A CIESIN Thematic Guide to Land-Use and Land-Cover Change (LUCC)

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1.0 – Land-Use and Land-Cover Change

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Abstract

Humans have been altering land cover since pre-history through the use of fire to flush out game and, since the advent of plant and animal domestication, through the clearance of patches of land for agriculture and livestock. In the past two centuries the impact of human activities on the land has grown enormously, altering entire landscapes, and ultimately impacting the earth's nutrient and hydrological cycles as well as climate. Land-use and land-cover changes are local and place specific, occurring incrementally in ways that often escape our attention. Yet, collectively, they add up to one of the most important facets of global environmental change. This thematic guide provides an introduction to these changes, and walks the readers through important topics in land-use and land-cover change research: deforestation, desertification, biodiversity loss, land cover and the water cycle, land cover and the carbon cycle, and urbanization.

How to Use this Guide

Note: Readers using the PDF version of this Thematic Guide may be interested in the additional functionality, described below, which is provided solely in the HTML version available through: ***http://sedac.ciesin.columbia.edu/tg/guide_frame.jsp?g=47***

The richness of this guide resides in the many and varied links to bibliographic resources, many of which are available on-line. Readers are encouraged to toggle between the written sections and the references and related resources to gain a better sense of the breadth of research in this important area of study. Note that references are dynamically linked to sections of the guide. The Reference section in the table of contents provides references for the entire guide, but when one toggles to references from a particular chapter or section, only references for that chapter or section will appear. The LUCC Guide's bibliography exceeds 1,300 entries, many of which were not specifically cited in the text. To access the larger bibliography, users are encouraged to use the bibliographic search page. A full description of CIESIN Thematic Guide functionality can be found by accessing the help page from the navigation bar.

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Dr. Thomas Rudel of the Department of Human Ecology at Rutgers University provided a database of almost 1,000 citations of journal articles, books, dissertations and reports addressing deforestation. These were incorporated into the database of references and related resources associated with this guide. Dr. Rudel's bibliography was compiled under contract with the Forest Inventory Section of the Forestry Division of the UN Food and Agriculture Organization (FAO).

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2.0 - Introductory Overview

This thematic guide addresses land-use and land-cover change in the context of global environmental change. Although natural land cover has changed over long time spans due to natural processes such as continental drift and glaciation, this guide is primarily concerned with human transformations of the earth's surface which have greatly intensified in the past three centuries.

Land use is the term that is used to describe human uses of the land, or immediate actions modifying or converting land cover. It includes such broad categories as human settlements, protected areas and agriculture. Within those broad categories are more refined categories, such as urban and rural settlements, irrigated and rainfed fields, national parks and forest reserves, and transportation and other infrastructure. *Land cover* refers to the natural vegetative cover types that characterize a particular area. These are generally a reflection of the local climate and landforms, though they too can be altered by human actions. Examples of broad land cover categories include forest, tundra, savannah, desert or steppe, which in turn can be sub-divided into more refined categories representing specific plant communities (e.g., oak-pine scrublands, mangroves, seasonally flooded grassland, etc.).

The scientific research community called for substantive study of land-use and land-cover changes during the 1972 Stockholm Conference on the Human Environment, and again 20 years later at the 1992 United Nations Conference on Environment and Development (UNCED). In the past decade, a major international initiative to study land-use and land-cover change, the LUCC Project, has gained great momentum in its efforts to understand driving forces of land-use change (mainly through comparative case studies), develop diagnostic models of cover change, and produce regionally and globally integrated models (Lambin *et al.* 1999, Geist 2002).

But why is such an understanding important? How do land-use and land-cover change processes link to broader changes in the global environment, and to efforts to obtain environmental sustainability? The strong interest in land use and land cover results from their direct relationship to many of the planet's fundamental characteristics and processes, including the productivity of the land, the diversity of plant and animal species, and the biochemical and hydrological cycles. Land cover is continually molded and transformed by land-use changes such as, for example, when a forest is converted to pasture or crop land. Land-use change is the *proximate cause* of land-cover change. The underlying *driving forces*, however, can be traced to a host of economic, technological, institutional, cultural and demographic factors.

In fact, humans are increasingly being recognized as a dominant force in global environmental change (Moran 2001, Turner 2001, Lambin *et al.* 2001). Changes in land use are likely the most ancient of all human-induced environmental impacts, and the first to obtain a magnitude to warrant the title "global." For example, land-cover change, especially the conversion of forested areas into other uses, has been identified as a contributing factor to climate change, accounting for 33 percent of the increase in atmospheric CO_2 since 1850, and a leading factor in the loss of biological diversity. Overgrazing and other agricultural practices in developing countries are causes of land degradation and desertification. Water diversion for land irrigation consumes about 70 percent of all water withdrawals and is sufficiently significant to stop the flow of such large rivers as the Colorado (US), Huang Ho (China), and Amu Darya (Central Asia) from reaching the sea during the dry season. Human uses of land usurp as much as 40 percent of the net primary productivity of the earth, and changes in these may alter ecosystem services locally and globally (Vitousek, *et al.* 1997).

Equally important is the impact of these regional and global changes on society. By altering ecosystem services, changes in land use and cover affect the ability of biological systems to support human needs, and such changes also determine, in part, the vulnerability of places and people to climatic, economic or socio-political perturbations. Take, for example, conversion of forested areas to crop lands, pasture or human settlements. Deforestation can result in the loss of biodiversity, especially in the tropics; biodiversity loss results in declines in ecosystem integrity, and also genetic losses that may impede future scientific advances in agriculture and pharmaceutics. Deforestation can also impact hydrological processes, leading to localized declines in rainfall, and more rapid runoff of precipitation, causing flooding and soil erosion. And finally, scientists have come to a better understanding of the role that forests play in the carbon cycle, and how forest burning in certain parts of the world are important contributors to greenhouse gases that contribute to climate change. Clearly, all of these changes impact society.

This dual role of humanity in both contributing to the causes and experiencing the effects of global change processes emphasizes the need for better understanding of the interaction between humans and the terrestrial environment. This need becomes more imperative as changes in land use become more rapid. Understanding the driving forces behind land-use changes and developing models to simulate these changes are essential to predicting the effects of global environmental change (Veldkamp *et al.*, 2001).

2.1 Historical Changes in Land Use and Land Cover

A major reason for researching historical land-use and land-cover change is that by understanding the past, we can better understand future trajectories. For example, maps depicting US counties with the high percentage of land in agriculture from 1790 onwards illustrate the steady progression of agricultural lands from the Northeast to the mid-West, with major concentrations also in the California Imperial Valley and other inland basins (Maizel *et al.* 1998). Land-use changes such as urbanization tend to radiate out from existing areas of the same class, and many models take advantage of this characteristic to make predictions of future change (Briassoulis 1999).

The most significant historical change in land cover has been the expansion of agricultural lands. Today close to a third of the earth's land surface is devoted to pastures or cropland, which amounts to approximately one-half of all lands suitable for agriculture. Since the dawn of plant domestication the progression of cropland was relatively slow. The past century witnessed over half of the worldwide increase in agricultural lands, and in the developing world half the land cover conversion occurred in just the past 50 years (Houghton 1994).

There are two major land-cover change databases, including the Global Croplands Dataset (Ramankutty and Foley 1999) and the History Database of the Global Environment (Goldewijk 2001), that chronicle past changes in cropland. Potential future expansion of croplands are examined by Fischer *et al.* (2001) in their Global Agroecological Assessment. The greatest increases in land used for cultivation are predicted for Africa and Latin America, with substantial additional parts of Europe/Russia and North America also coming under cultivation to meet future demands for food.

Historical changes in other land-cover types such as forest cover and urbanized areas are addressed in summary fashion in Turner (2001). As Houghton (1994) points out, the major reason for land-use change is to increase the local capacity of lands to support the human enterprise. Yet, together with the "positive" changes – i.e., those that make land more productive – there are also unforeseen impacts that can reduce the ability of land to sustain the human enterprise. Today, localized changes around the world add up to massive impacts that are altering planetary biogeochemical cycles. Thus, it can be argued that even modest changes in land cover have some unintended consequences.

3.0 – Deforestation Overview

Throughout history, the fate of the world's forests has strongly reflected the pattern and intensity of land use by societies. Demand for agricultural land, timber, and other forest products, as well as technological change in agriculture, significantly impacts the mode and rate of transformation of forested areas. Biophysical triggers may also play a role, such as fire dynamics, which are linked to agricultural activities or natural phenomena such as ENSO droughts. These demands are often linked to present-day developing countries experiencing deforestation, which will be the focus of much of this chapter. It is worth noting, however, that technological changes in agriculture (e.g., development of sod-busting plows that opened up the American mid-West) contributed significantly to a "forest transition" in many European countries during the 19^{th} and 20^{th} centuries, in which net national forest cover stopped declining and began to increase (Mather 2001). Thus, technology cuts both ways, leading in some regions to declines in forest cover, and in others to increases.

Society's special interest in deforestation, as compared to other land use/land-cover change issues, may be partly attributable to the stark nature of the transition from forest area to cleared land. Deforestation occurs relatively quickly, and in contrast to some other transitions (e.g., from crop land to pasture, or from productive land to degraded land), is easily observable by the human eye. Through the use of remote sensing technologies, large areas can be monitored, and estimates of deforestation can be obtained (see Section 3.1 for a short description of land-cover change monitoring methodologies).

Deforestation has a number of repercussions, many of which are dealt with in separate chapters of this thematic guide:

- Deforestation can lead to soil erosion or impoverishment, especially in tropical areas where soils tend to be thin and nutrient-poor.
- Deforestation is linked to habitat loss, which is a leading cause of species endangerment and biodiversity loss, particularly in humid tropical forests.

- Deforestation affects the hydrological cycle through changes in evapo-transpiration and run-off; and
- Deforestation, and particularly forest burning, contributes to green-house gas emissions that bring about climate change.

Despite its apparent ease of detection, deforestation rates are still a matter of some debate. Section 3.1 addresses monitoring of land-cover change, and the extent and rate of deforestation in temperate and tropical areas. Section 3.2 addresses the causes and processes of deforestation, drawing on a review of the most recent literature. Finally, Section 3.3 addresses potential policy interventions.

3.1 The Extent and Rate of Deforestation

Today, roughly 39 million square kilometers (29 percent) of the world's land surface is under forest cover (FAO 2000), and of that 28 million square kilometers is in so-called "closed forests" of 40 percent canopy cover or above (Singh *et al.* 2001). Since the end of the last ice age, approximately half the world's forest cover has been lost, most of it due to the expansion of human activities and settlements (Kapos 2000). In terms of primary forest, in contrast to secondary or other successional forests, much less remains. The World Resources Institute (1997) estimates that only one-fifth of the world's original forest cover remains, largely in blocks of undisturbed frontier forests in the Brazilian Amazon and boreal areas of Canada and Russia.

Measuring the extent and rate of deforestation is not as simple as it might at first appear (Singh *et al.* 2001). The first challenge is to define what is meant by a "forested area." In other words, what density of tree cover is required for an area to be considered a forest? Figure 1 shows a "continuous fields" tree cover map prepared by the Global Land Cover Facility (DeFries *et al.* 2000). This maps shows that far from being homogenous, land areas can vary from 10 to 100 percent forest cover and still be considered forests.

Figure 1. Continuous Fields Tree Cover Map

Source: Global Land Cover Facility, University of Maryland; see citation DeFries *et al.* 2000.

Once we define our threshold, whether it be closed forests (i.e., trees with interlocking crowns and a canopy density of 40% or above) or open forest (i.e., 40% crown cover or less), the next challenge has to do with how we monitor forest cover change. For smaller areas, it may be possible to do a parcel-by-parcel inventory to determine rates of change. However, for large or inaccessible areas such as the Brazilian Amazon, the only realistic approach is to utilize remotely sensed imagery (generally from satellites, but also from airplanes). This requires, then, that you have at least two sets of images, one set proceeding the deforestation event or events, and one set following.

The next step is image processing. Processing requires a classification of both sets of images (i.e., breaking the continuous field data into discrete categories such as forest, road, crops, pasture, etc.), and then a change matrix in which the analyst computes the change from one of the land use/land cover categories into other categories. In this way it is possible to obtain the percentage of land area that was forest and is now in one of several other types of land use. Note that an added difficulty, particularly with imagery from so-called "passive" sensors (sensors that rely on the sun's illumination), is that it is vital to obtain relatively cloud-free imagery, or else large areas may be obscured by cloud cover. This is a particular challenge in the humid tropics. Radar, or active sensors that bounce an energy pulse off the land surface, are being used in such zones with some success.

Because remote sensing imagery is expensive to acquire and to process, generally deforestation studies limit themselves to some sample area, say a sub-national administrative unit or a well defined geographic area. Thus, efforts must be made to obtain a random sample of forested areas, or else the estimates of deforestation will be biased.

The Global Forest Resources Assessment of the U.N. Food and Agriculture Organization (FAO) is a major assessment that has developed estimates of deforestation at the global, regional and national levels once every 10 years since 1980. For its 2000 assessment (also known as FRA 2000), the FAO utilized a relatively low threshold for forest cover of 10 percent minimum crown cover (FAO 2000). The assessment is based on a combination of reports by national authorities, and a 10 percent sample remote sensing survey for tropical areas.

Before presenting results of the FRA 2000, it is important to note that there is disagreement about the assessment's results, and even some recognition within the FRA report itself about the limitations of their methodology. A briefing paper by the World Resources Institute (WRI) identifies a number of potential problems with the FRA 2000 (Matthews 2000):

- Methodological changes for each assessment since the first one in 1980 make comparisons to past assessments difficult (and therefore estimates of deforestation rates subject to uncertainty);
- The use of self-reported data by countries is criticized on two grounds: (1) countries may have incentives to underestimate deforestation, and (2) data and monitoring systems in most countries are generally inadequate; and
- The report relies on remote sensing surveys that cover randomly scattered plots in the world's forest areas. According to WRI, because deforestation is not randomly

distributed, but tends to proceed outwards from transportation corridors, a 10 percent sampling rate is insufficient to identify how much forest is being lost.

There is a further concern that the 10 percent crown cover threshold includes lands that most non-specialists would consider to be tundra, wooded grassland, savanna or scrubland, not forest.

Interestingly, despite WRI's concerns that deforestation rates are being underestimated by the FRA methodology, the Tropical Ecosystem Environment Observation by Satellite (TREES) initiative has arrived at estimates of deforestation rates in the humid tropical domain (i.e. closed forests) for 1990-1997 that are 23 percent *below* the estimates developed by FRA 2000 for the same type of forest (Achard *et al.* 2002). Furthermore, Steininger *et al*. (2001) found in their "wall-to-wall" remote sensing study of the Bolivian Amazon that the rate of deforestation is almost four times lower than that reported by the FRA 2000. According to FAO sample survey estimates from 1981-1990, annual forest loss in Bolivia was proceeding at the rate of 5,810 square kilometers per year, whereas the estimate based on wall-to-wall remote sensing coverage for the period 1987-1993 was only 1,529 square kilometers per year. Nevertheless, the FAO estimated a slightly larger remaining forested area (483,100 sq. km. in 1995) than did Steininger *et al.* (437,904 sq. km. in 1994).

Bearing in mind, then, some of these methodological issues and difficulties inherent in establishing firm deforestation rates, FRA 2000 results at global and regional levels are shown in Table 1. From the assessment, some interesting patterns are evident. The two most forested land areas are the European republics of the former Soviet Union (including Russian Siberia) and South America, each with just over 22 percent of global forest resources, and each with approximately half of their land areas under forest cover. The regions with least forest cover are Asia (due to land conversion for agriculture and large desert areas) and Africa (largely due to deserts). The highest changes in forested area were Africa and the Caribbean, each losing close to 1 percent of their forest cover over the decade. In contrast, most temperate and developed regions saw net growth in forested areas of between 0.1 and 0.3 percent.

Table 1. Estimated Forest Cover and Forest Cover Change between 1990 and 2000

Region	Land area	Forest Area 2000				Area change (1990-2000)	
		Natural forest	Forest plantation	Total forest	% of land area		
	000 ha	000 ha	000 ha	000 ha	%	000 ha/yr	%
World	13,063,900	3,682,722	186,733	3,869,455	29.6	-9,391	-0.2
Africa	2,978,394	641,830	8,036	649,866	21.8	-5,262	-0.8
Asia	3,084,746	431,946	115,847	547,793	17.8	-364	-0.1
Europe*	2,259,957	1,007,236	32,015	1,039,251	46.0	881	0.1
W. Europe**	489,127	158,494	10,054	168,548	34.5	455	0.3
N. America	1,837,992	454,326	16,238	470,564	25.6	388	0.1
C. Am./Carib.	264,781	77,445	1,295	78,740	29.7	-658	-0.8
S. America	1,754,741	875,163	10,455	885,618	50.5	-3711	-0.4
Oceania	849,096	194,755	2,848	197,623	23.3	-365	-0.2

Source: FAO. 2000. The Global Forest Resources Assessment 2000, Rome: FAO.
* Europe includes the former Soviet republics of Belarus, Moldova, Russian Federation, and Ukraine.
** W. Europe does not include any republics of the former Soviet Union.

Collectively, the Forest Resources Assessment, TREES and Global Land Cover 2000 (a recent initiative which has yet to publish deforestation statistics) contribute to our understanding of deforestation patterns and dynamics, and provide firmer basis for decision-making.

3.2 The Proximate Causes and Driving Forces of Deforestation

This section is based upon on a recent study conducted by the Land-use and land-cover change (LUCC) project on the causes of tropical deforestation, which is the most complete examination of the topic to date (Geist and Lambin 2002, Geist and Lambin 2001). The study took the form of a meta-analysis – a statistical analysis of numerous case studies to examine patterns and processes of deforestation in many locations around the world. A phenomenon with as much local differentiation as land-use and land-cover change requires an over-arching analysis of individual case studies if we wish to generalize the findings and come up with policy recommendations.

In thinking about the processes of deforestation, it is useful to draw a distinction between the proximate causes and underlying driving forces. Proximate causes are human activities or immediate actions at the local level, such as agricultural expansion, that originate from intended land use and directly impact forest cover. For example, a proximate cause might be a farmer's decision to clear a plot of land for pasture. That decision, in turn, is embedded within a context, such as economic incentives and disincentives, government policies, access to markets, land tenure systems, and the socio-cultural environment in which the farmer lives. These constitute the driving forces – that is, the fundamental social processes that underpin the proximate causes, and that may operate at much broader scales.

The LUCC project meta-analysis examined 152 sub-national case studies – 78 from Latin America, 55 from Asia, and 19 from Africa – covering a time period from 1880 to 1996, with the majority of case studies falling in the fifty year period from 1940 to 1990. To be included, studies needed to quantify the rate of forest cover change, include quantitative data analysis or in-depth field investigations, consider clearly named factors as potential causes of deforestation, and be absent of obvious disciplinary biases. The study focused on four proximate causes: infrastructure extension, agricultural expansion, wood extraction, and other causes (e.g., predisposing environmental factors, biophysical factors, and social disruptions such as war and population displacements). These, in turn, were related to a number of underlying drivers which were subdivided into demographic, economic, technological, policy, institutional, and cultural factors (see Figure 1).

The study refuted two broad schools of thought that had hitherto dominated the debates about deforestation. One of them held that deforestation is the result of single-factor causation, such as shifting cultivation or population growth. The other school held that the causes behind deforestation are irreducibly complex. In other words, that correlations among deforestation and multiple causative factors are many and varied, revealing no distinct pattern.

What the meta-analysis revealed was that tropical deforestation is driven by identifiable regional patterns of causal factor synergies, of which the most prominent are economic factors, institutions, national policies and remote influences (at the underlying level) driving agricultural expansion, wood extraction, and infrastructure extension (at the proximate level).

3.2.1 Proximate Causes

In terms of immediate causation, tropical deforestation is best explained by multiple factors rather than single variables. Globally, the most prominent "triad" is agricultural expansion coupled with wood extraction and infrastructure expansion. These three factors combined were present in 25 percent of the 152 cases examined. Subsets (agriculture & wood, agriculture & infrastructure, and wood & infrastructure) were present in an additional 36 percent of cases. Agriculture leads the lists of causes. The expansion of cropped land and pastures is present, generally in combination with other causes, in 146 of 152 cases (or 96 percent).

Under these three broad categories – agriculture, wood extraction and infrastructure – it is possible to identify important subcategories. For example, within the category "extension of agricultural lands," permanent cultivation and cattle ranching were present in 48 and 46 percent of cases, respectively, whereas shifting cultivation was found in 40 percent. Under infrastructure, transportation extension (road building, railroads and water ways) was present in close to two-thirds of all cases. Settlement and market extension were less prominent, at just over a quarter of all cases. And, under wood extraction, commercial exploitation of forests outweighed fuel wood extraction almost two to one, with 52 percent and 28 percent of the cases respectively. Considering all the detailed categories, permanent cultivation, transport extension, and commercial wood extraction predominate, each being present in 50 percent or more of the cases.

There are some regional differences among the proximate causes. In Asia, agriculture-wood (22%) and agriculture-wood-infrastructure (38%) causes dominate, partly as a result of state enterprise forest exploitation and subsequent settlement of those areas by poor subsistence farmers. In Latin America, agriculture-infrastructure (32%) and agriculture-wood-infrastructure (19%) are predominate causes of forest loss. In Africa, all four factors (agriculture-wood-infrastructure-other) are found in 26 percent of all cases, with agriculture-other (16%) showing up also significant. The "other" in these cases includes civil wars and population displacements.

3.2.2 Underlying Driving Forces

At the aggregate level, it is striking that combinations of synergetic drivers rather than single drivers are associated with tropical deforestation. Eighty-eight percent of the cases are driven by multi-factor terms of causation, and the largest proportion of all cases (36%) includes some elements of each of the five major factors – economics, institutions, technology, culture, and demographic change.

Economic factors are present in 81 percent of all cases, and clearly dominate the underlying causes. Commercialization and the growth of mainly timber markets as well as market failures are frequently reported to drive deforestation. Low factor costs (for land, labor, fuel or timber), price increases for cash crops, and the "ecological footprint" of remote urban-industrial centers through the demand for raw materials underpin about one-third of the cases each. With few exceptions, factors related to economic development through a growing cash economy show little regional variation and, thus, constitute a strong underlying driving force of deforestation.

Institutional factors such as policies on land use and economic development (especially as related to colonization), transportation, or subsidies for land-based activities are found in 78 percent of the cases. Many of these policies directly or indirectly promoted the exploitation of resources in forest frontier areas. Lack of adequate governance structures, as manifested by corruption, lawlessness, cronyism, and mismanagement of the forestry sector, were found to be important institutional factors (42 percent of all cases). Land tenure and property rights issues, which are frequently highlighted in the literature on deforestation, showed up primarily in Asia (60% of Asian cases). Issues of open-access resources and squatting by landless farmers showed up in approximately one-fifth of all cases. So-called "land races," in which settlers clear forest in order to claim legal title to the land, were present in 13% of all cases, mostly in Latin America.

Technological factors in the wood and agriculture sectors, in combination with other driving forces, constitute the third most important driver, underlying 70 percent of all cases. Technological changes in the forestry sector in the form of chain saws and heavy equipment, and in wood processing, are associated with deforestation in 45 percent of all cases. Asia, in particular, was found to have a significant incidence of inappropriate logging technologies. Agro-technological factors were present in a similar proportion of cases, but the picture is complex and does not provide an easy-to-generalize pattern. Modification of farming systems through intensification (high-input, labor-intensive agriculture) and extensification (low-input, large area cultivation) was present in one-third of all cases; thus neither intensification nor extensification does a particularly good job of explaining deforestation in all cases.

Cultural factors were present in two-thirds of all cases. These include attitudes and perceptions such as unconcern for forests due to low morale and frontier mentalities, lack of stewardship values, and disregard for "nature." Such attitudes were more widespread in the Asian and Latin American cases. In parts of Asia (Thailand, Malaysia and Indonesia) and Latin America (Amazon lowlands, the Petén region of Guatemala, and Costa Rica) forest colonization is or has been viewed as important for national land consolidation, security, unity and military defense. In a more limited number of cases in Latin America, forest frontiers were viewed as an important safety valve to forestall land reform in more populated areas. Household-level behavioral factors were present in over half of all cases with less regional variation. These include profit-orientation of actors (both local settlers and absentee landlords), traditional or inherited modes of cultivation or land-exploitation, and a commonly expressed sentiment that it is necessary to clear the land to establish an exclusive claim.

Finally, demographic factors such as natural increase or in-migration were explicitly mentioned in 61 percent of all cases. Most of its explanatory power tends to be derived from interlinkages with other underlying forces, especially in the full interplay of all five major drivers. Many cases did not specify beyond broad notions of population pressure and growth, but those that did tended to identify in-migration more frequently than natural increase. The authors also investigated the utility of the I=PAT (impact=population x affluence x technology) formulation used by Ehrlich and Ehrlich (1990) in explaining cases of deforestation. They found that in 46% of all cases P, A and T, broadly speaking, operate together in a synergetic driver combination.

However, in 93% of theses cases, policy and institutional factors (which are left out of the I=PAT formulation) operated along with, or were even causative, of the PAT variables.

3.2.3 Conclusions

Deforestation is a complex, multiform process which cannot be represented by a mechanistic approach. Mechanistic models are built on the belief that we know the processes by which a system operates and that individual processes can be modeled using scientific laws, or rules, described by simple equations. Given the large number of interacting factors driving deforestation, and given interactions at different levels of causality (underlying forces, trigger events, mediating factors, proximate causes) only a system approach seems appropriate. System models are mathematical descriptions of several complex, interacting processes.

While the development of a “universal model” of deforestation is probably out of reach, a collection of specific models which represent the particular interactions between a reduced set of dominant driving forces for a given process of deforestation, specific to a geographic situation, is feasible. Some of the place-specific processes that could be modeled include subsistence agriculture, commercial agriculture, colonization activities, or logging, and some of the geographic situations in which different bundles of causal factors predominate include forest frontiers, roadside areas, and peri-urban areas.

In terms of research design, the authors conclude that the LUCC research platform (Turner et al. 1995) proved to be a fruitful platform from which to proceed to develop a general understanding of the drivers of land-use and land-cover change, and from which to conduct a systematic comparison of a large number of subnational case studies. Although the systematic comparison of local-scale case studies is labor intensive, the authors feel that it is a much more fruitful line of inquiry than cross-national statistical analyses such as those commonly conducted in the 1980s and early 1990s in which national level rates of deforestation are correlated with economic or population growth rates (e.g., Allen and Barnes 1985, Amelung and Diehl 1992; see Rudel and Roper 1997b for a more sophisticated example of such an analysis).

Readers desiring more details on the methodology and findings of the LUCC project meta-analysis may download the full report, *What Drives Tropical Deforestation* (LUCC Report Series No. 4), from the LUCC project website listed in the references and related resources associated with this section.

3.3 Policy Intervention in Deforestation

The previous section on causes of deforestation (Section 3.2) described the degree to which institutional factors (i.e., governmental and international policies) can affect deforestation. Just as policies can contribute to deforestation, they can also be one of the strongest mechanisms for reducing forest loss.

Before discussing some possible policy measures for reducing rates of deforestation, it is worth considering cases in which deforestation may not necessarily present a problem. A classic case is that of New England, where much of the forest cover was lost during the colonial and industrial periods, as land was cleared for agriculture, and wood was used in construction, ship building, and as a power source. Today, due to the complete restructuring of the New England economy, most of the forest ecosystems have been restored, and there is little evidence of the previous land uses apart from occasional stone fences and house foundations. In many parts of the world, selective tree cutting is a vital part of forest management, and actually enhances biodiversity and certain ecosystem functions. Properly managed, forests represent a renewable resource that has tremendous potential to contribute to sustainable economic development. Thus, it would be wrong to paint a categorically negative picture of deforestation.

Nevertheless, the introduction to this chapter lists a number of reasons why deforestation may, under certain circumstances, be a significant concern. Among other things, deforestation can lead to soil erosion or impoverishment, especially in tropical areas where soils tend to be thin and nutrient-poor; it is linked to habitat loss, which is a leading cause of species endangerment and biodiversity loss, particularly in humid tropical forests; it affects the hydrological cycle through changes in evapo-transpiration and run-off; and it releases stored carbon, and therefore contributes to climate change.

The concern over *tropical deforestation* in particular relates to their biodiversity, the risk of soil erosion, and their roles as major carbon sinks. Some have likened tropical rainforests to the “lungs of the world,” owing to the amount of oxygen that they generate through photosynthesis. Another important factor is the extent of these forests and their relative rate of depletion. The largest remaining rain forest blocks are in Central Africa and Brazil, measuring hundreds of thousands of square kilometers (World Resources Institute 1997). Yet they are disappearing at rates of up to 1-2 percent annually due to pressures from commercial interests and settlers.

So how can policies shape the future patterns and rates of deforestation? Major policy dialogues and approaches are outlined in the following subsections.

3.3.1 International Policy

International policy and policy dialogues often set the precedent for national-level policies, and therefore can be very important, their influence being felt even at local levels. At the 1992 United Nations Conference on Environment and Development (UNCED), a non-binding *Statement of Forest Principles* was signed pledging parties to more sustainable use of forest resources. In addition, Agenda 21 (Chapter 11) discusses (a) sustaining the multiple roles and functions of all types of forests, forest lands and woodlands; (b) enhancing the protection, sustainable management and conservation of all forests, and the greening of degraded areas through forest rehabilitation, aforestation, reforestation, and other rehabilitative means; and (c) promoting efficient utilization and assessment to recover the full valuation of the goods and services provided by forests, forest lands and woodlands. Agenda 21 promotes improved legislation, action plans, and research for halting deforestation.

The *International Tropical Timber Agreement* (ITTA) initially entered into force in 1985, and has been superceded by a new agreement negotiated in 1994. The ITTA has among its objectives to “encourage the development of national policies aimed at sustainable utilization and conservation of tropical forests and their genetic resources, and at maintaining the ecological balance in the regions concerned in the context of tropical timber trade." The ITTA has no price regulation mechanisms or market intervention provisions, and accords equal importance to trade and conservation. The primary purpose of its secretariat, the International Tropical Timber Organization (ITTO), is to provide an effective framework for consultation among producer and consumer member countries on all aspects of the world timber economy within its mandate. ITTO has a commitment to ensure that all tropical timber products traded by Member States, which account for 95% of all tropical timber trade, originate from sustainably managed forests.

The *UN Forum on Forests* (UNFF) is the successor to the Intergovernmental Forum on Forests (IFF) and the Intergovernmental Panel on Forests (IPF). Housed within the UN Economic and Social Council, the objective of the UNFF is to promote the management, conservation and sustainable development of all types of forests and to strengthen long-term political commitment to the implementation of existing agreements, such as the Forest Principles of Agenda 21 and those developed under the IFF/IPF, and in a manner consistent with and complementary to existing international legally binding instruments relevant to forests. Among its functions is to monitor and assess progress at the national, regional and global levels through reporting by Governments, as well as by regional and international organizations, institutions and instruments, and on this basis consider future actions needed. On the basis of this monitoring and assessment, the Forum will consider the development of a legal framework on all types of forests. This process will also develop financial provisions to implement any future agreed legal framework.

Although there is no international convention on forests, there are a number of conventions that touch on forest-related issues, including the Convention on Biological Diversity, the Convention on International Trade in Endangered Species, and the UN Framework Convention on Climate Change (issue number 206 of FAO's *Unasylva* addresses forestry-related conventions in more detail).

3.3.2 Economic Policy

According to Singh *et al.* (2000), "Forests will be protected when the people conclude that forest conservation is more beneficial (e.g., generates higher incomes or has ecological or social values) than their clearance." This succinctly summarizes the argument for economic policies: as long as there is a greater incentive to cut forests than there is to preserve them, deforestation is likely to continue.

Therefore, a key element of any policy response needs to be economic policy. In many countries, economic policies are geared more towards promoting deforestation than to reducing it. Examples of so-called perverse incentives (subsidies) to the forestry and agricultural sectors that include tax preferences, capital and infrastructure supports, credit and insurance support, and marketing and price supports. Internationally, such policies amount to billions of dollars each year that directly or indirectly underwrite the costs of large and medium-sized enterprises in the logging and agricultural sectors – the most significant contributors to forest clearance. Removing such subsidies, therefore, would reduce the economic incentive to deforest.

Another issue is under-valuation of forest resources. According to Noble and Dirzo (1997), "there has been a history of undervaluing the forest resource; for example, royalties, purchase costs, or 'stumpage' payments have often been set too low to recover the costs of management, let alone the costs of externalities." These low prices provide an incentive for land-managers to sell off forest resources so as to put into place agricultural systems with higher rates of return. The authors suggest putting into place full valuation of forest products, including non-timber products such as fruits, water catchment and other so-called "ecosystem services," and intangible values.

At the international level, debt-for-nature swaps have been introduced in a number of developing countries, in which a country arranges to have part of its debt canceled in return for setting aside land areas as protected areas. With agreement reached on the Kyoto Protocol, an increasing number of private sector firms in the energy sector are investing in carbon-sequestration projects in the humid tropics. The Protocol obliges industrialized (Annex 1) countries to reduce their greenhouse gas emissions, and creates innovative mechanisms by which emissions allocations can be traded among states. Parties may meet part of their emissions targets by sequestering carbon in forests, which are also referred to as carbon *sinks* or *offsets* (see Chapter 7 for details). The Protocol's Clean Development Mechanism permits Annex 1 parties to invest in afforestation and reforestation projects in non-Annex 1 (developing) countries. A number of developing countries have been exploring the possibility of entering the carbon market by protecting tropical forests or reforesting large areas. However, international prices for carbon still remain fairly low (generally between $1-15 per metric ton), and it is unclear how markets will respond in the future. So, the promise of carbon trading for forest conservation on a large scale remains to be seen.

At the local level, easements and management agreements can provide incentives to conserve forestlands. Easements represent a method commonly used in developed countries, in which property taxes are reduced in return for the landowner's commitment to preserve the natural resources and restrict certain kinds of land use. Conservation easements generally take the form of written contracts, and the intent is that although the forest area remains in private hands, it will be protected in perpetuity (Mitchell and Brown 1998). Management agreements take the form of tax incentives or direct support to land owners to engage in conservation-related behaviors. They are designed to keep land in an appropriate use, such as forestry or agriculture. The largest of these is the Federal Reserve Program in the United States.

Indirectly, policies that promote recycling and alternatives to wood in construction can reduce the rates of deforestation. OECD countries have increased the percentage of waste paper that is recycled by an average of 29 percent over the past decade. Paper recycling rates now average about 42 percent of for the OECD (CIESIN and YCELP 2002). Recycling reduces the economic incentive to cut down forests.

3.3.3 Legal Entitlements and Land Tenure Policy

One of the drivers of deforestation discussed by Geist and Lambin (2001) is the race to obtain legal title. This driver is or has been especially prevalent in countries in which frontier areas were essentially open to anyone who wished to stake a land claim. This is increasingly rare, though parts of the Brazilian and Ecuadorian Amazon continue to be settled in this way. In

Brazil, until recently settlers were required to keep one half of their allotment of 100 hectares in forest. This law was recently changed to reduce the threshold to 20 percent.

Secure land tenure has been posited as a crucial determinant of sustainable land management. This is based on the assumption that if the landowner has legal title to the land, he/she will be more likely to invest in the property and manage it properly than if title is unclear. However, research has not necessarily borne this out, and in Switzerland, Africa, and parts of South Asia, common property resource management has resulted in sustainable management of forestlands for generations (Gibson *et al.* 2000, McKean and Ostrom 1995).

Entitlements to forest resources can be customary or codified. For instance, land owners may allow certain uses on their land, such as gathering of non-timber-forest products (NTFPs), that are purely customary (Scoones 1998). These entitlements may be seasonal or year round, and may be limited to certain subpopulations (women, herders). As with common property resource management institutions, such customary entitlements can have enduring qualities that make up an important component of livelihood strategies.

3.3.4 Conservation Policy

Two major approaches can be summarized under conservation policy: conventional protected areas and collaborative management approaches. Both have their roles.

Conventional protected areas are areas set aside by governments for conservation purposes. The IUCN protected areas categories show that there are different levels of protection, each designed to meet specific conservation needs while permitting various degrees of use. Category I includes strict nature reserves, which are managed mainly for science of wilderness protection. Categories II and III are national parks and natural monuments managed mainly for ecosystem protection and recreation. Category IV are habitat and species management areas, managed primarily for species protection. Categories V and VI include, respectively, landscapes/seascapes and managed resource protected areas designated for sustainable use of ecosystems. By 2000, the world's 30,000 protected areas covered over 13,250,000 square kilometers of the earth's land surface (WCPA 2002).

Within conservation circles, there are debates about which policies are most effective in ensuring the protection forest resources. In a study of 93 protected areas in 22 tropical countries, Bruner *et al.* (2001) found that the majority of parks are successful at stopping land clearing, and to a lesser degree effective at mitigating logging. The researchers found that park effectiveness correlated with basic management activities such as enforcement, boundary demarcation, and direct compensation to local communities. The authors conclude that even modest increases in funding would directly increase the ability of parks to protect tropical biodiversity.

Collaborative management approaches seek to include communities, the private sector, researchers and other stakeholders in decision-making processes that lead to management plans. Collaborative or participatory management developed in response to what was perceived to be an over-reliance on "guns and fences" for conservation that overlooked local needs. The collaborative management approach operates along a continuum, from consultation to outright delegation of decision-making to stakeholders (Borrini-Feyerabend *et al.* 2000, Borrini-Feyerabend 1997, Participatory Management Clearinghouse). Collaborative or co-management has evolved out of many traditional forms of common property resource management, such as those practiced by Swiss communes or traditional forest-dwellers. The approach has been utilized with great success in India, where the Forestry Department has delegated forest area management authority to many local communities.

3.3.5 Population Policy

Although population dynamics was not the biggest factor in determining deforestation rates according to the study cited in Section 3.2 (Geist and Lambin 2001), population policy plays an important role in national sustainable development strategies. Because family planning and reproductive health services are generally scarce in isolated forest areas, efforts are being made to link conservation and family planning interventions in some regions. Governments that pay attention to population policy, and implement client-centered family planning programs, are more likely in the long run to experience population stabilization, an important component of overall sustainable development (Gardner-Outlaw and Engleman 1999, PRB 2001).

4.0 - Land Degradation and Desertification Overview

According to Article 1 of the United Nations Convention to Combat Desertification (UNCCD), "'desertification' means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities." Land degradation, in turn, is a reduction in the biological and economic productivity of terrestrial ecosystems, including soils, vegetation, other biota, and the ecological, biogeochemical and hydrological processes that operate therein (Reynolds 2001). Several other concepts are important in studying land degradation and desertification: *sustainability* or the ability of the land to remain productive over long time periods; *resilience* or that quality of a resource that makes it sustainable or resistant to degradation; *vulnerability* or the risk of specific adverse outcomes for people or ecosystems in the face of different stresses; and *carrying capacity* or the number of people and animals the land can normally support without being significantly stressed.

Land degradation results from human and natural processes that cause a reduction in the natural resource base or the regenerative capacity of terrestrial ecosystems. Natural processes such as floods, erosion, drought and forest fires have shaped natural landscapes well before human evolution. These transformations can benefit one community of plants or animals over another. However, implicit in the concept of degradation is a human value judgment – that is a switch from a desirable state to a less desirable state as perceived by humans. The prologue of the UNCCD emphasizes that "human beings… are at the center of concerns to combat desertification and mitigate the effects of drought." What has happened in the past two centuries is that the impact of human agricultural, industrial and extractive activities, when coupled with natural and human-induced climate variation, is leading to land degradation on an unprecedented scale.

Thus, land degradation and the related term "desertification" must be understood as the result of human activities and natural factors that produce negative outcomes for the livelihoods of people living in those environments. Land degradation can occur anywhere, and is particularly prevalent in areas of subsistence agriculture and mountainous environments. Land can also be degraded by extractive, waste disposal or industrial activities (see Chapter 8 on urbanization). There is less consensus over the definition of the term "desertification" (Glantz and Orlove 1993, Reynolds 2001), but for the purposes of this guide we will adopt an approach similar to the UNCCD: desertification is degradation that occurs in drylands, the arid, semi-arid and sub-humid areas of the world and particularly those in the lower latitudes.

The processes of land degradation and desertification are not new. Bunney (1990) offers evidence of land degradation from early human history in the area surrounding Lake Patzcuaro in Mexico. Olson (1981) examines clues from the collapse of ancient civilizations such as the Mayas (Central America) and Sardis (Turkey) that suggest that over-exploitation of land resources played a significant role. In the 1930s the United States experienced a prolonged drought in the mid-west called the "dust bowl" which led to localized economic collapse, farm foreclosures and population displacements. Only recently, however, have degradation processes commanded attention from policymakers at the regional and global levels.

The 1972 Stockholm Conference on the Human Environment was a milestone in concern over environmental preservation. In 1974, the United Nations called for global action on desertification with the passage of Resolution 3337 (XXIX) recommending a Conference on Desertification (UNCOD) in 1977. It took another 15 years, however, for an internationally sanctioned plan of action to be developed in the form of the UN Convention to Combat Desertification (UNCCD), one of the three "Rio Conventions" (so-named because they were created at the 1992 UN Convention on Environment and Development).

This chapter includes sections addressing: the causes of land degradation and desertification (4.1); the status and extent of land degradation and desertification (4.2); costs associated with land degradation and desertification (4.3); and Policies for Controlling Land Degradation and Desertification (4.4).

4.1 The Causes of Land Degradation and Desertification

In the context of land degradation and desertification, researchers speak of "fast" and "slow" variables. In terms of biophysical variables, crop yield, for example, would be a fast (or quickly changing) variable whereas soil fertility, which affects yield, is a slow (slowly changing) variable. In terms of socio-economic variables, household debt would be a fast variable whereas market access, which affects debt, is a slowly changing variable. Importantly, these biophysical and socio-economic variables are closely linked and constantly changing, both in the short- and long-term.

As this suggests, land degradation and desertification have natural (or biophysical) and human-induced components. It is sometimes difficult to determine where the biophysical component leaves off and the socio-economic drivers begin. As Reynolds (2001) notes, "The complex of socio-economic and biophysical causal factors involved in land degradation has differing levels of influence in different regions of the world and at different times." This section will begin by exploring the human causes of land degradation and desertification, followed by a discussion of human interactions with biophysical processes.

4.1.1 Human activities and their impacts

As with deforestation, it is possible to speak of proximate causes and indirect drivers of land degradation and desertification. The proximate causes include factors such as cropland expansion, intensification of agriculture and livestock extension, especially in so-called "constrained ecosystems" where environmental fragility is linked to periodic drought, poor soils, or steep slopes (Agbo *et al.* 1993). Wood extraction and infrastructure extension can also play significant roles. The latter includes the extension of human settlements, road extension, and the spread of irrigation technologies such as channels, boreholes, watering points.

The indirect drivers of land degradation and desertification include population density and growth, migration, and policies that encourage or subsidize unsustainable practices (e.g., overstocking of livestock, decreases in fire frequency, irrigation with saline water, etc.). Wars, internal conflicts and refugee resettlement programs can also cause population displacements into fragile environments. If refugees are resettled in new ecological zones, they may bring with them practices that are not adapted to local climatic conditions. Or they may be resettled at a population density that is inappropriate to the new environment. This same dynamic may occur when formerly nomadic peoples come to live in permanent settlements, which has happened in parts of Central Asia and the Sahel.

We can divide human activities that affect land degradation roughly into two realms. The first is the agricultural sphere, which includes cropping and pastoral activities that affect agro-ecosystems. The second are those activities that affect the ecology of natural or quasi-natural ecosystems.

Agricultural land degradation is a gradual process in which soil nutrients and organic matter are depleted. Cropland soil degradation occurs as a result of cropping in which soil conservation practices are either absent of insufficient. Soil conservation practices include application of external inputs (e.g., organic or chemical fertilizers); terracing, bunds or contour plowing; and fallowing (i.e., periodically taking the cropland out of production). Under continuous cropping with no external inputs, crop land will naturally become depleted of key nutrients (e.g., minerals such as nitrogen, phosphate and potassium) and organic matter.

Pasture land, on the other hand, can become degraded through over-grazing – i.e., a density of livestock in excess of the carrying capacity of the land. Livestock affect both the soil structure and the vegetation cover of herbaceous plants. Removal of vegetation cover exposes soil to the elements (wind and rain), which when combined with soil disturbances, can speed erosive processes.

There are three principal soil degradation processes: physical, chemical and biological. The first involves a decline in soil structure, leading to reduction in infiltration, increase in rainfall runoff, and exacerbation in erosion by water and wind (Lal 2001). The second, chemical degradation, involves processes such as salinization, alkalinization, leaching, and acidification. The last of these includes reduction in humus quality and quantity or declines in soil biodiversity. The overall result of these processes is:

- reduction in biomass productivity
- water pollution, contamination and eutrophication
- decline in air quality through suspended dust particles
- emission of carbon, nitrous oxides and other greenhouse gases into the atmosphere

Soil degradation is particularly severe in regions of the world where continual cropping and low-input agriculture is practiced. This includes large regions where subsistence farming is the rule: much of East, Southeast, and South Asia; sub-Saharan Africa; and parts of Latin America. Mountain and hill regions are particularly prone to land degradation through physical processes (soil erosion), though investments in terraces in those areas have greatly reduced erosive processes. However, it is important to note that soil degradation is not limited to the developing world. Soil erosion affects large parts of the American mid-West, as witnessed by the thousands of tons of topsoil that are carried via the Mississippi River into the Gulf of Mexico each year (Anderson and Magleby 1997).

Soil: A Critical Natural Resource

Soil is much more than a simple medium for crop production. It is a dynamic ecosystem, a living membrane that cycles life-sustaining nutrients between bedrock and atmosphere. Good soils are home to some of the world's highest and most diverse populations of species, including earthworms, insects and microorganisms that help plants absorb nutrients and even protect against disease. These organisms break down dead plant and animal tissue to form humus, the dark and crumbly carbon-based portion of soil. Healthy soils rich in humus soak up water, invite airflow and resist erosion. Humus-poor soils shed water, restrict root growth and break apart in rough weather. Soil ecosystems are threatened by the progressive loss of organic material as farmers abandon organic for chemical fertilizers and offer the land less fallow, or resting, time. Currently, however, little research is being conducted on the species composition and biological properties of soils.

Cultivated soils lose not only humus and organisms but also micronutrients needed for plant and human health. Fertilizers replace nitrogen, phosphorus and potassium in soils, but rarely much else. As crop after crop is reaped from the soil and shipped elsewhere, with little return of comparable organic material to the soil, there is no assurance that sufficient micronutrients will remain in the soil for future crops and future generations.

Source: Engleman and Leroy 1995.

Drylands are prone to land degradation in the process commonly known as desertification. Drylands are regions in which the ratio of precipitation to evapotranspiration is 0.65 or lower (this ratio is also referred to as the index of ariditiy). The vast majority of drylands are in pasture or rangelands (88 percent). Only nine percent are in rainfed cropland, and three percent are under irrigation (UNEP 1992). The most commonly cited reason for dryland degradation is over-grazing. Firewood collection in some regions, particularly for large urban areas, has resulted in reductions in tree cover and consequently greater exposure of land to erosion. Salinization and water logging can also be a problem in irrigated drylands. The former occurs in areas with insufficient drainage, where salts contained in the irrigation water remain in the soil and increase in concentration (Dregne 1986). The latter results from a rising water table, to the point where plant roots are permanently saturated.

Human impacts on natural or quasi-natural dryland ecosystems include habitat fragmentation and loss; introduction of alien and invasive species; air, soil and water pollution; and climate change (Reynolds 2001). Activities that affect these ecosystems include some of those agro-pastoral and firewood collection activities mentioned above. Another activity is fire management, which depending on the circumstances may mean either excess use of fire, or reduction of fire. Wildfires are an important part of dryland ecosystem functioning, so any change in fire regimes can have adverse impacts.

4.1.2 Human-Biophysical Linkages

The human activities described above tend to exacerbate pre-existing conditions. These can be divided into meteorological dimensions and ecological dimensions.

The meteorological or climatic dimension of desertification relates to the paucity and variability of rainfall, and to the extremely high rates of evapotranspiration. With or without human settlements, arid and semi-arid regions are characterized by highly variable rainfall. The tragic droughts in the Sahel and Ethiopia of the mid-1970s and 1980s are testimony to the variability of rainfall, the fragility of these environments and the vulnerability of the populations that live in them. However, there is evidence to suggest that changes to land cover itself can affect the micro-climate in certain regions (Taylor 2001, Kumar *et al.* 1998). Progressive removal of vegetation cover changes the surface albedo (the degree to which the land surface reflects the sun's energy) and can also reduce atmospheric humidity, which in turn affects cloud formation and precipitation. Thus, land clearance activities may have positive feedbacks that create localized reductions in atmospheric humidity and rainfall. Links between the land surface characteristics and the hydrologic cycle are further explored in Chapter 6.

Research suggests that airborne dust and smoke from fires may cause reductions in rainfall. Activities such as grazing and agricultural cultivation that expose and disrupt topsoil can increase the amount of dust blown into the air. Land clearing activities through burning sends up plumes of smoke (often visible on satellite images). Dust and smoke have relatively large particle sizes. These larger-sized nuclei have the effect of increasing the threshold for droplet formation in clouds, thereby reducing rainfall (Rosenfeld 2001).

The ecological dimensions of desertification relate to the natural characteristics of dryland areas. Dryland soils are sensitive to disturbances because they contain small amounts of organic matter and have low aggregate strength. Tillage and grazing by domesticated animals can have profound effects on these soils, including lowering their permeability to water (thus decreasing infiltration), disturbing their surface integrity (thus increasing erosion), and decreasing their nutrient levels for plant growth (Reynolds 2001). Vegetation is composed of grasslands, shrublands, and savannas, with trees scattered or concentrated along water courses. Under these circumstances, tree cutting activities or grazing has significant long-term impacts if done at an unsustainable rate.

Thus, the complex of pre-disposing factors and human activities work together to adversely affect the delicate ecological balance. Communities in dryland areas are adapted to periodic drought conditions, but a fundamental question is whether or not the same traditional practices of low-intensity agriculture and herding can be carried out higher levels of intensity (due to higher population densities) without causing long-term damage. Add to this the policy measures implemented by some governments to sedentarize nomadic peoples, and the pursuit of sustainable development in drylands becomes even more complicated.

4.2 The Status and Extent of Land Degradation and Desertification

One of the largest efforts to date to measure soil degradation was the Global Assessment of Human Induced Soil Degradation (or GLASOD; UNEP 1990). The GLASOD data base contains information on soil degradation within map units as reported by numerous soil experts around the world through a questionnaire. It includes the type, degree, extent, cause and rate of soil degradation. According to this expert assessment, the land area prone to soil degradation is estimated at about 2 billion ha (or 20 million Km^2), of which 562 Mha (29.7 percent) is agricultural land, 685 Mha (34.8 percent) is permanent pastures and 719 (35.5 percent) is forest and woodland (Oldeman *et al.* 1991 in Lal 2001). Some 1.6 billion ha are reported by GLASOD to be subject to erosion – 1.1 billion to water erosion and 500 Mha to wind erosion (Middleton and Thomas 1997).

Drylands account for roughly 47 percent of the global land mass, or approximately 5.2 billion ha. Of this, roughly 60-70 percent are said to have undergone some level of desertification. Sixty-four percent of all drylands are found in Africa and Asia (32% each). Another 12 percent are found in North America, 11 percent in Australia, and 9 percent in South America. Though these regions may appear to have less drylands, they nevertheless make up important proportions of their landmasses (e.g., over 75 percent of the Australian continent). Region by region assessments of drylands and desertification can be found in Dregne (1986) and Dregne and Chou (1992), and an assessment for China can be found in Zhu and Wang (1993).

GLASOD was an important benchmark, but it has come under criticism recently for being overly generalized. According to Orone (1996), "the accuracy, meaning, and practical usefulness of these estimates of global desertification trends are increasingly questioned, particularly given the difficulty of determining the causal relationships of such complex processes." Others suggest that there is a need to move beyond such global estimates by undertaking localized studies and on-the-ground measurements (Niemeijer and Mazzucato 2002).

This reflects the desire on the part of scientists to put the understanding of land degradation and desertification extent and processes on firmer empirical footing. Current data deficiencies are due to the limited number of databases, and to the fact that these data have a limited temporal scale and mainly reflect biophysical conditions. The socioeconomic dimensions are derived from simple overlay techniques (man/land ratios, human population carrying capacity), and no systematized and global data sets exist on human causes, since individual case studies follow different protocols. A new direction would be to link biophysical and socioeconomic properties such as, for example, soil properties (physical, chemical, biological) with landscape or ecosystem dynamics, which in turn are linked to land-use practices (land tenure, livestock, wealth, etc.). Such a data set would need to be georeferenced and allow for measuring system changes.

Understanding of the extent and rates of desertification have also been clouded by definitional confusion and various myths, such as the "the myth of the marching desert" (Forse 1989), which have sometimes served to further the objectives of international development agencies rather than clarify the nature of the problem (Warren and Agnew 1988). One of the common misconceptions is that deserts expand outwards from a core. This would suggest that the way to combat it is to put up "green fencing" as a way to stop the progression of dunes from swallowing up the land. Actually, desertification can be highly localized, spreading from an area that is degraded outwards (Forse 1989, Dregne and Chou 1992). Stopping the southward movement of the Sahara, therefore, is more easily achieved by increasing the sustainability of farming systems in the savanna belt (just south of the Sahel) than by tree-planting further north.

Some recent evidence throws into doubt the notion that the Sahara is actually growing at all. An examination of AVHRR satellite data covering the southern fringe of the Sahara shows that while the fringe of the desert (as marked by the 200 mm rainfall isoline) has fluctuated markedly, there has been virtually no net increase in the desert's area from 1980 to 1997 (Tucker and Nicholson 1999). In fact, the trend line suggests that the region just to the south of the Sahara (known as the Sahel) has actually become slightly greener (moister) during this time period. Schulz (1994) suggests that the Saharan desert may not have changed much in overall extent since the 19th century.

Research on soil degradation in one Sahelian country, Burkina Faso, examined the evidence in support of desertification using several approaches. They looked at correlations at the provincial level between agricultural yields, population density, rainfall, and manual versus animal traction tillage. The researchers then examined soil nutrients and characteristics for samples taken from the same area in 1960 and the mid-1990s. Finally, they examined the difference in soil characteristics between long-term cultivated and uncultivated lands. Results showed little supporting evidence for widespread degradation of crop and fallow land; yield fluctuations were found to be more highly correlated with rainfall than with population densities or level of technological inputs (Niemeijer and Mazzucato 2002).

It is likely that future studies of land degradation and desertification will need to rely on combinations of satellite observations of climate and land cover, coupled with ground-based assessments of human activities and soils, to be able to draw firm conclusions about trends and severity. An example of this approach is a quantitative assessment of observed wind erosion in the Manix Basin of the Mojave Desert in southeastern California from 1979 to 1997 was based on field trips, Landsat Multispectral Scanner (MSS) imagery, and Airborne Visible Infrared Imaging Spectrometer (AVIRIS) data (Okin *et al.* 2001). It revealed that 3,000 ha of land were directly disturbed by central-pivot irrigated fields, housing developments and roads, and 3,000 to 9,000 ha of land may be expected to be indirectly disturbed through sand blown several kilometers beyond the downwind boundary of a field. This sums to 6,000 to 12,000 ha total disturbance, or 15-30% of the total basin floor area, and approximately 23-45% of the non-playa area of the basin.

4.3 The Costs of Land Degradation and Desertification

Desertification costs are often borne by the poorest of subsistence farmers and herders. Globally, UNEP estimates that economic losses from desertification are more than $42 billion. The costs of land degradation and desertification are most often measured in terms of lost productivity. This could mean reduced crop yields, grazing intensities, etc. Secondary costs include loss of ecosystem services, and indirect costs are those associated with mitigating desertification.

Dregne and Chou (1992) provide criteria for a global assessment of desertification, classifying land according to usage and range of desertification severity, and offer a cost-benefit analysis for recapturing lands. They also present tables on the annual income foregone due to desertification and on the cost of rehabilitation over a 20-year period.

In the United States, loss of crop yield due to soil degradation has been a subject of extensive study. Langdale and Shrader (1982) provide tables on crop yield estimates associated with various levels of soil erosion. Mokma and Sietz (1992) report on a study of soil erosion's effects on crop yields in South-central Michigan. The authors found that production in severely eroded plots averaged 21 percent less than production in normal or slightly eroded soils.

Indirect costs of land degradation and desertification generally include the effects of damages due to sediments in streams, canals, dams, and reservoirs. These are usually harder to assess, and many of the impacts may not be felt directly by the farmer. Reynolds and Stafford-Smith (2002) suggest that a distinction needs to be made between the local costs and the regional impacts. Gully erosion to the local land manager may not result in any discernible decrease in income, yet to the manager of the hydroelectric dam downstream, the increased sedimentation may represent real costs in terms of reductions in power generation. Should it be determined that the gully erosion is having an impact on hydroelectric power generation, it still remains to be determined if the gullies can be economically rehabilitated and who should bear the cost. These issues make desertification mitigation complicated.

4.4 Policies for Controlling Land Degradation and Desertification

In this section we focus first on policies to prevent land degradation, and then examine desertification control.

4.4.1 Land Degradation

Approaches to prevent land degradation have been around since the dawn of plant domestication. Indigenous knowledge systems the world around have been employed for centuries to ensure that soil and water are conserved for optimal cropping. For example, in Central America the dibble stick is used to punch holes for seed planting on steep slopes, where plowing would lead to severe erosion. Elephant grass is planted on hillsides in East Africa both as forage, and as a valuable means to prevent soil erosion. Terraced rice cultivation in Nepal and the Philippines has been in practice for hundreds of years. And farmers in West Africa have long used branches and stones to slow rainwater runoff, thereby increasing infiltration.

Since the early 20th century, governments began to be actively engaged in soil conservation in efforts to protect a vital part of the national patrimony. The Natural Resource Conservation Service (formerly the Soil Conservation Service) of the United States has thoroughly mapped and tested soils in every corner of the country, and provides advice to farmers on how best to manage their croplands. Conservation tillage is becoming increasingly popular, both for its soil conservation attributes, and for reductions in greenhouse gas emissions that result. Sophisticated technical equipment for precision farming, which utilizes global positioning systems to customize fertilizer and pesticide applications, are now being deployed in large-scale industrial agriculture.

In the developing world, some have posited that increasing population densities in rural areas inevitably lead to land degradation and declining yields. And there is evidence to support this argument, though population size or density is rarely the sole contributing factor. Rather, population variables tend to be part of a matrix of factors that include failed institutions, climate conditions, inherently poor soils, and lack of incentives for proper soil management (e.g., tenure insecurity, low market prices). However, there is much to be learned from regions where the downward spiral of soil degradation and poverty has not inevitably resulted from increasing population density.

Case studies from Machakos District in Kenya and in Chivi communal area in Zimbabwe suggest that improved soil productivity and more secure livelihoods can and do occur in a context of increased population density, and even benefit from it (Tiffen *et al.* 1994, Scoones 1997). The factors that can be important for averting land degradation include appropriate technologies for soil management adopted and propagated by local farmers (rather than imposed from outside); access to markets, road infrastructure and development of local market towns for food processing; cash-cropping as opposed to purely subsistence agriculture; and development of local management capacity and skills through education and agricultural extension. Rather than blanket solutions, Scoones (1997) urges more fine-tuned and people-centered development interventions in which the historical context and local specificity of needs are acknowledged. Such an approach recognizes local environmental knowledge, and sees the agricultural researcher as a facilitator rather than an expert prescribing solutions.

Integrated soil fertility management (ISFM) responds to many of these concerns. ISFM emphasizes context-specific adaptive responses, tailored to local conditions and opportunities and constraints faced by farmers, and it advocates a careful management of nutrient stocks and flows (IIED 2000). Recognizing that efforts to improve soil fertility through the use of organic fertilizers alone have been stymied because of the lack of sufficient organic matter in the local environment (e.g., manure, crop residues and household wastes) and the high labor requirements to collect and apply organic matter, ISFM supports approaches that combine organic and mineral fertilizers (Breman & van Reuler 2000). Furthermore, recognizing that farmers need adequate incentives to manage soil resources, policies that promote ISFM include a supportive macro-economic environment (e.g., adequate farm-gate prices), access to inputs at reasonable cost, and research and extension tailored to farmer needs and constraints.

4.4.2 Desertification

Because desertification is essentially land degradation that occurs in drylands, many of the remedies discussed above are also applicable in dryland environments. Desertification is a significant problem in the world's least developed countries, from the countries of the Sahel in West Africa, where per-capita incomes hover around $1000 per year, to arid parts of the Indian Subcontinent. With this in mind, the UNCCD has promoted approaches to combat land degradation that focus on poverty alleviation and that utilize local-level participatory methodologies, similar to ISFM. According to Article 1 of the Convention, "combating desertification includes activities which are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development."

The Convention text refers frequently to sustainable development, climate change, biological diversity, water resources, energy sources, food security, and socio-economic factors. The interactions between these issues and desertification are often not fully understood, but they are clearly important. The Convention therefore emphasizes the need to coordinate desertification-related activities with the research efforts and response strategies inspired by these other concerns. The Convention has already succeeded in promoting the development of national action plans and in leveraging donor resources to support implementation.

Reynolds and Stafford Smith (2002) provide five policy-relevant assertions from a major conference on desertification hosted by Dahlem University in Berlin in June of 2001 (see Table 1). These assertions represent state-of-the art thinking on desertification that are relevant to decision-making.

The Dahlem workshop came to a number of recommendations of relevance to implementation of the UNCCD:

- Desertification has no universal solution, yet there are a limited number of sensible approaches to be pursued. What works in grasslands with nomadic pastoralists will likely not be transferable to environments were rainfed subsistence agriculture is practiced; and what works for the rainfed farms will not necessarily work where irrigation is prevalent.
- Everything to do with desertification is affected by the scale and purpose of concern. Desertification must be disaggregated to specific types of degradation and other changes in human-environment systems at the community or, possibly, the national level.
- It is better to address the underlying causes or drivers of desertification (the 'slow' variables) rather than to try to address only the consequences (the 'fast' variables). Greater understanding of the drivers is necessary, and there needs to be better interaction between scientists and policy makers at all levels.
- Coordination of aid programs addressing desertification is needed.
- National governments, as parties to the UNCCD, should be urged to take their commitments under the convention seriously. In particular governments should identify, through integrated natural and social science research, the critical 'slow'

variables at the community and national level so as to address them before critical thresholds are crossed in which intervention costs markedly increase.

There are a number of initiatives underway that aim to contribute to a better understanding of desertification and to explore policy responses. The Dryland Land Degradation Assessment, a proposed project under the UNEP Global Environmental Facitlity (GEF), is intended to assist in the development of drylands through the provision of better information on land degradation. The Assessment, Research and Integration on Desertification (ARID) is a joint LUCC and Global Change and Terrestrial Ecosystems (GCTE) initiative, the goal of which is to test and refine the Dahlem Desertification paradigm (described above). Finally, there is AIRDnet, an international network of researchers with a multitude of case studies, the goal of which is to classify what matters in terms of fast and slow variables, drivers, etc., in which locations, and why, and to develop integrated assessment models.

Table 1. Policy-Relevant Conclusions about Desertification

General Statement	Assertion	Therefore…
Change in human-environment systems is experienced by humans in the form of fast moving variables, such as crop yields. However, there are only a small number of critical 'slow' variables underlying these changes in any particular system at its particular scale. These include things like soil nutrient change, which occurs over time scales of decades. Slow variables constitute the critical human/environment goods and services for that system.	1. Slow variables define long-term change by constraining the fast variables.	To understand vulnerability to desertification, it is important to pay attention to cause rather than effect by identifying the slow variables of importance to the system.
As the state of the linked human-environment described by these slow variables declines, the cost of recovering the system increases. This increase may be steady or sudden, but in general there are stages of decline at which it is necessary to call on resources from a higher scale in order to reverse the change (e.g., national or regional institutions, donor intervention, etc.)	2. Non-linearities in the system create thresholds at which there are significantly higher costs in recovery.	Efficient intervention should focus on the most critical slow variables (e.g., adding nutrients to the soil or building community social capacity), preferably before the points at which the cost of intervention increases markedly. These relationships are reasonably predictable.
Given that desertification concerns biophysical change, the slow variables of importance always include factors in both the biophysical and human dimensions. Neither dimensions can simply be regarded as the universal predisposing factor.	3. The risk of desertification is always determined by factors from both human and environment dimensions.	To assess the risk of future desertification and to intervene efficiently, both human and environmental variables must always be considered.
The human-environment system evolves over time, resulting in different suites of 'slow' variables becoming important as changes in human factors such as standards of living or market access and environmental factors such as climate and regional vegetation take place at the next scale up from that of concern.	4. The slow variables of importance at any particular scale are nested hierarchically within a suite of even slower human-environment variables.	To ensure that intervention is still appropriate and timely , the evolution of the human-environment system must be monitored. Interventions at one scale generally alter the human-environment system at the next scale down.
Although the previous point might suggest that it is hopeless trying to keep track of what human-environment factors matter, there are in fact only a limited numbers of pre-eminent ways in which the systems operate at any given scale, and each scale is governed by the same assertions as above.	5. There are a limited and determinable number of sets of slow variables of importance at any scale.	Problems at one scale may be fixed by intervention at that scale or by evolution of the system. Interventions must be compatible with these processes. Subsidies from outside the system are a particular case in point.

Source: Reynolds and Stafford Smith (2002)

5.0 – LUCC and Biological Diversity

Biodiversity is the web of life that distinguishes planet Earth from the other lifeless spheres in our solar system, if not the universe. There are three different levels of diversity: ecosystem diversity, species diversity, and genetic diversity (i.e., diversity within species). Our focus here will be on terrestrial (as opposed to aquatic) ecosystem diversity, and on species diversity within terrestrial ecosystems.

The number and types of organisms inhabiting the planet have varied immensely during geologic history. In part, these variations have been caused by the evolution of new types of organisms and the elimination of others due to environmental changes and mass extinctions, as occurred at the end of the Mesozoic period 65 million years ago which saw the extinction of the dinosaurs.

Now, however, human transformations of the earth's surface are a force of geologic proportions that is affecting biodiversity in almost every corner of the world. Changes are occurring rapidly enough that the result is a net loss of species rather than a proliferation of new life forms. Species have been disappearing at 50-100 times the natural rate, and this is predicted to rise dramatically. Based on current trends, an estimated 34,000 plant and 5,200 animal species – including one in eight of the world's bird species – are critically endangered. According to the IUCN Red List (2000), almost 10 percent of animal species and 14 percent of plant species are critically endangered.

The greatest human impact on biodiversity is the alteration and destruction of habitats, which occurs mainly through changes in land use: draining of wetlands, clearing of land for agriculture, felling of forests for timber, and pollution of the environment and fragmentation. Other impacts on biodiversity, which will not be dealt with in this guide, include the development and potential proliferation of genetically modified organisms (GMOs), direct exploitation (e.g., over-harvesting of plants or animals), and introduction of alien (non-native) species.

Loss of species is significant in several respects. First, breaking of critical links in the biological chain can disrupt the functioning of an entire ecosystem and its biogeochemical cycles. This disruption may have significant effects on larger scale processes. Second, loss of species can have impacts on the organism pool from which medicines and pharmaceuticals can be derived. Third, loss of species can result in loss of genetic material, which is needed to replenish the genetic diversity of domesticated plants that are the basis of world agriculture (Convention on Biological Diversity).

In recent years, the international scientific community has made considerable progress toward fostering global awareness of the importance of biodiversity. As a result, a number of multiagency organizations have been established, and many conservation programs have been implemented. Nevertheless, the task of biodiversity conservation is daunting. This chapter will explore several issues at the interface of land-use and land-cover change and biodiversity. Section 5.1 provides an overview of the current distribution of terrestrial biodiversity. Section 5.2 explores those land conversion practices that are most harmful to biodiversity. Section 5.3 explores approaches to biodiversity conservation. Section 5.4 addresses biodiversity and climate change, and the ways in which current conservation efforts may fall short if they do not adequately account for likely ecosystem alterations and movements.

5.1 The Current Status and Distribution of Terrestrial Biodiversity

Nobody knows for sure exactly how many species exist, or how rapidly species are disappearing through extinction (*species* are defined here as a population of organisms that are able to interbreed freely; Wilson in Glowka *et al.* 1994). About 1.75 million species out of an estimated total of 10-20 m. have been collected and named by systematists, with the most undercounted species being found among bacteria, protoctista (microorganisms), insects and fungi. Though the total number of species is unknown, biologists and taxonomists have accomplished reasonably complete samples in specific regions such as Western Europe. Species inventories show that some ecosystems are richer in terms of biodiversity than others. Groombridge and Jenkins (2000) go so far as to say that "the single most important fact about biological diversity is that it is not evenly distributed over the planet."

In general, species diversity per unit area tends to increase with decreasing latitude, with highest diversity found in the tropics. Thus, in terms of natural land cover classes, tropical forests have the highest densities of biodiversity per unit area; desert, tundra, and boreal forests have the lowest. Topographical variations in the landscape lead to higher species diversity, and some highly localized ecosystems, such as wetlands, are also species-rich. Recognition that some areas possess higher levels of biodiversity, and especially endemics (plants or animals that are only found in localized areas), has fueled interest in the identification of biogeographical areas of species richness, and therefore of high conservation value.

5.1.1 Biodiversity Hotspots

A variety of approaches have been utilized to identify areas of high species richness and endemism. The "hotspots" term was coined by Norman Myers (1988) to indicate areas of high conservation value that are facing significant threats to conservation. Myer's first version was entirely focused on tropical rain forests. In its most recent iteration (Mittermeier *et al.* 1998), the hotspots analysis identified 24 high priority areas, including some temperate areas such as the California coast, the Mediterranean and New Zealand. Collectively, these 24 areas constitute just 2 percent of the earth's land surface, but contain an incredible 45 percent of known plant diversity and 35 percent of all non-fish vertebrates that are endemic (meaning they can be found no where else).

The Global 200 approach, adopted by the World Wide Fund for Nature (WWF), identifies 233 high priority areas that are globally representative of all habitat types. Olson and Dinerstein (1998) suggest that although tropical moist forests contain over half of all species diversity, the many other ecosystems that contain the remaining 50 percent also deserve consideration. These include tropical dry forests, tundra, temperate grasslands, polar seas, and mangroves, which all contain unique expressions of biodiversity with characteristic species, biological communities, and distinctive ecological and evolutionary phenomena. Given their focus on ecoregions, large units of land or water containing a characteristic set of natural communities, and given the large number of regions included on the list, the Global 200 ecosystems comprises a much larger proportion of the terrestrial land surface.

Hotspots and the Global 200 represent priority-setting efforts that focus on high value and highly threatened ecosystems. The Global 200 report states that, among terrestrial ecosystems included on their list, 47 percent are considered critical or endangered and 29 percent are vulnerable, leaving a little over a quarter that are stable or intact. An alternative approach, developed by Wildlife Conservation Society and CIESIN (2002), is to identify the world's last great wild areas, and to concentrate resources and attention to securing as much of those regions under some kind of conservation status. Presumably, this can be done at far less cost than conservation in densely settled areas. Ultimately, however, the two approaches are complimentary; Mittermeier *et al.* (1998) suggest that the hotspots approach be undertaken in combination with efforts to conserve the last remaining “pristine” wilderness areas.

5.1.2 Methods for Measuring and Mapping Species Diversity

A number of methods have been developed to estimate populations in a given environment. May (1988) reviews the kinds of information needed to make the answers more precise. The author considers various factors affecting biodiversity, including structure of food webs, relative abundance of species, number of species and of individuals in different categories of body size, and other determinants of the commonness and rarity of organisms. Reid (1992) takes the question a step further. Using a species-area curve (a curve that defines the relationship between land area and the number of species contained in it), he attempts to define a relationship between extinction rates in a region and the amount of habitat that is lost. Wilson (1988) uses archipelago systems to illustrate the relationship between habitat size and species diversity. The author presents a table of current estimates of the number of described species of earth organisms and also discusses the natural longevity and rate of decline of species.

Researchers have sought methods for extracting biodiversity information from remote sensing imagery. Obviously remote sensing cannot detect individual organisms, and therefore will never fully replace field surveys. However, analysis of images has helped researchers to identify areas that are likely to be species rich based on their spectral signature. Podolsky (1996) has developed a software tool called Diversidad to analyze Landat imagery of different ecosystem types, and has found through field verification that it consistently identified the locations of highest and lowest diversity. Beyond mapping landscape-level diversity, Rey-Benayas and Pope (1995) explore applications of Landsat TM imagery for monitoring of natural resources, planning development, and designing nature reserves. Similar corridor and park planning initiatives utilizing remote sensing are underway in Central America (NASA/CCAD Mesoamerican Biological Corridor) and in Brazil’s Atlantic Rainforest. Remote sensing can also be used to develop indicators related to the compositional, structural and functional components of biodiversity (Noss 1990).

5.2 LUCC and Biodiversity Loss

This section examines a number of land-use and land-cover change patterns that are leading to biodiversity loss. Given the importance of forests to biodiversity conservation, readers are encouraged to review Section 3.2 of this guide, which describes the drivers of deforestation. Many of the same LUCC processes are also driving biodiversity loss.

As noted in the introduction to this chapter, species extinction predates the appearance of hominids on the planet, yet there is no doubt that even prehistoric human activities have speeded species loss. Through their use of fire and through hunting, it is thought that early hominids contributed to the extinction of many large terrestrial mammal and bird species (Groombridge & Jenkins 2000). It is really only with the advent of large-scale agriculture, though, that species extinction rates began to rapidly increase. Today, agriculture channels some 40 percent of the planet's net primary productivity to meet human needs. According to Tilman *et al.* (2001), "land use and habitat conversion are, in essence, a zero-sum game: land converted to agriculture to meet global food demand comes from forests, grasslands, and other natural habitats." Today, 1.54 billion ha (or 15.4 m. square km.) is in cropland, and 3.47 billion ha is in pastureland, and according to Tilman *et al.* these are projected to increase 1.89 billion hectares and 4.01 billion ha respectively by 2050. Thus, by 2050 approximately 45 percent of the world's land surface will be dedicated, in one way or another, to agriculture.

While agriculture sometimes represents a wholesale conversion of land from natural states to crop or pastureland, often the process is a gradual one in which a succession of land uses "punches holes" in the fabric of nature in ways that can be deleterious to biodiversity. This process is known as forest or habitat fragmentation. Fragmentation can lead to reductions in total genetic variation, dispersal barriers and, for plants, the potential loss of key biotic interactions with pollinators and dispersal agents (IAI 1994).

The effects of fragmentation on species viability vary from species to species. Some species may actually benefit from the additional "edge effects" that are produced as fragmentation progresses, creating more boundary areas between forest and cleared lands. However, the majority species are likely to be negatively affected, especially as habitat patch sizes decline below a minimum required for population viability. If a species becomes marooned on a patch, this means that it is effectively cut off from reproduction with the larger population. This can lead to inbreeding and its attendant negative impacts on the genetic makeup of the population. Fragmentation can also make species more vulnerable to disease and storms, and alter relationships between predator and prey.

Looking to the future, it is likely that future demands for land, not just from agriculture, but for urban and industrial land uses and extractive activities will continue to put pressure on natural areas. The debate over oil drilling in Alaska's Arctic National Wildlife Refuge illustrates the tensions over conservation versus economic development. Opponents argued that drilling would interfere with caribou breeding grounds and trammel upon an otherwise pristine natural area. Proponents argued that the United States is overly dependent on foreign oil, that oil from the refuge would be a vital step towards energy self-sufficiency, and that drilling had not harmed conservation on the north slopes of Alaska. A similar debate is taking place in the Ecuadorian Amazon, where oil exploration and drilling have been underway for several decades, and have led to the opening up of vast tracts of land for settlement.

A study of human population and biodiversity distribution in Africa showed that human population density was highest in areas of high biodiversity, leading the authors to conclude that "conflicts between conservation and development are not easily avoided because many densely inhabited [areas] contain species found nowhere else" (Balmford *et al.* 2001). In the more densely settled northeastern U.S., others have sought a solution by channeling human settlements in a way that will not eliminate wildlife habitat (White *et al.* 1997).

Recognizing these inherent challenges to biodiversity conservation, Section 5.3 addresses several approaches to addressing biodiversity conservation.

5.3 Approaches to Biodiversity Conservation

Two major approaches to conservation policy, traditional protected areas and collaborative management, are outlined in Section 3.3 on policy intervention in deforestation. Briefly, traditional protected areas harness the power of the state to define areas in which varying degrees of conservation (from strict preservation to protected multi-use landscapes), to set policies for land and resource use, and to enforce those policies through allocation of resources and prosecution of offenders. Collaborative management or community-based natural resource management works with multiple stakeholders – government, community, and private sector – to identify and implement approaches to conservation that may include varying degrees of sustainable natural resource use (See NRM Changelinks). These two approaches are not mutually exclusive, and many instances of collaborative management in and around protected areas have been documented (Borrini-Feyerabend 1996).

There are also a number different approaches or theories that guide on-the-ground conservation as it relates to land use and land cover. One of these is the development of conservation corridors that connect a series of protected areas with protected landscapes so as to provide animal migration routes in response to habitat fragmentation. In Central America, which owing to its location as a land bridge between North and South America contains some 7-8 percent of the world's biodiversity on just one percent of its land surface, an ambitious initiative is underway to create a Mesoamerican Biological Corridor (MBC; see NASA/CCAD and PROARCA). The MBC intends to use a combination of land purchases and incentives to convince farmers living in the corridors to abandon slash and burn agriculture and cattle ranching for planting shaded coffee and cacao, which an serve as habitat for birds (Kaiser 2001). Similar corridor initiatives have been undertaken to link habitat remnants in Florida, and new initiatives are planned for Europe, western Australia, the Himalayas, and Brazil's Amazon and Atlantic forests.

Gap analysis is a tool that was developed to identify the gaps between species distribution and existing protected areas (Scott *et al.* 1993). In contrast to a species-by-species approach, or habitat protection for a single flagship species (e.g., lions or pandas), gap analysis identifies the gaps in representation of biodiversity in areas managed exclusively or primarily for the long term maintenance of populations of native species and natural ecosystems. Once identified, gaps are filled through new reserve acquisitions or designations, corridors, or through changes in management practices.

Conservation of agro-biodiversity through improved land-management is an important objective of the Convention on Biological Diversity (see CBD’s Agricultural Biodiversity website). A dozen crops together provide about 75 percent of the world's caloric intake. In terms of animal protein intake, just three domestic animals – pigs, cattle and chickens – constitute the largest sources (Groombridge & Jenkins 2000). The importance of this greatly reduced number of crops and animals means that conscious efforts will need to be taken to protect agro-biodiversity, if not for other reason because little utilized or exploited crop varieties provide important genetic information that can help to combat diseases and pests in the future. Some of the most valuable genetic resources are in the fields of subsistence farmers in the developing world, and countries like Mexico have made a conscious effort to exclude genetically modified crops in order to preserve the purity of their local varieties.

5.4 Biodiversity and Climate Change

There are a number of major issues at the interface of biodiversity, land use and climate change. As climate changes, ecosystems will respond to changes in temperature and precipitation as well as changes in the carbon-dioxide concentrations in the atmosphere. These changes are likely to favor some species and to negatively affect others, which will alter competitive relationships and may cause invasions by “generalist” species (Walker and Steffan 1997). Perhaps most significantly, there is a risk that climatic changes will occur more rapidly than individual species are able to adapt. For those species that are able to migrate with climate change (seeking appropriate habitat as it literally moves out from under them), there is a risk that migration “escape routes” will be closed due to anthropogenically altered landscapes or natural barriers, such as mountains, rivers and oceans (Malcolm and Markham 2000). The ultimate result could be large-scale extinctions.

An analysis of WWF’s Global 200 ecosystems (see Section 5.2) suggests that more than 80 percent of these biologically rich regions will suffer extinctions of plant and animal species as a result of global warming; changes in habitats from global warming will be more severe at high latitudes and altitudes than in lowland tropical areas; the most unique and diverse natural ecosystems may lose more than 70 percent of the habitats upon which their plant and animal species depend; and many habitats will change at a rate approximately ten times faster than the rapid changes during the recent postglacial period (Malcolm *et al.* 2002).

Unlike the introduction of invasive species, land conversion, and other threats to biodiversity, because climate is globally pervasive, it will affect even remote wilderness areas that to date have experienced little of anthropogenic change. Walker and Steffan predict that more natural ecosystems will be in an early successional state, and that the biosphere will be “weedier” and structurally simpler, by comparison with ecologically complex old-growth areas. The study of climate change impacts on biodiversity is still in its infancy, but several path breaking workshops and research initiatives suggest future research directions for those interested in how humanity can mitigate the impacts of climate change on other species (Global Change in Terrestrial Ecosystems, IAI 1994). There is also increasing interest in how to address, at the policy level, the complex linkages between climate change and biodiversity (IUCN 2001, Convention on Biological Diversity).

6.0 – Land Use and Land Cover and the Water Cycle

There are many connections between land surface characteristics and the water cycle. First, and most obviously, land cover can affect both the degree of infiltration and runoff following precipitation events. Secondly, the degree of vegetation cover and the albedo (degree of absorption/reflection of sun's rays) of the surface can affect rates of evaporation, humidity levels and cloud formation. This section of the guide briefly covers factors that affect the infiltration and/or runoff of precipitation, and how the land surface in turn affects precipitation. Then it turns to dams and reservoirs as important land cover features. Lastly it examines the relationship between land cover and natural hazards such as droughts and floods.

6.1 Infiltration and runoff

There are two paths of escape for surplus water – through infiltration into underground aquifers, and as surface water flows. Natural land cover has various properties that help to regulate water flows both above and below ground. Forest canopy and leaf litter, for example, help to attenuate the impact of raindrops on the earth's surface, thereby reducing soil erosion. Roots hold the soil in place, especially on steeper slopes, and also absorb water. Openings in leaf litter and soil pores permit the infiltration of water, which is carried through the soil into the ground water. Where ground cover is insufficient, sheet, rill and/or gully erosion may result (Field 1997). Such erosion reduces the productivity of the land and may result in sedimentation of water courses down stream.

Streams eventually carry excess surface water to the ocean, though they may feed intermediate destinations such as lakes and wetlands. In their natural states, the network of streams in a catchment will slow down water flows so that there is a significant lag time between a period of peak precipitation and peak runoff further downstream. Riparian forests can serve as important buffers, reducing sediment loads and keeping runoff from moving too quickly into streams.

Wetlands are natural parts of the landscape where water collects. Wetlands act like sponges, absorbing water during periods of high runoff, and gradually releasing it. Wetlands also serve as natural water filters, removing impurities and sediments (see "Background papers on Wetland Values and Functions" in related resources). At one time the function of these ecosystems was relatively undervalued, and many wetlands were drained for agriculture and other forms of development. Today, however, there is increasing recognition of the valuable ecosystem services provided by wetlands, from flood control to fisheries.

Mountains and uplands are recognized as the water towers of the world, providing reliable supplies of freshwater to lowland areas (Becker and Bugmann 2001). High mountain areas with significant snow pack release water gradually in the summer months, helping to ensure steady water flows even in the driest months. Climate change is reducing snow pack in some regions, with consequences for the sustainability of these water supplies. Just as important, land-cover change can affect runoff to lower elevation areas; extensive deforestation, for example, can contribute to flash flooding at lower elevations.

Urbanization is associated with a proliferation of impervious surfaces, such as paved roads, parking lots, and rooftops. In built-up environments the impervious surfaces may exceed 80 percent of land cover. The effect of such surfaces is two fold. First, it increases the speed of runoff, with rain water being channeled to streams much more rapidly than under conditions of natural vegetation cover. Secondly, infiltration is reduced, which reduces the groundwater levels and therefore the base flow of streams (the "steady state" stream flows that are fed by groundwater between precipitation events; more on this topic can be found in How Urbanization Affects the Hydrologic System under related resources). In urban areas, streams are also frequently "channelized" using cement bottoms and embankments. Under such conditions, streams have been stripped of their natural character, and flood runoff peaks dramatically after rainfall events.

6.2 Land surface interactions with weather and climate

Land surface characteristics can, in turn, affect temperature and humidity levels in the lower atmosphere. Thus, vegetation patterns and soil moisture levels can affect cloud formation and precipitation through convection (the spontaneous rise of air). Certain land cover types, such as bare ground, heat more rapidly and transmit radiant heat to the overlying air. As air rises it also cools, and the moisture in the air condenses and eventually forms clouds, leading in some cases to precipitation.

Research conducted under the Hydrological-Atmospheric Field Experiment in the Sahel (HAPEX-Sahel), the semi-arid region of West Africa, found positive feedbacks between land surface and climate. According to Taylor (2001), after initial rainfall events in the Sahel,

> "…growing vegetation and moister soil are able to absorb more solar energy than the previously arid and sparsely vegetated surface. In addition moisture is… available for evaporation, both at the soil surface and in the root zone. These changes affect the temperature and humidity of the lower atmosphere and make rainfall more likely."

Conversely, in dry years soils tend to have higher albedos (absorbing less of the sun's energy) and there is less moisture available for evaporation, which can lead to a positive feedback in the opposite direction, yielding lower rainfall.

Research on land-use and atmospheric interactions is now underway in the savanna belt of the Volta Basin with the goal of better predicting how future land use and climate changes will affect agricultural water availability and electricity generation at Lake Volta (GLOWA Volta). Also, scientists are doing research on land-cover and cloud formation in the tropical humid environment of the Amazon Basin under the auspices of the Large Scale Biosphere-Atmosphere Experiment (LBA) (Silva Dias 2001). The complex interactions between land surface and weather and climate patterns are not yet fully understood by scientists. Part of the difficulty is isolating the effect of local or regional land cover from other factors, such as atmospheric circulations and ocean surface temperatures.

6.3 Dams and reservoirs

In the past half century, dams and reservoirs have become an increasingly important part of anthropogenic land-cover change. Today there are over 45,000 large dams (dams over 15 m height, or with reservoirs containing 3 million cubic meters of water), and total annual freshwater withdrawals today are estimated at 3,800 cubic km, twice as much as 50 years ago. Dams are constructed for hydroelectric power, flood control, irrigation, and water supply, and many dams serve multiple purposes. Even though they make up only a small percentage of total land cover, these artificial water bodies often facilitate other forms of land-cover change, such as development of large-scale irrigated areas and urbanization, that cover far larger areas.

According to the World Commission on Dams (2001), large dams can have numerous impacts on ecosystems. These include:

- the loss of forests and wildlife habitat, the loss of species populations and the degradation of upstream catchment areas due to inundation of the reservoir area;
- the loss of aquatic biodiversity, of upstream and downstream fisheries, and of the services of downstream floodplains, wetlands, and riverine, estuarine and adjacent marine ecosystems; and
- cumulative impacts on water quality, natural flooding and species composition where a number of dams are sited on the same river.

Furthermore, dams and reservoirs impact the hydrologic cycle by increasing evaporation (dams in arid areas can lose 5 percent of total withdrawals to evaporation) and loss of downstream aquifers due to reduced replenishment. Environmental flow requirements (which include managed flood releases) are increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream.

The Commission notes that sedimentation and the consequent long-term loss of water storage is a serious concern globally, and the effects will be particularly felt by basins with high geological or human-induced erosion rates. Thus, land-cover change that promotes increasing sediment loads, such as agricultural land uses or deforestation, affect the water storage and electricity generation capacity of dams.

6.4 Natural Hazards: Drought and Flooding

Land-use and land-cover change can contribute to natural hazards such as drought and flooding. Some of the linkages between land degradation and drought that lead to desertification were explored in Chapter 4. The link between land cover and flooding is also important. Detailed historical research in one watershed, the North Fish Creek in Wisconsin, suggests that rapid deforestation for farmland contributed to sedimentation and flooding in the 19th century (Fitzpatrick *et al.* 1999). According to the researchers:

> “hydrologic and sediment-transport modeling indicate that modern flood peaks and sediment loads in North Fish Creek may be double that expected under pre-settlement

> forest cover. During maximum agricultural activity in the mid-1920's to mid-1930's, flood peaks probably were about 3 times larger and sediment loads were about 5 times larger than expected under pre-settlement forest cover."

Floods, together with earthquakes and severe weather events, are ranked among the most severe natural disasters, both in terms of human casualties, but also in financial losses. Flooding and land slides in the aftermath of Hurricane Mitch in Central America (1998) and in the hillsides of Caracas, Venezuela after heavy rains in late 1999 cost thousands of lives and millions of dollars in flood damages. Analysis after the disasters in both cases pointed to land clearing on steep slopes, and haphazard development, often by those too poor to invest (without outside assistance) in improved practices. A forward looking strategy of preserving natural forests and investing in sustainable agriculture, especially in uplands, can significantly reduce potential losses caused by flooding (Jackson and Scherr 1995).

7.0 – LUCC and Climate Change

Overwhelming scientific evidence suggests that emissions of several greenhouse gases –carbon dioxide, methane, and nitrous oxides in particular – are bringing about climatic change. The scientists participating in the Intergovernmental Panel on Climate Change Third Assessment conclude that "an increasing body of observations gives a collective picture of a warming world and other changes in the climate system" (IPCC WGI 2001).

Recognition of man's role in changing the climate, and concern for adverse impacts, has spurred the negotiation and implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. It has also spurred intensive research into the carbon cycle. In fact the Kyoto Protocol of the UNFCCC represents the first attempt by mankind to manage a global biogeochemical cycle of any kind, and the task is daunting. If it stands any chance of success, it needs to be based on the best scientific data about how the carbon cycle is affected by anthropogenic emissions and land-use change, and how humans can mitigate climate change through altering the carbon cycle.

7.1 Carbon Cycle Overview

The transport and transformation of substances in the environment, through living organisms, the atmosphere, oceans, land, and ice, are known collectively as biogeochemical cycles. The Earth system is composed of a number of biogeochemical cycles, all powered by the sun's energy. These global cycles include the circulation of certain elements, or nutrients, upon which life and the earth's climate depend. Carbon is one of the most significant elements in that cycle. Plants and animals are approximately 50 percent (by dry weight) carbon. Carbon in the form of carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4) is also a significant contributor to greenhouse gases that trap the sun's energy as it is stored and released as long wave emissions from the earth's surface.

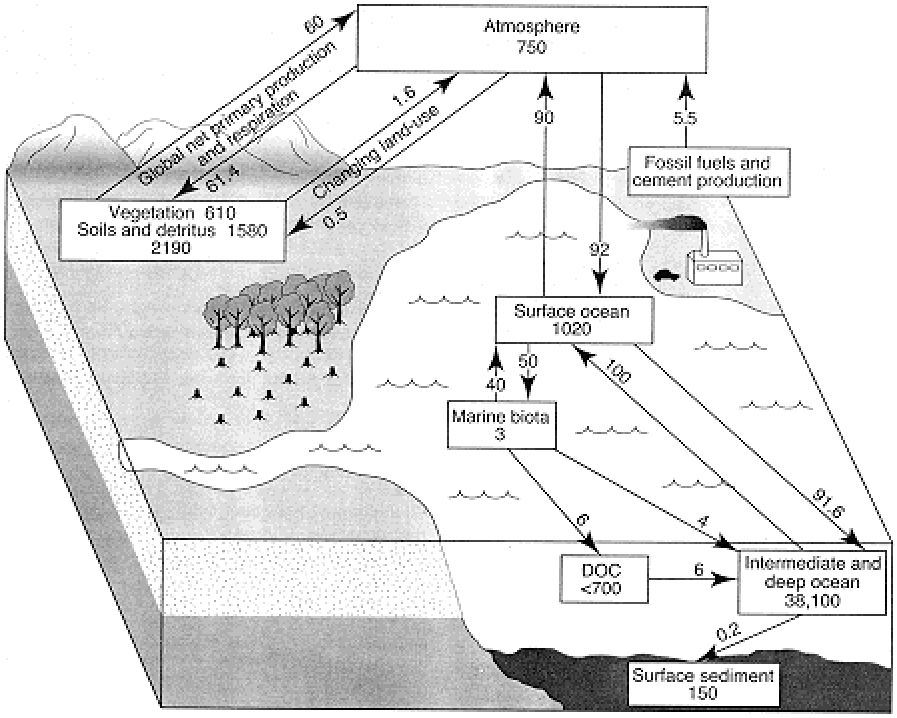
Carbon represents only 0.27 percent of the elements in the earth's crust, but because it exists in both reduced and oxidized states it is vital for life processes (Houghton and Skole 1993). Only plants and some microbes are capable of reducing carbon. Cellulose, carbohydrates, proteins and fats are all forms of organic matter or reduced carbon. Ultimately, they are all derived from photosynthesis, which converts the sun's energy into embodied (or latent) energy. Fossil fuels represent organic matter that was formed millions of years ago that escaped oxidation and was buried in the earth.

Oxidation occurs through two processes, respiration and combustion. All living organisms engage in respiration; it is the process that releases the latent energy stored in organic matter. Combustion occurs through the burning of organic matter or fossil fuels. Burning of fossil fuels that have been buried for millions of years beneath the earth's surface provides a net contribution of new carbon dioxide to the short-term system (as opposed to the long-term system in which cycles occur in geologic time over millions of years). It is the combustion of fossil fuels that has now raised the specter of climatic change.

The major reservoirs of carbon are, in decreasing order, the intermediate and deep oceans (36,730 billion tons, or Gt), fossil fuels (4,130 Gt), soil (1,200 Gt), atmosphere (720 Gt), surface ocean (670 Gt), and plants and animals (biomass at 600-1,000 Gt) (Falkowski *et al.* 2000). Rocks also store some 75 million Gt of carbon, but these are largely inert and therefore do not contribute to the carbon cycle. The most significant fluxes occur between the biota/soil layer and the atmosphere (on the order of 120 Gt per year of uptake and release by the biota/soil layer), followed by the ocean surface and atmosphere (on the order of 100 Gt/year in both directions, with a net uptake by oceans of 2.5 Gt).

Throughout most of human history these flows have been in approximate balance. Only recently has the consumption of fossil fuels, which contribute 5.2 Gt/year to the atmosphere, and the large-scale transformation of landscapes, which contribute a net of between 0.4 and 2.5 Gt/year, threatened to upset this balance (Houghton & Skole 1993). The result is that carbon dioxide concentrations in the atmosphere have risen by 28 percent since 1850, from approximately 285 ppm to roughly 366 ppm at present (IPCC 2000). If we take a longer time horizon, concentrations have actually risen by two-thirds, from the 220 ppm average that has been in effect for the past 420,000 years (Falkowski *et al.* 2000).

Figure 1. Diagram of the Carbon Cycle
(note: stock and flow quantities may differ slightly from the text above)



Source: Schimel, et al. 1995. CO2 and the Carbon Cycle. In: Climate Change 1994. Cambridge, UK: Cambridge University Press.

The uptake of carbon in so-called "sinks" (reservoirs of carbon) is governed in part by other nutrient cycles. Falkowski *et al.* (2000) note that humans have also had a major impact on the cycles of nitrogen, phosphorus, and sulfur. Agricultural activities (chemical fertilization and nitrogen fixing plants) have doubled the fluxes for nitrogen and quadrupled the fluxes for phosphorus. Fossil fuel and biomass burning emissions have doubled the fluxes of sulfur. Though the increase in these other nutrients should in theory increase carbon uptake, the effects of theses changes on the carbon cycle are poorly understood.

The uptake and release of carbon by natural and anthropogenically altered ecosystems will also be affected by temperature. According to the latest IPCC scenarios, average global temperatures will increase by between 1.4 and 5.8^{o} C by 2100, and by even more at higher latitudes. One of the "wild cards" of global warming is that scientists do not know precisely how this warming will affect carbon fluxes from biomass and soils. Depending on how ecosystems respond, they may either mitigate or reinforce warming trends through uptake or release of carbon dioxide.

For standing biomass, it is understood that increased temperatures, all things being equal, lead to higher rates of photosynthesis. For soils, although increased temperatures lead to higher rates of respiration (and therefore CO2 release), field experiments in North American grasslands and highland tropical forests suggest that at already high temperatures, such as those that pertain during the summer months, incremental changes in temperature do not significantly affect soil respiration (Rustad 2001). One region of greater concern, however, is boreal forests, where due to low year-round temperatures, detritus collects on the forest floors but does not decompose. Temperatures are increasing faster towards poles than at lower latitudes, and as temperature increases, these substantial carbon reservoirs may be subject to significantly enhanced respiration (BOREAS Project).

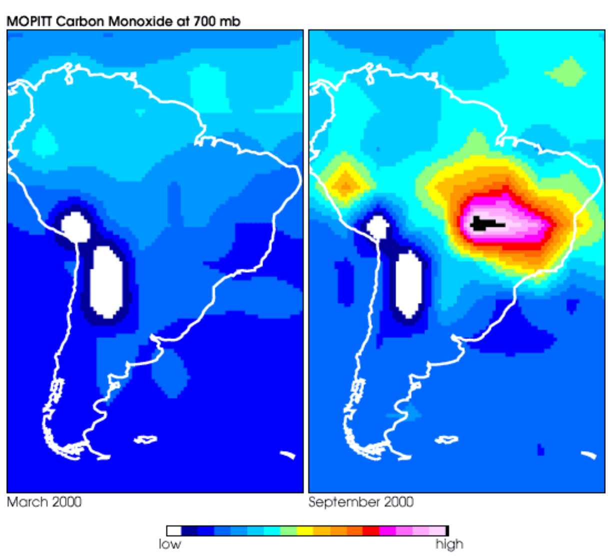
In terrestrial ecological systems, carbon is retained in live biomass, decomposing organic matter, and soil. Changes in land use can result in the release of carbon into the atmosphere, or withdrawal of carbon from it. In the former, land-use change is a *source*, and in the latter it is a *sink*. The following two sections explore the mechanisms for release and storage of carbon through land-cover change.

7.2 Contribution of GHG Emissions from Land-use change

Forests are among the most carbon-dense ecosystems, comprising approximately 75% of live organic matter. When soils are included, forests hold almost half of the carbon of the world's terrestrial ecosystems (Houghton & Skole 1993). Although some changes in land use increase the amount of carbon stored, the trend over the past 300 years has been to decrease the area in forests. Woods Hole Research Center estimates that annually 1.6 Gt of carbon are released from changes in land use, resulting in a net decline in terrestrial carbon stocks. Since 1850, the total carbon emissions from land-use change are on the order of 136 Gt.

Deforestation can take a number of forms, each of which has different implications for carbon emissions. If the forest is burned, this results in a direct emission of greenhouse gases into the atmosphere. Remote sensing images such as the MOPITT image below (Figure 1) show the dramatic increase of carbon monoxide emissions during the dry season over the Brazilian Amazon, when farmers are preparing their fields and ranchers are clearing forest for cattle.

Figure 1. MOPITT Carbon Monoxide Emissions Monitoring over South America



Source: NASA's Visible Earth.

Other forms of deforestation may have a less significant impact on climate change. For instance, deforestation for firewood collection may result in a net carbon balance, because as trees are cut, new trees take their place and begin absorbing CO2 through photosynthesis. Deforestation for construction materials or furniture can have varied effects, depending on how long the wood is "locked up" in some useable form. Plywood for concrete molds may be discarded soon after it is used, thereby immediately contributing to emissions through burning or decay, whereas wood locked up in furniture or building construction may remain that way for years. According to the Woods Hole Research Center, From 1850 to 1990 about 107 Gt of carbon were lost from terrestrial ecosystems, but 10 Gt accumulated in wood products.

Conversion of natural ecosystems to croplands and pastures has resulted in net releases of 73 Gt. These agro-ecosystems continue to take up carbon, but at levels generally inferior to the previously forested ecosystems because their carbon density is far lower. Furthermore, harvested crops and decaying residues in the fields eventually result in releases of carbon back into the atmosphere.

For its heat trapping potential and its significance in global biogeochemical cycles, carbon dioxide is one of the most important greenhouse gases. However, land-use changes can result in emissions of other greenhouse gas emissions as well. Aber and Mellilo (1991) list 10 additional greenhouse gases that are released by terrestrial ecosystems, many of which have much greater heat-trapping capacity that carbon. Among others, these include:

- methane (CH_4), which is emitted by wetlands, rice paddies, and animals (i.e., an indirect contribution from pasture lands)
- nitrous oxide (N_20) and nitrogen oxides (NO_x) which is emitted by fertilized agriculture and biomass burning
- ammonia (NH_3), which is emitted by animals, fertilized agriculture, and biomass burning
- carbon monoxide (CO) from biomass burning
- sulfur gases from wetlands, wet tropical forests, oceans, fertilized agriculture, biomass burning
- water vapor from forests

Those with longest atmospheric lifetimes have received greatest attention because of the potential for increased production to result in lasting increases in atmospheric concentrations. After carbon dioxide, methane and nitrous oxides are thought to have the greatest potential to trap outgoing long-wave radiation, thus contributing to the greenhouse effect.

7.3 Sequestration of Carbon through Land Management

In the past decade there has been growing interest in mitigating human impacts on the climate through activities in two principal domains: emissions reductions through increased fuel efficiency and sequestration of carbon in terrestrial ecosystems. There is also ongoing research into how to increase carbon sequestration in rocks and oceans. The IPCC's Special Report on Land Use, Land-Use Change, and Forestry is dedicated to an assessment of the feasibility, from scientific, technical and institutional perspectives, of withdrawing carbon from the atmosphere through the use of terrestrial sinks (IPCC 2000).

The largest terrestrial reservoirs of carbon are tropical and boreal forests, which store 428 and 559 Gt of carbon respectively in above- and below-ground biomass. Savannas and grasslands also store large amounts of carbon (over 300 Gt each), wetlands store 240 Gt, and temperate forests store 159 Gt (IPCC 2000). Because of the importance of forests as carbon sinks, most of the policy attention has been focused on how to increase carbon uptake through these ecosystems.

Trees grow (and gain carbon) when the amount of carbon fixed through photosynthesis exceeds the amount of carbon lost from respiring leaves, branches, stems and roots (Barnes *et al*. 1998). At the forest ecosystem level, the net carbon uptake or emission will be determined by the balance of plant photosynthesis and respiration, as well as respiration by decomposers (Aber & Mellilo 1991). Newly planted or regenerating forests will continue to uptake carbon for 20 to 50 years after establishment, depending on species and site conditions. The rates vary depending on forest type and latitude, from a low of 0.4-1.2 t/ha/yr^{-} in boreal regions to a high of 4-8 t ha/yr in tropical regions. A forest ecosystem as a whole will tend toward a zero carbon balance at maturity.

In July 2001, the contracting parties of the UNFCCC, with the exception of the United States, reached agreement on a plan for implementing the Kyoto Protocol. The Protocol obliges industrialized (Annex 1) countries to reduce their greenhouse gas emissions, and creates innovative mechanisms by which emissions allocations can be traded among states. In addition, parties may meet their emissions targets by sequestering carbon in forests. The Protocol's Clean Development Mechanism permits Annex 1 parties to invest in afforestation and reforestation projects in non-Annex 1 (developing) countries. A number of developing countries have been exploring the possibility of entering the carbon market by protecting tropical forests or reforesting large areas (de Sherbinin *et al.* 2002).

One such effort is taking place in the Noel Kempff Mercado National Park in northeastern Bolivia (see Noel Kempff Mercado Climate Action Project in related resources). The park covers more than 3.7 million acres of dense tropical rainforest, and the project is expected to sequester 7 million to 10 million tons of carbon during its 30-year life, largely through protection of existing forests and accumulation of additional biomass in currently unforested areas. As part of the justification, project proponents need to prove that the encompassed area would otherwise have been deforested; in other words, by protecting the forest, the project is yielding carbon sequestration benefits that would not otherwise have accrued had the area been left open for logging. Similar pilot projects are testing approaches to carbon sequestration in Costa Rica, Uganda and several industrialized nations.

Although the potential for carbon sequestration in forests is quite significant, the way forward is fraught with difficulties (IPCC 2000). The challenges have to do with accurately measuring carbon uptake that would not have occurred apart from the project intervention (so-called additionality), or leakage of emissions that occurs when one forest is adequately protected but the forest cutting activity is simply displaced to another area that is not subject to such restrictions. There are also technical matters of setting up a carbon accounting system, and identifying appropriate tools (such as remote sensing) so that carbon monitoring over vast tracts of land can be done in a cost effective manner. Some have also voiced concern that monocropped tree plantations might supplant natural forests, with their biodiversity and ecosystem values. Finally, there is the issue of permanence. Though sequestration may be useful in the short term, for slowing the rate of climate change by soaking up "surplus" carbon-dioxide, protecting a forest indefinitely would require institutional arrangements that would also last indefinitely, something that humans have never attempted.

Globally, drylands are more important than temperate forests in terms of carbon storage (199 Gt versus 159 Gt). Some experts see great promise for linking actions to combat desertification to actions that would mitigate against climate change through carbon sequestration (Olson *et al.* 2001). Dryland agricultural soils are extensively degraded in many parts of the world, which means they lack nutrients and organic matter. Increasing nutrients and organic matter is good not only for increasing crop productivity; it also happens to lead to increases in soil carbon. By judicious use of chemical fertilizers and organic matter inputs, some see the possibility for reversing the steady decline in agricultural productivity in some regions while simultaneously stockpiling carbon in agricultural soils (USGS 2000, Woomer *et al.* 2001).

There are many other land management activities that can enhance carbon uptake, and a number of other land-use change activities that are not addressed above. These are enumerated in Table 1 below. Such activities are being considered under Article 3.4 of the Kyoto Protocol.

Table 1. Potential "Additional Activities" Under Article 3.4 of the Kyoto Protocol

A. Improved management within a land use	
Land Use	**Activity**
Cropland	Reduced tillage, rotations and cover corps, fertility management, erosion control, and irrigation management
Rice paddies	Irrigation, chemical and organic fertilizer, and plant residue management
Agroforestry	Better management of trees and cropland
Grazing land	Herd, woody plant, and fire management
Forest land	Forest regeneration, fertilization, choice of species, reduced forest degradation
Urban land	Tree planting, waste management, wood product management
B. Land-use change	
Land Use	**Activity**
Agroforestry	Conversion from unproductive cropland and grasslands
Restoring severely degraded land	To crop-, grass-, or forest land
Grassland	Conversion of cropland to grassland
Wetland restoration	Conversion of drained land back to wetland

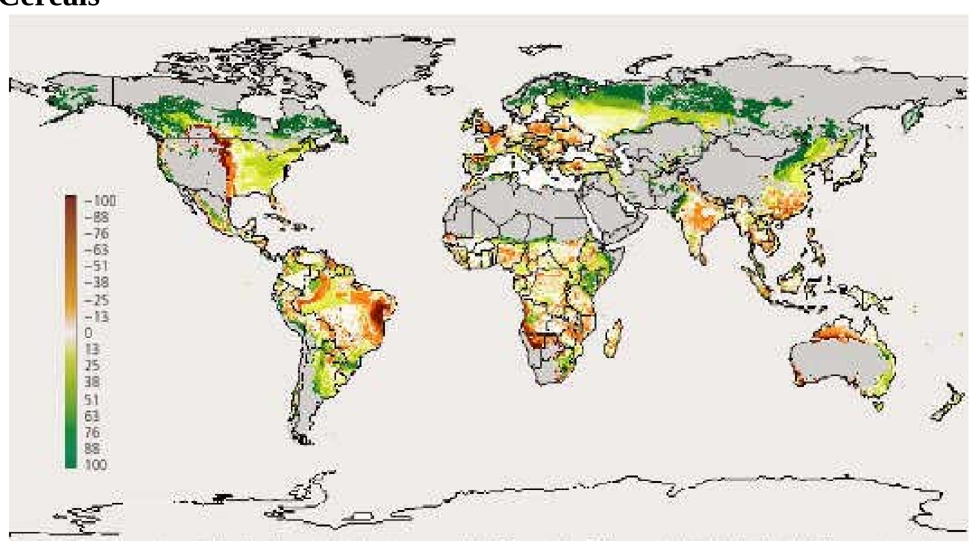
Source: IPCC. 2000. Land Use, Land-Use Change, and Forestry, Cambridge, UK: Cambridge University Press.

7.4 Climate Change Impacts on Land Use and Land Cover

The location of today's terrestrial ecosystems is the result of multiple factors, including latitude, altitude, topography, geology, soils, and climate. If projected changes in temperature and rainfall occur, there will be a displacement of ecosystems from their current locations, in some cases by hundreds of kilometers. This has left some conservationists wondering if the current network of protected areas will adequately protect species that exhibit limited ranges (so-called endemics), or if species will even be able to migrate fast enough to keep up with climate change. The issue of climate change impacts on biodiversity and ecosystems is addressed in greater detail in Section 5.4; connections between desertification and climate change are addressed in Section 4.1.

Aside from direct impacts of climate change on crop yields (Rosenzweig & Iglesias 2000), climate change may also result in the migration of agro-ecosystems in ways that can affect global food production (Walker & Steffen 1997). The US National Assessment on Climate Change Impacts (USGCRP 2000a, 2000b) devotes substantial space to the question of climate change and agriculture, and finds that the Southeast's forests and agricultural lands may be transformed into a savanna and grassland due to warming and drying, and that the currently arid areas of the Southwest are likely to become moister. Fischer *et al.* (2001) predict migration of agro-ecosystems northwards in the northern hemisphere, which will benefit some temperate countries, particularly those with large frontier lands to the north (e.g., Russia and Canada). Figure 1 shows these changes in productivity, with green representing positive change and red representing negative change.

Figure 1. Impacts of Climate Change on Cropping Production Potential of Rain-fed Cereals



Climate change impacts by grid cell are visualized using a normalized difference index. They are calculated by dividing the difference in cereal production capacity between future and current production potential by their sum. The index ranges from a value of −100 to +100; the former indicates complete loss of production, the latter occurs in areas where cereal production is not possible under current climate conditions but would be feasible with climate change.

Source: Fischer, G., M. Shah, H. van Velthuizen, and F. O. Nachtergaele. 2001. Global Agro-ecological Assessment for Agriculture in the 21st Century. Laxenburg, Austria: IIASA.

Sea level rise resulting from melting glaciers may result in a net loss of land as oceans inundate low-lying coastal areas. Coastal flooding from sea level rise is already occurring in many regions that are affected by land subsidence (e.g., the northeastern United States, the Mississippi Delta, and eastern China) (see Sea Level Rise Reports). Sea level rise may result in coastal wetlands being lost, alterations in delta and estuarine environments, changes in coastal erosion, and farmland loss (Eisma 1995, Titus and Richman 2001). A number of studies have sought to estimate the number of people vulnerable to sea-level rise (Gornitz 2002, Small and Cohen 1999). Other studies have focused on the vulnerability of coastal cities to sea level rise (Schiller *et al.* 2001, Nicholls 1995). Due to trade and relations with agricultural hinterlands, many large urban agglomerates have developed on coastlines. Although coastal defenses may be greater around urban areas as compared to rural areas, the infrastructure and fixed capital that could be negatively affected are also more significant.

8.0 – LUCC and Urbanization

Recent analyses suggest that 83 percent of the earth's land surface has been affected by human settlements and activities, leaving only 17 percent in wilderness (WCS & CIESIN 2002). According to one set of estimates, urban built-up areas, with average population densities of approximately 200 persons per square km., probably comprise around four percent of all land uses worldwide (Small 2002). A joint project by CIESIN, IFPRI and the World Bank (2002) is currently testing and implementing methodologies for measuring the extent of urban built-up areas. Urban areas are expanding, particularly in the developing world. UN Population Division estimates suggest that the world's population will become majority urban by 2010; in contrast the world was only 37 percent urban in 1970.

Though the extent of urban areas is not that large when compared with other land uses such as agriculture or forestry, their environmental impact is significant. This is due not only to the large concentrations of population that are found in cities, but because they are centers of political, cultural and economic influence, and are often the location of significant industrial activity. In the era of economic globalization, so-called "megacities" like New York, London, Sao Paulo and Singapore draw on resources and economic activities around the world to build their wealth and prominence (Schiller *et al.* 2001).

This is sometimes referred to as the urban ecological footprint (Turner 2001). Urban areas rely on vast hinterlands for food, raw materials for industry, energy, water supplies, construction materials, recreational areas and myriads of other goods and services. A whole field of study has emerged in the area of urban or industrial metabolism, defined as the "integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes" (Ayres and Simonis 1994). Folke *et al.* (1997) estimated that the cities of Baltic Europe appropriate for their resource consumption and waste assimilation an area of forest, agricultural, marine and wetland ecosystems that is 565-1130 times larger than the area of the cities themselves.

In terms of urban impacts on the environment and land-cover change, there are direct and indirect impacts. The direct impacts include human settlements, industrial and infrastructure land uses, and the expansion of these land uses into areas of natural or agricultural lands. A number of researchers are examining the impact of urban sprawl on crop-land loss (Heilig 1999, Vincent *et al.* 2002). Urban built up areas have direct impacts on the hydrological cycle, as addressed in Chapter 6. And, because urban paved and built up land surfaces tend to absorb heat and to re-radiate it at night, they can also create heat islands that affect plant physiology as well as the health and welfare of urban dwellers (see Urban Growth Seen from Space).

The indirect impacts of urban areas on land use and land cover can be even more important. For example, cities expropriate water from large distances; in some cases, such as in the New York City water supply districts, this may have the effect of conserving large areas of land that might otherwise be developed (NYC-DEP). In others, such as in Los Angeles, the expropriation may have a negative impact on the ecology of natural water bodies such as Mono Lake and the Colorado River.

A significant indirect impact of urban areas is the need for sinks or dumping sites for the great volumes of waste they produce. Urban wastes can be solid, liquid or gaseous. Problems of solid waste disposal have become increasingly problematic as land fills have reached their maximum capacities. Cities generally have few solutions other than to truck their waste at great cost to distant landfills, or to incinerate it. Owing to shortages of space for land fills, European and a number of North American cities have increasingly opted for incineration. Problems arise from emissions of toxic fumes, especially dioxins, lead and mercury, and then the disposal of toxic ash. New York City faces a waste removal crisis of mammoth proportions with the closure of its major dump, Fresh Kills on Staten Island. Currently it is shipping trash to landfills as far away as Pennsylvania and Virginia.

Liquid waste, or sewerage, are generally treated and released into water bodies. This can, under certain circumstances, result in completely dead water bodies in which rivers, lakes or bays can no longer sustain life due to an excess of biochemical oxygen demand. For example, daily discharges into Rio de Janeiro's Guanabara bay include 465 tons of organic matter, 68 tons of which receive adequate treatment, and 9.5 tons of oil, and the Iguacu and Estrela Rivers which drain the Bay's watershed are often anoxic (Kreimer *et al.* 1993). In Northern Europe, natural wetlands are often used to filter impurities from water during the latter stages of sewerage treatment. This builds on the natural characteristic of wetlands as nutrient sinks (Folke *et al.* 1997).

Atmospheric pollutants can have a significant impact on land use and land cover. Folke *et al.* estimate that the CO_2 emissions of major cities alone would consume 95 percent of the carbon absorptive capacity of the world's forests. Another major problem is air pollutant impacts on natural vegetation and crops. Acid rain has been a documented problem that damages forest lands in Eastern Europe and North America (see Effects of Acid Rain: Forests). Chameides *et al.* (1994) examine the impact of ground-level ozone on crop production in three large "metro-agro-plexes" – areas of intense agricultural and industrial production in North America, Northern Europe and China/Japan – and find that it may be reducing global crop production by a few percent. This impact is likely to intensify due to projected increases in nitrogen oxides, an important precursor to ozone.

Urbanization pathways lead to different impacts on rural landscapes in the developed and developing world. In the *developed world*, large-scale urban agglomerations and extended peri-urban settlements fragment the landscapes of such large areas that various ecosystem processes are threatened. Ecosystem fragmentation, however, in peri-urban areas may be offset by urban-led demands for conservation and recreational land uses. In a different vein, economically and politically powerful urban consumers tend to be disconnected from the realities of resource production and largely inattentive to the impacts of their consumption on distant locales. Urbanization in the *developing world* outbids all other uses for land adjacent to the city, including prime croplands. Cities attract a significant proportion of the rural population by way of permanent and circulatory migration, and the wages earned in the city are often remitted by migrants to rural homelands, in some cases transforming the use of croplands and creating "remittance landscapes." Perhaps most importantly, this urbanization changes ways of life ultimately associated with demographic transitions, increasing expectations about consumption, and potentially a weakened understanding of production-consumption relationships noted for the well-developed world (Lambin et al. 2001).

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