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Global Land-Use/Land-Cover Change: Towards an Integrated Study

Human actions are altering the terrestrial environment at unprecedented rates, magnitudes, and spatial scales. Land-cover change stemming from human land uses represents a major source and a major element of global environmental change. Not only are the global-level data on land-use and land-cover change relatively poor, but we need a much better understanding of the underlying driving forces for these changes. Many forces have been proposed as significant, but single-factor explanations of land transformation have proved to be inadequate. How the human causes interact, and under what circumstances each is important, are questions needing systematic research. An international and interdisciplinary agenda is currently being developed to address these issues, through several closely-connected foci of study. A division of the world according to common situations of environment, human driving forces, and land-cover dynamics will be followed by detailed study of the processes at work within each situation. The results will form the basis for a concurrent effort to develop a global land model that can offer projections of patterns of land transformation.

Wind and water erosion following forest clearance in loess area near Yan'an, Shaanxi Province, China. Photo: B. L. Turner II.

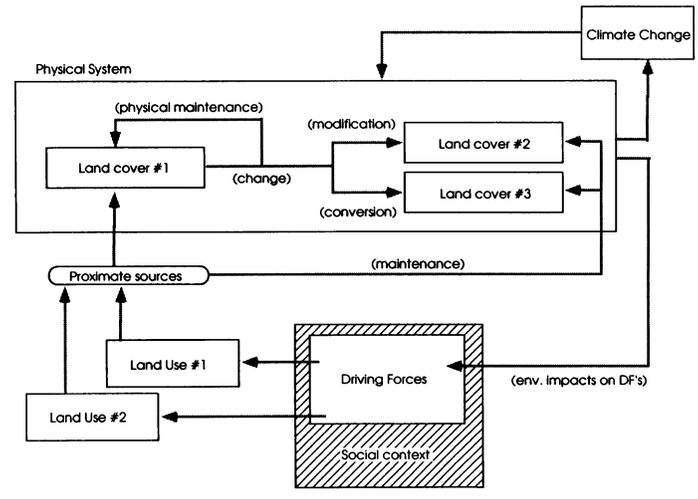


Figure 1. Linkages between human driving forces, land use and land cover.

INTRODUCTION

Scientists and the public alike now understand that contemporary change in many realms of the biosphere is largely the product of human activities. Human impacts on the global environment are operating at unprecedented magnitudes, rates, and spatial scales. For example: at least half of the ice-free surface of the Earth has already been substantially altered for a variety of human uses (1); the annual human diversion of water is about a quarter of the total yearly stable runoff on all of the world's lands, and the amount either diverted or polluted is more than a third (2). In addition, the methane content of the troposphere has been doubled, and the level of carbon dioxide increased by 25%, since preindustrial times (3).

The immediate human sources of these changes lie in two clusters of production and consumption activities (4). The first is the world's industrial metabolism; the flow of energy and materials through the processes of resource extraction, processing, use, and disposal in the industrial sector of the world economy (5). The second is global land-use and land-cover change. The division is a pragmatic one designed to make the field of study—the human sources of global environmental change—more manageable. No sharp division exists between the environmental effects that each cluster produces. Their impacts span a wide range of spatial scales and overlap in many areas. Industrial metabolism and land-use and land-cover change both contribute to such globally systemic changes as greenhouse-gas accumulation in the troposphere, and stratospheric ozone depletion. Over the past 150 years, for example, land-cover changes and fossil-fuel combustion have released approximately equal amounts of carbon dioxide to the atmosphere (6). Other impacts of both industrial metabolism and land-use and land-cover change are localized in their immediate reach and become globally significant, if they do at all, only by widespread cumulative occurrence.

LAND-USE/LAND-COVER RELATIONSHIP

The most spatially and/or economically important human uses of land globally include cultivation in various forms, livestock grazing, settlement and construction, reserves and protected lands, and timber extraction. These and other land uses have cumulatively transformed land cover at a global scale. The consequences have been significant not only for land cover but for many aspects of local, regional, and global environments, including climate, atmospheric composition, biodiversity, soil condition, and water and sediment flows. These kinds of impacts are generated by both

Massive irrigation scheme, Amu Darya, near the Aral Sea, Central Asia. Photo: B. L. Turner II.

Wet-dry tropical forest degraded to Cohune palm forest by intensive slash-and-burn use in Belize. Photo: B. L. Turner II.

the modification and the conversion of land cover, the former involving alterations in the attributes of a cover (e.g., from grassland to degraded grassland by overgrazing) and the latter a complete change from one cover type to another (e.g., from forest to grassland by clearance for pasture). A third form of human intervention is the maintenance of land cover; examples are the upkeep and repair of soil terraces, of improved pasture, or of irrigation systems. Much more is known about the global extent of conversion and, perhaps, of maintenance than of modification, possibly because the last is the most difficult of the three to observe and record.

A better understanding of land-use and land-cover change is of crucial importance to the study of global environmental change. The pursuit of this understanding carries us deep into the realm of the social or human sciences because changes in cover are caused by land uses, which, in turn, are governed by human driving forces (7). What we henceforth call the cause-to-cover relationship, between physical land transformation and its social drivers, is not a new topic of concern. Past work on the subject has mapped the broad course of land use and cover over the long term and at the global scale. These assessments, however, typically do not permit the major human forces of change to be disassociated or the processes at work to be specified. Over the long term, an association is evident between land-use and land-cover change and population growth, but the same relationship can be found with technological growth, affluence, and changes in political economy. The tasks remain of untangling their relations with one another and with environmental change and of explaining why land transformation at lower scales (spatial and temporal) of analysis does not uniformly display the same associations.

Global-scale assessments typically mask critical sub-global variations. A decrease in the world's forest cover and an increase in cultivated land has been evident over the past 40 years, for example, but in western Europe, forest cover has expanded during the same period and cropland has declined. At the global scale, deforestation has been associated with increases in population density and per capita consumption, but in western Europe, afforestation has accompanied further increases in what were already some of the highest regional population densities and consumption rates in the world.

Local and regional case studies can provide the spatial and temporal resolution required to identify and account for major variations in cause-to-cover relationships. Understanding of the details of the cause-cover relationship improves greatly when the focus is narrowed to individual regions or areas and shortened in time scale. Many case studies have examined the human sources of environmental transformation in particular places in the recent or distant past under a wide variety of circumstances, demonstrating the complexities of society-environment interactions and the inadequacy of simple models to explain their details (e.g., 8–12). Single-factor explanations, at the macro or the micro scale, have not proven to be adequate.

Unfortunately, these important contributions do not tell the global change community all that it needs to know about the cause-to-cover relationship. Such case studies as have been done, though rich in insights and suggestions, almost invariably are not comparable with one another in a strict or quantitative way. Although useful lessons can still be gleaned from less rigorous comparisons (13, 14), it is not immediately possible to build up from existing case studies to a global model.

Yet a major aim of the global-change community is to improve the modeling and projection of various kinds of global environmental change (7). Many global change models, including those dealing with climate and trace-gas dynamics, require projections of land-cover change as inputs. Furnishing these projections requires global modeling of cause-to-cover relationships. To undertake such modeling demands the use of an approach that has not been widely followed in human dimensions research or indeed in the social sciences generally; a coordinated program of rigorous comparative studies conducted at the regional or local level. Specifically, it requires the demarcation of the world into generic cause-to-cover situations as the basis for case studies that can uncover the dynamics of land-use and land-cover change within them and inform global modeling. Regionally sensitive global modeling constructed on such a foundation will let us better address many critical questions. Under what conditions, for example, do population growth, increased per capita consumption, technological innovation, and changes in political-economic structure lead to deforestation, to grassland modification, to expansion in croplands, or to wetland drainage?

RESEARCH NEEDS AND DATA PROBLEMS

The International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP) are jointly creating a research agenda dealing with these aims and questions. Following the recommendations of an ad hoc committee on global land-use and land-cover change (7), the two programs are engaged in developing the science plan for a joint *Land-Use/Cover Change* (LUCC) project that will implement this agenda. The basic objective of this effort is to understand the cause-to-cover relationship in such a way that changes in land use and land cover can be modeled and projected. Two integrated research foci have been identified as crucial to this goal.

The first focus comprises two activities. *Activity 1* is the design of a conceptual framework for identifying common cause-to-cover situations, and an initial formulation of these situations. This activity seeks to divide the world's land area into a number (unspecified, but on the order of 10–50) of categories. Each of these categories or situations is to be characterized by broadly similar social and environmental conditions and by similar clusters of human driving forces producing similar patterns of land-use and land-cover change. The aim of dividing the world in this way is to achieve much sharper resolution of cause-to-cover dynamics than is offered by a global aggregate approach. The number of situations to be distinguished will depend on the tradeoff between the improved understanding obtained as the number of units is increased and the need to keep them down to a manageable number for individual study and global modeling.

Activity 2 will begin with the design of a common protocol for case studies by which the cause-to-cover dynamics in the different situations can be specified and, if necessary, the framework of situations adjusted. The case studies must provide empirical data and theoretical assessments that are quantitatively comparable, and the design and completion of such studies require cross-disciplinary and international cooperation. The protocol must identify a common set of independent variables (and surrogate measures for them) derived from the important competing conceptualizations, which include, among others, the neo-Malthusian, Boserupian, neoclassical economic, and neo-Marxian political economy perspectives. The independent variables or driving forces to be examined must include those widely suggested in the literature: population, technology, affluence and poverty, economic and political structures, and cultural beliefs/attitudes (15). Factors belonging to all of these categories have been advanced as significant influences on land use, but there has been little effort to examine their interaction and weigh the relative importance of each, whether globally or regionally. Work to date suggests that the immediate role of each variable in the cause-to-cover relationship depends on the context. It is this context that the meso-scale framework of situations is designed to capture.

These activities will feed into the second focus. Its aim is to develop the basic framework, including the required attributes, for global land-use and land-cover models, based on the situations emerging from the first focus. This model must organize the existing data on land transformations, specify the relationships of use and cover changes with driving forces (ultimately drawing on the case studies), and furnish projections of future regional and global change.

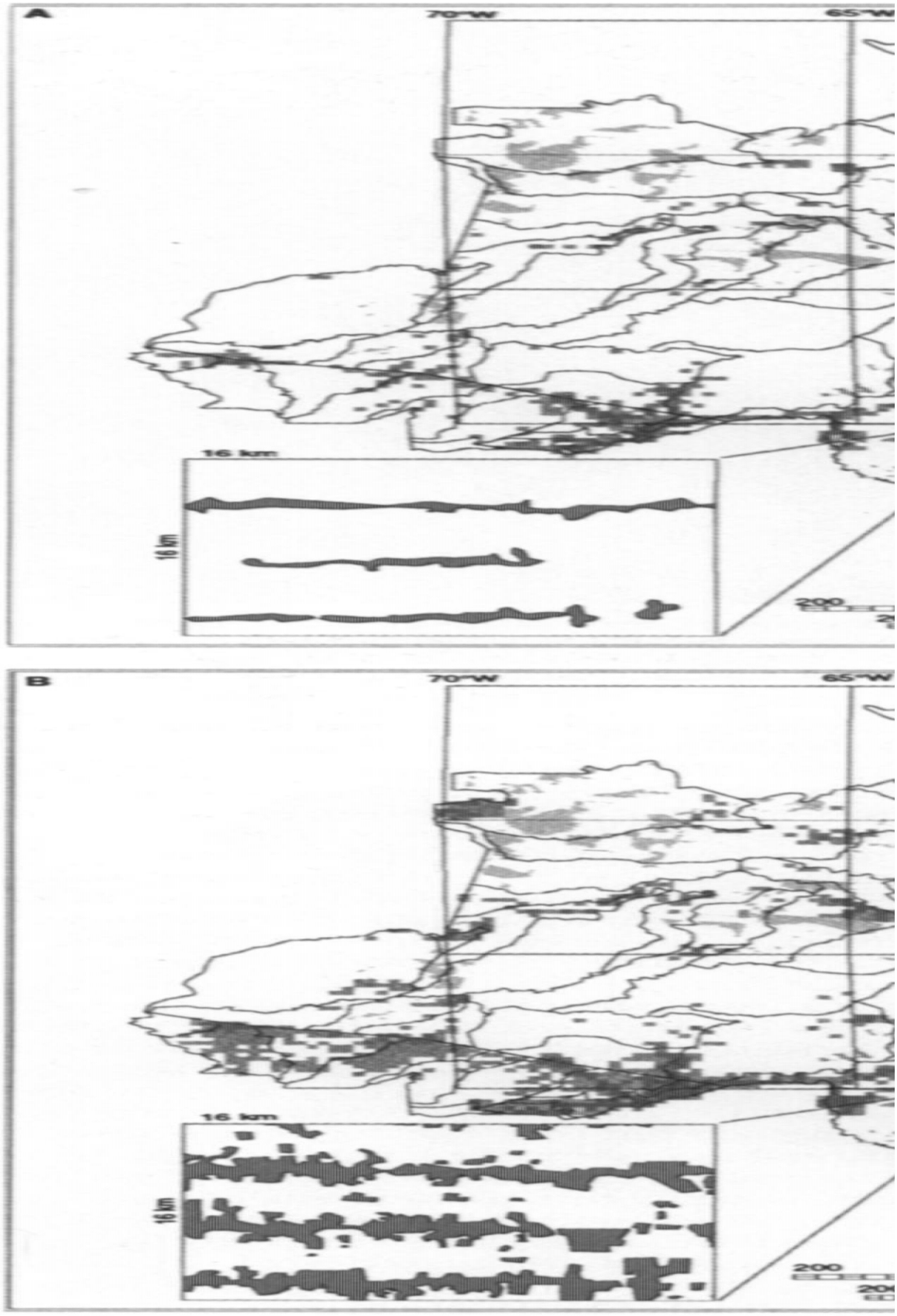
Problems of data will, of course, confront researchers working in both foci. It can be said that the quantity and quality of available worldwide data decline as one moves from land cover to land use to driving forces. Current global data sets in all of these are of doubtful validity. In addition, they often combine cover and use. A common category like forest, for example, may refer to either. It may also be too general to be useful. Forest cover can vary greatly in such attributes as biomass and species composition. The land uses subsumed under forest range from parks and reserves to timber concessions to sparsely inhabited frontiers. Distinctions will likewise be needed within the land-use category of cropland. Are we dealing with rain-fed, irrigated or wetland cultivation? What crops are grown, and how frequently is the land cultivated? Are chemical fertilizers used and to what degree? The data on human driving forces are even less adequate. With the possible exception of population and some items in national accounts, reliable worldwide comparable data on the various potential driving forces do not exist. For example, we do not have a standard classification of land-tenure systems, let alone figures detailing their distribution across the world.

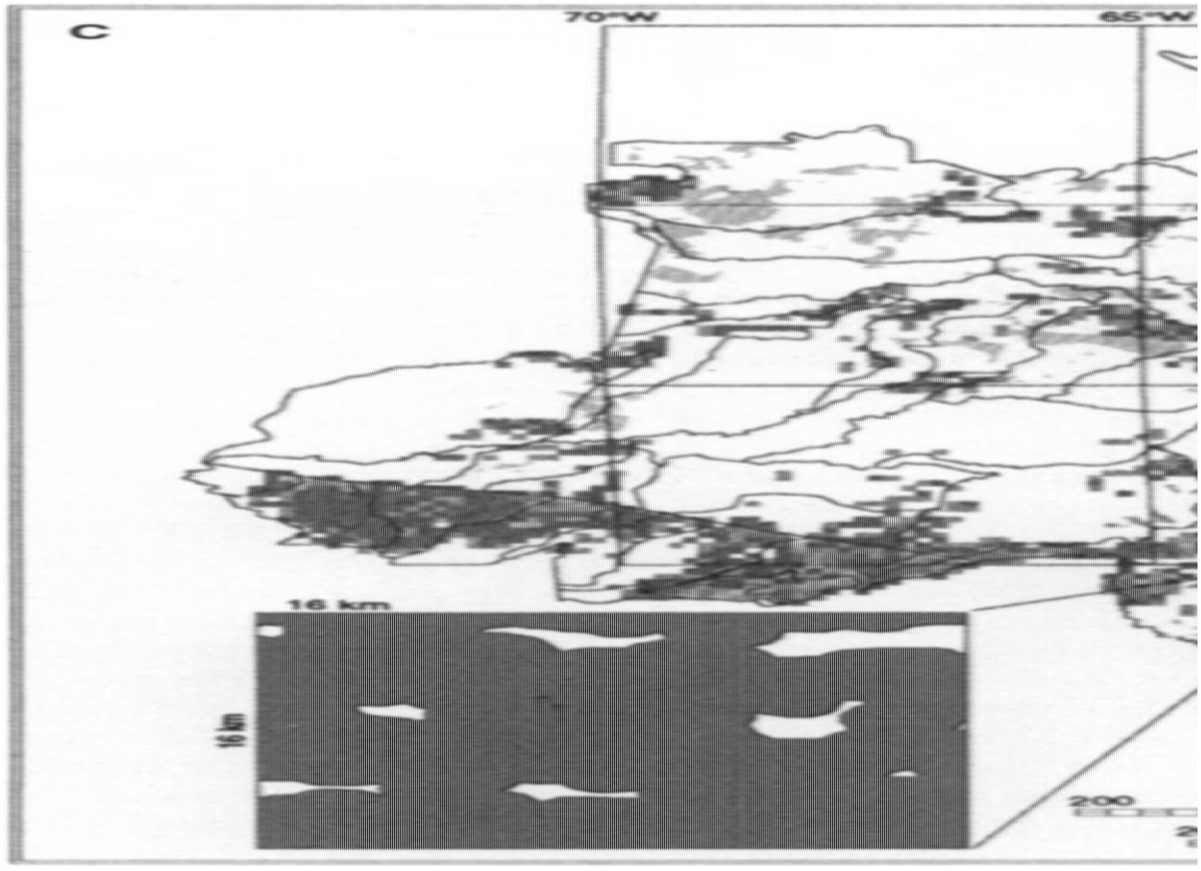
These data problems make the broader goals of the IGBP-HDP initiative difficult, but not unattainable. The effort will call the attention of the global community to the kinds of data that are needed, and it may encourage and assist in the development of new data bases through international programs. Already datasets are being developed that could benefit the proposed LUCC project. For instance, the IGBP is creating a satellite-based dataset of land cover at 1-km spatial resolution from daily acquisitions of AVHRR data globally. This dataset is being developed through a coordinated effort of over a dozen ground stations worldwide and could be used for information on vegetation zones, seasonal phenology of natural and planted land-cover, fires, and other important components of land-cover/land-use change on a global scale (16). To map land cover conversion, such as tropical deforestation, at high spatial resolution Landsat data are being analyzed over large areas (17) (Fig.2). Since high resolution remote-sensing data show what is occurring in the landscape as it is being transformed by human activities, they provide information upon which land-use models could be built and tested.

Loss of forest and spread of agriculture on high-energy slopes, Middle Mountains, central Nepal. Photo: B. L. Turner II.

A second cross-cutting aspect of the proposed agenda is attention throughout its activities to questions of scales of analysis, both temporal and spatial. These questions have rarely been systematically addressed but may be very important. How do the cause-cover relationships identified vary as the level at which associations are sought changes from the local to the global, or from that of decades to centuries? If such variations occur, are they continuous or discontinuous across scales? What are the implications for global modeling? More generally, a coordinated research project of the kind suggested will do much to clarify what at present we know and do not know, and what we need to learn, about global land transformation.

Figure 2. Use of satellite data to quantify land-cover changes in the Brazilian Amazon: comparison of deforestation in 1978 (A) and 1988 (B), derived from Landsat Thematic Mapper imagery. This analysis indicated that previous estimates of deforestation rates were overestimates, by up to ~ 50%; however, effects on biodiversity (C) were greater than previously estimated. The proximate and underlying driving forces for land use change in Amazonia are discussed in Turner, Moss and Skole (7). (Maps: ref. 17, copyright 1993 by the AAAS).





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18. This paper is a brief synthesis of a number of other papers and reports generated by the authors and their colleagues as part of the on-going IGBP and HDP-sponsored activities. The most current of these publications are cited in the text. An abbreviated earlier version of this paper appears in the Proceedings of the 1992 Watershed Management Symposium *Watershed Resources: Balancing Environmental, Social, Political, and Economic Factors in Large Basins* (in press). We thank the members of the IGBP-HDP ad hoc committee on global land-use and land-cover change and colleagues from the George Perkins Marsh Institute at Clark University who have contributed to our work.

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