large variety of chemical pollutants, which can locally exceed threshold levels for safe human habitation. They also exert enormous influence on their hinterlands, exacerbating or lessening rural land-use changes. The human management of wetlands also has far-reaching impacts on water regimes, biodiversity, and biogeochemistry.

Changes in Land-Use Patterns

The two largest land uses, in terms of their spatial domain, are arable cultivation and livestock production. Around 14-15 million km^2, an area about the size of South America, is in some form of cultivation. An additional 70 million km^2 is used for some form of livestock production, as either rangeland or pasture (Table 1). In contrast, settlements of all kinds and their infrastructure (e.g., roads) cover only a few per cent of the world's land area. Understanding global-scale patterns in land-cover change therefore requires detailed investigation of the changes in the rural land use.

Cropland has increased in area by about 12 million km^2 over the last 300 years, at the expense mostly of forest, but also of some grasslands and wetlands (Myers 1991; Richards 1990). This change has been accompanied by other impacts, such as the depletion and pollution of groundwater. Despite recent deforestation in parts of the tropics for livestock production, the area of rangeland and pasture has remained virtually the same over the last 300 years. The intensity of livestock production has increased significantly, however, creating substantial modifications of grassland ecosystems (including both enrichment through fertilizers and degradation through overgrazing).

Cropland expansion will undoubtedly continue in the near future, but land-cover modification, through increasing intensification of agriculture, is likely to be of greater importance than further land-cover conversion (Ruttan 1993). Most of the prime agricultural lands of the world, with the exception of some areas in the tropics, are already cultivated, and major increases in food production are likely to come from yield improvements on these lands through the application of fertilizers, pesticides and herbicides, and irrigation. Irrigation of cropland has expanded some 24-fold over the past 300 years, with most of that increase taking place in this century. This practice has increased methane emissions, while the increasing frequency of land tillage world-wide has affected soil carbon (e.g., Cole *et al.* 1989; Rozanov *et al.* 1990). We know very little about the overall land-cover and environmental impacts of the intensification of cultivation, although its significance through greenhouse gas emissions to global environmental change is apparent (Vitousek and Matson 1992; IGBP 1990).

General global trends in land-use changes are characterized by considerable temporal and spatial variations. Although the total area of rangeland and pasture is at present relatively stable, these uses are expanding in tropical Africa and Latin America while shrinking in Europe, North America, and Southeast Asia (Richards 1990). The great expansion in croplands over the last 300 years began with the European settlement of North America and Australia, continued with expansion in the former USSR, and more recently has been concentrated in the tropical world (Wolman and Fournier 1987). Croplands currently appear to be decreasing in the developed world (Europe and North

America) and increasing in the former socialist bloc and the less-developed world. This spatial pattern is important because it affects different kinds of land cover (e.g., mid-latitude versus tropical forest).

Documentation of land-use patterns for several regions of the world exists for the past 80-100 years, but very little of this information has been used to investigate the regional and local dynamics of major land uses (cropland, livestock raising, settlement), regionally important sub-classes of these uses (such as paddy cultivation), or the modifications in land cover brought on by the intensification of agricultural processes.

4. Human Causes of Land-Use Change

Land use is obviously constrained by environmental factors such as soil characteristics, climate, topography, and vegetation. But it also reflects the importance of land as a key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchment and storage. Land is a fundamental factor of production, and through much of the course of human history, it has been tightly coupled to economic growth (Richards 1990). As a result, control over land and its use is often an object of intense human interactions.

Human activities that make use of, and hence change or maintain, attributes of land cover are considered to be the *proximate sources* of change. They range from the initial conversion of natural forest into cropland to on-going grassland management (e.g., determining the intensity of grazing and fire frequency) (Schimel *et al.* 1991; Hobbs *et al.* 1991; Turner 1989).

Such actions arise as a consequence of a very wide range of social objectives, including the need for food, fibre, living space, and recreation; they therefore cannot be understood independent of the *underlying driving forces* that motivate and constrain production and consumption. Some of these, such as property rights and the structures of power from the local to the international level, influence access to or control over land resources. Others, such as population density and the level of economic and social development, affect the demands that will be placed on the land, while technology influences the intensity of exploitation that is possible. Still others, such as agricultural pricing policies, shape land-use decisions by creating the incentives that motivate individual decision makers.

Interpretations of how these factors interact to produce different uses of the land in different environmental, historical, and social contexts are controversial in both policy-making and scholarly settings. Furthermore, there are many theories regarding which factors are the most important determinants. Particular controversy arises in assessing the relative importance of the different forces underlying land-use decisions in specific cases (e.g., Kummer 1992). For example, apparent dryland degradation could be the result of: overgrazing by increasingly numerous groups of nomadic cattle herders; an unintended consequence of a "development" intervention such as the drilling of bore holes which increases stress on land close to the wells; or the political clout of groups that, through governmental connections, are able to over-exploit land belonging to the state or local communities (Pearce 1992; NERC 1992). Identifying a particular cause may have implications for the rights of competing user groups or the formulation of policy responses.

Candidate Driving Forces of Land-Use Change

The possible forces driving land-use and land-cover changes can be grouped into six categories: population; level of affluence; technology; political economy; political structure; and attitudes and values (e.g., Turner and Meyer 1991; Stern *et al.* 1992).

The first three have been linked to environmental change in the I = PAT relationship that considers environmental impact (I) to be a function of *population* (P), *affluence* (A), and *technology* (T) (Commoner 1972). The relationships of these three categories of driving forces with environmental change have been statistically analyzed. Some of this work specifically addresses land-use and land-cover change (*Ambio* 1992; Meyer and Turner 1992) and suggests measures for each category: respectively, population density, GNP or GDP per capita, and energy consumption per capita.

Of these three categories of driving forces, population produces the most controversy. It is, however, one of the few variables for which worldwide data of reasonable accuracy are available, providing a basis for statistical assessments of its role in various kinds of environmental change (e.g., *Ambio* 1992). At the global level of aggregation, the neo-Malthusian and "cornucopian" positions use the same data to reach opposite conclusions: that population growth is or is not a cause of environmental damage (Boserup 1965, 1981; Ehrlich and Ehrlich 1990; Ehrlich and Holdren 1988; Simon 1981). At the regional scale, several studies relate population growth and deforestation in developing countries in the tropics (e.g., Allen and Barnes 1985; Palo 1990; Rudel 1989), although their findings and methods have been questioned (Kummer 1992).

Comparative assessments of population and land use suggest that: (i) population growth is positively correlated with the expansion of agricultural land, land intensification, and deforestation, but (ii) these relationships are weak and dependent on the inclusion or exclusion of statistical outliers (Bilsborrow and Geores 1991; Bilsborrow and Okoth-Ogendo 1992). Sub-continental comparisons for Africa have led Zaba (1991) to conclude that population density and growth ranked below environmental endowment and economy as factors in environmental degradation. Population density was found to be related to agricultural expansion and intensification everywhere, but only in some regions to deforestation. Detailed studies of specific regions for example, modelling exercises with Amazonian data likewise indicate subtle and varying relationships (Jones and O'Neill 1992; Skole 1992).

The interactions of population, affluence, and technology as causes of environmental change have been explored extensively (for implications appropriate for land-use, see Lee 1986), but research on the direct association of affluence or technology with land-use change is not as common. This is because of the paucity of globally comparative data for statistical assessments and because of the common assumption that level of

affluence or technology do not by themselves govern human-environment relationships but must be considered within a larger set of contextual variables.

Nonetheless, some historical assessments associate high levels of affluence and industrial development (and thus the ability to draw resources from elsewhere) with the return of forest cover (Williams, 1989; Hägerstrand and Lohm 1990; Pfister and Messerli 1990). Global comparisons indicate that afforestation is largely a phenomenon of advanced industrial societies, which are both affluent and have high technological capacity (Young *et al.* 1990). Wealth, however, also increases per capita consumption, bringing about environmental change through higher resource demands, although these higher demands can be reduced by advanced technologies available to wealthy societies. Poverty is often associated with environmental degradation (IDRC and SAREC, 1992), although recent research shows that this relationship is strongly influenced by other factors as well (Kates and Haarman 1992). These mixed conclusions indicate the importance of further studies of the relationship between level of affluence and environmental change.

The role of technology as a potential cause of past and prospective changes in land use and land cover also requires further study. It is obvious that technological development alters the usefulness and demand for different natural resources. The extension of basic transport infrastructure such as roads, railways, and airports, can open up previously inaccessible resources and lead to their exploitation and degradation. Technological developments and their application (such as improvements in methods of converting biomass into energy; use of information-processing technologies in crop and pest management; and the development of new plant and animal strains through research in biotechnology) may lead to major shifts in land use in both developed and developing countries during the coming decades (Brouwer and Chadwick, 1991).

To these three sets of candidate forces, three others have been added: *political economy*, which includes the systems of exchange, ownership, and control; *political structure*, involving the institutions and organization of governance; and *attitudes and values* of individuals and groups. The candidate driving forces grouped within these categories have received much less attention than population growth. They do not yet encompass clearly defined variables and causal relationships, but comprise similar explanations of relationships of societal and environmental change (Blaikie and Brookfield 1987). Changes in land tenure (an institution in socio-economic terms) have direct impacts on land use, as does the move from non-market to market exchange of resources (political economy). Changes in attitudes and values may add a dimension to environmental change that cannot be explained otherwise, such as impact on land use of the "green" movement. Identifying the key variables within each set of potential driving forces and developing proxy measures for them will be one of the objectives of the IGBP-HDP project on land-use and land-cover change.

Detailed examinations link all of these candidate forces (e.g., Scott *et al.* 1990). For example, the model of socio-economic and environmental interactions with land use developed at Oak Ridge National Laboratory explores the interrelated effects of changes in technology, political economy, and political structure in Amazonia (Jones and O'Neill 1992). Improved transport facilities are expected to exacerbate land degradation if the region in question is small, but its impact on larger regions will vary by circumstance. Additional comparative studies are needed to address the interactions of different driving forces with their environmental context.

Finally, environmental transformations - whether potential climate change or localized impacts such as soil depletion - themselves affect land use. Assessments of the impacts of climate change on land use and land cover (e.g., Glantz 1989; Parry, Carter and Konjin 1988; Riebsame 1991) rely on assumptions about land-use change that can only be improved through studies of the dynamics of land use. For example, a study in Oaxaca, Mexico, indicates that local deforestation has caused a drop in the local water table and/or a reduction in local rainfall, and that the local population has responded by expanding the area under cultivation to maintain production (Liverman 1990). Crosson (1990) calls for a better understanding of the interactions of soil depletion, land-use systems, and environmental changes.

Relatively few global aggregate or regional comparative studies have explicitly investigated the role of these proposed driving forces, either independently or as a group. Still fewer have investigated statistical relationships among them. In contrast, many regional or smaller-scale case studies have been undertaken that offer detailed insights into specific cases that cannot necessarily be generalized. Thus the literature is rich in insights and "stories", but weak in comparative assessments that illuminate the causes and courses of land cover change. As a result, research is driven by subjective interpretations and assumptions rather than by attempts to test different hypotheses.

Knowns and Unknowns

- *The major categories of driving forces have been identified*

The six categories (above) have both empirical bases and theoretical rationales. We are not certain, however, which specific variables would best represent themes implied in the category, nor which forces are dominant and under which conditions.

- *Many candidate driving forces are associated with environmental change over the long term and at a global level*

Globally, population, technological capacity, and affluence have all increased, just as the Earth's land cover has been transformed. At the same time, social organization, attitudes, and values have also undergone profound changes. The specific role of any of the proposed driving forces is extremely difficult to demonstrate at this global scale of analysis, however, because of their complex interrelationships, and interactions with other factors such as social organization, attitudes, and values, which have also undergone profound changes.

- *Global-level aggregate relationships are difficult to demonstrate at sub-global scales of analysis*

A number of empirical relationships between driving forces and changes at a global scale have been documented for the modern period (20th century) (e.g., Newell and Marcus 1987). Comparative regional assessments, however, show considerable variability among these variables and environmental impacts (Young *et al.* 1990).

- *Regional studies suggest the existence of generic relationships between the causes of land-use change and changes in land cover*

Comparative studies suggest that common *situations* exist (e.g., rapid growth in population and international commodity demand in frontier forest areas) and that classifying them will improve our understanding and modelling of land-use change (Clark 1989).

- *Integrated theories of the relationships between the human causes of land-use change and resulting changes in land-cover are not suitably developed for testing or comparison*

While empirical assessments should provide strong clues about driving forces, experience suggests that "inductive" assessments will not be sufficient. Further insights will follow from tests of theories that specify the processes and relationships in question.

A Schema for Relating Land Use and Changes in Land Cover

To understand global land-cover change as an element of global environmental change, it will be necessary to specify the links between human systems generating changes both in land use and in the physical systems that are affected by the resulting changes in land covers. This understanding is facilitated through a simple systems description of the basic states, processes, and flows involved (Figure 2).

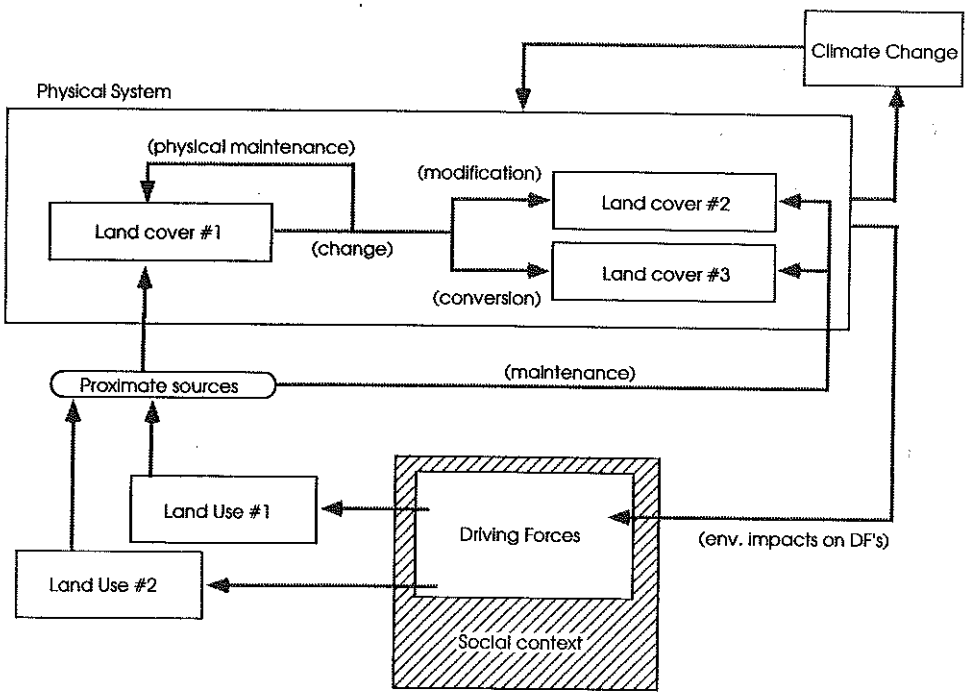

Fig. 2 Linkages among human causes and land use and cover

In this schema, a land cover (physical system) exists in a systemic relationship with human uses (land use) and the causes of those uses. Driving forces interact among themselves and lead to different land uses depending on the social context in which they operate. At time t_1, the underlying human driving forces lead to actions precipitating demand for land use #1 (# corresponds to Figure 2), which requires the manipulation of the land cover by means of technology employed in human activities such as clearing, harvesting, or adding nutrients (proximate sources of change). This manipulation is directed either to changing the existing land cover (#1 to #2 or #3) or to maintaining a particular cover (#1). In the former, the existing cover is changed to a new state that must be maintained in the face of natural processes that would alter it (physical maintenance loop).

Changes to a new state of land cover are of at least two kinds: modification as in land cover #2 (e.g., fertilization of cropland or planting exotic grasses in pastures) and conversion as in land cover #3 (e.g., forest to cropland or dryland to paddy agriculture).

Maintenance processes sustain the land-cover conversion (#3) or modification (#2). Therefore, proximate sources can be seen as those of conversion, modification, or maintenance.

The environmental consequences of uses of land cover (changes in the state of cover) affect the original driving forces through the environmental impacts feedback loop. Likewise these land-cover changes (#2 and #3) can be repeated elsewhere such that they reach a global magnitude that triggers climate change, which, in turn, feeds back on the local physical system, affecting land cover and, ultimately, the driving forces through the environmental impact loop. Regardless of the stimuli - local or global environmental impacts or the interaction of the driving forces in their social context - changes in driving forces at time t_2 may trigger a new land use (#2), with new consequences for the land-use/cover system.

This perspective indicates that understanding of global environmental change must consider the conditions and changes in land cover engendered by changes in land use; the rates of change in the conversion-modification-maintenance processes of use; and the human forces and societal conditions that influence the kinds and rates of the processes.

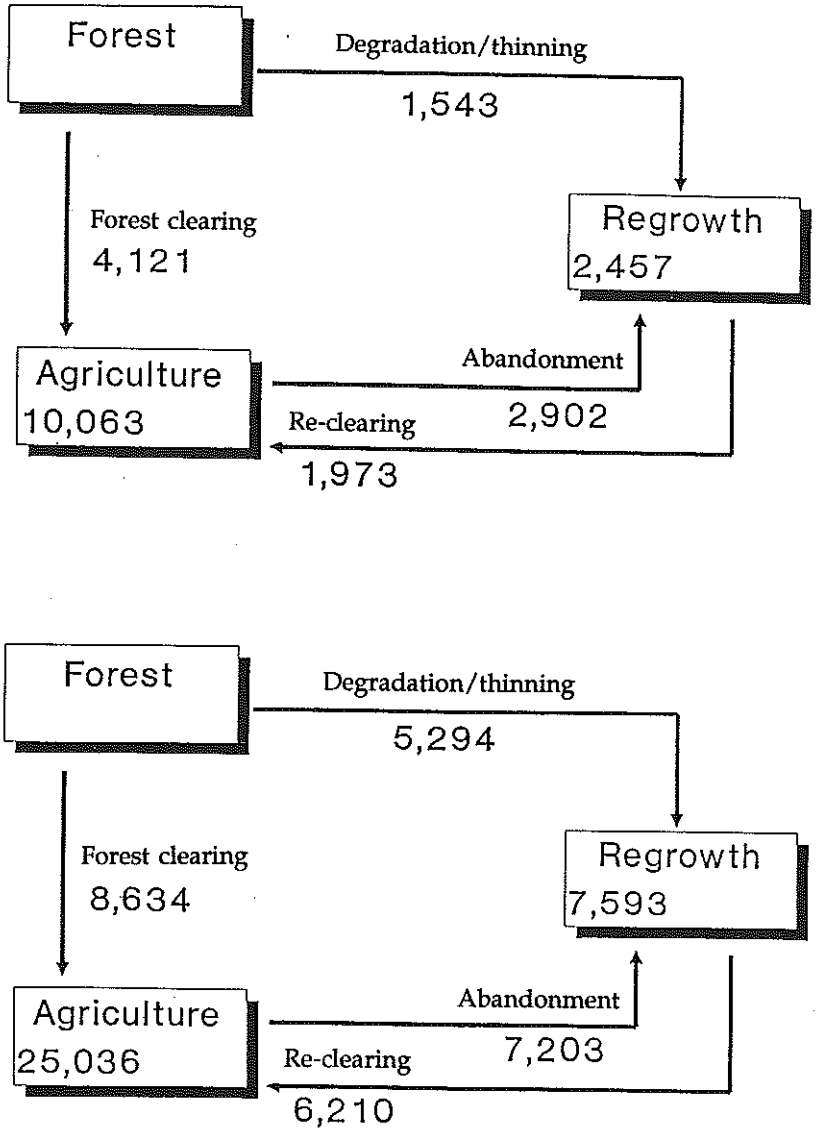

Fig. 3 Rates of transition between land-cover types from a test site in the Brazilian Amazon, 1986-1988 (top) and 1988-1989 (bottom). Values with arrows are annual transition rates in ha. Values within the regrowth and agricultural boxes are retention rates in ha.

5. An Illustrative Case: Deforestation in Amazonia

Amazonia, a region that holds the largest contiguous tropical forest in the world, is estimated to be undergoing deforestation at rates from 1.1 to 2.1 million ha annually (Fearnside *et al.* 1990; INPE 1992; Skole and Tucker, submitted). Studies indicate that rates of this magnitude will affect the increase of carbon dioxide in the atmosphere, regional hydrology, and climate (Crutzen and Andreae 1990; Houghton and Skole 1990; Houghton *et al.* 1992; Salati and Vose 1984; Shukla *et al.* 1990).

Much of the land in Amazonia currently being deforested is not primary forest but is actually in some stage of secondary succession. This is indicated by high-resolution satellite data, which show that human activities comprise a dynamic pattern of clearing, abandonment, and reclearing. Figure 3 shows the rates of forest clearing and land abandonment measured at a test site in the Brazilian Amazon between 1986 and 1988, and again between 1988 and 1989. These data provide a basis for interpreting the coupling between land in active agriculture and land abandoned to secondary growth in the same area; they indicate that the land cover subsequent to deforestation is not uniform but linked to the specific management strategies in place. The fact that secondary, not primary, forest is being converted calls into question conclusions regarding the precise magnitude of contributions of deforestation in the Amazon to anthropogenic carbon flux.

Large-scale deforestation in the Amazon had its beginning in the mid-1970s through an effort to develop this tropical frontier. The most important agent of deforestation at this time was agricultural expansion, through both increasing numbers of smallholder farmers and large-scale, commercial activities, the latter including the conversion of forest to pasture for livestock production (largely for a regional market). This expansion followed two geographical fronts: along (i) a north-south corridor adjacent to the Belém to Brasília highway, and (ii) a northwesterly corridor into the state of Rondônia. Although the southern sections of Brazil continued to have the highest density of agriculture during the period, the Amazon region showed the most dramatic increases in deforestation rates. This was particularly true in Rondônia, which had the highest density of frontier deforestation in Brazil from 1970 to 1980, and where 13 per cent of the forests was cleared by 1987 for colonization and settlement programmes.

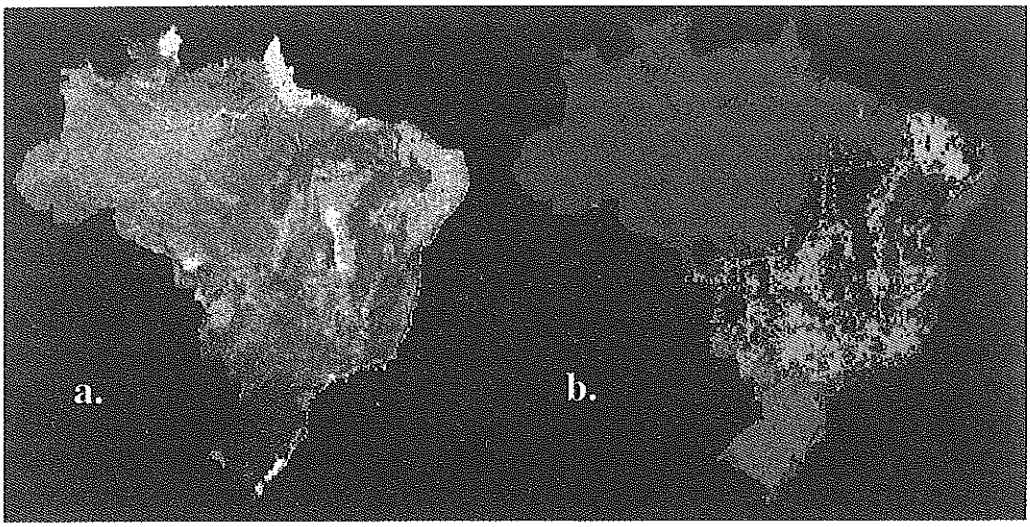

Fig. 4 Simple classification of land-cover types in Brazil using AVHRR satellite data: (a) 30 class analysis, (b) 15 class analysis (image courtesy of Ludovic Andres)

Satellite observations provide precise, quantitative data for the measurement of deforestation and a means of monitoring land-cover change. They permit observations about the proximate sources of land-cover change, such as biomass burning. They cannot, however, provide detailed information about the specific management practices that are employed in the different possible uses of deforested land. These practices are influenced by the interaction of underlying human driving forces within their socioeconomic and environmental context. Understanding the trajectory and consequences of deforestation in Amazonia or elsewhere requires understanding the interaction of the human driving forces with the environment, something that cannot be achieved without collaborative research in the natural and social sciences. Figure 4 shows a simple classification of land-cover types in Brazil using 16 km resolution Advanced Very High Resolution Radiometer (AVHRR) data. It is derived by taking advantage of seasonal differences in the "greenness" of the vegetation. This view from space gives little indication of human activity, although even at this scale large areas of cultivation and biomass burning are potentially visible. With increased spatial resolution, available from Landsat or SPOT satellite imagery (Fig. 5), the mark of human activity becomes clearly evident.

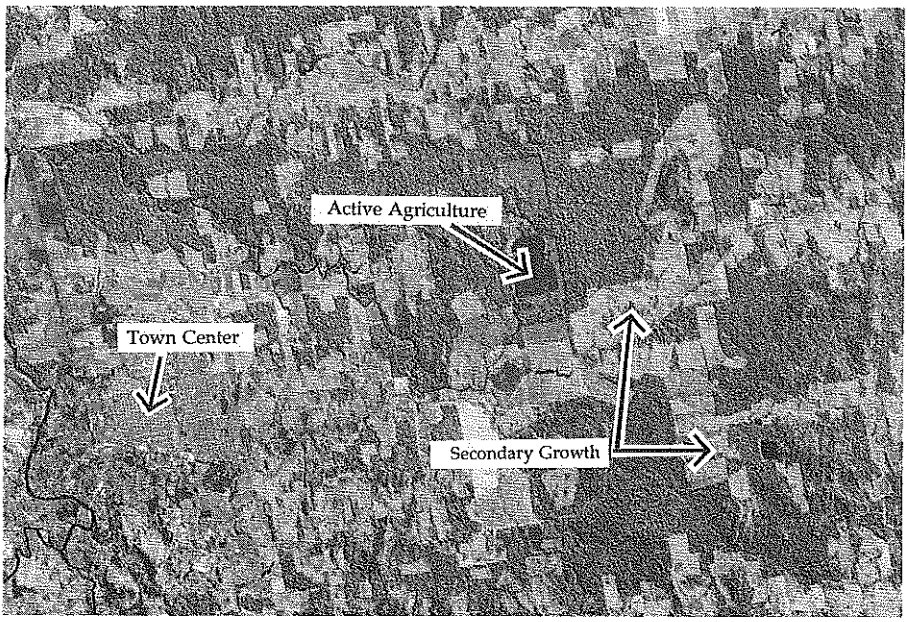

Fig. 5 Landsat image from the Amazon Basin showing deforestation and some land-use/cover types. Such data can be used to map the precise extent of land cover conversion and calculate its rate of change. (Image courtesy of Bill Salas)

Resettlement and agricultural expansion/modernization programmes were established as national policy by Brazil in the 1970s as a way to encourage migration from "overpopulated" regions in the south and northeast of the country. Rondônia and other colonization "poles" in the state of Pará were earmarked for "people without land in a land without people" (Moran 1981). The vast Amazon was seen by many as an empty frontier, which could be consolidated under Brazilian national sovereignty and provide immense opportunities for the exploitation of mineral and biotic resources, for the benefit of millions of poor and landless (e.g., Bunker 1984, 1984b).

How did "over-population", the existence of the frontier, and other human forces interact to "drive" the policy of frontier development and make it economically feasible and desirable? One study reports a good correlation ($r^2 = 0.8$) of deforestation with several anthropogenic variables, including the density of population, and supports the conclusion that population growth and density are related to "deforestation density" or the fraction of an administrative district deforested (Reis and Margulis 1990). This study, however, assumes that the areas in question were completely forested at the beginning of the study. It also overlooks environmental factors such as soil type and fertility, topography, temperature, and precipitation (which define the spatial concentration of deforestation), as well as the spatial congruence between population and forest change.

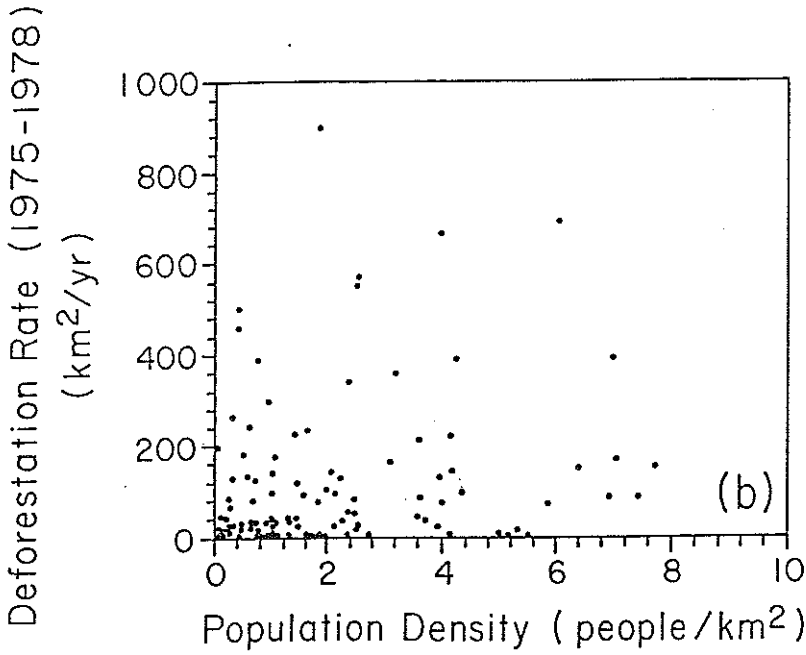

Fig. 6 Relationship between population density (1980) and the deforestation rate (1975-1978) for the entire Brazilian Amazon

Some studies indicate that population growth should be seen as part of a multiple feedback system, where it is as much a consequence of poverty and land degradation as it is a cause of deforestation. Using data compiled on Brazilian deforestation from both statistical land-use surveys and satellite data which provide the location of deforestation, a low correlation between population density and rates of deforestation is obtained (see Figure 6).

In a study of cattle ranching in the Amazon, Hecht (1983) and Hecht and Cockburn (1989), found that government policies, fiscal incentives, and the fact that cattle are a good way of storing wealth in an inflationary economy were more significant determinants of deforestation than were demographic considerations alone. These results and those of other studies (e.g., on deforestation in the Philippines, Kummer 1992; on declining wood stocks in sub-Saharan Africa, Anderson 1986) suggest that in isolation, demographic factors may not be a good basis for projecting future land-use and land-cover change.

The Underlying Human Driving Forces

In Amazonia, a broader set of circumstances made the policy of frontier development possible and established its basic course. These circumstances flowed from the OPEC-stimulated increase in the price of oil (from U.S. $1.30 a barrel in 1970, to $10.72 per barrel in 1974, and to $28.67 by 1980), which resulted in a large net transfer of wealth from industrial economies to OPEC nations, which in turn deposited these revenues in U.S. and European banks (Pool and Stamos 1987). Banks and other commercial institutions lent to developing countries such as Brazil, which desired foreign capital for economic development, modernization, and industrialization programmes (as well as to pay for oil). Brazil borrowed heavily to finance development programmes including agricultural modernization, which was central to increasing agricultural exports and repaying loans (Mahar 1989).

Large-scale investment in agriculture, including an extensive programme of crop credits, followed during the 1970s. The export crops of wheat, soybeans, and coffee consumed almost half of all crop credits, with the largest portion of the credits invested in soybean production (Figure 7).

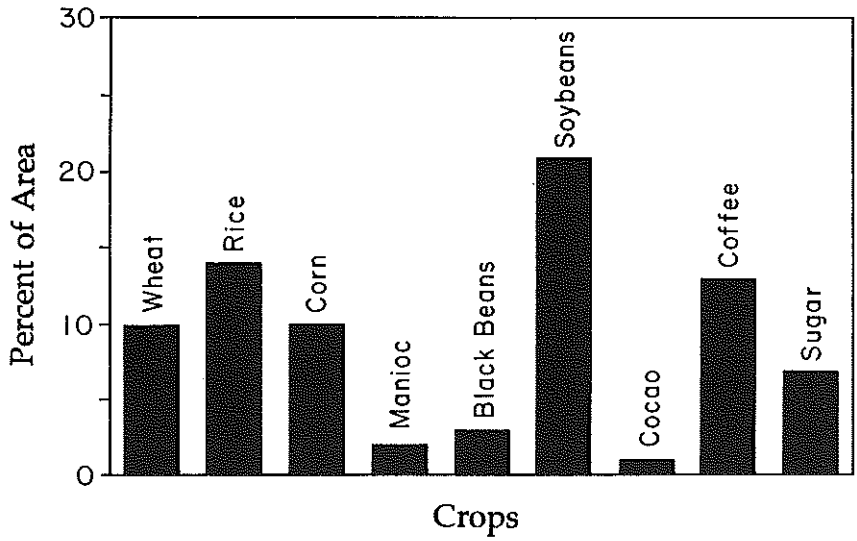

Fig. 7 Allocation of crop credits in Brazil (1978) as a percentage of crop area planted

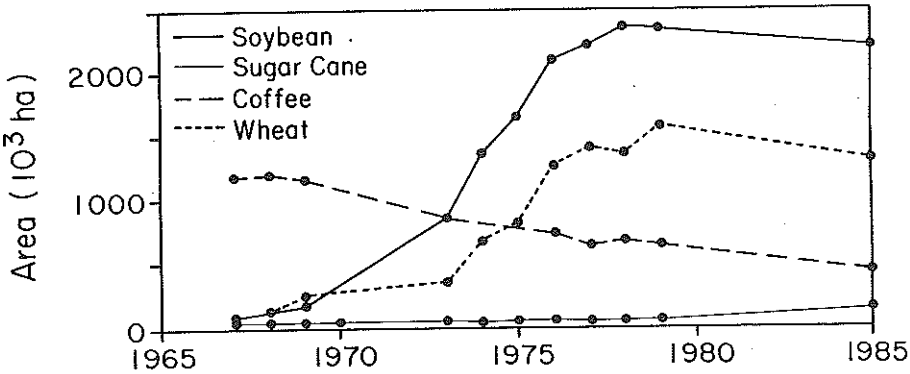

Fig. 8 Change in the area planted in major crops in the State of Paraná, Brazil, 1965-1985

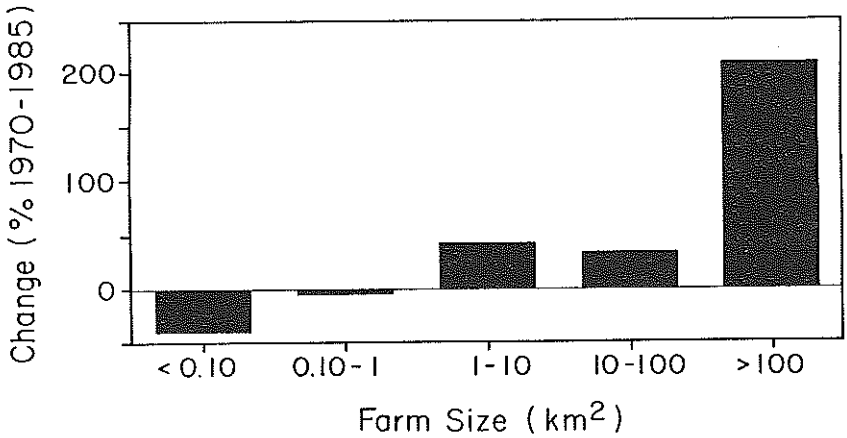

Fig. 9 Change in farm size distribution in the State of Paraná, Brazil, 1970-1985 (% increase or decrease)

As a result, the area under soybean production increased 6-fold in the 1970s, ten times more than most other crops, and yields increased five-fold. The combination of land, fertilizers, improved seeds, and government-sponsored credits and incentives made soybeans one of Brazil's major internationally competitive export crops. Most soybean production was concentrated in two states: Rio Grande do Sul and Paraná. Figure 8 shows that soybean production (and wheat) replaced coffee as the major crop in Paraná. This development was encouraged by government programmes (World Bank 1982) because the international market for coffee was highly variable and undependable.

Consequently, a labour-intensive crop (coffee) was replaced with a capital and energy intensive component of the national export economy, particularly in Paraná. Land prices rose significantly, as land was consolidated into larger holdings. This transformation of land use changed the average size of land holdings from small farms to very large, presumably commercial, farms, as illustrated for the State of Paraná in Figure 9.

Another consequence was that from 1970-1980, migration from rural to urban areas increased. Part of this migration was in response to "pull" factors as industrial development increased wages in urban areas. But commercialization of agriculture in Paraná shifted the means of production from labour to machinery, creating a "push" factor. Large numbers of people left the state of Paraná during this period; out-migration was higher than from any other state. Undoubtedly many, if not most, of the migrants left for urban areas, but a large number also went to new opportunities in the Rondônia frontier (Hecht 1989).

Linking Human Driving Forces to Land-Cover Change

In this interpretation, then, the deforestation of the Legal Amazon is not solely the product of a burgeoning poor population pushing at the frontier margin. Rather, it is the product of specific national policies aimed at transforming the agricultural base elsewhere in Brazil and commercially developing the Amazon. These policies also had the effect of altering land prices, the size of land holdings, and the options available to the rural poor and those who could invest in development.

The deforestation of Amazonia illustrates the challenges encountered in trying to link human driving forces to changes in land cover through land use. It demonstrates that:

- land-use changes that drive land-cover change are tied to numerous human factors, some of which may be spatially distant from the area affected

- the processes involved in land-cover and land-use change operate across many spatial (and temporal) scales

- an understanding of land-cover change would be factually incomplete and lead to inadequate projections if its causes were sought only in the proximate sources of change or in forces operating within the region in question (e.g., land clearance or population growth). Events in international politics and economics influenced the course of deforestation in the Brazilian Amazonia

- simple correlations between human causes and land-cover consequences found at the global aggregate scale do not always appear at sub-global scales.

6. Research Plan

Understanding the past and future impacts of land-use and land-cover change on the states and processes of the biosphere is central to the study of global environmental change. It is thus proposed to establish an IGBP-HDP Core Project to address four overarching and interrelated questions:

- How has land cover been changed by human use over the last 300 years?
- What are the major human causes of land-use change in different geographical and historical contexts?
- How will changes in land-use affect land cover in the next 50 years?
- How might changes in climate and global biogeochemistry affect both land use and land cover?

In order to address these questions, the physical and biological science communities need an improved understanding and synthesis of land-cover change issues. The three requirements for this understanding are to:

(i) develop geographically-referenced data on land-cover change from historical analyses as well as contemporary sources such as remote sensing (e.g., a long-term data set on the distribution and expansion of cropland world-wide)

(ii) develop data sets on land-use change, providing external information that can be used to specify models (e.g., long-term data sets on agricultural uses, including frequency of fallow, amount and distribution of fertilizer use, and so forth)

(iii) develop a comprehensive understanding of the dynamics of land-use change and of how these changes influence land cover over time (e.g., use of formal models).

To this end, it is important to develop several areas of multi- and interdisciplinary research that link social and natural science. This research will not only benefit the natural science research communities involved in global change research, it will also challenge and benefit the participating disciplines of the social sciences. Conceptually and theoretically, this research will provide opportunities to test and refine current theories regarding a number of social and behavioural phenomena and relationships. Two sets of these phenomena and relationships that now seem particularly germane to research on land-use change are: the interaction of population and economic growth,

including factors influencing the rate at which societies pass through the demographic transition, and the impact of these factors on demand for land and the resources derived from it; and the impacts of different political and economic institutions on responses to scarcity of land, including allocation of access to land resources and regulations or customs that influence the efficiency of land-use practices.

To participate effectively in the proposed multi- and interdisciplinary research activities, the social science community needs to:

(i) develop and refine a system for classifying and grouping socio-economic-environmental settings (cases that share similar socio-economic characteristics such as rate of population growth, political or economic system, access to technology, etc.) even though the cases may be geographically or historically disparate

(ii) identify and improve measurement of proxy variables for diverse characteristics of socio-politico-cultural environments that could facilitate comparative research and modelling

(iii) improve our understanding of hierarchies among different levels of analysis from the macro-scale to the micro-scale, and to develop principles for nesting variables at different scales

(iv) refine quantitative modelling techniques of social phenomena

(v) develop a data and information system for accessing the disparately-held socio-economic data sets relevant to research on land-use change, hence standardizing these data and allowing them to be related to geo-referenced data on land-cover changes.

The research plan described below identifies the next steps needed to address the causes and trajectories of change in land use and land cover. While the basic elements of the research plan are in place, a Core Project Planning Committee (CPPC) will further develop the details of a global land-use/cover change project. It is expected that the CPPC will complete its task within 18 months of its formation. The project will be built around three foci, illustrated in Figure 10. Two foci - situational assessment, and global modelling and projections - are central to the interests and needs of both the IGBP and the HDP. The third focus, the identification of rules for linking different levels of analysis, is important over the long run for HDP contributions to studies of a variety of global change issues.

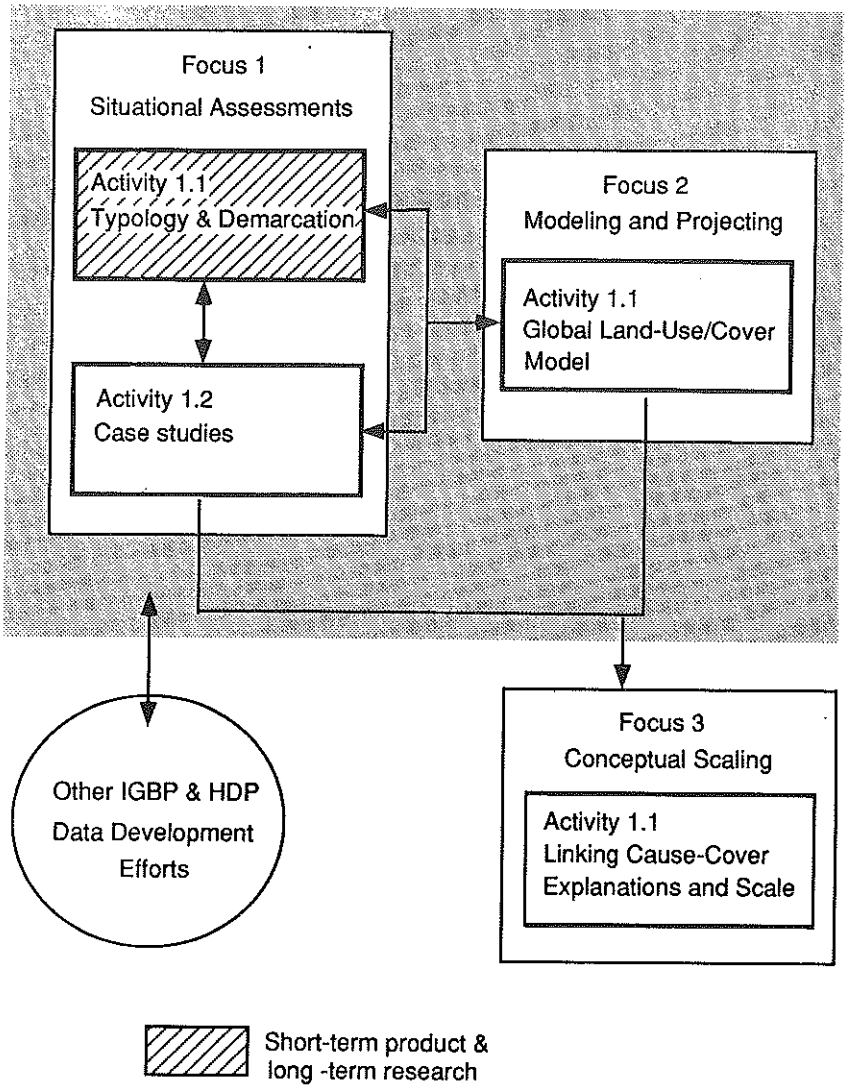

Fig. 10 Linkages among Foci and Activities for a proposed study of global land-use and-cover change

The CPPC will need to develop links with other IGBP and HDP projects. It is expected that the CPPC will call on the resources of IGBP-DIS, HDP-DIS, and START in formulating the detailed science plan. The key projects and relationships are identified in the research plan and potential links to those within IGBP are summarized in Table 2.

Table 2. IGBP projects with major links to the proposed land-use/land-cover study

GCTE	Focus 1: *Ecosystem physiology*, especially in determining the effects of land use on biogeochemical cycles of carbon, nitrogen and other elements
	Focus 2: *Change in ecosystem structure*, development of patch-to-region models that include landscape change, and region-to-global models
	Focus 3: *Global change impact on agriculture and forestry*, including impacts on selected crops, pasture and rangeland, and soil degradation
BAHC	Focus 2: *Regional scale studies of land surface properties and fluxes*, effect of land surface heterogeneity (in land use, vegetation type, soil etc) on water and energy budgets
LOICZ	Focus 1: *Effects of changes in external forcing or boundary conditions on coastal fluxes*, including assessment of land use and vegetation changes in catchment zones, and their effects on sediment and nutrient transport
	Focus 2: *Coastal Biogeomorphology and Sea Level Rise*, including the role of coastal ecosystems (and land use) in determining coastal geomorphology
	Focus 4: *Economic and Social Impacts of Global Change on Coastal Systems*, including evolution of coastal land covers under different scenarios of global change, and effects of changes on social and economic activities
IGAC	*Tropical Focus* includes anthropogenic perturbations of atmospheric chemistry due to tropical land-use changes, biomass burning and rice cultivation
	Mid-Latitude Focus includes atmospheric consequences of fertilization of croplands and drainage of wetlands
PAGES	*Stream I* includes human impacts on the terrestrial biosphere in the past 2000 yr, at fine temporal resolution, and their links to climate variability
GAIM	Modelling studies of the *Contemporary Era* (1980 - 2000) and the *Fossil Fuel Era* (past 400 yr) require standardized land-use data, geographically resolved, to determine their contribution to changes in atmospheric composition
IGBP-DIS	Focus 1: *Data Set Development*, involves the production of global data sets on land-use and land-cover, with special attention given to vegetation classification, wetlands, biomass burning and soils
START	Promotion of regional studies and data exchange networks that contribute to the science agendas of IGBP, HDP and WCRP, with initial emphasis in the tropics (S E Asia, North Africa and equatorial South America)

Focus 1: The Situational Assessment

Comparative studies suggest that the relationships among human causes, land-use change, and land-cover change vary considerably across space and time. This sub-global complexity is currently masked in global-scale approaches that rely on global aggregate data and relationships. The loss of variability in relationships through aggregation diminishes the accuracy of models and projections of land-cover change and lessens their meaning for regional and local assessments. The dynamics of land-use/cover change are better understood at sub-global levels, and global-scale models and projections will be improved if they are made regionally sensitive.

Focus 1 will establish the basis for the incorporation of sub-global complexities in the relationships among human driving forces, changes in land use, and consequent impacts on land cover by creating a typology of socio-economic-environmental driving forces (*situations*), associated conversion and modification processes, and end-states of land cover. It involves two sets of activities, one aimed at identifying and delineating the situations (or groups of regions) with common patterns of human causes of land use and associated changes in land cover, the other at validating and elaborating this framework through case studies carried out according to a common protocol.

Activity 1.1: Typology and Demarcation of Situations

This activity will create a classification scheme that abstracts the essential human and physical characteristics from episodes of land-cover change with similar human causes, even though these episodes may be located in different geographic regions or have taken place in different historical periods. It will do so by identifying and defining a conceptual unit of analysis that not only captures more of the details of and variability in the dynamics of land-use and land-cover change than can the global aggregate scale, but which is also analytically more streamlined and efficient for global modelling. This approach is based on the recognition that it is impractical to address the global situation through separate studies conducted in many small areas, because of the enormous effort required and the problems in "scaling up" (moving from the micro level to the global). At the aggregate level of the globe or even continents, key processes and important variations in use and cover are obscured. The problem, then, is to find a basis for grouping like areas together and keeping different ones separate, avoiding the gloss of macro-scale aggregation without sacrificing too many of the practical advantages of a relatively small number of study units. We define the building blocks of these middle-level units of study as regions and seek to classify them in groups of situations that have common human driving forces, land uses, and land covers (cause-to-cover situations).

Specifying the characteristics of these cause-to-cover situations is more difficult than might be imagined, particularly if the diversity of cover types and processes of change within the study units is high. The divisions must be made on the basis of broad but critical attributes of the human and physical realms involved, and the dynamics of their relationships. Few attempts of this kind have been made, let alone tested for their value in providing an understanding of specific cases or for making generalizations across cases.

The 1991 Global Change Institute (GCI) held in Snowmass, Colorado, USA, developed a trial framework to be used for creating a typology of regional cause-to-cover situations (McNeill *et al.* 1993). This approach recognises that both the physical setting (land cover) and the social setting (e.g., population density, level of economic development, type of economic and political system) differentiate situations of change from one another. The framework can be seen as a cubic matrix (Figure 11) whose three dimensions are proximate sources of change, possible driving forces, and predominant types of land cover. Nineteen proximate sources are identified, grouped as activities of harvesting, replacement or conversion, and transfer (importation of resources to sustain the change involved). The driving forces of change include both human factors (e.g., population growth, degree of political centralization) and natural processes (e.g., climate variability on desert margins). Appropriate surrogate variables for the human forces are suggested.

With respect to cover types, the GCI working group sought initially to identify priority land-cover regions for study rather than to demarcate the entire land surface of the Earth. Using spatial extent and significance of different cover types for global change as the main criteria, it identified seven priority land-cover types, excluding such covers as desert, tundra, and urban settlement. There is no reason, however, that the excluded cover types could not be brought into the cubic matrix in order to complete the demarcation of the terrestrial surface.

Not every possible combination of variables within the cubic matrix will occur or be significant globally. It is expected that recurrent patterns will be identified that indicate common conditions of cause-to-cover relationships. The degree to which units of a particular size can be characterized by any of the three dimensions or by particular situations may vary and pose some challenges. Temporal dimensions may also require attention; for example, do rates of change matter in the typology?

The proposed schema of regional cause-to-cover situations offers a way of standardizing context in order to identify the circumstances under which particular driving forces are or are not significant. It also provides a framework within which areas of the world can be selected for in-depth case study examination as exemplifying globally significant trends. The matrix detailed here may be too detailed for practical application, but it provides a beginning from which regional situations could be established.

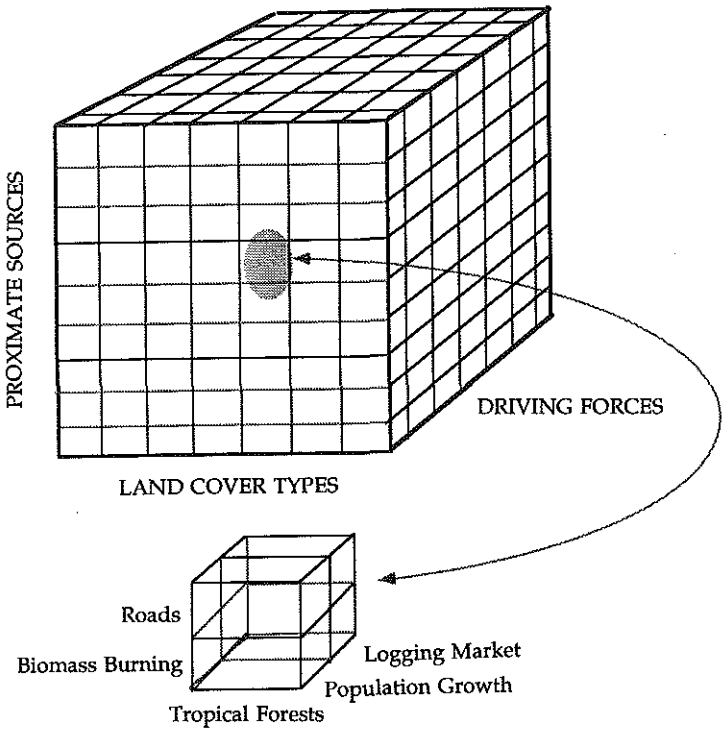

Fig. 11 Cubic system for identifying cause-to-cover situations

The typology and demarcation Activity is fundamental to all others proposed for the land-use and land-cover change project. It involves both a near-term product - an initial typology and demarcation - and longer-term research leading to refinements and changes in the typology and demarcations. The near-term product is proposed for development over the life of the CPPC, providing a base for the modelling and case study activities. The longer-term research activity awaits results from the case studies and modelling activities as they progress.

Short-term Objective

- To delineate the world into a system of regions, each regional type possessing common patterns of relationships between human driving forces and land-use/cover change.

Task 1.1.1

- To define a systematic set of "regional" *situations* by identifying common cause-to-cover relationships.

Task 1.1.2

- To group similar cases and areas and thus demarcate the world into these situations.

Long-term Objective

- To evaluate the effectiveness of the original system of situations and make modifications or changes where required.

The objectives of Activity 1.1 are relevant to other IGBP activities, especially BAHC, GCTE, GAIM, and to other components of HDP (Table 2).

Implementation

Tasks 1.1.1 and 1.1.2 should be completed during the stage of Core Project planning (1993), serving as a catalyst for Activity 1.2 and Focus 2, and should be developed in close consultation with both. The long-term objective awaits the results of the research that is involved in Activity 1.2 and Focus 2.

Activity 1.2: Case Studies

As noted, different areas of the world with similar land covers display different courses and rates of land-cover change, and these differences are related to their socio-economic and physical context. Beyond this recognition, the impacts of socio-economic context on land-cover change is a source of considerable debate, little of which is well grounded empirically. It is true that numerous case studies (local and regional) have been conducted that contribute to our collective understanding of varying cause-to-cover dynamics. Almost all were individually undertaken, however, lacking a common protocol of study and standardized data sets, and thus are virtually impossible to compare in a rigorous way. One of the most important mechanisms of improving understanding and, ultimately, global models, is through systematic case studies designed to collect common data sets to answer standard questions about the impact of socio-economic context on land-cover change.

Short-term Objective

- To establish a common protocol for comparative assessments of the impact of socio-economic context on land-use and land-cover change, and to identify an appropriate set of case studies, drawing as much as possible on previous or on-going work that can be included within the framework.

Task 1.2.1

- To develop a common protocol or framework for comparative assessments of cases.

Such a framework must be open to the range of possible driving forces and the interactions among them, while simultaneously striving to elucidate those that are sufficiently recurrent to be useful in global modelling and projection. Analysis of a broad range of driving forces is facilitated by exploration of cause "stories," which add detail and perhaps reveal common but under-appreciated variables (Glaser and Strauss 1967). The role of recurrent driving forces should be examined quantitatively, not only through individual and co-varying assessments (e.g., population and technology as related to cultivation), but also through theories purporting to explain land-use and land-cover change. These assessments require that a standard set of variables and theories be identified in advance and applied to each case study. Several sets of candidate driving forces exist (e.g., Turner and Meyer 1991; Meyer and Turner 1992; Stern, Young, and Druckman 1992), almost all of which are derived from conceptualizations or theories that can be structured to fit land-cover change. These sets require pruning, selecting variables within them for which there is a strong likelihood of obtaining common data for each region and time period. The theoretical frameworks to be examined have yet to be determined, and they constitute a high priority for the next stage of development of this project.

Task 1.2.2

- To identify a set of case studies representing a sufficient sample of the situations identified in Activity 1.1.

Several groups and committees have considered part of this task (Meyer and Turner 1993; CGC 1990; SSRC 1991) based largely on the broad category of land cover, but with implications for the general patterns of land use. The main cover types identified as essential in coverage are forest, grassland/pasture, cropland (including irrigated land), wetland, and settlement. Task 1.2.2 must determine: (a) what subsets of these covers, if any, should be emphasized; and (b) how they should be addressed, individually or through multiple covers matched to regional socio-economic situations. This task should also take into consideration the variation in global change impacts on the regions.

Task 1.2.3

- To identify previous and on-going case studies that fit the requisite sample of situations (Task 1.2.2), and determine the degree to which they can be modified or expanded to fit the needs of this Activity.

This task requires a survey of case studies of land use and land cover that broadly fit the framework developed in this Activity. Few will have covered the spectrum of data and theories proposed in the framework, but the potential of drawing upon them or their authors to contribute to the project needs should be assessed. Examples of major studies involving comparative regional changes in land-use are: the International Institute of Applied Systems Analysis (IIASA)/United Nations Environment Programme (UNEP) assessment of agriculture and climate change (Parry, Carter, Konjin 1988); the Project on Critical Environmental Zones (Kasperson *et al.* 1990) and Collaborative Research on Population Growth, Land Transformation and Environmental Change (under development; Brookfield 1992); the IGBP-DIS pilot study of land cover (Rasool and Ojima 1989); the IIASA/Food and Agriculture Organization of the UN (FAO)/UNEP study of food production potential and population carrying capacity in the lands of the developing world (Harrison 1984); and the Wageningen Agricultural University Model of International Relations in Agriculture (MOIRA) (Linneman *et al.* 1979) and recent derivatives.

Long-term Objective

- To create a series of comparative case studies of regional situations to be used to fine-tune the typology of those situations and the dynamics of global land-use/cover models and projections.

The objectives of Activity 1.2 are relevant to other IGBP activities, especially BAHC, GCTE, IGAC, LOICZ, and all HDP activities (Table 2).

Implementation

All tasks should be completed during the Core Project planning stage, although they cannot be fully completed until the first stage of Activity 1 is completed. Task 1.2.1 can begin independently of Activity 1, but the other two tasks await the completion of the typology of regional situations. Activity 1.1 and 1.2 must be tightly integrated.

Focus 2: Modelling and Projecting Global Land-Use and Land-Cover Change

Global models of land-use and land-cover change are essential components of quantitative models of global environmental change. Computer models permit the use of large quantities of social and environmental information needed for monitoring and projecting land transformations, linking data and theory through formal equations. They allow logical and internally consistent analysis of the relations between, and dynamics of, driving forces and land-cover change, providing the possibility of testing and

calibrating these formulations through simulations of past and short-term future land-use/cover changes and comparison of the model results with observed changes. They allow us to examine the implications of current trends in driving forces and land transformations for future environmental changes, and can be used for sensitivity and policy "experiments" to examine the impacts of policy initiatives and economic and social reform pertinent to land use. Computer models, combined with Geographic Information Systems (GIS), provide the best possibility for integrating geographical and ecological units at various spatial scales of analysis. They also provide the potential to "fill in" holes where data are incomplete or unknown.

Activity 2.1: Framework for Models and Projections

Short-term Objective

- To develop a framework for global land-use/cover models. These models will have two characteristics: first, that they can be integrated with other global models, and second, that they can be used to generate projections of land-use/cover change.

Task 2.1.1

- To develop a framework for a global land-use/cover model.

The 1991 GCI on land-use/cover change initiated the development of such a framework (Robinson *et al.* 1993). It outlined a number of general aims of this effort to:

- organize existing data on land use/cover and their driving forces with the goal of identifying the gaps in data and providing data for building and calibrating land-use models

- specify the relationships between driving forces and land transformation at various levels of empirical and theoretical complexity

- review existing regional and global models that deal with land transformations and/or the relationship between social driving forces and the use of the environment

- construct a range of models from the most simple, empirical projections of land use/cover to dynamic simulations of globally integrated, yet regionally modelled, relationships between human activity and the environment, with feedbacks from land transformation to driving forces and land cover

- test and revise these models (i) against past experience of land-use change; (ii) against the immediate future of land-use change; and (iii) across a cause-cover typology

- examine the sensitivity of land-use change to social driving forces at regional and global scales as well as to errors in data or model specifications

- establish methods for transforming data to common spatial and temporal scales to complement physical, social, and policy models.

The development of a framework for global models should consider (i) analyses of the current (1975-1995) dynamics of land-cover change in significant world regions; (ii) analyses of the history of land-cover change globally over the past 300 years; (iii) analyses of specific case studies in selected regions; and (iv) global-scale projections of the state of land cover between now and 2040.

The framework must also take account of the evolution of analytical tools for modelling and projections, and the varying scale of resolution among data on land cover (1 km x 1 km, IGBP-DIS), land use, and driving forces (typically collected by political boundaries). Current social data may be manipulated to complement land cover, but cannot be used to specify models over the past 300 or even 100 years.

Long-term Objective

- To develop and implement global land-use/cover models that incorporate the results of work in Focus 1 and to develop land-use/cover projections from the models.

The objectives of Activity 2.1 are especially relevant to GAIM, GCTE, BAHC, IGAC, and LOICZ (Table 2).

Implementation

Development of the framework will take place throughout the core project planning process. It must, however, be coordinated with both activities of Focus 1.

Focus 3: Conceptual Scaling

Land cover and use are governed by variables that connect different spatial scales, and do not fit the simple categories of global, regional, and local. Causal links identified at one scale may not appear at others, and relationships among scales may be discontinuous.

Activity 3.1: Linking Cause-Cover Explanations and Scale

Generally, to the degree that land-use research is conducted at the macro-scale, it is assumed that the levels of analysis are continuous and that there is a relatively clear hierarchy beginning with the international or global system level and descending to the local land manager or plot. So, for example, world agricultural prices govern the decision-making of an individual farmer, hence the agricultural conversion rate within a region, and so on. This presumed nesting of relationships leads to a presumed nesting of explanations, each descending explanatory scale embedded in the previous one.

While such assumptions are familiar to a range of studies geared towards the international level, they have not been examined systematically in relation to land-use/cover change. Indeed, the general issues of scale and nesting are not adequately understood within the human sciences (e.g., Meyer *et al.* 1992), still less tied to considerations in the physical sciences (e.g., Clark 1987). Yet inferences and implications regarding scale and hierarchy abound in the emergent studies of global environmental change. The existence of continuity or discontinuity requires examination and should not be assumed.

Long-term Objective

- To specify relationships among different driving forces, from the global to the local level of analysis, in explanations of changes in land use and land cover.

Successful completion of this task has far greater implications for future land-use/cover studies than might appear at first. Resolution is currently so coarse that it is difficult to select competing explanations or theories for the various tasks in Foci 1 and 2. The results of the tasks in those foci, however, provide an exceptional opportunity to provide a better level of resolution. Specific questions guiding this task are:

- How do driving forces vary by spatial (and temporal) scale?

- Is there a consistent hierarchy among driving forces at different scales or a general set of principles to govern the nesting of different levels of analysis?

- Does the hierarchy among driving forces at different scales vary from one socio-economic *situation* to the next?

- Is there continuity or discontinuity in explanations as scales vary?

- What models are most appropriate for each scale, and how many levels of study are necessary to reveal the dynamics of human driving forces?

The objectives of Activity 3.1 are relevant to all HDP activities, as well as to GAIM and GCTE (Table 2).

Implementation

This activity will be implemented when the results of activities in Foci 1 and 2 become available.

Data Development Activities

The development of an improved understanding of the dynamics of land-use change and the forces that drive it will require a solid foundation of data. As noted above, much attention must be given to improving the "global accounts" of land use and cover, and of the environmental impacts of changes in them. Other efforts of the IGBP through the activities of IGBP-DIS have begun to define the types of data needed to support basic research in biogeochemistry, water and energy balance, and terrestrial ecosystem dynamics (e.g., Townshend 1992; Moore 1993). Some of these data will also be needed in development of global land-use/cover models and case studies. For instance, data on biomass burning will be needed for studies of land-use change (where biomass burning figures as a proximate source of deforestation or a grasslands management practice), as well as for studies of biogeochemistry (where it contributes to the flux of carbon to the atmosphere). Data on biomass burning and other proximate sources of land-cover change, which can be obtained from satellite observations, provide the link between the activities of the other IGBP Core Projects and land-use modelling. Some components of models of land-use change - particularly those related to their spatial and temporal characteristics - can be checked and perhaps validated using this sort of data.

An effort will need to be mounted to define the data sets required to support directly the research into land-use change, including those that would be used as primary forcing functions in the modelling or as parameters to define typologies. Data sets are also required for validation of models. This activity involves the land-use effort with the IGBP-DIS as well as with IGBP-GAIM (e.g., Townshend 1992; Moore 1993).

Many of the global-scale data efforts now under way or planned by IGBP-DIS lack adequate resolution for land-use/cover studies. For instance, the IGBP-DIS plan to obtain 1 km resolution AVHRR data for land-cover classification and mapping, which is a high resolution data set on a global scale, is inadequate for detailed analysis of land-use change. However, finer resolution information for specific areas is becoming available. For instance, the NASA Landsat Pathfinder project is mapping deforestation as a land-use change for selected regions of the humid tropics, and this will provide 1:1 000 000 scale or better digital data sets. Such fine resolution data will be essential for specifying models coming from a global land-use/cover effort and for validating results of models. The CPPC should specify the requirements for such fine resolution data sets in close coordination with IGBP-DIS and HDP-DIS.

One aspect of the study of land-use change is the feedback from anthropogenic perturbation in climate, biogeochemistry, and terrestrial ecosystem dynamics. These changes, in turn, influence human activities in positive or negative ways as indicated in Figure 1. For instance, biotic impoverishment from deforestation may affect the rate of future deforestation in the area, or it may influence a transition from extensive to intensive use of inputs such as land and fertilizers. There must be close linkages between the other Core Projects of the IGBP and HDP and the land-use/land-cover change project so that data produced can be easily exchanged and integrated.

The HDP data assessment series will provide sources and evaluations of existing socio-demographic data (HDGEC 1991). Published reports include assessments of survey research data (Worcester and Barnes 1991), demographic data (Clarke and Rhind 1992), and economic data (Yohe and Segerson 1992). The following questions will need to be addressed:

- What data are required for specification of global land-use/cover-type models?
- What data are required to validate or cross-check results of these models?
- What data are required for the development of regional situations and case studies?
- What types of data outputs are needed by other Core Projects?
- What types of data inputs from the other Core Projects are needed by these efforts to incorporate biophysical feedbacks?
- Which of these data can be generated for the past 300, 200, and 100 years, and how will they be generated?

Close coordination should be maintained with, and support sought from, IGBP-DIS, GAIM, and HDP-DIS to answer these questions. Each activity in the next stage of the land-use/land-cover change programme, however, must address these data issues, particularly as they apply to past land-use and -cover evidence. The various assessments that should follow may require that a fourth activity be added to the land-use and -cover effort, or that such an activity be generated between this effort and others of the IGBP and HDP.

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Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
CPPC	Core Project Planning Committee
DIS	Data and Information System
FAO	UN Food and Agriculture Organization
FRN	Swedish Council for Planning and Coordination of Research
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GCI	Global Change Institute
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GDP	Gross Domestic Product
GIS	Geographic Information System
GNP	Gross National Product
HDP	Human Dimensions of Global Environmental Change Programme
ICSU	International Council of Scientific Unions
IDRC	International Development Research Center
IGAC	International Global Atmospheric Chemistry Project (IGBP)
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change
IIASA	International Institute of Applied Systems Analysis
ISSC	International Social Science Council
Landsat	Land Remote-Sensing Satellite (USA)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
MOIRA	Model of International Relations in Agriculture
NERC	National Environmental Research Council (UK)
OPEC	Organization of Petroleum Exporting Countries
SAREC	Swedish Agency for Research Co-operation with Developing Countries
SPOT	Système pour l'Observation de la Terre (France)
UNEP	United Nations Environment Programme

Terms of Reference

Joint IGBP-HDP Core Project Planning Committee on Land-use/Land-cover Change

1. Introduction

The International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP) decided in 1992 to establish a Core Project Planning Committee (CPPC) to set up a joint project on Land-use/Land-cover Change. This action was taken in recognition of the importance of land-cover change in the study of global environmental change and its human dimensions, and noting the main conclusions of the joint IGBP-HDP Working Group on Land-use/Land-cover Change, namely that:

- understanding the past and future impacts of changes in land cover is central to the study of global environmental change and its human driving forces and impacts, including hydrology, the climate system, biogeochemical cycling, ecological complexity, and land degradation and its impacts on agriculture and human settlement

- land-cover modelling will require improved knowledge of land use; it will be difficult to make projections of future states of land cover without knowledge of the factors that determine land use and drive land-use change

- the most likely determinants of land use are: demographic factors such as population size or density; technology; level of affluence; political structures; economic factors such as systems of exchange or ownership; and attitudes and values

- additional basic research is required to understand how these factors interact to determine land use and drive land cover change and how information about these factors could be used to project future patterns of land use, future rates of land-cover change, or future states of land-cover

- regionalization and coordinated case studies are necessary for further investigation of changes in land use, its causes, and its implications for the functioning of the Earth system

- the knowledge gained through regionalization and case studies will be crucial to developing regional and global land-use/cover-change models

2. Tasks

The CPPC is charged with drafting a detailed science plan for an IGBP-HDP project on land-use/cover change, building on the framework of study outlined in the report of the joint Working Group. The science plan prepared by the CPPC will: address the needs of the Core Projects and proposed Core Projects of the IGBP, in particular GCTE, IGAC, BAHC, and LOICZ; contribute to the projects and activities of the HDP, including Social Dimensions of Resource Use; the Impacts of Local, National and International Social, Economic and Political Structures and Institutions; and Environmental Security and Sustainable Development; define the data needs of the project and specify how these needs can be fulfilled in cooperation with IGBP-DIS

As appropriate, the plan will also: contribute to the definition of relevant START activities; make use of the outputs of PAGES; and make use of the outputs of the HDP Data Programme.

3. Composition

The CPPC will be composed of 8-12 individuals with broad scientific backgrounds and will be international and multi-disciplinary in composition. The members of the CPPC will be appointed jointly by the Scientific Committee of the IGBP (SC-IGBP) and the Standing Committee of the HDP (SC-HDP).

4. Mode of operation and timetable

In preparing the detailed science plan, the CPPC will actively interact with the Core Projects and activities of the IGBP and the HDP; and hold an open scientific meeting to discuss and assess its detailed science plan.

The IGBP and the HDP will contribute to funding the work of the CPPC.

The CPPC will complete its work in approximately eighteen months. At the conclusion of the work of the CPPC, and assuming approval of the proposed plan by the SC-IGBP and the SC-HDP, a Joint Scientific Steering Committee for the project will be formed to carry out the scientific plan.

IGBP Reports

(Listing limited to Reports that are still in print)

No. 12 The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)

No. 13 Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Edited by P A Matson and D S Ojima. (1990)

No. 14 Coastal Ocean Fluxes and Resources. Edited by P M Holligan. (1990)

No. 15 Global Change System for Analysis, Research and Training (START). Report of the Bellagio Meeting. Edited by J A Eddy, T F Malone, J J McCarthy and T Rosswall. (1991)

No. 16 Report of the IGBP Regional Workshop for South America. (1991)

No. 17 Plant-Water Interactions in Large-Scale Hydrological Modelling. (1991)

No. 18.1 Recommendations of the Asian Workshop. Edited by R R Daniel. (1991)

No. 18.2 Proceedings of the Asian Workshop. Edited by R R Daniel and B Babuji. (1992)

No. 19 The PAGES Project: Proposed Implementation Plans For Research Activities. Edited by J A Eddy. (1992)

No. 20 Improved Global Data for Land Applications: A Proposal for a New High Resolution Data Set. Report of the Land Cover Working Group of IGBP-DIS. Edited by J R G Townshend. (1992)

No. 21 Global Change and Terrestrial Ecosystems: The Operational Plan. Edited by W L Steffen, B H Walker, J S I Ingram and G W Koch. (1992)

No. 22 Report from the START Regional Meeting for Southeast Asia. (1992)

No. 23 Joint Global Ocean Flux Study: Implementation Plan. Published jointly with SCOR. (1992)

No. 24 Relating Land Use and Global Land Cover Change. Published jointly with HDP. Edited by B L Turner II, R H Moss, and D L Skole. (1993)

No. 25 Land-Ocean Interactions in the Coastal Zone. Science Plan. Edited by P M Holligan and H de Boois (1993)

List of HDP Reports

No. 1 A Framework for Research on the Human Dimensions of Global Environmental Change. Edited by H K Jacobson and M F Price. ISSC/Unesco, Paris (1990)

No. 2 Dynamics of Societal Learning about Global Environmental Change. Edited by R M Worcester and S H Barnes. ISSC/Unesco, Paris (1991)

No. 3 Population Data and Global Environmental Change. Edited by J T Clarke and D W Rhind. ISSC/Unesco, Paris (1992)

No. 4 Economic Data and the Human Dimensions of Global Environmental Change: Creating a Data Support Process for an Evolving Long Term Research Program. Edited by G Yohe and K Segerson. HDP, Barcelona (1992)

No. 5 Relating Land Use and Global Land-Cover Change. Edited by B L Turner II, R H Moss, and D L Skole. IGBP/HDP, Stockholm (1993)

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