Changes in Land Use and Land Cover:

A Global Perspective

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Toward a Typology and Regionalization of Land-Cover and Land-Use Change: Report of Working Group B

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Making sense of changes in global patterns of land use or land cover requires drastic simplification. The complexity of changes on the world scale easily defies the most acute and informed observer. But simplification is no simple process. To be useful it must bring out into sharp relief what is most important and relegate to obscurity what can most safely be ignored. Hard decisions and expert judgments are necessarily involved. In making these decisions and judgments we are acutely aware that others might well have been made in their stead, and perhaps with equal justification. We regard our work as a first step that we hope will help others to take long strides toward a more complete understanding of global patterns of land-use and land-cover change.

The Objective: A Comprehensive Schema

Our aim is to provide a comprehensive analytic framework that will lead to a systematic typology, and ideally a scheme of regionalization, of land-use/land-cover change. We call this framework a schema. Regrettably but inevitably, the framework cannot include every instance of change; we have instead tried to capture the major and most important varieties of land-use and land-cover change. The major changes are those of great magnitude, defined by the area involved or the numbers of people affected. The most important changes (a set that obviously intersects with the set of major changes) are distinguished by their criticality from the points of view of human and scientific concern. For instance, certain land-cover changes, even ones small in magnitude, have extreme social costs, while others have few or none. The costly ones we regard as more important from the human point of view. Other changes, not necessarily large in magnitude, have vast consequences from the point of view of biogeochemical flows or of biodiversity. In concentrating on the largest-scale and most important types of land-use and land-cover change we intend also to isolate and identify the most interesting types from the point of view of research

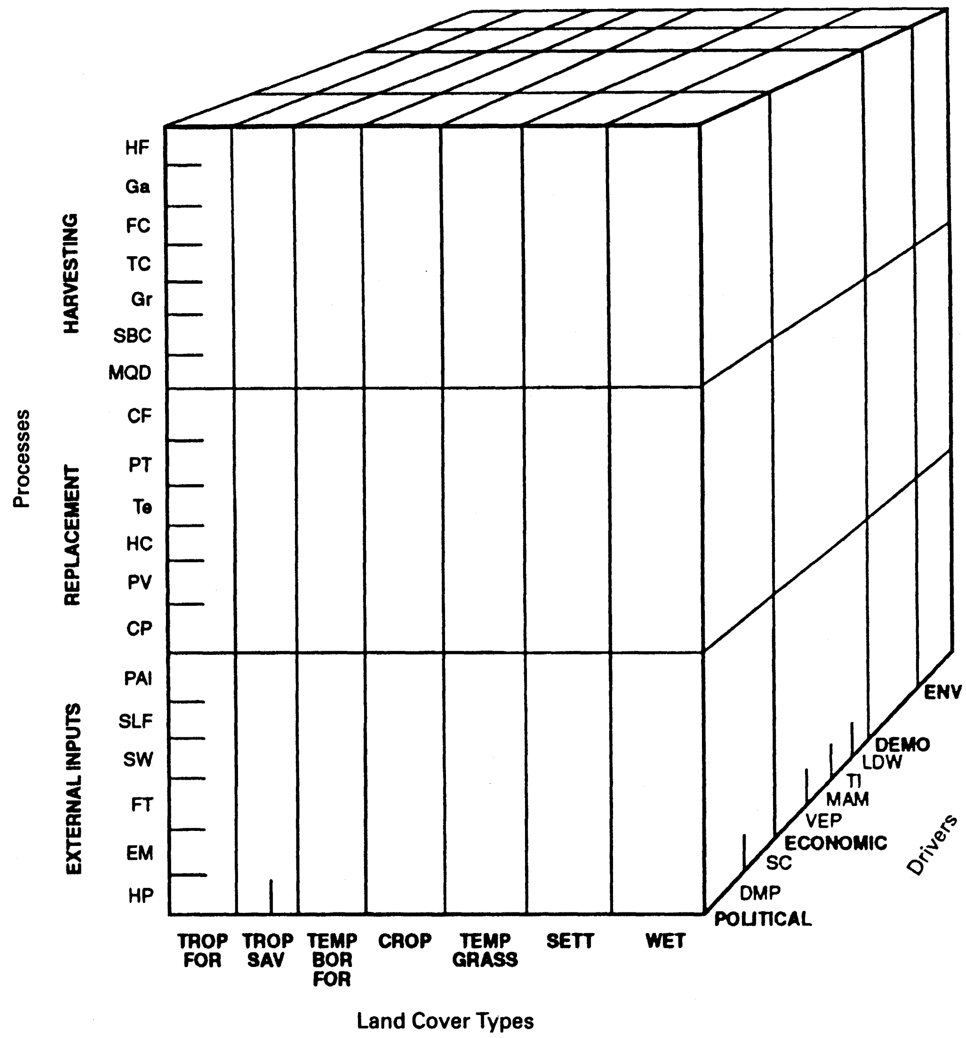

Figure 1. The cube

Land cover types

TROP FOR	Tropical forest
TROP SAV	Tropical savanna and grassland
TEMP BOR FOR	Temperate and boreal forest
CROP	Cropland
TEMP GRASS	Temperate grassland
SETT	Settled and built-up area
WET	Wetland

Drivers

Political

DMP	Decision-making process
SC	State capacity

Economic

VEP	Vulnerability to external pressure
MAM	Market allocation mechanism
TI	Technological intensity
LDW	Level and division of wealth
DEMO	Demographic
ENV	Environmental

needs. We hope our schema not only will lead to a deeper understanding of global change, but also will point to questions and cases that deserve high priority as research subjects. In the new and necessarily confused world of global change research, helping to sharpen the definition of research agendas is no small ambition.

Towards a Typology: The Axes and the Cube

Specific instances of change in land use or land cover may be defined by any set of characteristics. Possible examples include the duration, intensity, purpose(s), and consequence(s) of change. But confining ourselves to the most distinguishing characteristics, and keeping matters simple, we have selected only three, which taken together give a reasonably precise idea of any given land-use or land-cover change. These are:

- The *land-cover type* in which any given change takes place
- The *driving forces* producing change
- The specific *processes of conversion* of land cover.

Any single transition in land use or land cover can be analyzed from these three perspectives. Imagined in three-dimensional space, these three characteristics form axes, which taken together define a block or cube, in which every example of land-cover/land-use change occupies certain spaces (see Figure 1). After some elaboration of each of these axes, we will discuss how this schema works. In the appendix to this chapter, the schema is applied to actual cases of land-use or land-cover change.

Land-Cover Types

Scholars have created numerous classification systems of land cover. Each has its merits and its faults, and is appropriate for certain uses but not others. Ours has its

Caption for Fig. 1. *(cont.)*

Processes

Harvesting

HF	Hunting/fishing
Ga	Gathering
FC	Fuelwood cutting (industrial and domestic
TC	Timber cutting
Gr	Grazing
SBC	Slash-and-burn cultivation
MQD	Mining/quarrying/ drilling

Replacement

CF	Clearing/firing
PT	Plowing/tilling
Te	Terracing
HC	Hydrological control (irrigation, drainage)
PV	Planting or vegetation change
CP	Construction, paving, earth shaping

External Inputs

PAI	Plant or animal introductions
SLF	Supplementary livestock feed
SW	Supplementary water
FT	Fertilizer/trace elements
EM	Energy/machinery
HP	Herbicides/pesticides

faults (it is not all-inclusive, for example), but has the merit of reflecting the concerns of scientists interested in global land-use and land-cover change. We think it is the most appropriate system of classification for our purposes. It includes seven major types of land cover (see Table 1). Some of these are zones of natural vegetation; others represent land uses. But in every case, they describe what actually occupies the land.

The hard decisions and expert judgments behind this classification system of land-cover types rest upon criteria that ought to be made clear. First, we have included cover types that are important to global change research from the points of view of (1) the physical climate system on the global scale, (2) regional and continental energy and water balances, (3) global biogeochemistry, (4) atmospheric chemistry, and (5) biodiversity. Second, we have emphasized cover types important to the human dimensions of global change research as revealed in (1) land quality, soil fertility, and biodiversity (again); (2) sustainable development, sustainable agriculture, and resource development issues; and (3) land tenure, land access, and land-use issues. Beyond these two general guidelines governing our choices, we have also given weight to considerations of the current rate and magnitude of changes, to the simple areal extent of cover types, and, bowing to necessity, to gaps and uncertainties in available data. How these criteria for selection led to the seven cover types represented in our classification scheme is explained briefly in the second column of Table 1. The land-cover types in the table are arranged from most to least important according to the criteria listed above.

The underlying choices were hard, but the resulting classification scheme is simple. While this is a virtue not to be discarded rashly, the system may easily be expanded and/or subdivided to provide more complete coverage of the globe or to distinguish more finely among land-cover types. Indeed, one could easily create a classification system that recognized the gradients between desert and grassland and forest. For the moment, however, we prefer the simplest formulation that captures the most important varieties of land cover.

Driving Forces

The motors of land-cover/land-use change are countless. Some act slowly (and often obscurely) over centuries, while others trigger events quickly and visibly. In every case, several forces are at work, sometimes operating independently but simultaneously, sometimes operating synergistically. No aspect of global change is more complicated than the driving forces.

Our system of classification of driving forces, like our land-cover classification system, is one among many possible such schemes. It represents a theoretically informed set of choices and distinctions, designed specifically for the purposes of capturing the most consequential human and environmental causes of land-cover/land-use change. The major categories of driving forces are political, economic, demographic, and environmental (see Table 2). Within these broad categories, we identify specific attributes that strongly influence land-use and

Table 1. Important land-cover types

Cover Type	Rationale	Location
1. Tropical forest	• Large conversion extent • High rate of change • Wet regimes, high trace gas flux • Climate/water influence • Biodiversity • Difficult soil management • Sustainable development • Largest frontier • Developing countries • Typology for agricultural and commercial enterprise, geopolitical/	Amazon, West Africa, Southeast Asia, Central Africa, Central America
2. Tropical savanna and grassland	• Large extent of occupation • Large conversion extent • High rate of change • Frequent burning, non-CO_2 trace gases • Sustainable development • Dwindling frontier	Brazil, Sahel-Sudan, South Africa
3. Temperate and boreal forest	• Commercial timber harvest is dynamic • Agriculture unknown • Potential sink • Land intensive • Indirect effects	U.S., USSR, Europe, Canada, Scandinavia
4. Cropland	• Land intensive = trace gas • Land extensive = CO_2 • Rapidly increasing area • Tenure conflict • Sustainable development issues • Impact on frontier	Global
5. Temperate grasslands	• Unknowns in key regions: central Asia • High soil carbon • Potential degradation	
6. Settled and built up	• Extent unimportant • Sphere of influence could be important: core/periphery	
7. Wetlands	• High loss rate, large area uncertainty	

land-cover patterns. Each of these attributes can be expressed as a variable or set of variables. For example, almost every land-use or land-cover change takes place within a political context. At some level, international, state, or local, a decision-making process—or perhaps several of them—is involved. This process might be one with high public participation in an open system in which power is decentralized; or it might be just the opposite, a process in which few people are involved, exclusion rather than openness prevails, and power is centralized. Each polarity—

Table 2: Driving forces behind land-use change

Attribute	Variable	Kinds of Indicators
1. Political		
Decision-making process	Degree of public participation (open/closed, centralized/ decentralized	• Unitary or federal structure • Number of special-interest groups
State capacity	Public sector pressure/ influence	• Public sector expenditure/GDP • Public/total land area
2. Economic		
Vulnerability to external pressure (economic/ political)	Open vs. closed economy	• Exports/GDP • Partner concentration
	Primary sector dependence	• Primary sector exports/ total exports
	Type of exchange rate management	• PEA (Population economically active) agriculture/PEA total • Real exchange rate • Debt service ratio
Market allocation mechanism	State controlled, market driven	• Agricultural subsidies • Public sector expenditure/GDP
Technological intensity	High-low	• Energy intensity of GDP
Level and division of wealth (asset inequality)	Wealth/poverty-induce consumption	• Primary sector/GDP • Energy consumption/ capita • PEA agriculture/PEA total • Percent absolute poor in total population
3. Demographic		
Population pressure on the land	High-low	• Cultivated/arable land • Change in population density • PEA agriculture/PEA total
4. Environment		
Natural resource quality	Scarcity	• Stock, yield, flow

centralized vs. decentralized, e.g.—can be visualized as a continuum. Every polity falls somewhere along these continua. To know where, one must use indicators that provide an approximation of the degree of centralization or the degree of public participation in a given polity. The third column of Table 2 provides a list of appropriate indicators for each of the variables we find useful in characterizing driving forces. Most of these indicators are quantitative measures, although some are cruder instruments permitting only yes/no statements. Inevitably, some indicators are more amenable than others to precise measurement. This is part of the devilish complexity of dealing with the driving forces of global change.

Our system of classification differs from others in several respects. First, it gives great weight to the economic and political differences among societies. This is essential, because the same climatic or even demographic pressures can produce sharply different results in different political and economic circumstances. Recognizing the distinctions among political and economic systems, even on a fairly rudimentary basis, is a step away from crude demographic or climatic determinisms. Second, we have incorporated technology into the broader category of economic attributes rather than designating it as a major driving force in its own right. We do not consider technology to be a major determinant of land-cover or land-use change on the global scale. Technologies appear to us as social responses to needs and opportunities, devised, diffused, and used wherever they do well what people want done. It is the needs and opportunities that motivate people to adopt a given technology that seem to us fundamental.

This is a view that will leave many scholars uneasy, including some members of our working group. Certainly there are many historical examples that seem to run counter to it. To choose only one, the adoption of the heavy plow in the Russian steppes after the 16th century permitted the extensive conversion of grasslands to croplands in southern Russia and the Ukraine for several centuries. Without the right technology, that land-cover change could not have happened. But, equally, without the demographic expansion of Russian population, the new market opportunities that large-scale grain producers enjoyed, and the increasing military dominance of the Russian state over the pastoral peoples of the steppe, the change would not have happened either. In this example, all elements of the mix were necessary to produce the land-use change. In the modern world we find this to be true more rarely. More commonly it seems to be the case that social, political, economic, and demographic circumstances summon applicable technologies, and that the technologies themselves are not major variables. The chief exception is in transport technology. The presence or absence of transport infrastructure is so important that it commands special attention. The conspicuous difference in land-cover change between Zaire's tropical forests and Brazil's is in large part a direct result of the absence or presence of roads. However, even in this case, the construction of Brazil's Amazonian roads was in large part the result of political decisions.

A second noteworthy feature of our classification system for driving forces is the absence of any overt consideration of culture. All scholars working on land-use/land-cover change grant culture some importance, but most despair of forming any useful generalizations about it. Great discrepancies arise when one studies what people say, what they believe, and how they behave. The most accessible of these—what people say—is probably least relevant to land-use/land-cover change, and the most relevant is unhappily also the most difficult to ascertain and measure.[1] Furthermore, culture is so localized, so fragmented, and so mutable in most societies

[1] L. Arizpe, the Working Group B leader, prefers the view that what people say is especially important to understanding cognitive and political negotiations that have to take place to change people's land-use practices. (See also Rockwell, this volume.)

that it defies scholars' attempts to give it due weight. Only in local studies, where variations are minimized, is culture easily factored in to explanations of land-use or land-cover change. We have no simple solution to these problems. To some extent, cultural differences are present behind the political and economic variables that figure prominently in our classification scheme. Indeed, catching the manifestations of cultural traits indirectly, through political, economic, and even demographic variables, provides a more manageable approach to culture's impact on land use than the direct one, which so confounds measurement and generalization.

This axis, like the land-cover type axis, could easily be amended to be more inclusive or more refined in its distinctions. Our choices and judgments represent a compromise between simplicity and full accuracy.

Land Conversion Processes

This third axis of the cube in Figure 1 represents purposeful human activities aimed at increasing the productivity of land (whatever their real consequences). We have arrived at 19 discrete processes that have direct impacts on land cover and land use, and also have clear purposes, if often unclear side effects. These 19 processes are grouped for analytic convenience into three main categories: (1) harvesting, which is the appropriation of natural products resulting in modification but not conversion of land cover; (2) replacement, i.e., the conversion from one land cover to another; and (3) transfer, meaning processes that import from an external source additional resources or energy in an effort to improve or intensify production. The specific processes in each of these three broad categories are listed in Figure 1.

To our knowledge this system of classification is unique in trying to lend coherence to the welter of specific human actions affecting land use and land cover. Like the other axes, it is potentially subject to expansion or contraction. The present set of choices aims not to be all-inclusive, but merely to represent the principal mechanisms of land-use and land-cover change abroad in the world today.

From the Three Axes to a Typology

Every case of land-use or land-cover change takes place within a specific land-cover type or types, has certain specific driving forces that cause it, and consists of certain specific processes of conversion from one land use or cover to another. Hence every case, if analyzed from the perspectives represented by the three axes of Figure 1, can be plotted within three-dimensional space. Every case occupies a set of minicubes, each of which represents the intersection of a given land-cover type, a given driving force, and a given land conversion process. This set of minicubes we call a constellation, to emphasize that in practice the set is not likely to be contiguous. Obviously, several driving forces and often several conversion processes will be at work in any given case. As a hypothetical example, let us say that in a tropical forest zone, population pressure, security concerns of a military government, and foreign capital investment are driving conversion from forest to settled land and to cultivated land. This case would occupy 12 minicubes to account for all intersections of tropical forest land cover with the demographic, political (state capacity), and economic (vulnerability to external pressure) drivers and with the following processes: clearing/firing, plowing/tilling, slash-and-burn cultivation, and planting or vegetation change.

Translating the characteristics of a given case into the appropriate minicubes is not a mere mechanical business. Careful judgments are required, especially in identifiying the key driving forces. Is an internal colonization scheme sponsored by the military best captured as 'high state capacity' or as some other political attribute? In many instances modest amounts of research would be needed to generate the data and the judgments necessary to translate a case reliably into a constellation of minicubes. But if this can be accomplished, this method of analysis summarizes precisely what is going on, where, and why in any given case.

The next step is to amass and analyze cases. Imagine 20 or, better yet, 100 cases plotted in three-dimensional space and translated into 100 constellations. One is now in a position to ask, and answer systematically, a series of questions that will lead to the distillation of large numbers of cases into a few prototypical 'situations.' With 100 constellations to compare, one could easily examine how these relate to one another in space. Do the constellations cluster together? Which constellations overlap and where? Are there minicubes, or sets of minicubes, that show up again and again in the constellations? Do similar sets of driving forces and conversion processes operate in different cover types, or are the same cover types playing host to similar driving forces and/or conversion processes? There is probably no end to the variety of questions researchers might wish to ask of the data. This is perhaps the most appealing promise of our construct: the possibility of reducing the daunting irregularity of existing ecological, economic, political, social, and demographic data to a common template so that systematic and precise comparisons can be made and a clearer idea of what is afoot in global land use and land cover can be obtained. Naturally something is lost in reducing the irregular data that most closely correspond to the real world to a common template. But without this step, however brutal, comparison, typing, and aggregation among individual cases rest on impressions and intuitions: more an art than a science. We will return to this question of data and their handling below, when we take up the subject of further research.

With 100 cases plotted as constellations, and then compared and analyzed, it would be possible to map cases or groups of typical cases ('situations') on any scale desired, local, regional, or global. The visual display of the information yielded by our methods will be a simple and, we hope, extremely useful and revealing step.

The Time Dimension

Translating land-use or land-cover change data into easily comparable constellations of minicubes provides only a snapshot of what is happening. A more complete picture must be a moving picture, one that incorporates time. Of course time is implicit in the three axes described above: the driving forces operate gradually, at great or lesser speeds; the conversion processes themselves take time; and land-cover types, even if left undisturbed by human agency, change over time—usually very slowly. But this implicit recognition of time does not sufficiently capture the importance of historical change. To do that one needs a series of cubes to yield a series of snapshots, permitting one to analyze the gradual evolution of land uses and land covers. Many apparent changes in land use or cover are but brief fluctuations, soon to be changed again, and sometimes changed back. Over the long haul forests may be replaced by fields and return again to forest, as many landscapes in the Yucatan and New England attest. To know the difference between fluctuations and trends, between temporary conditions and new realities, one must systematically incorporate time into one's analysis.

Theoretically this is a simple procedure. Imagine a series of cubes, representing 5- or 50- or 100-year intervals. With sufficient data (on which question see below), one could plot cases over time, generating a series of constellations. If the selected intervals were short enough, one could visualize constellations evolving, as it were, before one's eyes, just as a series of photographs taken at very brief intervals and then seen in rapid succession becomes a movie. With the help of our schema—and sophisticated computer graphics—the trajectories of these constellations could be plotted in space and then compared and analyzed, just as described above for individual constellations. Comparing and analyzing quantities of trajectories would permit the same sort of generalization and aggregation as with the constellations. If one could detect similar trajectories through time among certain constellations, this would hold out the promise of some predictive capacity for our analytic schema.

All of this hinges on the availability of sufficient and suitable data. Historical data may be recoverable for many parts of the world for the last century, although certainly there will be many gaps. For some unusual places, it will be possible to uncover adequately precise historical data for several prior centuries. With sufficiently intense and directed efforts at data collection, it should be possible to do this with great precision for the present and future. The utility of analyzing trajectories is so much greater than that of analyzing snapshots that we fervently hope data will be recovered where possible for the past and collected widely in the future, whatever the time and labor required.

Research Implications of the Schema

Before any but the most rudimentary of the projected benefits of this schema may be realized, three major paths of research must be probed and ideally followed to their logical conclusions. These are the further refinement of the three axes, the development of reliable data sets, and the development of procedures and technology for integrating the three dimensions represented (or four, including time). We will take these up briefly in order.

The systems of classification portrayed on each of our three axes represent decisions made in the course of five days' discussion. We do not pretend that they are the product of carefully considered and prolonged investigation. Consequently, each one merits further review and is surrounded by questions in need of close scrutiny. The land-cover type axis, for instance, ought perhaps to be articulated further so as to incorporate soil types and climatic variables, or ought perhaps to be arranged in gradients. The driving forces axis confronts more difficult problems in classifying human behavior as it affects land use and cover, and our efforts here presumably require significant modification. The proper status of technology and culture need more attention than we could give them. How could one best quantify those attributes that are not easily susceptible to objective measurement? More generally, have we captured the important ways in which land-use and land-cover change is caused? The land conversion processes axis is beset with uncertainties as well. Have we compromised suitably between inclusiveness and simplicity? Does the general classification system of harvesting, replacement, and transfer hold up under scrutiny? How can one best determine whether a given process is worthy of attention? Further work on all three axes is called for. It will require teams of scholars from several disciplines.

Equally necessary is the collection and organization of sufficient data. To make the best use of our schema one would need as many cases as possible with full ecological, demographic, political, economic, and social data sets, for the past as well as the present. And those data must be converted into forms suitable for translation into the systems of classification of the three axes. That hope is unrealistic; but the closest approximation to it will yield the most reliable and useful results. Fundamental questions remain about the character and scale of data needed. Where are the gaps in existing data? Which gaps are most crucial? Which can be filled at lowest cost? At what scale will this schema operate best—for example, Amazonia in its entirety, a square 200 km by 200 km, or a single mountain valley in the Andes?

Finally, it also seems clear that further work is necessary on the integration of the three (or four) dimensions. There are technical problems in the processing and analysis of spatially arrayed data, and complex computations and visualization graphics will be required.

Conclusion

Our working group sought to create a typology of world situations in land-use/land-cover change that took proper account of the myriad causes, processes, and circumstances involved. Deviating from this goal somewhat, we created what we regard as a systematic method, called here a schema, by which this could be done, and by which a far deeper understanding of land-cover and land-use change in the past, present, and the future is obtainable. But while we have sketched the underlying concepts and the governing procedures, we have not yet made operational our schema. That requires far more work in refining procedures and collection of data than five days, however feverish, permitted.

Appendix A: Case Studies

Amazonia

Diogenes Alves

Two 'snapshots' of the tropical forest in the Brazilian Amazon at two different times illustrate two different situations of land-cover change. The first is the early 1900s; the second, the intensive colonization cycle during the 1960s, 1970s, and 1980s.

Early 1900s in the Brazilian Amazon

In the early years of this century, the process of human settlement in the Brazilian Amazon was limited to areas along the major rivers. There were no roads, and most transportation was by river. Agriculture was concentrated in the eastern part of the region. Rubber tapping was the most important source of revenue, but development of rubber plantations in South Asia ended the 'rubber cycle' in the Amazon.

Land-cover type:
- Tropical forest

Drivers:
- Economic (vulnerability to external pressure in the form of competition from Asian rubber)

Processes:
- Harvesting: timber cutting, grazing, gathering
- Replacement: clearing/firing, planting
- External inputs: plant or animal introductions

Amazon Colonization after 1960

An intensive process of colonization took place in the Brazilian Amazon during the 1960s, 1970s, and 1980s. A combination of several factors stimulated immigration, agriculture, and several other economic activities that led to land-cover changes in the region.

Beginning in the 1960s, and continuing throughout the 1970s, the development of infrastructure, especially roads, improved access to the area. Federal and state governments offered incentives for farmers and industries to move to the Amazon, where land was usually cheaper than in other parts of the country.

Both intensive and extensive agriculture can be found in the region. In several areas of significant settlement, soils are poor. Incentives and subsidies used to be proportional to area cleared, leading to unnecessary clearing and later abandonment. Traditional gathering activities such as rubber tapping are still popular in the Amazon. Much of the clearing has been related to the conversion of forest into pasture.

The development of infrastructure has been stopped for more than a decade, incentives have been cut, and the development of agriculture is not always competitive due to the quality of the land and the distance to major consumer centers. These factors are causing new changes in land use, such as the abandonment of some areas and urban expansion due to migration from rural areas, that are still insufficiently studied.

Land-cover type:
- Tropical forest

Drivers:
- Political (decision-making processes and state capacity through the incentives program)
- Economic (market allocation mechanism)

Processes:
- Harvesting: timber cutting, gathering, grazing, mining
- Replacement: clearing/firing, planting, dam construction
- External inputs: plant/animal introductions, fertilizers, machinery.

The Burma Delta under British Rule

John F. Richards

In 1852 the East India Company, the ruling colonial government in India, defeated the Konbaung regime in Burma and annexed the lower half of the kingdom. Immediately thereafter British rule opened the Irrawaddy Delta lands to a new form of intensive exploitation under world capitalism. Between Burma's initial conquest and the world depression in 1930, the Burma delta tropical wetland forest was converted to a domesticated wetland. By 1930 there were 4 million hectares of intensively cultivated wet rice fields in the delta. How would we model this massive transformation in land use by using the three-axis cube?

Land-cover type:
- Wetlands

The lower reaches of the delta were subject to daily tidal inundation from the sea. Along the nine branches of the Irrawaddy and their many creeks, species of mangrove (*Rhizopora*) and palms grew luxuriantly. Slightly inland were heavy formations of the kanazo tree (*Heritiera fomes*), which often grew to heights of 45 m. Annual flooding in the rainy seasons meant that these areas were completely covered for several months of the year. Abundant wildlife, including tigers and elephants, roamed these tracts. Kanazo faded into drier, mixed scrub delta forests. At conquest the entire delta was very thinly populated with subsistence rice farmers, salt-makers, fishermen, and bandits.

Processes:
- Replacement: cutting, firing, tilling, hydrological control, planting

Increasing numbers of pioneer settlers engaged in intensified replacement activities. They cleared land by cutting and firing. They controlled water by digging drainage channels and erecting *bunds* (embankments) around rice fields. They tilled the land and planted rice as the main cash crop. The colonial state repaired and extended embankments along the Irrawaddy to protect thousands of hectares from annual flooding.

Driving Forces:
- Political (state capacity)
- Economic

The decision to open the delta to settlement and cultivation was taken by a foreign, colonial government that permitted virtually no public participation in this decision. Certain special interest groups were considered. For example, Indian immigrant brokers, merchants, and money-lenders and British merchant houses that were prepared to handle the wholesale trade in rice were favored. This was an open export economy with no protection against the vagaries of the world market. Burma rice soon became one of the two major exports in bulk, along with timber taken from the hilly teak forests.

The state asserted control over all 'unoccupied' delta lands. This control was codified in the Burma Land and Revenue Act of 1876. Land was free to any Burmese who would clear and cultivate the jungle. Pioneer settlers could obtain full rights of ownership if they grew rice and paid taxes to the state for 12 years. They could also obtain written permission for occupancy, hold the land tax-free for 7 years, and then obtain ownership. Ownership conveyed permanent, heritable, alienable rights to the Burmese small holder.

Previously unknown technologies were deployed by the new colonial government. Public works officials designed and built new port facilities at Rangoon and subsidized the rapid development of steamship service up the Irrawaddy River.

British engineers using immigrant Indian laborers repaired existing river embankments and built miles of new embankments to protect delta fields from annual flooding. Newly built canals connected various tributaries of the great river. Permitted to enter freely, immigrant Indians supplied labor for these projects. Other Indian groups, especially the Chettiars from Madras, brought in capital to act as money-lenders for peasant settlers. They also financed the processing of paddy and its transport to the warehouses and docks of Rangoon. British agency houses took over the business of overseas shipment and sale of Burmese rice.

Burma was certainly not overpopulated in the mid-19th century. Land and other natural resources were ample for the population. New state policies made vacant land in the delta an attractive resource for Burmese farmers from upper Burma. Income differentials were such that individual families responded with alacrity to new monetary incentives. No new technologies were employed in clearing land, managing water, or growing wet rice. The extant bundle of agrarian techniques was more than sufficient for the task at hand.

The Aral Region

Olga Bykova

The Aral region includes the Aral Sea basin; the basins of the Syrdarya, Amudarya, Tedjen, and Murgab rivers; the Karakumsky Canal; small rivers running from the West Tien Shan and Kopet-Dag; closed basins; and areas between the rivers and around the Aral Sea. Its area in the USSR is 1.4 million km^2 and its total area 2 million km^2. Its population of around 31–32 million is growing rapidly at a rate of over 2% annually.

Land-cover type:
- Sand and stone deserts in the temperate and subtropical climatic zones

Drivers:
- Political (high state capacity)
- Economic (high technological intensity)
- Demographic (rapid population growth)

Processes:
- Harvesting: grazing, fishing
- Replacement: irrigation, drainage
- Transfer: planting, application of herbicides and pesticides, fertilizing, use of machinery

In the early 1960s, the government decided to begin large-scale expansion of irrigation within Central Asia to meet several goals:

- To increase cotton production to meet internal demands for cloth and increase exports
- To increase production of fruits and vegetables
- To provide the population with meat and rice
- To create new jobs for the growing population.

In the following decades, the total area of irrigated land increased in the Uzbek and Tajik Soviet Republics by 1.5 times, in the Kazakh Republic by 1.7 times, and in the Turkmen Republic by 2.4 times. During the same period, agricultural subsidies grew several-fold; energy consumption increased by 6 times; application of fertilizers increased by 3.5–6 times; and the number of tractors increased by 3.2 times.

The new large-scale irrigation, and the application of chemical inputs and other human impacts, have caused intensive transformation of the natural environment, economy, and population of the Aral region:

- River runoff in the Aral Basin has decreased from 56 km^3 in 1960 to 7–11 km^3 in the mid-1970s and practically nothing in the 1980s, the runoff regime being transformed by water consumption.
- The hydrographic network has spread with the creation of irrigation and drainage canals.
- The total area of the Aral Sea has decreased from 67,000 to 41,000 km^2 while salinity has increased from 10 to 28–30%.
- Salt transfer from the seabed has increased greatly, according to recent estimates reaching 40–150 million tons/year.
- Irrigation has led to a significant rise of the groundwater level, leading in turn to intensive secondary salinization of the soil. Moderately and highly salinized soils now occupy 50% of the irrigated area.
- The lowered water level in the rivers and in the Aral Sea has caused intensive desertification of the coastal and delta areas.
- Drainage runoff into the rivers has changed their chemical composition. Mineralization of the Amudarya's waters increased from 0.8 g/l in 1960 to 2.8 g/l in 1985.
- Soil and water pollution from fertilizers, pesticides, and herbicides is very high; the content in most of the rivers exceeds sanitary norms several-fold.
- The climate in the Aral region has become more continental, and dust storms have become more frequent and affect larger areas.
- The diversity of mammals has decreased from 70 to 30 species and of birds from 173 to 38, while 54 plant species are endangered, including relic and endemic ones.

The social consequences and indicators have included a growth in child mortality rate, which in some areas exceeds 110 per 1000. Further, disease and mortality rates have grown in the adult population. There also has been a significant decrease in the size and quality of the cotton crop. The Aral Sea's fishing industry is defunct. Pasture lands have decreased, with a consequent decrease in the total number of livestock and the production of wool and karakul (astrakhan fur).

It is estimated that remediation of the area will cost approximately 37 billion rubles.

This report is based on: Glazovsky, N. F. 1990. *The Aral Crisis: The Origin and Possible Way Out.* Nauka, Moscow.

California's Central Valley

Peter M. Morrisette

The Central Valley of California is one of the most intensively irrigated agricultural regions in the world. Over 7 million acres of land are under irrigation, supporting a nearly $8 billion annual industry. Irrigation water in the Central Valley is provided through two publicly supported water systems: the federally operated Central Valley Project (CVP) and the state-operated State Water Project (SWP). Irrigation water provided by the Bureau of Reclamation through the CVP is highly subsidized, reflecting neither the full operational cost of providing the water nor environmental or opportunity costs. State water is not subsidized, although its price also does not reflect the environmental or opportunity costs of using that water for irrigation. The development of irrigated agriculture in California's Central Valley represents a fundamental change in land cover from a semiarid grassland to intensively used cropland. This conversion has not been without economic and environmental costs.

Land-cover type:
- Cropland

Processes:
- Replacement (plowing, tilling, hydrological control)
- External inputs (plant introduction, supplementary water, fertilizer/trace elements, energy and machinery, herbicides and pesticides)

Hydrological control includes the valley's extensive network of canals, aqueducts, and reservoirs used for irrigation and drainage.

Driving forces:
- Political (decision-making process)
- Economic (technological intensity, market allocation mechanism)

The Central Valley, with its massive irrigation network and its use of external inputs such as fertilizer, energy, and machinery, represents perhaps the zenith of modern technological agriculture. While it would be a mistake to discount the importance of technology, however, the evolution of the agricultural landscape of the Central Valley is probably best understood in the context of the role of special interests and their manipulation of the water allocation system.

For example, because water provided to farmers from the CVP is so heavily subsidized (the price reflects only about one-fourth of the delivery costs and does not take environmental costs into account), there is little incentive to use this water efficiently. The National Research Council, in a 1989 report entitled *Irrigation-Induced Water Quality Problems: What Can Be Learned from the San Joaquin Valley Experience*, argues that the low cost of water is 'the most pervasive economic issue contributing to irrigation-related water quality problems and affecting the choice and success of solutions' (p. 5). The report further notes that 'the subsidized low cost of water results in more water being used, encourages farmers to cultivate less desirable lands, and leads to increased agricultural runoff' (p. 5). This system of water allocation, which undervalues water and does not internalize external costs, is defended by agricultural interests in the Central Valley and a bureaucracy with a vested interest in maintaining the status quo.

Nevertheless, change is occurring. For example, because of concern over serious environmental problems, the 222,750 hectare Westlands Water District in the San Joaquin Valley has been forced to internalize the environmental costs of disposing of toxic drainage water. The Westlands district now has an incentive to develop less costly means of dealing with its drainage problem. One possible alternative would be for farmers in the district to sell water that would otherwise be used on lands with drainage problems to the SWP or to Southern California's Metropolitan Water District, where it would be used for higher value municipal uses. Despite the fact that water would be used more efficiently and environmental damage would be mitigated, there are major institutional barriers to this alternative. While progress in breaking down these barriers has so far been slow, it is likely that the economics and politics of water in California (increasing demand relative to supply) and growing concern over environmental problems will necessitate such a change.

Returning to the cubic typology of world situations, the minicubes that would best represent the case of irrigated agriculture are those identified by the intersection of croplands (cover type) with external inputs (processes) and economic/market mechanism and political/decision-making process (drivers). By itself, the exercise of using the cube in this case does not tell us anything that was not already obvious; what will be interesting, however, is to see what other cases might be similar. In other words, what areas share these minicubes with the Central Valley?