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HUMAN POPULATION GROWTH AND GLOBAL LAND-USE/COVER CHANGE

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INTRODUCTION

Contemporary interdisciplinary research on human-induced global environmental change recognizes two broad and overlapping fields of study (67). That of industrial metabolism investigates the flow of materials and energy through the chain of extraction, production, consumption, and disposal of modern industrial society. That of land-use/land-cover change, our concern here, deals with the alteration of the land surface and its biotic cover. Environmental changes of either kind become global change in one of two ways (106): by affecting a globally fluid system (the atmosphere, world climate, sea level) or by occurring in a localized or patchwork fashion in enough places to sum up to a globally significant total. Land-use change contributes to both kinds of global change: to such systemic changes as trace-gas accumulation and to such cumulative or patchwork impacts as biodiversity loss, soil degradation, and hydrological change.

Land-use/land-cover change is a hybrid category. Land use denotes the human employment of the land and is studied largely by social scientists. Land cover denotes the physical and biotic character of the land surface and is studied largely by natural scientists. Connecting the two are proximate sources of change: human activities that directly alter the physical environment. These activities reflect human goals that are shaped by underlying social driving forces. Proximate sources change the land cover, with further environmental consequences that may ultimately feed back to affect land use.

Contemporary global environmental change is clearly unique. The human reshaping of the earth has reached a truly global scale, is unprecedented in its magnitude and rate, and increasingly involves significant impacts on the

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biogeochemical systems that sustain the biosphere. On the other hand, the land covers being reshaped have long been modified by human action (6, 44, 84, 93, 99, 101, 104). Such terms as "native ecosystem" or "virgin forest" are of questionable usefulness.

The antiquity of land-cover changes is reflected in their prominence in the early classics of environmental science. George Perkins Marsh's *Man and Nature* (58) was a monumental assessment of data and theories, many dating back much earlier, on the effects of land-cover changes, particularly deforestation. Global inventories of arable land date back at least a century (77) and those of forest resources almost as far (119). Specialized studies of land change have proliferated, but broader syntheses remain rare. Surveys of global change such as the World Resources Institute reports and the recent volume *The Earth as Transformed by Human Action* (104) assemble much historical and statistical material and outline the broad global and regional trends. A SCOPE volume on *Land Transformation in Agriculture* (117) covers the principal agricultural impacts on land cover.

Several recent and on-going global change research initiatives have dealt in whole or part with land use/cover issues. An ad hoc working group of the Committee on Global Change (National Research Council) offered an initial outline of study of global land-use/cover change (42). Building on it, the Land-Use Change Working Group of the Social Science Research Council Committee on Global Environmental Change (94) identified the priority forms of change and the contributions that the social sciences might make to understanding them; an appendix (118) assessed the principal global data sources and undertook some simple tests of candidate human driving forces of change. The forthcoming volume of the 1991 Global Change Institute of the Office of Interdisciplinary Earth Studies (61) is devoted to global land-use/cover change; the chapters deal with the major recent trends in change, their environmental consequences, their human causes, and problems in data and modeling. Drawing on these efforts, the International Geosphere-Biosphere Programme and the International Social Science Council are contemplating the development of a land-use/cover change study; a report by their ad hoc working group was planned for spring of 1992.

For many types of change, both the global condition itself and its implications for nature and society remain extremely ill-documented (10). Crosson (18), for instance, writes that "we have very little reliable information about the amount of soil erosion in [the developing] countries and even less about its productivity and water quality effects," and that a similar gap exists for the problems of tropical deforestation, aquifer depletion, and soil degradation. An overview of what we know about major global land-cover changes, their environmental significance, and their human causes is in order. We assess first the broad changes brought about by human activity in five categories of land cover: cultivated land, forest/tree cover, grassland/pasture, wetlands, and settlement. A review follows of the major secondary environmental consequences that have been attributed to these cover changes. Finally, we examine the theoretical and empirical literature that investigates the role of human population growth and other social factors in driving land-use/cover change.

LAND-COVER CHANGE

Land-cover changes take two forms: conversion from one category of land cover to another and modification of condition within a category. Conversion is the better documented and more readily monitored of the two, but too great an emphasis on it obscures important forms of land-cover modification. The problem will vary with the categories of cover used; the broader and fewer the categories, the fewer the instances of conversion from one to another. If one's classes are as coarse as forest/woodland, permanent pasture, cultivation, and "other lands," for example, forest thinning, replacement of old forests with tree plantations, intensification of cultivation, and severe overgrazing will not register as conversion, nor as land-cover change if conversion totals alone are used to measure change.

These four classes—forest/woodland, permanent pasture, cultivation, and other lands—are those of the most widely used global figures, published in the UN Food and Agriculture Organization's *Production Yearbooks*. They purport to show national-level change year by year since the 1950s. The FAO data are so often used, however, less because of their quality than because of their convenience. The FAO does not gather the data independently for the *Yearbooks;* it collates numbers reported by member states. Hence the data quality varies greatly by country, and country size determines the scale at which the (national-level) data are presented. The FAO class of "other lands" combines several important and distinct forms of land use/cover. Definitions of all classes (save "other lands," which is essentially a residual category) have been at once too loose (not clearly specifying the criteria for identifying each class) and too rigid (accounting poorly for sporadic or fluctuating uses of some lands). In the Organization's own words, "it should be borne in mind that definitions used by reporting countries vary considerably and items classified under the same category often relate to greatly differing kinds of land" (109). Global data compilations by the USDA and the CIA draw principally on the FAO numbers and share their problems.

The climatic modeling literature is another source of global land data. Matthews (59) constructed data bases of presumed preagricultural vegetation types and of present-day land cover on 1½ by 1½ cells: her work has received extensive use in modeling efforts. Work on the global carbon flux (35–38) has necessarily involved detailed reconstruction of change in land-cover patterns and the critical assessment of a range of data sources from archival materials to remote sensing. The carbon-modeling literature served as the basis for Richards' (80) continental-scale reconstruction of land-use changes from 1700–1980 (using as categories cultivation, forest/woodland, and grassland/pasture). A valuable feature of this literature is that it deals with ecosystem modification ("degradation" of forests) as well as conversion (e.g. 34). These efforts, however, treat land use and cover as broad, simple categories and at a scale that inhibits connections with social variables. Other digitized data and maps deal with ecoregions (5, 70) and life zones (51), but these data are not transferable to land use or cover. Several Soviet maps of global land use and cover demarcate the world into an intricate array of land use and cover types readily linked to social variables, but problems with validation and data format have thus far prevented their ready use.

Issues of data quality and comparability make global-scale assessments of land-use/cover change difficult. We note in the following sections (see also Table 1) the principal trends in change in major cover categories as they can be assessed from the literature.

Cultivated Land

DEFINITION Cultivated lands are those regularly used to grow domesticated plants, ranging from long-fallow, land-rotational systems to permanent,

Table 1 Global human-induced conversions in selected land covers

Cover	Date	Area ($\times 10^6 km^2$)	Date	Area ($\times 10^6 km^2$)	% Change
Cropland	1700	2.65	1980	15.01	+466
	1700	3.0	1980	14.75	+392
Irrigated cropland	1800	0.08	1989	2.00[a]	+2400
Closed forest	pre-agricultural	46.28	1983	39.27	−15.1
Forest and woodland	pre-agricultural	61.51	1983	52.37	−14.9
Grassland/pasture	1700	68.60	1980	67.88	−1[b]
Lands drained			1985	1.606	
Urban settlement			1985	2.47[c]	
Rural settlement			1990	2.09	

[a] See text for another estimate
[b] The change is small; the data errors are large.
[c] Includes substantial areas not built up; see text for discussion.

multicropping systems. Their full range is difficult to measure because some cultivation occurs in very small units and some in settings not easily distinguished from other cover types. Rotational cultivation and agroforestry (including plantations) are often classified as forest, leading perhaps to an underestimate of cultivated land. Further complications arise in distinguishing cultivated from agricultural land, a broader term that can include land used for livestock production. Perhaps the most common distinction recognizes fodder species grown for livestock as cultivated land and improved pasture as grassland and pasture cover. It is not clear how strictly such distinctions are followed in the data.

CHANGE AND PROXIMATE SOURCES The world total of cultivated land is estimated to have increased by 466% from 1700 to 1980: during this time, a net area of more than $12 \times 10^6 \text{ km}^2$ of land was brought into cultivation (80). This expansion did not occur evenly across the world; the USSR, Southeast Asia, Latin America, and North America all experienced greater expansion of cultivation than the world average. The increase in North America, for example, was 6,666% (80). Two estimates of current cultivated land are $14.75 \times 10^6 \text{ km}^2$ and $15.00 \times 10^6 \text{ km}^2$ (47, 80).

Global expansion of cultivated land (conversion) is accelerating, as is the intensification of use of lands already cultivated (modification). With a few noteworthy exceptions, most prime environments for rainfed cultivation have been consumed. The area suitable for rainfed agriculture is estimated by some to be about $18.74 \times 10^6 \text{ km}^2$, only 3.75 to $4.00 \times 10^6 \text{ km}^2$ above the area currently taken to represent this land cover (47). Land expansion will increasingly occur in environments assumed to be more marginal and fragile for cultivation (102). Tropical forests and grasslands and, to a lesser extent, boreal forests are under increasing pressure from agricultural expansion, as are wetlands.

While the global pattern is one of the expansion of cultivated land, some regions have experienced losses, from either the abandonment of cultivated land or its degradation promoting nonuse. Cultivated land has been decreasing, for example, in Europe (by 3.5%, 1973–1988) (47), to be replaced by settlement and forest. Such benign losses are more than matched by forced abandonment owing to degradation. The FAO estimates that $5.44 \times 10^6 \text{ km}^2$ of rainfed cultivated land have been lost worldwide to degradation; another study estimates that $20.00 \times 10^6 \text{ km}^2$ of former cultivated lands have been irreversibly lost due to degrading uses and to permanent cover changes (e.g. water impoundments, settlements) (85). Both estimates are controversial.

These changes in land cover have been driven by real and perceived needs for expanded agricultural production. Regardless of the underpinning causes (see below), the major proximate sources of conversion have been fire and clear-cut timbering (in forested areas), tillage technologies (in grasslands and heavy soils), drainage (in wetlands; see below), and irrigation (in arid lands or where paddy is used). Irrigated land has expanded, according to one estimate, from 0.08×10^6 km^2 in 1800 to 2.00×10^6 km^2 in 1989 (4). Perhaps no other form of cultivation is so disputed in terms of its current area, however; estimates range from 2.00×10^6 km^2 to 4.58×10^6 km^2 (56). The major sources of the modification of cultivated land cover have been switches in cultigens (among cereals, root crops, agroforestry) and the intensification of cultivation through green revolution hybrid crops, synthetic inputs, and, more recently, biotechnology. Unfortunately, the available data do not allow assessments of the spatial magnitude of these changes.

Forest/Tree Cover

DEFINITION The term "forest" has a variety of meanings that have not yet been standardized in global change studies. Some writers confine it to closed as opposed to open woodland; others would include savanna environments and lands used in fallow agriculture within a forest/woodland category. Some ecological usages would exclude tree plantations from forest. The FAO's tropical forest inventories (49, 50) use a figure of 10% canopy cover to separate forested from deforested areas. Because these problems remain largely unresolved (116), care must be taken in comparing data that may use different definitions.

CHANGE AND PROXIMATE SOURCES Changes in the world's tree cover are of two kinds: clearance and conversion to another land cover (whether cultivation, grassland, or settlement), and change of condition (e.g. forest thinning without outright conversion). The literature focuses overwhelmingly on the former process, although carbon modellers have begun to pay considerable attention to the implications of the latter (34).

The world's current area of closed forest, based on comparison of such sources as the FAO data and a World Resources Institute inventory, is estimated to be around 29×10^6 km^2, or 21% of the world's land area. "Open woodland," an ill-defined category that overlaps significantly with other standard cover types, adds about 18×10^6 km^2 (13% of the land area). Drawing on Matthews's (59) reconstruction of preagricultural land cover, Williams (116) estimates that an original 62×10^6 km^2 of forest and woodland has been reduced by 9×10^6 km^2, of which 7×10^6 represents loss of closed forest (a net global decrease of about 15%). Estimates of contemporary change vary considerably and are hampered by problems of data, definition, and method, though the broad pattern is one of stability or even net gain in the developed countries and rapid, if fluctuating, loss in the developing tropics, adding up to an annual net global loss on the order of 0.1–0.2 $\times$ 10^6 km^2 (116).

Goals and proximate sources of forest change differ considerably across the world (116). Clearance for cultivation, often associated with planned and spontaneous frontiers of colonization, is probably the most widespread. Ranching and pasture development have been significant causes of clearance in Central and Latin America. Timber extraction in excess of regrowth is exemplified in Southeast Asian contexts and to some extent in the tropical forests of western Africa; fuelwood extraction exceeds regrowth in Africa and some portions, especially mountainous ones, of Latin America and the Indian subcontinent. Waldsterben or forest decline associated with atmospheric pollutants and other stresses is a relatively new source of damage in the developed world (North America and western Europe). Finally, reforestation or afforestation can result naturally from land abandonment or can be undertaken deliberately by state or private action; many governments have instituted such programs.

Grassland/Pasture

DEFINITION Grassland/pasture represents land having a ground story of vegetation cover in which grasses are the dominant life form (25). The natural distribution and extent of grasslands on the earth's surface is controlled by climate, soil, and fire, only the last of which has been significantly altered by human actions.

CHANGE AND PROXIMATE SOURCES The world area of grassland and pasture in 1700 is estimated at 68.60 $\times$ 10^6 km^2, and today at the nearly identical value of 67.88 $\times$ 10^6 km^2 (80). Factors increasing and decreasing the global area of grassland have maintained a rough balance over this long period. The FAO figures indicate a decrease of less than 1% from 1971 to 1986 (25). The principal processes of change are loss through conversion to cropland and gain through deforestation. The former process has led to marked net decreases from 1700 to 1980 in grassland/pasture in Europe (−27.4%), North America (−13.7%), and Southeast Asia (−26.4%). The latter has driven increases in tropical Africa by 10.1% and in Latin America by 26.2% (80).

Changes of condition of grasslands are perhaps of greater significance. Desertification has been widely identified as a major human-induced global change associated with excessive pressure on grasslands. The now-vast literature on this subject received a particular stimulus from the 1977 United Nations Conference on Desertification. The UNCOD report identified 6% of the world's area as "man-made deserts" and close to a quarter of the world's surface as threatened by desertification. The 1984 UNEP assessment further estimated the annual degradation of land "to desert-like conditions" as 60,000 km^2 and the area annually "reduced to zero or negative net economic productivity" as more than 200,000 km^2 (57, 76).

Desertification remains an ill-defined concept. In the meaning that has been used for some time by UNEP, desertification is "the diminution or destruction of the biological potential of the land, and can lead ultimately to desertlike conditions." Mortimore (64) prefers to define desertification as the loss of primary productivity of ecosystems in arid or semi-arid regions. The problems in measurement to achieve reliable and current global estimates are enormous; the UNEP literature routinely acknowledges them and has not shown that they can be overcome. Mortimore (64) and others (30a, 111) criticize several other pervasive features of the desertification literature, notably the vast claims made about the extent of land "destroyed" and the assumptions that desertification—however defined—is irreversible and is largely the product of human action. These assumptions, it is argued, lack a solid empirical base, and they ignore what detailed local studies suggest: the resilience of many arid and semi-arid ecosystems and the possible climatic origin of much desertification. Recent studies of the expansion and contraction of the Sahara during the 1980s underline the last point (100). While questioning many of the global figures offered for human-induced desertification, however, Graetz (25) concludes that degradation of grasslands by overgrazing is a globally significant change of threatening proportions.

Wetlands

DEFINITION The term "wetlands," a recent coinage (110), has been associated with more than its share of ambiguities, but recent work has helped clarify the concept. Cowardin et al's (18) definition, "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" is widely accepted. The category includes such subtypes as marshes, swamps (including mangrove swamps), peat lands, and riparian floodplains. Wetlands as usually defined are thought to cover about 6% of the world's land area (24, 114), but some suggest as much as 10% (83). It is not, however, exclusive of the other principal land-cover categories; most forested wetlands, for instance, are included in the standard forest/woodland category. By Williams's (114) estimate, three quarters of the world's wetlands represent inland freshwater systems and the rest, coastal ones.

CHANGE AND PROXIMATE SOURCES Conversion through drainage is the key proximate source of wetland change. Overall, "the overwhelming amount of wetland conversion is undertaken for agricultural purposes," perhaps 85–95%

(115). Urban-industrial-port expansion (74) accounts for much of the rest. The global area of artificially drained lands is estimated at 1.606×10^6 km^2 (114). Wetland losses, however, cannot be computed directly from drainage figures because not all areas affected by drainage were wetlands initially. Gosselink & Maltby (24) discuss the global picture of losses and gains. Past conversion is thought to have been most rapid in the developed world, and current conversion in the developing nations; reliable global data, though, are unavailable.

Settlement

DEFINITION The term settlement can denote a form of land cover or a form of land use; the area thus indicated may differ in a number of regards. The category of settlement as a land use includes areas devoted to human habitation, transportation, and industry. As land cover, it incorporates highly altered surfaces such as buildings and pavement, but such cover represents only a portion of the total area that a land-use classification might accord to settlement. Suburban land in the developing world, for example, usually incorporates a large proportion of tree cover. Estimates of the world area of settlement as land use do not claim high precision. Rozanov et al (85) offer the figure of 6% of the world's land surface as lands "radically changed ... for productive human uses, such as settlement, roads, and reservoirs." For the more restricted category of settlement (land "occupied for human living space"), Douglas (20) suggests 2.5%, 60% of it representing rural settlement and the rest urban; rural settlements in the developed world take up 1.03×10^6 km^2 and in the developing world 1.06×10^6 (20). The United Nations (108) estimated the global area of urban land at 2.47×10^6 km^2. As intensively occupied land cover, such settlements would account for a much smaller area. Of the land area of cities, less than half is built up even in large agglomerations; the built-up area has been estimated at only about 10% of urban land worldwide (20, 26).

CHANGE AND PROXIMATE SOURCES The urban share of the world population has increased from 14% at the beginning of the twentieth century to almost half today: it is highest by far in the developed countries. Definitional and data problems even with current or recent settlement areas make estimates of typical rates of change in urban land difficult. The striking growth in absolute urban numbers has, however, during this century, been clearly exceeded by the growth in the land area required by cities, given improvements in transportation and the spread of low-density forms of settlement. The countries of most rapid urban growth today are in the developing tropics, where many large and expanding metropoli—though of relatively high density compared to developed-world cities—are responsible for the most striking urban transformations of the land surface (8, 20).

ENVIRONMENTAL CONSEQUENCES OF LAND-COVER CHANGE

Each category of land-cover change is associated with a number of secondary environmental consequences: wetland drainage, for instance, can affect biodiversity, trace gas emissions, soil, and hydrological balance. In economic terms, these effects often represent the externalities of land-cover changes, the costs or benefits passed on to others by the land user. Secondary impacts of land-cover change can be difficult to distinguish from natural variation. Climatic change and water flows are cases in point.

Land-cover change impacts on biodiversity are not covered in this volume. We examine here five other classes of impacts, focusing on those fairly directly connected to land-cover change: trace-gas emissions, changes in water quality and water flows, soil alteration, and climatic change. Apart from increases in long-lived trace gases in the atmosphere (and their possible global climatic effects), the main secondary changes that can be traced to land-cover change are widely repeated cumulative changes rather than systemic ones.

Trace-Gas Emissions

Much of the human contribution to atmospheric trace species occurs through the processes of industrial metabolism, but land-cover changes significantly contribute to increases in a number of important components. A recent review by Penner (72), on which the following discussion is based, assesses the literature on the major trace components and provides ranges of estimates both for the human inputs as opposed to the natural and for the contribution of land-cover change as opposed to industry.

Atmospheric trace gases affected by human action fall into two broad categories: the relatively reactive and nonreactive, or the short- and long-lived. Several of the greenhouse gases implicated in global climatic change are the key long-lived trace components increased by land-cover change: CO_2 from forest clearance and soil carbon oxidation as well as from fossil fuel burning, methane from rice paddies, landfills, biomass burning, and livestock, and N_2O from soils, fertilizers, and biomass burning. The relative importance of land and industrial sources is a matter of much controversy as regards CO_2 emissions; current estimates of the former's share range from 10% to 50% of present anthropogenic releases. Matters are further complicated by the "missing sink" problem in global models of the carbon budget: the failure of modeled sinks to account for the estimated releases. Methane has doubled in atmospheric concentration since 1800, but the high diversity of sources both natural and anthropogenic leaves the possible contribution of land-cover change to total (natural plus human) emissions anywhere between 25% and 80%. N_2O contributes both to greenhouse forcing in the troposphere and to ozone depletion in the stratosphere; land-cover and land-use changes are known to be the principal (about 70%) human sources of emissions.

Reactive species significantly affected by land transformation include CO, nonmethane hydrocarbons, nitrogen oxides, and tropospheric aerosols. The last are of particular global importance for their role in scattering or absorbing incoming solar radiation; biomass burning is the principal source associated with land-cover change and fossil fuel combustion with industrial metabolism.

Hydrological Change

Hydrological (surface and groundwater) impacts of land-cover and land-use changes include changes in water quality and in water flows. Water pollution due directly to land-cover change stems from cultivation (principally application of fertilizers and pesticides) and settlement (urban sewage). It is largely pollution from non-point or dispersed sources (save for urban sewage plant releases) and as such is more difficult to control than point sources: the techniques exist for managing it, however, where the benefits to be gained justify the expense (83, 92).

Changes in water quantity and flow associated with land alteration result both from deliberate withdrawals and from land-cover changes such as deforestation. Irrigation—largely a consumptive use—is by far the largest element of global withdrawal from the hydrologic cycle; it accounts for about 75% of demand, though the share varies greatly across the globe (highest in Asia and minimal in many countries). Industry and energy generation account for most of the rest of the water withdrawn (56). Secondary hydrologic effects of irrigation include depletion of downstream rivers and water bodies; the desiccation of the Aral Sea in Soviet Central Asia is an extreme case (45, 62, 75). Many groundwater aquifers have been severely depleted, but the worldwide human impact is unknown; "there is no readily available set of data to indicate their magnitude and depletion rates on a continental scale" (56).

Claims have long been made that deforestation, especially in highlands, increases the frequency and severity of flooding downstream. Some of the most notable examples asserted in the literature have been called into question: the Amazon Basin (81, 96) and the Himalaya Mountains-Ganges Basin (40). While most claims of such dramatic and large-scale consequences now seem dubious (40), forest clearance or thinning generally increases annual flow while also making its distribution more uneven. Grassland change has analogous effects, while increases in flood height due to wetland drainage are well documented locally (83).

Soil and Sediment Impacts

Many of the global human impacts on soil erosion and sediment transport are extremely difficult to sum up at the global or even regional scale because of problems of spatial and temporal scale and natural background processes. Worldwide, soil loss and degradation and sediment transport have undoubtedly been increased greatly as a consequence of land-cover change (19a, 85). Most global-scale studies, however, emphasize the uncertainties, local variations, and methodological problems associated with creating reliable estimates of net human impact.

Important processes of soil degradation include erosion, salinization (as a result of irrigation), waterlogging, compaction, acidification, nutrient impoverishment, and dehumification (14). Figures on global change are most readily available for salinization. One study (85) estimates the area of land destroyed for productive use by salinization at one million km^2, with about the same area significantly lowered in productivity by the same processes. Soil changes are assessed in a recent *World Map of the Status of Human-Induced Soil Degradation* (69), which is to be made available in digitized form.

Climatic Change

Various microclimatic changes as a result of land-cover changes are clear and well-documented; claims for regional effects are more controversial, and possible global changes, if they occur, would occur through the effects of trace gas emissions. Suggestions that deforestation may affect global temperature through albedo change, largely discounted (32, 33), have been cautiously reopened by way of regional-level modeling (19, 31).

The urban heat island effect is the best-studied micro-to-meso climatic consequence of settlement expansion. Landsberg's (48) volume on the urban climate remains standard, but recent research on tropical and third world cities has suggested a more varied picture of the relations of city size and growth to heat island magnitude (1, 65). The claim that curves of global temperature rise may in large part be artifacts of the near-urban locations of recording stations has focused attention on urban effects.

Claims of regional impact of land-cover change on climate are in more dispute. The long-discredited (73) claim that forests increase rainfall has been revived in recent years in reference to the tropical rainforests, especially those of Amazonia. Salati & Vose (87) claim that regional forest clearance would have severe climatic consequences because of the high proportion of water recycled by the rainforest; deforestation would significantly lessen rainfall and increase temperatures. Possible regional effects on temperature and precipitation of vegetation loss through overgrazing also remain a lively focus of research.

HUMAN DRIVING FORCES OF CHANGE

The proximate sources of change—the human actions that directly alter land cover—reflect underlying human driving forces. Its importance notwithstanding, research on the human driving forces of global change is in considerable intellectual disarray. "Many studies in the literature are . . . either weakly connected (shopping lists of 'causes' unrelated to one another) or unduly hypothetical (plausible arguments unsupported by case-specific data)" (64). Two extremes in approach are ultra-empiricism and ultra-theoreticism. In the former vein, Newell & Marcus (68) present a correlation of +0.9985 between world population growth and tropospheric CO_2 levels since the 1950s as proof of population's fundamental role. In the latter, Harvey (27) deprecated neo-Malthusian arguments for the primacy of population growth in resource depletion as politically founded. The former is apt to mistake correlation for cause (or absence of correlation for causal unimportance) in a highly complex area; the latter is apt to narrow excessively the scope of investigation without recourse to data. Theory—including theory from the social sciences—and evidence need both to be drawn upon.

Three important points must be kept in mind. First, the driving forces of change may vary with the type of change involved; forces that drive some changes may lessen others. Southgate (95) provides a simple illustration: rising interest rates or agricultural prices will increase deforestation because they provide an incentive for further clearing; at the same time, they will decrease soil erosion on cultivated land because they provide an incentive to adopt soil conservation measures, whose value to the farmer or landowner would be enhanced. Second, the same kind of land-cover change can have different sources in different areas even within particular world regions. Deforestation in Borneo and parts of the Philippines is largely the result of timber extraction for export (13, 46); in peninsular Malaysia, agricultural clearing is the main proximate source (13). Third, in the dynamics of underlying "causes," no agreement exists on the level at which adequate explanation is achieved. To one, deforestation by agricultural expansion may be driven by population growth; to another, that population growth can only be explained in terms of certain sociopolitical and economic conditions that promote it (e.g. an economic context that makes large families valuable to subsistence cultivators); while yet others would emphasize the role of agricultural expansion in causing population growth.

The single comprehensive approach to the question of driving forces is the $I = PAT$ equation used by Ehrlich & Ehrlich (21), and by Commoner (16, 17), where I represents environmental impact, taken to be the product of P (population), A (affluence), and T (technology). Human impact is a product of the number of people, the level at which they consume, and the character of material and energy flows in production and consumption. The *IPAT* formula, however, suffers from the handicap of a mismatch between its categories of driving forces (apart from population) and the categories customarily used in the social sciences. Neither "affluence" nor "technology" as defined is associated with a substantial body of social science theory; any bridges between the *IPAT* and other approaches would have to be built between these categories and those better-conceptualized aspects of behavior and social structure that may drive and limit changes in production and consumption.

To detail the possible human driving forces is a formidable task, not only because of the array that can be found in the literature (66, 107), but because little evidence exists for their pan-global associations with land-cover/use change. We emphasize population because of its prominence in the literature and because it is one of the few candidate driving forces for which there is a simple measure.

Population

Population as a driving force of environmental change is unique in its plausibility and ease of quantification. It incorporates the basic level of resources required per capita for survival and reproduction (biological demand). This role of population is not in dispute: what is controversial is its relative importance among the other forces generating environmental pressures and the conceivably positive character of its role in resource use. We can simplify the various arguments into several broad positions.

In the neo-Malthusian position, global population increases are accorded primary importance in most environmental change because of the resources required to sustain the demands of five billion people. Population growth is seen as having exceeded the capacity of the biosphere, as managed by society, to sustain it (21, 22). Directly opposed is the cornucopian position (89, 90), which holds that population increases stimulate technological and social advances that improve the conditions of life: greater numbers can transform the environment for the better.

Population is relegated to secondary status in other theories in which it is held only to worsen degradation stemming from other factors. The Faustian position holds that runaway or careless use of technology is primary to environmental degradation, though population increase may exacerbate the problems created (16). Neoclassical political economy locates the cause of environmental damage in obstacles to the proper allocation of costs. These obstacles may lie in the distortion of efficient solutions by government policies or property institutions or in imperfect information regarding resources (7). Neo-marxist political economy emphasizes the role of the means of production in the global economy of international capitalism. Profit-seeking and capital accumulation require the unsustainable exploitation of natural resources, and socioeconomic differentiation creates a situation in which the "haves" place heavy demands on the world's resources, driving environmental change, while the subsistence needs of the "have-nots" put marginal environments under stress (9, 54, 79, 98, 102).

The role given to population in any of these positions reflects less conflicting evidence than conflicting interpretations of the same evidence. Case studies of the long-term records indicate major ebbs and flows in regional populations through time, but with varying types of transformation, longevity of impacts, and recoverability of the environment, suggesting caution in assuming a simple population-transformation association (112). This does not undermine the role of population as an important driving force in environmental change, but underlines its significance in the context of the technology and sociocultural organization in question.

It is this context—not the experience of a population outbreak alone —that makes the contemporary global environmental situation novel. The past 300 years, but particularly the latter half of this century, have witnessed an unparalleled magnitude of human-induced environmental changes, including those of land cover (104). These changes have coincided not only with unparalleled numbers of our species, but with major shifts in global affluence, technological capacity, and socioeconomic organization. A pilot study (using the FAO categories and data) reports a strong global-level correlation between modern population growth and annual change in land cover (forest, cropland, and pasture use), but finds equally strong correlations with surrogate variables for technology and affluence (118).

Comparative assessments assume that if population is a key driver of environmental change, then the pressures of population (e.g. density) should closely match the magnitude of various kinds of environmental change across regions and locales. Do such regional or national-level (the unit with which most land-use/cover data are generated and reported) comparisons show that the proportion of change in forest, cropland, and pasture lands correlates well with increases in population densities? The same pilot study did not find significant correlations in these relationships examined at the national level across the world (118).

In contrast, significant correlations between population and land-cover change have been found when investigation is restricted to regions possessing similar socioenvironmental characteristics. Several comparative studies offer statistical evidence supporting the claim that population growth drives or strongly contributes to forest clearance (2, 55, 71, 86). All of them deal only with part or all of the developing tropics, and the results would probably not apply elsewhere. Case studies even in the tropical developing world have contested the primacy of population growth as a driving force of clearance, attacking the "persistent myth that tropical deforestation is caused by overpopulation" (3) and emphasizing such factors as uneven land distribution and a complex array of policies, institutions, and economic forces that promote and reward clearing (29, 30, 97). A recent work analyzes the interactions of population growth and land cover change in several developing countries, and concludes that population growth is an important factor but one significantly modified by natural and institutional context (8a).

Too much must not be made of the comparative studies cited. The accuracy of the data used is highly questionable. Almost all of the statistical studies use the FAO *Production Yearbooks* data, whose drawbacks have been noted. Kummer (46) cites other characteristics of studies of forest-cover change that may undermine the results. In some cases, country-wide population and forest cover change are correlated, masking the fact that population growth and deforestation occurred in different locales; in others, current changes in population are misleadingly compared to changes in forest cover that have transpired over longer periods of human occupation (41, 91).

These cautions aside, population remains one of the few candidate driving forces that is readily measured and for which statistical associations have been found. Surely better data—particularly the spatial congruence of population with particular land covers—and assessments will clarify its role. The evidence to date, however, suggests an interesting insight: that population is an important macro-scale (global) variable in that there is a direct relationship between total world population and total biological demand for resources. Its connections to land-cover change become weaker at increasingly smaller spatial scales because of the importance of other variables that affect demand or spatially deflect its impacts. It is these other variables that must be incorporated in order to improve our understanding of the human causes of land-use/cover change.

In contrast to these studies, which have sought statistical linkages without a well-developed theory, others stress the importance of examining data only within a theoretical framework. Studies of population-agricultural relationships are exemplary. Among the various kinds of environmental change, none is so plausibly linked to population as the land use and cover changes associated with agriculture. Neoclassical economics typically accounts for the role of population change through its influence on demand as manifested through the market. As market signals change, so does land use. But some themes linking population more directly to agriculture have gained considerable attention over the last quarter century: those that identify population pressure as a driving force of agricultural change or that incorporate it as a force in theories of induced innovation or intensification.

The architecture of the modern population-pressure theory is found in the works of Boserup (11, 12; also 15). To simplify, this thesis attributes agricultural development, including its technological base and kind (subsistence to market), to the pressures for production that mount from a growing population and that operate through the process of intensification (increased output per unit area and time). Given sustained growth in population, agricultural land use expands and intensifies, involving conversion and modification of land cover. Sustained population decline has the opposite effect. Many studies among farmers whose production includes a substantial subsistence component have supported the principle that, all else equal, growth in population leads to growth in agriculture [see Turner & Brush (103) for an extensive review: this theme also applies to livestock production (23)]. Intensification is held ultimately to stimulate specialization and market development, shifting the role of agricultural land-use change to one more consistent with neoclassical theories. This portion of the thesis, however, has had less success, in part because of the complexity of factors that influence the development of a full market economy, including the resistance among peasants to entering one completely (39, 53).

The population pressure thesis has been elaborated by a number of "induced intensification" themes (43, 103). Induced intensification explains expansion and intensification by a farming unit as responses to a larger set of driving and mediating forces, the latter including environmental opportunities and constraints. Farmers display subsistence behaviors in response to the food needs of the farming unit and market behaviors in the desire to increase their material standard of living. The results are hybrid farming behaviors that all culminate, in the face of increasing demand (other things equal), in similar trajectories of agricultural land-use/cover change. Taken to a national and international scale, themes of induced innovation also link changes in agricultural land use, particularly in well-developed market systems, to changes in agricultural technology and management resulting from increased levels of research and development (28).

The lessons are that agricultural land uses and covers have much to do with the character of the economy, but that a key element of demand in the economy is the level of population. This population linkage tends to be spatially congruent with land use in economies with a strong subsistence component, and the population-land use connection is most easily demonstrated in local and regional studies where subsistence agriculture remains strong, although some major anomalies have developed in Africa (52, 105). The connection is far harder to trace in market economies, not only because of the spatial incongruencies noted but because the element of demand from population growth alone is difficult to disentangle from other factors.

Other Candidate Forces

Supplementing or contesting the primacy of demographic explanations, numerous candidate driving forces of land-cover (and, more broadly, environmental) change have been advanced in the literature. Turner & Meyer (66, 107) class the principal arguments into four categories: those emphasizing (i) technological change, (ii) socioeconomic organization, (iii) level of economic development, and (iv) culture. Literature reviews and assessments with regard to land-cover change are provided by Grübler (26) on technology, Sanderson (88) and Morrisette (63) on socioeconomic organization (institutions and political structure respectively), and Rockwell (82) on cultural attitudes. All conclude that little can yet be said with confidence. Many of these categories pose methodological problems of defining appropriate and measurable variables and of resolving the problems of interaction and covariance with other candidate forces. We know of no global aggregate or comparative assessments of these driving forces with land-cover change comparable to those undertaken for population.

Most localized studies (regional and historical) that address the complex interlinkages among the causes of change do not employ general and replicable categories. For example, Skole's (91) explanation for the high rates of deforestation observed in the state of Rondônia (Amazonia) in the 1980s invoked the conjuncture of such elements as the 1970s OPEC oil price increases, the spread of commercialized farming in Brazil financed by the consequent oil profits, resulting smallholder dispossession and migration to the Amazonian frontier, and the concurrent efforts of the Brazilian military government to develop the Amazon. Many regional/local case studies of land-cover change offer similar examples of "conjunctural" explanations or of what are termed in the philosophy of science "Cournot processes," where an event is produced by the intersection of two or more independent causal chains. Because of the independence of the causes and the dependence of the outcome on the specific point at which they meet, there is a large element of chance and unpredictability about the result and a consequently low likelihood of successfully generalizing the findings to other situations or of forecasting change in the future.

CONCLUSION

The broad patterns of major land-use/cover changes are known with some confidence, and the literature is rich in contending explanations for them. The area of driving forces requires the most attention. To advance, we need much more precise and spatially congruent data. The quality of the physical data, if still inadequate, is far better than that on the human variables, a disparity that will only be widened by the proposed space platform projects. The reluctance of national and international institutions to fund the collection of social data is an obstacle that must be addressed.

Several other avenues for progress on the issue of driving forces recommend themselves. One is that of a wiring diagram, based on the Bretherton framework of earth system science, to outline the structure of interaction between society and the land (78). A wiring diagram is not a causal model (though it might develop into one), but a structure of cooperation and information flows among disciplines such that the relevant models and theories of different fields can be wired together in integrated studies. A second is to seek a middle scale between the global and the local at which to address driving force-change relationships. The identification of a set of world-regional situations, defined by both socioeconomic and evnironmental variables, may make possible generalizations that cannot be made at the global scale (60).

A number of projects are under way that address directly or indirectly the causes of global land-cover change. They include the Project on Critical Environmental Zones (Roger Kasperson, PI) of the George Perkins Marsh Institute, Clark University, which is comparing nine case studies, and the Working Group on Critical Environmental Zones (International Geographical Union). A proposed joint effort of the IGBP and the ISSC on the study of the human causes of global land-use/cover change offers the opportunity for integrative assessments merging global average and comparative studies addressed to the problems noted above.

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