LAND USE CHANGES DURING THE PAST 300 YEARS

Kees Klein Goldewijk,
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

Navin Ramankutty,
Center for Sustainability and the Global Environment (SAGE), University of Wisconsin, Madison, USA.

Keywords: historical land use, land cover, forest, deforestation, conversion, agriculture, cultivation, pasture, rangeland, urbanization, built-up land

Contents

Summary

The human sphere of influence on world's natural environment has increased during the last 300 years at a staggering rate. Dramatic increases in population numbers boosted the need for food and fodder production. Land used for crops and ranching expanded at the cost of forests and natural grasslands. Estimates for the decrease in global forested area during the last 300 years range from 8 to 13 million km^2, corresponding with 15 to 25 % of the original extent in 1700. A great part of the large uncertainty in this estimate (and others given in this whole section on historical land use) can be explained by the use of different classification schemes of the historical inventories (forest or woodland, tundra or wooded tundra, grassland versus savanna, etc.). Other reasons are the different methodological approaches used (interpolations, proxies used for filling in the gaps) and the absence of present day technology like satellite derived data. Approximately 15 to 19 million km^2 of natural grassland and savannas were also domesticated in one way or another. It is generally accepted that these land use changes have contributed to an increasing extent the enhancement of the so-called global greenhouse effect. Estimates of the IPCC stated that roughly one fifth of the total anthropogenic emissions of greenhouse gases during the 1990s originated from changes in land use.

Land use change does not occur evenly, neither temporarily nor spatially. In fact, it has become clear that in some parts of the world, the process of massive conversion of natural land cover has stopped, or has even been reversed, the so-called "forest transition". This transition is marked by a first gradual or sudden depletion of the forest resources, later by slow or radical changes in economic structures or organization.

These lead to a new appreciation of the resources and eventually in an increase in forest area again. This process is currently happening in North America, Japan, and some European countries. It seems to be a first step towards a more sustainable world.

1. Introduction

Since the dawn of civilization, humans have altered the face of the Earth while acquiring valuable resources such as food, fiber, and fresh water. Human alterations of the landscape and their deleterious consequences have been noted for a long time. Greek philosophers like Plato or Aristotle, and Roman Emperors such as Hadrian have already reported about the deterioration of natural vegetation and the erosion of fertile land. George Perkins Marsh's book "Man and Nature", written in 1864, was one of the first widespread manuscripts to recognize mankind's harmful effect on nature. Since then, various writers such as Henry David Thoreau, John Muir, Aldo Leopold, and Rachel Carson have contributed to the rise of consciousness about environmental issues. More recent publications, like "The Earth as Transformed by Human Action" by Turner et al., and voluminous integrative reports of the IPCC, UNEP and WRI document some of the historical changes in land use and land cover due to human action over the last decades to centuries.

More recently, tropical deforestation has drawn attention to human impacts on the environment. The loss of pristine tropical rainforests in the Amazon basin, and the associated loss of biodiversity and accelerated extinction of species have captured the global imagination. According to the Forest Resources Assessment 2000 of the FAO, the current loss of forest amounts to roughly 0.146 million km^2 per year. Since pre-agricultural times, several estimates indicate that the loss of forests ranges between 11 and 17 million km^2, which corresponds roughly to the size of the continental U.S.

There have been surprisingly few global-scale estimates of the changes in land use and land cover. Estimates range from a reduction of 15% to 30% of the total forest area since pre-agricultural times, and roughly half of the land surface (three-quarters of the habitable area) has been disturbed in some way or another by human beings. Richards (1990) summarized different calculations to estimate that over the last 300 years, we have lost roughly 20% of our forests and woodlands, 1% of grasslands and pastures (most pastures came from grasslands), while cropland areas increased by 466%! Currently, croplands occupy roughly 15 million km^2 of the Earth's surface, which corresponds to an area roughly the size of South America, while grazing lands cover approximately 34 million km^2. Thus, more than one-third of the global land surface is devoted to agricultural land, which has now become one of the largest biomes on the planet, for example roughly equal to the global extent of forests.

Such large-scale changes in land use and land cover can have significant consequences such as the depletion of valuable ecosystem goods and services. For example, forests are the source of fiber and valuable pharmaceutical products, and provide important services such as the regulation of climate and surface water, and protection of the soil. Furthermore, tropical rainforests provide a valuable habitat for an enormous number of plants and animals on this planet.

The changes in land use and land cover have accelerated over the last three centuries, since the onset of the Industrial Revolution. Land use is one of the most obvious and major drivers of global change. With this recognition, there have been an increased number of studies of the causes and consequences of land use and land cover change. In this paper a summary is given on the current understanding of historical changes in land use and land cover.

2. Terminology

Before launching into a discussion of the historical changes in land use and land cover, some clarification on terminology is needed. Land use refers to the purpose or intent for which a piece of real estate is being used. Land cover refers to the perceivable alteration of the land surface. Cultivation, grazing, ranching and urbanization, are all examples of land use activities, while cropland, pasture, rangeland, built-up land, and so on are all examples of land cover. Generally, the management of land, including tilling, fertilization, and irrigation, is also characterized as land use activities.

Furthermore, a distinction is often made between land cover *modification* and *conversion*, although this is generally a matter of scale of observation. A land use activity usually modifies the land cover only. For example, firewood gathering or selective logging will usually leave a forest behind, only degrading it or modifying it. On the other hand, clear-cut logging or the clearing of a forest for cultivation will convert the woodland into bare ground or cropland. Land cover conversions are much more obvious than land cover modifications.

3. Human Activities on the Land in Pre-industrial Times

The earliest influence of humans on their natural environment started with the domestication of fire. It helped to open up natural savannas and grasslands for hunting and early forms of agriculture. Gradually, over millions of years humans learned not only to use tools, but to make them as well. This phase is also known as agrarization. Being able to control the important factors of fire and tools, it enabled groups of people to leave their original habitat, the savannas of Africa and migrate to other parts of the world. They spread out towards remote corners of Eurasia (Euphrates and Tigris region), and later on to areas like the Indus valley in northern India, and eventually to the America's and Australia. The humanoids evolved towards a more sedentary existence and adapted new crops and some domestication of animals as well. This has lead to an increasing population over time, albeit a very modest increase over thousands of years.

Most, if not all, of the early forms of agriculture developed in the hills and valleys around the large mountain ridges. Examples of these are the Iranian Plateau and its edges with traces of farming ca. 6000-12000 yr BP, and the hilly regions in northern China and Central America. This transition from (mobile) hunting/gathering to (sedentary) farming is often referred to as the "Neolithic Revolution". Europe was another relatively favorable region for early human settlement. The continent has lots of shorelines for fishing, a relative temperate climate combined with numerous fertile river valleys that are quite suitable for agriculture, vast areas of open grassland plains for

nomadic herd rearing, and above all plenty of forest/woodland to provide fuel, fodder and shelter. Archeological evidence along with pollen analyses shows that even in those early days the influence of humans on the surrounding woodlands in Europe and the Mediterranean was not negligible. Humans have been sailing from Central Asia into the Mediterranean Basin since early 4000 BP, spreading their agricultural practices and thus influencing their natural environments.

The (Pre-) Greek Era - In 6000 BP, the Southern Argolid, the Argive Plain and the Larissa Basin of Greece show clear signs of early agriculture. Rainless winters, frost and wind erosion led earliest settlers to adopt subsistence strategies such as risk avoiding through a mixed-cropping or sheep holding as low-risk meat providers. Archaeological and paleological evidences suggest that their grazing and farming activities on the valley slopes already resulted in catastrophic erosion. Aristotle claimed in 2500 BP that the land had undergone considerable alteration, and Plato described the permanent damage to the environment, probably resulting from overexploitation of primary forestland. The local forests in Greece were denuded, and as a result, the Athenians had to import an extensive amount of timber, most notably from Phoenicia. It is this wood that contributed to the development of the great Athenian fleet of ships.

The deforestation of the Levant region (currently Lebanon) is a good example on how human activities of different kinds have affected the land cover in this area. By the seventh century BC Levantine iron was being exported to Babylon. Iron oxides occur locally in the Lebanon mountains and were amongst the first iron ores ever to be exploited. Unfortunately, iron smelting requires high temperatures and, therefore, was a major factor in the deforestation. The limestone has also been used, both as a building stone and as fertilizer and cement; and the treatment of those products also use a lot of wood. The results of the commercial interests of the Phoenicians and sea-faring exploits had a special impact on the timbered areas of Lebanon, as near-total denudation took place.

Of an almost equal importance were the effects of military campaigns and the commercial demands on wood. Along coastal strips and lowlands of the Mediterranean, the primary areas of settlement, forested land was rapidly cleared. As a consequence, a lumber trade developed between forested regions and sparsely-timbered or deforested regions around the Mediterranean. For nearly three millennia (c. 2600 BC - 138 AD), the timber from the mountains of Lebanon served obvious needs of early settlement, demand for fuel, ship and other building material, as well as timber for cabinets inclusive. Due to their geographic location close to the sea, the Phoenician cities like Byblos and Sidon acted as ports for trade, wherein cedar logs from the outlying mountains were felled and transported. The destinations were, in these cases, often-populous coastal lowland nations, for example Egypt and Palestine, which had little timber and yet had a high demand for building materials.

The Roman Era - In classical Rome, forests were the source of fuel, building and war material. Forests had also to be cleared before agriculture could be practiced. Deforestation started around the city (states) and spread throughout the Greek colonies, in Africa or other Roman provinces. In the absence of coal and oil, forests were the main fuel for domestic and industrial purposes (more than 90% of the total wood

demand was used for fuel), mostly in the form of charcoal. Charcoal has the advantage of being more easily transported, thus given way to exploit more distant forests instead of nearby town/village forests, who were over-exploited quite soon when population numbers increased in the towns.

The fate of the forest cover depended on a combination of climate, location and control, viz. demands for agricultural land and forest products. The drier climate in the eastern Mediterranean resulted in sparse forests, and in combination with the shallow limestone soils produced much less resilient forests than in the wetter (often mountainous) parts. After exhaustion of forests in the vicinity of villages, people turned to nearby rivers and seaports as means of transport for wood products from more distant forests. Inaccessible forested mountain areas were likely to remain intact.

China - A comparison between Europe and China is very difficult to make, because of the lack of information from the Asian part before the beginning of the Ming dynasty (AD 1368). There is some written evidence of the flourishing iron and steel industry in the Shantung region in northeast China during the Northern Sung period (AD 910 and AD 1126). The substitution of coal for charcoal suggests not only a precocious technological development, but also a widespread devastation and shortage of fuel. Production numbers of charcoal at the end of the Sung period are comparable to the total West European production (including the European Russian part!) at the beginning of the eighteenth century. By the year 1300, the Sung production had declined by half, whether through exhaustion of fuel, Mongol invasions or other unknown factors.

Central America – The human impact on the forests in Central America was already very evident before the Europeans arrived. Indigenous people have been using the forest already for centuries for hunting, the collection of medicinal products, building materials, as well for small-scale agriculture. It resembled the shifting cultivation of the tropical forest of today. In the southeast of Mexico, Mayan exploitation of tropical fruits increased the extension of useful tree species. Besides, original forestland was cleared for a limited agriculture and fuel needs. When the first Europeans arrived, relatively important sections of forestland had already been changed to a more open, park-like vegetation, and the original forest composition had well been altered in some areas.

The Middle Ages - Catastrophic events like the outbreak of epidemic diseases, a deteriorating climate (Little Ice Ages), and economic recessions (due to war) had an opposite effect on forests in Europe during the Middle Ages. Population fell back in numbers in some areas with a staggering 30% due to the Black Plague. This lessened the pressure on the forests in the neighborhood of cities and villages. Also, other areas which were occasionally used for grazing like swamps and marshes were regarded as "evil" places and left aside. Nevertheless, even in the Middle Ages forest exploitation was already highly-planned and regulated in Europe. Certain trees were favored (Oaks were sometimes not used for wood but for acorns as food for pigs) and over-exploitation was avoided as much as possible, by means of controlled grazing and/or with strict laws. Despite or perhaps thanks to the selection of and preference for certain species and the introduction of exotic species the composition of forests changed gradually over time, in many cases even irreversible. This, in combination with over-exploitation could not be avoided and took their toll. The result was a decrease of total forest areas

especially in poor soils.

4. Land Use and Land Cover Changes since the Industrial Revolution

Changes in land use and land cover accelerated over the last 3 centuries, largely driven by technological changes associated with the Industrial Revolution. It is estimated that more forests were cleared between 1950 and 1980 than in the early eighteenth and nineteenth centuries combined. While the forest cover decreased by 20% since 1700, cropland areas quintupled!

Worldwide, the patterns of land use and land cover change followed the patterns of European settlement and economic development. In 1700, most of the land use activities were confined to the Old World. This changed since the great discoveries, in particular the discovery of the Americas.

	Forest/	Steppe/	Shrubland	Tundra/	Cropland	Pasture	Total
Reference Year	Woodland	Savanna/		Hot Desert/			
		Grassland		Ice Desert			
Matthews [1983]							
Pre-agricultural	61.5	33.9	13.0	23.1	0.9	-	132.4
1980	52.4	27.4	12.1	22.9	17.6	-	132.4
Richards [1990], after the original work of Houghton et al. [1983] [b]							
1700	62.2	68.6	-	-	2.7	-	133.4
1850	59.7	68.4	-	-	5.4	-	133.4
1980	50.5	67.9	-	-	15.0	-	133.4
Williams [1990]							
1860	-	-	-	-	5.7	-	-
1978	-	-	-	-	14.2	-	-
Klein Goldewijk [1997], after Richards [1990]							
1700	62.2	63.3	-	-	2.7	5.3	133.4
1850	59.7	60.6	-	-	5.4	7.8	133.4
1980	50.5	34.5	-	-	15.0	33.4	133.4
Ramankutty and Foley [1999]							
Undisturbed	55.3	33.4	17.9	23.6	0.0	-	130.1
1700	52.8	32.3	17.4	23.5	4.0	-	130.1
1850	49.9	31.4	17.1	23.5	8.2	-	130.1
1992	43.9	26.7	15.9	23.3	20.3	-	130.1
Klein Goldewijk [2001]							
Undisturbed	58.6	34.3	9.8	31.4	0.0	0.0	134.1
1700	54.4	32.1	8.7	31.1	2.7	5.2	134.1
1850	50.0	28.7	6.8	30.4	5.4	12.8	134.1
1990	41.5	17.5	2.5	26.9	14.7	31.0	134.1

[a] Estimates are given in million km^2. Note that the amount of pasture after 1970 does not correspond completely with the statistical input. This is due to the allocation scheme. Because the initial land cover map was calibrated for the IMAGE toward 1970 the amount of pasture after 1970 exceeds for some

countries the area in which it can be allocated resulting in some areas holding a fraction of pasture which can not be allocated (10% of world total in 1990 mostly in the United States, Eastern Africa, Middle East and Southeast Asia).
[b] Pasture is here included in the Savanna/Grassland category.

Table 1: Comparison of Land Use Changes to Other Estimates in Absolute Terms

In the New World the landscape modifications and conversions by the native people were relatively limited and for sure not at the scale practiced by European occupants with their modern technologies. With European settlement, intensified land use activities rapidly spread through the Americas. During the nineteenth century and early twentieth century, nations such as the United States, Canada, Argentina, the Former Soviet Union, and Australia developed at the expense of their natural vegetation cover. Land use activities have over the last 50 years slowed down in these countries.

In the developing nations, land use activities accelerated mainly during the twentieth century, and continue today. These countries are trying to expand their agricultural production, and as a result, are depleting their natural resource base.

In Europe, most countries have continued to expand and intensify their land use activities over the last 300 years. However, many of these activities have stabilized as well.

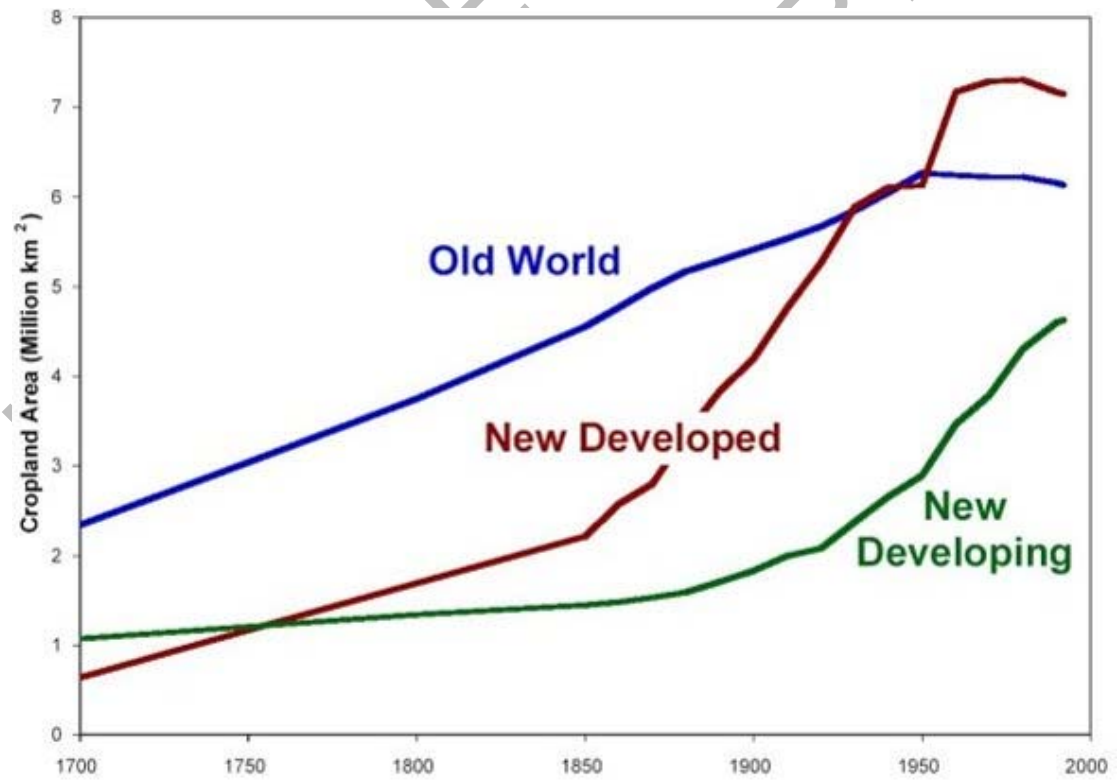

Figure 1: Increase cropland developed/developing world.

The major pattern of land cover change over the last three centuries has been deforestation and agricultural expansion. However, changes in land use practices such

as agricultural land management, fire suppression, and urbanization have also been significant drivers of global change. In this section, the various sources of contemporary and historical land use data are first discussed, and then the changes in land use over the last 300 years. The discussion will be mainly on agricultural expansion because it has been the major driver, and also because more is known about it.

4.1. The Era of Colonization: Agricultural Expansion

This section refers to the changes in land use and land cover. It also deals with the indicative causes and drivers of the change over the last 300 years, based on various sources of information, including historical data on agricultural land cover change described in the foregoing section.

4.1.1. Introduction

The European expansion towards the "New World" had a major influence from 1600 to 1850. The emergence of a global economy at the end of the fifteenth century boosted the migration of people into the "New World". New politics (imperialism), hand in hand with religion, new technology (new types of ships and navigation skills, advanced weaponry) and the discovery of similar natural environments as at home (temperate forests which were not depleted, in contrast to a lot of European countries) enabled old economies of the European continent to explore huge virgin forest areas in Asiatic Russia and Northern America. With European settlements progressing, initially along the eastern seashores of North America, forestland was cleared for timber, cultivation and grazing.

With the arrival of steam-powered transportation of goods, mail and people, and electronically transmitted information by wire and cable, a truly integrated new world economic order emerged. Projects such as the construction of the Suez Canal in 1869 speeded transport enormously from Europe to Asia, and also later the Panama Canal in 1914 resulted in a lowering of transaction costs, thus boosting the amount of goods transported from and to Europe and the US. Another side effect was the forming of business capital, making it possible to finance further exploitation of the New World. A global railway network started to get into shape after 1850, with its voracious appetite for steel, coal and timber.

The nineteenth and the early twentieth centuries were the high point of large plantations in Asia and Latin America. Earlier successes in the Caribbean with sugar and cotton in North America created confidence and finances to look further into the New World. European owners mobilized local labor to clear jungle lands in order to grow - for example - rubber in Malaysia, cacao in Africa, tea in India, coffee in Brazil, and bananas in Central America.

4.1.2. Asia

Extensive research on land use changes in Asia is available during the period 1880 – 1980 (Richards and Flint, 1994). This involves an area of 8 million km^2 and 13

countries (India, Sri Lanka, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia, Brunei, Singapore, Indonesia and the Philippines). In this area as a whole, forest/woodland and wetlands declined over a hundred years by 131 million ha (minus 47%). At the same time, the cultivated area increased by 106 million ha, which is nearly a doubling since 1880. Thus, 81% of the lost forest and wetland vegetation appears to have been converted into expanding agricultural land. Intensified timber extraction for domestic and export markets and the exploitation of firewood, fodder and forest products all contributed to deforestation in this part of the world.

All totals in 1000 km2		1880	1920	1950	1970	1980
Bangladesh	Total land area	148	148	148	148	148
	Total forest area	24	20	16	14	12
	Total net cultivated area	72	74	84	85	84
	Population per km2	168	226	283	482	588
	Livestock per km2	258	368	400	846	885
	% forest area	16%	13%	11%	9%	8%
	% net cultivated area	49%	50%	57%	57%	57%
Brunei						
	Total land area	6	6	6	6	6
	Total forest area	5	5	5	5	5
	Total net cultivated area	0	0	0	0	0
	Population per km2	3	4	8	23	32
	Livestock per km2	1	1	3	6	7
	% forest area	87%	85%	81%	81%	78%
	% net cultivated area	0%	1%	3%	3%	2%
India						
	Total land area	3197	3197	3197	3197	3197
	Total forest area	1027	948	825	743	646
	Total net cultivated area	1008	1068	1232	1409	1424
	Population per km2	71	79	112	168	210
	Livestock per km2	108	129	190	260	294
	% forest area	32%	30%	26%	23%	20%
	% net cultivated area	32%	33%	39%	44%	45%
Indonesia						
	Total land area	1928	1928	1928	1928	1928
	Total forest area	1592	1510	1439	1307	1218
	Total net cultivated area	55	119	166	222	293
	Population per km2	13	26	41	61	76
	Livestock per km2	5	6	11	16	19
	% forest area	83%	78%	75%	68%	63%
	% net cultivated area	3%	6%	9%	12%	15%
Kampuchea						
	Total land area	181	181	181	181	181
	Total forest area	148	145	134	124	126
	Total net cultivated area	5	7	17	24	16
	Population per km2	9	14	24	38	35
	Livestock per km2	8	12	10	29	12

	% forest area	82%	80%	74%	69%	70%
	% net cultivated area	3%	4%	9%	13%	9%
Laos						
	Total land area	237	237	237	237	237
	Total forest area	202	200	192	188	179
	Total net cultivated area	3	5	8	12	14
	Population per km2	4	5	8	11	14
	Livestock per km2	3	4	2	11	9
	% forest area	85%	84%	81%	80%	76%
	% net cultivated area	1%	2%	3%	5%	6%
Malaysia						
	Total land area	330	330	330	330	330
	Total forest area	321	306	295	288	279
	Total net cultivated area	5	17	26	38	45
	Population per km2	4	11	18	31	40
	Livestock per km2	1	4	4	7	10
	% forest area	97%	93%	89%	87%	84%
	% net cultivated area	2%	5%	8%	11%	14%
Myanmar						
	Total land area	677	677	677	677	677
	Total forest area	517	449	419	398	380
	Total net cultivated area	30	64	61	77	83
	Population per km2	11	20	28	42	52
	Livestock per km2	5	12	14	19	28
	% forest area	76%	66%	62%	59%	56%
	% net cultivated area	4%	9%	9%	11%	12%
Philippines						
	Total land area	300	300	300	300	300
	Total forest area	210	193	163	138	103
	Total net cultivated area	20	35	47	64	97
	Population per km2	20	36	68	122	160
	Livestock per km2	13	25	29	61	74
	% forest area	70%	64%	54%	46%	34%
	% net cultivated area	7%	12%	16%	21%	32%
Singapore						
	Total land area	1	1	1	1	1
	Total forest area	0	0	0	0	0
	Total net cultivated area	0	0	0	0	0
	Population per km2	225	698	1654	3357	3906
	Livestock per km2	246	819	388	4414	5331
	% forest area	29%	26%	13%	8%	13%
	% net cultivated area	50%	48%	28%	27%	18%
Sri Lanka						
	Total land area	66	66	66	66	66
	Total forest area	49	44	39	32	26
	Total net cultivated area	7	11	15	20	21
	Population per km2	42	69	117	193	226
	Livestock per km2	20	36	46	71	76
	% forest area	75%	68%	60%	49%	39%
	% net cultivated area	10%	17%	22%	30%	33%

Thailand						
	Total land area	513	513	513	513	513
	Total forest area	386	347	300	272	246
	Total net cultivated area	16	36	80	127	180
	Population per km2	12	18	36	67	92
	Livestock per km2	8	13	38	43	51
	% forest area	75%	68%	59%	53%	48%
	% net cultivated area	3%	7%	16%	25%	35%
Vietnam						
	Total land area	332	332	332	332	332
	Total forest area	250	207	189	164	147
	Total net cultivated area	26	53	44	57	67
	Population per km2	22	47	86	126	162
	Livestock per km2	5	12	10	52	55
	% forest area	75%	62%	57%	50%	44%
	% net cultivated area	8%	16%	13%	17%	20%

Table 2: Expansion of the anthroposphere in South and Southeast Asia 1880 – 1980.

Some examples from several Asian countries are presented below with a view to elucidate the different processes of land use changes in the past.

Malaysia - Over the course of a century, the temporary (annual) cropping area tripled, but the area planted to permanent (tree) crops virtually exploded with an increase of 1202%. Rubber, introduced as cash crop in the late nineteenth century, was planted in great quantity, first on large estates and then in thousands of native smallholdings. Massive plantations of oil palm subsidized by the Malaysian government contributed to an additional large area. As a result, perennial crops comprised more than 80% of the agricultural land in Malaysia by 1980. In addition, 40% of the total wetlands were transformed to other land-use categories. Loggers were well established in Peninsular Malaysia by 1920 and have now cut over virtually all of the forest/woodland vegetation outside the limits of protected reserves. The British Borneo Company initiated commercial timber exploitation for export in Sabah early in the twentieth century. Large removals took also place after 1950, in Sarawak which experienced massive deforestation after 1965.

Indonesia - The land use history of Indonesia shows two different faces. The islands of Java and Bali accommodate a huge population supported by intensively managed paddy rice cultivation (sawah), upland field crops and countless home gardens. Not surprisingly, Java had been largely deforested before 1880. In contrast, the islands of Sumatra, Kalimantan (Borneo) and Sulawesi support relative sparse populations and were scarcely exploited before 1920 (Richards and Flint, 1994).

Commercial logging started in Kalimantan only during the 60s, and boosted in 1967 with huge financial injections of Japanese companies. By 1980, one-fifth of Kalimantan's forests were logged. The final phase of deforestation took place when small agricultural fires started by small cash crop farmers, slash-and-burn agriculturalists, and grazers went out of control in 1982 and 1983. Almost 3.5 million hectare went into flames, and studies have concluded that much of the fires were

attributable to side effects of logging activities.

India, Bangladesh and Sri Lanka - Richards and Flint (1994) estimated a forest loss of 40% for this region during the last century. Important driving forces were a livestock increase of 108% (217 million head), a rise in the cultivated area by more than 40% of 44 million ha and a staggering population increase by well over half a billion people (210%).

As population increases, the food demand rises as well. In a technologically limited culture, the natural first response is the expansion of cultivated area. Sometimes, crop production was intensified, for example through the introduction of multiple cropping practices (more than one crop is produced per year). In other cases more land was cleared, often at the extent of forests. Although India has a long history of protective laws for forested areas, in the sense that the Indian Forest Act of 1878 severely restricts access to reserved forests by adjacent agricultural populations for fodder, fuel wood and other forest products, the same Act stimulates forest clearance for agriculture. Thus, deforestation that began with direct clearance of wooded land for agriculture was exacerbated by overexploitation of the surviving forests in agricultural areas. The individual right to exploit forests for fuel were functionally liberalized rather than restricted, causing a steadily transformation of the existing woodland/forests to a lower biomass content.

The removal of timber from poorly managed forests timber took its toll as well. Forests in the Himalayan part of India were considered inexhaustible in the early nineteenth century. Railway construction opened up large parts of the land, and massive lumps of wood were burned to fuel the trains. Forest management was often altered for short-term revenue as an explicit goal, and during the two world wars the excessive exploitation of the forests was even intensified in order to meet wartime needs.

Another factor that has added to deforestation in India is its enormous livestock population (377 million heads in 1980), the providers of draft power and dung (largely used as fuel). Unfortunately, the fodder must be provided from the same limited land resources that supply humans with food. Degradation from overgrazing has therefore been a chronic issue in Indian land use.

Also vast areas of lowland wetland forests were converted into wetland rice fields (sawahs) during colonial times. Burmese pioneer-cultivators cleared the forested wetlands of the Irrawaddy Delta for paddy. Similar actions took place in the Mekong Delta of Vietnam, the Chao Phraya Delta in Thailand and the Ganges-Brahmaputra Delta in Bengal.

The first European settlers arrived in Australia around 1780 and it took a while before the expansion of cropland was noticeable. Estimates range from 4.5 – 9.7 million ha in 1860, 3 – 16 million ha in 1900, 10 - 22 million ha in 1930 and 12 – 35 million ha in 1960.

The Eighth Wonder of the World. Forests were not only cleared directly for rice fields

and sugar cane plantations, but also for providing fuel for refineries (Photo credit: Justin Mog, University of Wisconsin-Madison, U.S.A.).

Figure 2: The Ifugao Rice Terraces in the Philippines. Carved by the native Ifugao tribe roughly 2000 years ago, these rice terraces span 20,000 hectares and are considered.

Central Europe and Central Asia - Already during the sixteenth and seventeenth century there existed an intensive trade with Western European ports. The European Hanze trading towns were major import centers for shipped goods from the Baltic region. Poland, Hungary, and Russia were important providers of timber and grain. Estimates for the expansion of cropland in Russia range widely from 49 - 95 million ha in 1860, 113 – 208 million ha in 1900, 109 - 259 million ha in 1930 and 196 - 369 million ha in 1960. The latter was strongly supported by the "Virgin and Idle Lands" Program for 1954-1960, initiated by Khrushchev in Central Asia, particularly Kazakhstan. He attempted to solve the nation's problems only on a short-term level. The plan was designed to increase grain production. But by the early 1960s, much of the land, which had never been touched before Khrushchev, had become a dust bowl. The differences in estimates can partly be explained by the exact definition of cropland or land under cultivation. Another reason might have been the notorious exaggerations of the bureaucrats in the official statistics in order to meet the ambitious reform plans.

4.1.3. North America

European settlers, initially established along North America's eastern seashores, cleared quite extensive areas of forestland for timber exploitation, cultivation and grazing purposes. In the U.S.A., the Homestead Act of 1862 (providing each settler 160 acres of free given government land for cultivation over at least 5 years) led to a rapid settlement of public lands in the next decades. The end of the civil war and the disbanding of armies further stimulated this process. The Great Plains region looked very promising to

people who had lost everything they owned in the war. Furthermore, the soils of the Midwest were much better suited for cultivation than on the East Coast. The increasing flow of immigration added further to the movement of people into the Midwest. The building of canals in the early 1800s, and the subsequent expansion of railroads facilitated the rapid transport of goods to the markets. In the 1850s, corn and wheat belts began to develop. Wheat was constantly extending westward by the rising price of land and by encroaching corn areas. In the 1860s, the Corn Belt moved westward, and toward the end of the decade stabilized in its present area. The consumption of timber was huge: for example, farm fencing in Kentucky alone during the 1870s was estimated to consume 10 million trees annually. Heavy agricultural settlement on the Great Plains began in the 1870s and 1880s. Dryland farming in the semiarid regions of the Midwest began in the 1880s.

Figure 3: Extensive agricultural land in the Midwestern State of Wisconsin, U.S.A. (Photo courtesy: Chris Kucharik, University of Wisconsin-Madison).

In 1902, the government passed the Reclamation Act of 1902 to provide irrigation resources to small farmers, which further spurred the agricultural development of the Midwest. Since 1900, cropland area increased mostly in the Great Plains region, replacing grasslands. The period from 1898 to 1914 is sometimes known as the Golden Age of American Agriculture. By 1920, grain production had reached the most arid regions of the Great Plains and cotton moved into western Texas and Oklahoma. Some states show a reduction in crop acreage between 1930 and 1940, probably because of the negative effects of the Dust Bowl.

Between the 1930s and the 1950s, the federal government sponsored large irrigation projects in the western states, leading to subsequent agricultural development of California and other western states. Around the 1940s, crop acreage in the U.S.A. began to stabilize. In the 1960s, soybean acreage expanded in the Great Plains, as an alternative to other crops. The early twentieth century also saw the abandonment of croplands and re-growth of forests in the eastern portions of the U.S.A., starting in New England, followed by the Mid-Atlantic States, and more recently in the Southeast. The abandonment of croplands in the eastern U.S.A. was partly due to competition from more fertile regions of the Midwest, and also due to competing demands on land within the east.

In what is now Canada, timber export trade took off at the beginning of the nineteenth century. Until that time, The British Navy relied heavily upon imports from the Baltic lands, but with supplies threatened during the Napoleonic Wars they began to look elsewhere. British imports of timber from colonies were negligible in 1800, (10,000 loads in 1803) but reached already 175,000 in 1811. Favorable tax regulations from the new colonies boosted timber extraction, later on replaced by a growing demand from the rapidly growing towns and cities in the New World. The railways reached Winnipeg in 1885, and provided easy access to the prairies. Roughly a decade later, immigration into the Canadian West reached huge proportions. Roughly one million settlers came to the Canadian West from the United States, and several thousand others from Europe. The Prairie Provinces had almost no crop cover in 1900, but was agriculturally developed by 1930.

4.1.4. Latin America

European exploitation of forests in Brazil started with the rubber plantations along the Atlantic coast. This was soon followed by sugar cane. Tropical rainforests once stretched all the way from Pernambuco to Sao Paolo. A striking example of destructive deforestation in South America is the clearance of the Araucaria forests in Southern Brazil. The original extent was around 25 million ha, and now there is only 445,000 ha left. Mainly for agricultural purposes, the bulk of the timber was simply burned. Exploitation in those days was often inefficient and wasteful, as well as destructive. Pioneers tended to have an exploitative and antagonistic attitude towards the forests. As result, erosion became a severe problem on hillslopes. The drainage basin of the Igaucu River in Parana state is so disturbed by deforestation activities in the past, that navigation is no longer possible.

The introduction of cash crops added extra pressure on the remaining forest area in Brazil. Three million ha of forest had been converted into coffee plantations during the nineteenth century. Logging for timber was discovered rather late as a valuable economic enterprise. For example, during the 1920s in Chile, massive deforestation of the lenga forest took place in the province of Aysen. Half of the original forest area, dominated by hardwoods as Nothofagus pumilio was simply burned down to make place for sheep and cattle ranching. Not until the late 1970s they recognized the value of the hardwoods and export to Europe began.

Massive conversion of land for large-scale cattle ranching occurred especially during the last decades of the twentieth century (e.g. Argentina, Brazil). Also large-scale infrastructure projects like the Trans-Amazonian Highway opened-up pristine tropical forest areas, often followed by the spread of settlers on fallow land. Between 1850 and 1985 an amount of 370 million ha forest in Latin America was converted into other land uses (this is equal to 28% of the area in 1850, different assumptions on definitions and classifications gave a range of 25-30%). Most of this reduction of forest area was due to the expansion of pasture (for cattle ranching, 44% of the reduction), croplands (25%), degraded lands (20%) and shifting cultivation (10%). Grigg (1987) presented figures for the expansion of cropland in Argentina, 6 million ha in 1900, 24 million ha in 1930 and 22 million ha in 1960. (The issue of deforestation in the Amazon basin is developed in more detail in paper 15-51 of this Encyclopedia.)

4.1.5. Africa

There is not as much literature on deforestation in the African continent as for other parts of the world. Estimates of forest areas exist for the Ivory Coast (14.5 million ha in 1990 and 3.9 million ha in 1980), Liberia (6.5 million ha in 1920 and 2 million ha in 1980), and Ghana (9.8 million ha in 1920 and 1.7 million ha in 1980). Intensive forest clearing is currently going on in Gabon and the Congo's. Clearance for plantations (cacao, coffee) occurred at a level which is generally not as high as in the Far East.

A decline of the local iron industry during the colonial period in Togo in West Africa is an example of the reduced local demand for charcoal, and thus a relief of one of the greatest pressures on the remaining forest. But especially after the Second War the increasing population and livestock numbers in Sub-Sahelian Africa took their toll on the remaining woodlands and forests. The expansion of cropland, illegal and destructive logging operations, overgrazing, and droughts caused a decrease of the total forest/woodland area of 735 million ha in 1961 to 713 million ha in 1994, a loss of 22 million ha in just three decades.

4.2. Recent Historical Land Use and Land Cover Data Sets

Data on land use and land cover change are available from various sources such as census and tax records, land surveys, forest inventories, paleo records, estimates by historical geographers and remote sensing (aerial photographs and satellite-based sensors, for the more recent decades).

4.2.1. Ground-based Data

Historically, data on land use and land cover change were collected systematically by conducting censuses. The first World Census of Agriculture was conducted in 1930, and FAO has promoted a worldwide census every 10 years since then. FAO has compiled national-level data on agricultural land use for every year since 1961 (known as the FAOSTAT database). FAO has also performed frequent global inventories of forests (Forest Resources Assessment). Sub-national data on land use are also available from various national census organizations at roughly five-to-ten-yr intervals (e.g. U.S. Department of Agriculture for the U.S.A., Fundação Instituto Brasileiro de Geografiae e

Estatística (IBGE) for Brazil, Directorate of Economics and Statistics for India, etc.).

Unfortunately, the quality of census data prior to World War II is very poor. The British Colonies kept extensive tax records and conducted frequent cadastral and forest surveys. Furthermore, historical maps, aerial photographs, population-based estimates, pollen records, and land use models have been used to reconstruct historical land use information.

4.2.2. Remotely-Sensed Data

For the more recent time periods, remote sensing has provided a very valuable means of surveying the land. The first remotely-sensed photograph is credited to Gaspard Felix Tournachon, who took a picture of a village near Paris from a balloon in 1858. Initially, a lot of experimentation was done using rockets, kites, pigeons, etc., but during World War I and II, aerial reconnaissance technology improved greatly, and moved beyond visible photography to use infrared and radar systems. The aircraft also provided a stable platform for placing a sensor. In 1959, satellite-based remote sensing was born, with the first space photograph taken by the Explorer 6 satellite. Landsat 1 launched in 1972 was the first satellite to monitor the Earth's natural resources. Landsat 7 was launched in 1999 and both Landsat 5 and 7 are operating today, making it the longest running space-based remote-sensing program.

The first three Landsats (1972-83) used the Multi-Spectral Scanner (MSS) that had four bands (intervals of continuous wavelength in the radiation spectrum that the sensor views), with a resolution of 79 m (finest level of detail). The subsequent three Landsats (1982 till present [written 2002]) used the 7 bands of the Thematic Mapper (TM), at 30 m resolution. The latest in the series, Landsat 7, launched in 1999 uses the Enchanced Thematic Mapper (ETM+), which has a 15 m resolution in the panchromatic band.

Recently, global characterization of land cover has become possible with the use of moderate-resolution (1 km) remotely sensed data. Using the seasonal characteristics of land surface reflectance measured from satellites, two separate efforts have developed global land cover classification data sets. The University of Maryland (UMD) produced a global data set of 15 different land cover types at 1° x 1° resolution by comparing AVHRR data with ground-based observations. More recently, UMD also created a 1 km resolution land cover classification data set of 13 cover types (including a cropland category) by training AVHRR data against Landsat scenes. Another global land cover data set at 1 km resolution was created jointly by the United States Geological Survey's EROS Data Center, the University of Nebraska-Lincoln, and the European Commission's Joint Research Centre. The development of this DISCover data set was co-ordinated by the International Geosphere-Biosphere Programme's (IGBP).

These two satellite-based efforts have provided a spatially and temporally consistent global land cover classification product. The previous efforts, although painstakingly compiled, were a compilation of different maps that were inconsistent in terms of the definitions of land cover, and were from different periods in time. Although the Landsat data have much finer resolution, they are expensive to compile and classify at a global scale. Recently, efforts have begun to obtain global land cover characterisation using

Landsat data, but these are still in process.

4.2.3. The BIOME 300 Data Set

The recognition of large-scale changes in land cover resulted in a great interest of the scientific community to study the potential causes and consequences of these global changes. However, comprehensive global data sets of historical land cover changes were lacking, until recently.

Two separate efforts recently emerged in the reconstruction of global historical land use databases, one based at the National Institute of Public Health and the Environment (RIVM) in the Netherlands, and the other at the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin-Madison in the U.S.A. These two efforts used historical statistical inventories on agricultural land (e.g. census data, tax records, land surveys, historical geography estimates, etc) and applied different spatial analysis techniques to reconstruct land cover change due to land use for the last 300 years.

	1700	**1800**	**1850**	**1900**	**1920**	**1950**	**1970**	**1990**
Houghton et al [1983]	3,00							
Esser [1991]				13,90	15,70	19,10	20,60	
Richards [1990]	2,65		5,37		9,13	11,70		
FAO [1996]							14,06	14,71
Ramankutty and Foley [1999]	4,00		8,20					20,30
Klein Goldewijk [2001]	2,66	4,02	5,37	8,13	9,44	12,30	14,06	14,71

Table 3: Global cropland estimates for the period 1700 to 1990 (in million km^2).

In particular, the data sets focused on reconstructing the historical expansion of cropland and pasture areas. A data set of global potential natural vegetation was also created. By overlaying the agricultural land data sets over the potential vegetation data set, the change in extent of natural vegetation types was estimated.

Simultaneous with this development, the need for global land use databases was voiced in the global change community, especially among scientists involved in the International Geosphere Biosphere Program (IGBP). Two activities within IGBP, Land Use and Land Cover Change (LUCC) and Past Global Changes (PAGES), came together to take up the challenge of providing the global change community with historical land use data sets. PAGES, having participated in the BIOME 6000 project, had experience with the use of paleo techniques for historical reconstruction of land cover for 6000 years before present. A new joint PAGES-LUCC initiative, labeled BIOME 300, was created to reconstruct historical land use/land cover data sets for the last 300 years. The initial efforts at SAGE and RIVM were harnessed to create a "fast-track" land use data product, which was subsequently widely distributed using CD-ROMs. The data sets are available at a spatial resolution of 0.5 degree in latitude and

longitude, and at an annual resolution from 1700-1992. Table 3 provides an overview of 300 years of land use changes and the rate of change per century.

Results from these studies suggest that cropland area increased from 2.7 - 4 million km^2 in 1700 to 15 - 20 million km^2 in 1990. 7% of the Earth's primary forests were cleared for agriculture by 1700, and this increased to almost 30% by 1990. Including the conversions of natural grasslands/savannas (6% in 1700 and almost 50% in 1990 compared to their natural undisturbed area) and some shrub-lands/deserts areas, the total estimate of land disturbed by humans for agriculture amounts to 34% of the total land area.

5. Consequences of Land Use and Land Cover Change

The conversion of natural land cover to other types of use can have different consequences. A process like selective logging can disturb the ecosystem but, if left alone afterwards, the forest can re-grow and biodiversity is not really endangered. Deforestation results in complete loss of biodiversity and in direct emissions of greenhouse gases (GHG) to the atmosphere (mostly in the form of massive burning of residue, the so-called slash and burn techniques), and indirect emissions as a result of disturbances in the soil (e.g. enhanced decay of soil organic carbon in the weeks and months after the clear-cut). Estimates of emissions stemming from land use changes during the last 2 decades add up to 20% of the total human induced emissions.

Since the suitability of soils – and in particular tropical soils - for agricultural purposes is mainly related to the fertility of the surface layer, soil erosion can be a serious problem in many regions. After clear-cutting of the forest, farmers tend to work their fields for a couple of years and then are forced to abandon the plots (slash-and-burn agriculture), since the soil is rapidly depleted and they have no means in rapidly improving it. These bare fields are very vulnerable to wind and rain erosion and can degrade to such an extent that recovery of forest is no more possible. The expansion of humans into marginal lands (e.g. very dry savannas on the edge of deserts, shrub- lands) faces the same problem, since these lands are very sensitive to disturbance and have – as a result of irregular moisture regimes – hardly any means of recuperating when exploited too heavily (e.g. overgrazing).

Glossary

AVHRR: Advanced Very High Resolution Radiometer; used in satellites for detection vegetation. Normally active photosynthetic vegetation absorbs the visible wavelength (AVHRR channel 1) and reflects near-infrared radiation (AVHRR channel 2).

IGBP: International Geosphere-Biosphere Programme. IGBP is a scientific research program built around a family of core projects. Each core project carries out integrative research in a focused area of Earth System Science.

FAO: Food and Agricultural Organization of the United Nations, Rome, Italy

GEO: Global Environmental Outlook, supervised by UNEP

GHG:	Greenhouse gas (such as carbon dioxide, methane and nitrous oxide)
IPCC:	Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The role of the IPCC is to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change. It bases its assessment mainly on peer reviewed and published scientific/technical literature.
Pasture:	land used for grazing of livestock
Paleological evidence:	fossil pollen analyses (often used for the reconstruction of vegetation zones in pre-historic time periods, thousands of years ago).
UNEP:	United Nations Environmental Program, Headquarters in Nairobi, Kenya.
WRI:	World Resources Institute, Washington D.C., USA.

Bibliography

Bhere K-E. (1988). The Role of Man in European Vegetation History. In: Huntley B. and Webb T. III, eds.: *Vegetation History*. Kluwer Academic Publishers, Dordrecht, The Netherlands. [In-depth analysis of European vegetation from the Middle Ages till present].

Carson R. (1962). *Silent Spring*. Houghton Mifflin Company, Boston, USA. [Biologist, writer, ecologist (1907-1964), the first public evidence how pesticides, used without proper control or knowledge, were poisoning our environment, see http://www.rachelcarson.org].

Esser G. and Overdieck D. eds. (1991). *Osnabrück Biosphere Model: Structure, Construction and Results.* Modern Ecology, Basic and Applied Aspects Series, Elsevier Sci., New York. [Provides data for historical global cropland estimates].

FAO, Food and Agricultural Organization of the United Nations, Rome. [General website for food and agriculture-related topics http://www.fao.org. The forestry inventories can be found at http://www.fao.org/forestry].

Frost, W. (2002). Did they really hate trees? Attitudes of farmers, tourists and naturalists towards nature in the rainforests of Eastern Australia. *Environment and History***, 8**: 3-19. [A good example describing the portrait of an era of colonization].

Goudsblom J. and De Vries B.eds. (2002). *Mappae Mundi, Human Society and their Habitats in a Long-Term Socio-Economic Perspective*. Amsterdam University Press, 368 pp. [This book provides a comprehensive overview of the influence of mankind on their natural environment over the last 10,000 years, including myths, maps and models].

Grigg, D. (1987). The Industrial Revolution and Land Transformation. In: Wolman, M.G. and Fournier F.G.A. eds., *Land transformation in agriculture*. SCOPE 32, John Wiley & Sons, Chichester, New York. [Historical population estimates].

Houghton R.A., Hobbie J.E., Melillo J.M., Moore B., Peterson B.J., Shaver G.R. and Woodwell G.M. (1983). Changes in the Carbon Content of Terrestrial Biota and Soils between 1860 and 1980: A Net Release of CO2 to the Atmosphere. *Ecol. Monogr*, **53**(3): 235-262. [Provides data on historical land use evolution].

Houghton, R.A., Lefkowitz D.S. and Skole D.L. (1991). Changes in the Landscape of Latin America between 1850 and 1985, I. Progressive Loss of Forests. *Forest Ecology and Management*, **38**: 143 – 172. [Detailed land use study for Latin America].

Klein Goldewijk, K. (2001). Estimating Global Land Use Change over the Past 300 Years: The HYDE Database. Global *Biogeochemical Cycles*, **15**(2): 417-433. [Geo-referenced global population and land use tables and maps over the last three centuries, see also http://www.rivm.nl/env/int/hyde].

Klein Goldewijk C.G.M. and Battjes J.J. (1997). *A Hundred Year (1890-1990) Database for Integrated Environmental Assessments (HYDE Version 1.1).* National Instit. Public Health and the Environment (RIVM), Report 422514002, Bilthoven, The Netherlands. [Provides data on historical global land use changes].

Leopold A. (1949). *A Sand County Almanac*. Oxford University Press, New York. [An American conservationist, ecologist and conservator (1887-1948), promoter of sustainable agriculture, see http://www.ag.iastate.edu/centers/leopold/aboutcenter/faq.html].

Marsh, G.P. (1864). *Man and Nature*. Charles Scribner Editors, New York, 656 p. [Marsh is often named the father of the environmental movement. A revised edition was published in 1874 called 'The Earth as Modified by Human Action: Man and Nature' as to emphasize his intentions].

Mather, A.S. (1990). Historical Perspectives on Forest Resource Use, Chapter 3 in: *Global Forest Resources*. Belhaven Press, London, 335 p. [Chapter 3 deals explicitly with historical changes in forest areas, underlying causes and regional examples].

Matthews E. (1983). Global Vegetation and Land Use: New High-Resolution Data Bases for Climate Studies. J. *Clim. and Applied Meteor*., **22**: 474-487. (Provides data on historical global land use changes).

Muir J. (1901). *Our National Parks*. [America's most famous and influential naturalist and conservationist (1838-1914). Due to his efforts America's national parks like Yosemite, Sequoia and Grand Canyon were established].

Ramankutty, N. and Foley J. (1999). Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*, **13**(4): 997-1027. [On the basis of present day satellite imagery and historical inventories provides estimates of cropland cover for the last 300 years].

Richards, J.F. (1990). Land Transformation. In: Turner, B.L.II., W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds.: *The Earth as Transformed by Human Action*. Cambridge Univ. Press, New York, pp. 163-178. [one of the few sources with a global estimate of land use change for the last three centuries].

Richards, J.F. and Flint E.P. (1994). *Historic Land Use and Carbon Estimates for South and Southeast Asia 1880 – 1980*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 4174. [Extensive study for land use of South and Southeast Asia].

Semple, E.C (1931). *Geography of the Mediterranean Region*. Henry Holt and Co, Editors, NewYork. [Specific information about land use during the Roman Era].

Thoreau, H. Walden. [American author (1817-1862), naturalist, philosopher].

Turner, B.L.II., Clark W.C., Kates R.W., Richards J.F., Mathews J.T., and Meyer W.B., eds. (1990).*The Earth as Transformed by Human Action.* Cambridge Univ. Press, New York, pp. 713. [Very good overview of different scientific disciplines towards the global land use change over the past centuries]

Williams M. (1990). Forests. In: Turner B.L et al., eds. *The Earth as Transformed by Human Action*. Cambridge Univ. Press, New York, pp. 179-202. [Provides data on historical global land use changes].

Williams, M. (2001). Dark Ages and Dark Areas: Global Deforestation in the Deep Past. *Journal of Historical Geography*, **26**(1): 28-46 [Good overview of deforestation in the Middle Ages].

Biographical Sketch

Kees Klein Goldewijk is a researcher at the National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands. Research activities include integrated assessments such as the Global Environmental Outlook (GEO) of UNEP, contributions to the IMAGE model as input for the reports of the Intergovernmental Panel on Climate Change (IPCC), and the Millennium Ecosystem Assessment. His special interest is the History Database of the Global Environment (HYDE). This

database is a compilation of historical time series and geo-referenced data on several land use, population, and economic indicators for the last 300 years and may serve as input for integrated models of global change.

Navin Ramankutty is a research scientist at the University of Wisconsin-Madison. His major research interest is in mapping contemporary and historical land use and land cover change, and evaluating the consequences for ecosystem services. In particular, he uses a combination of numerical models, and satellite- and-census-based land use data sets, to evaluate the impacts on the global cycles of carbon and water.