6. Land-Use Issues

Overview

Land-use and forestry issues are important to national and global inventories of greenhouse gases in three ways:

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and below-ground biomass, as well as in soils. Soils, trees, crops, and other vegetation may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks."
- Harvested wood put into wood products, or eventually into landfills, can potentially sequester carbon dioxide from the atmosphere for decades before the carbon stored in the wood products decays and is released to the atmosphere.
- Human-induced land-use changes and forest management practices can alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere.[120]

Land-use issues are of particular interest to U.S. policymakers, because U.S. forests and soils annually sequester large amounts of carbon dioxide. Much of the forest land in the United States was originally cleared for agriculture, lumber, or fuel in the hundred years before 1920. Since then, however, much of the agricultural and pasture land has reverted to forest land, increasing its ability to sequester atmospheric carbon dioxide.

The amount of carbon being sequestered annually is uncertain, in part because of an absence of data and difficulties in measuring carbon sequestration. Moreover, in addition to technical uncertainties, there are also policy and accounting questions about the aspects of the carbon cycle that should be included in national inventories as anthropogenic emissions and removals.

The 1996 revised guidelines for national emissions inventories, published in 1997 by the Intergovernmental Panel on Climate Change (IPCC), include methods for calculating carbon sequestration and net carbon dioxide flux to the atmosphere resulting from land-use changes and land-use activities, such as forestry.[121] The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration in 2003, based on data generated by the U.S. Department of Agriculture (USDA), at 828.0 million metric tons carbon dioxide equivalent ($MMTCO_2e$), a decline of approximately 21 percent from the 1,042.1 $MMTCO_2e$ sequestered in 1990[122] (Table 33). Land use, land-use change,

Table 33. Net Carbon Dioxide Sequestration from U.S. Land-Use Change and Forestry, 1990 and 1997-2003
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1997	1998	1999	2000	2001	2002	2003
Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks	949.3	851.0	805.5	751.7	747.9	750.9	751.5	752.7
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks	8.1	7.4	4.3	4.3	5.7	7.1	6.2	6.6
Settlements Remaining Settlements	84.7	71.6	71.2	70.0	68.9	68.9	68.8	68.7
Urban Trees	*58.7*	*58.7*	*58.7*	*58.7*	*58.7*	*58.7*	*58.7*	*58.7*
Landfilled Yard Trimmings and Food Scraps	*26.0*	*12.9*	*12.5*	*11.4*	*10.2*	*10.3*	*10.2*	*10.1*
Total Net Flux	**1,042.1**	**930.0**	**881.0**	**826.0**	**822.5**	**826.9**	**826.5**	**828.0**

Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2005.html.

[120]The net numerical difference, or "flux," between carbon sequestration and carbon release due to natural factors can be viewed as a measure of the relative contribution of biomass to the carbon cycle.
[121]Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Vol. 3 (Paris, France, 1997), web site www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.
[122]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2005.html.

and forestry practices offset approximately 16.9 percent of total U.S. anthropogenic carbon dioxide emissions in 1990 and 11.9 percent in 2003.[123]

New IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry

The estimates of carbon sequestration in this chapter involve several categorical and methodological changes from previous years, which have been implemented by the EPA in response to new land-use guidelines issued by the IPCC in 2003. The IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry*[124] (LULUCF GPG) recommends reporting carbon stocks according to several land-use types and conversions—for example forest land remaining forest land, non-forest land becoming forest, and forest land becoming non-forest land. These categories of "land-use type remaining land-use type" and "land-use type becoming land-use type" are a new convention adopted in the LULUCF GPG.

Currently, there are no consistent datasets for the entire United States that would allow the results for forest lands, croplands, and settlements to be disaggregated in this fashion. Thus, the net changes in carbon sequestered are aggregated to one category for each land-use type: forests, croplands, and settlements. For example, in the case of forest lands, net changes in forest carbon stocks for "forest land remaining forest land" encompass all forest-related land, including non-forest land converted to forest and forest land converted to non-forest land.

The EPA report, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, upon which this chapter is based, is the first to follow the LULUCF GPG. The LULUCF GPG had to be consistent with the 1996 IPCC Guidelines, because there was an existing agreement among Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to use the latter.[125] The IPCC defines this consistency as: (1) traceability of specific sources or sinks addressed by the LULUCF GPG to categories in the IPCC Guidelines; (2) use of the same functional forms (or their equivalent) for the equations in the LULUCF GPG that are used in the IPCC Guidelines; and (3) facilitation for the correction of errors or deficiencies in the IPCC Guidelines by application of the LULUCF GPG.

In its most recent inventory, the EPA followed the LULUCF GPG, reporting fluxes according to changes within and conversions between forest lands, croplands, settlements, grasslands, and wetlands. Due to the lack of consistent datasets, the EPA limited its estimates of greenhouse gas flux to: (1) forest land remaining forest land, (2) croplands remaining croplands, and (3) settlements remaining settlements. This new categorization provides additional sources of information on nitrous oxide emissions by major land-use type. Further, the EPA cautioned that other land-use and land-use change activities cause fluxes of greenhouse gases other than carbon dioxide that are not accounted for, including methane from managed forest soils and artificially flooded lands.

Significant differences between the sequestration values in this report and those in EIA's previous reports on U.S. greenhouse gas emissions are broadly attributable to changes that have been made in order to conform with the LULUCF GPG, as well as a variety of differences in calculation methods. Definitional changes include the following:

- The forest soil pool is now termed "soil organic carbon."
- The forest floor is now termed "litter."
- Previously, the tree pool included the mass of standing dead trees; now, the mass of standing dead trees, together with down dead wood, is categorized as "dead wood."
- Previously, the remainder of the tree pool, live biomass, and understory pool was divided into above- and below-ground portions; now, the above-ground tree and understory pools are summed into an above-ground biomass pool, and the below-ground portions are summed into a below-ground biomass pool.

Important differences in calculation methods include the following:

- The USDA's State Soil Geographic (STATSGO) database[126] and its relationship with data from the

[123]EIA does not include sequestration from land-use change and forestry as part of its annual estimate of emissions of greenhouse gases in the United States. Note that land use refers to maintaining land within a particular category of use, such as forests remaining forests, whereas land-use change refers to changing from one land-use type to another, as when forest is converted to grasslands, or wetlands drained to create more land for agriculture.

[124]Intergovernmental Panel on Climate Change, *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Hayama, Japan, 2003), web site www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm.

[125]Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Vol. 3 (Paris, France, 1997), web site www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

[126]The State Soil Geographic (STATSGO) database is a 1:250,000 scale generalized soils database, prepared by the National Resources Conservation Service of the U.S. Department of Agriculture. See web site www.ncgc.nrcs.usda.gov/products/datasets/statsgo.

USDA's National Forest Inventory and Analysis (FIA) survey[127] are now interpreted differently for the estimation of soil organic carbon. For this report, soil organic carbon in the conterminous United States was calculated using the STATSGO database, and data gaps were filled with representative values for similar soils. Links to regions and forest types were developed with the assistance of the USDA's FIA Geospatial Data Services, by overlaying FIA forest inventory plots with existing soil carbon maps.

- The newer USDA Forestry Inventory and Analysis Database (FIADB) datasets were considered for non-soil forest carbon estimates, along with the USDA Resources Planning Act (RPA) data.[128] For last year's estimates, only RPA data were used when needed.
- Final values for all carbon pools were extrapolated from the last carbon stock change values calculated from the FIA survey data, because it was not possible to model final stocks in a manner consistent with available inventory data. Previously, the estimates of final carbon stocks were based on model results.

Forest Land Remaining Forest Land

The values for forest carbon dioxide fluxes reported in this chapter are based on estimates of changes in forest carbon stocks. The components analyzed are aboveground biomass, below-ground biomass, dead wood, litter, soil organic carbon, harvested wood products in use, and harvested wood products in landfills. The estimated carbon dioxide flux from each of these components was calculated using FIADB data and methodologies consistent with the LULUCF GPG and the Revised 1996 IPCC Guidelines. Nitrous oxide emissions from fertilized forest soils were calculated by using a default methodology consistent with the LULUCF GPG. Pine trees, being the dominant species planted for timber in the southeastern United States, were taken as representative of fertilized forests in the country, and the average reported fertilization rate of 150 pounds of nitrogen per acre was multiplied by the area of pine receiving fertilizer.

Croplands Remaining Croplands

Estimates of carbon fluxes from croplands include changes in agricultural soil carbon stocks on both croplands and grazing lands, because datasets necessary to separate the two were not available. Changes in agricultural soil carbon stocks result from the use and management of cropland and grazing land and emissions of carbon dioxide from the application of crushed limestone and dolomite. The estimation methods used for this report are consistent with the Revised 1996 IPCC Guidelines and the LULUCF GPG.

Settlements Remaining Settlements

Fluxes from settled lands include methane from landfilled yard trimmings and food scraps, carbon from urban trees, and nitrous oxide from fertilized soils. Changes in carbon flux were estimated by analyzing life-cycle emissions and sinks associated with waste management. Stock changes in urban trees were estimated on the basis of field measurements and data on national urban tree cover, using a methodology consistent with the LULUCF GPG to estimate carbon flux. Nitrous oxide emissions from nitrogen applied to turf grass were estimated as 10 percent of all synthetic fertilizer used in the United States.

Land-Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land-use change and forestry in 2003 include three main sink categories: (1) changes in forest carbon stocks for forest land remaining forest land (752.7 $MMTCO_2e$ or 91 percent of the total); (2) changes in agricultural soil carbon stocks for cropland remaining cropland (6.6 $MMTCO_2e$ or 0.8 percent of the total); and (3) changes in settlements remaining settlements (68.7 $MMTCO_2e$ or 8.3 percent, including 58.7 $MMTCO_2e$ from urban trees and 10.1 $MMTCO_2e$ from landfilled yard trimmings and food scraps).[129] For a discussion of worldwide trends in forest and croplands see the box on page 78.

Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks

In the United States, the most significant pressures on the amount of carbon sequestered through forest lands are land management activities and the continuing effects of past changes in land use. These activities directly affect carbon flux by shifting the amount of

[127]The USDA's Forest Inventory and Analysis (FIA) Program provides the information needed to assess forests in the United States. Through an annual survey, FIA reports on status and trends in forest area and location. See web site http://fia.fs.fed.us.

[128]The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Secretary of Agriculture to conduct an assessment of the Nation's renewable resources every 10 years. In the most recent assessment, which was done in 2000, the emphasis was expanded from solely economic concerns to resource conditions, ecosystem health, and sustainability. See web site www.fs.fed.us/pl/rpa/what.htm.

[129]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

Millennium Ecosystem Assessment: Forest and Cultivated Systems

In 2000, United Nations Secretary-General Kofi Annan called for the Millennium Ecosystem Assessment (MA) in his report to the United Nations General Assembly. The global assessment was completed in 2005,[a] and work continues on sub-global assessments. The MA was carried out under the auspices of the U.N. Environment Program and was governed by a multi-stakeholder board of representatives of international institutions, governments, businesses, non-governmental organizations, and indigenous peoples. More than 1,300 authors from 95 countries worked to prepare the global assessment, and hundreds are continuing to work on more than 20 sub-global assessments, to be published in 2006. In addition, 850 experts were involved in peer reviews of the global assessment.

The objectives of the assessment were to gauge the effects of ecosystem change on human well-being and establish a scientific foundation for enhancing the conservation and sustainable use of ecosystems. The MA responds formally to government requests for information received through four international conventions, the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species. Forest and cultivated land systems were an important part of the assessment.

Forest Systems

The MA defines forest systems as areas with a canopy cover of at least 40 percent provided by woody plants taller than 5 meters, including temporarily cut-over forests and plantations, but excluding orchards and agroforests that mainly produce food crops. Forest systems regulate 57 percent of total water runoff, and they ensure all or some of the water supply for about 4.6 billion people worldwide.

According to the MA, the global area of forest systems has been halved over the past three centuries; 25 countries have lost all forests; and another 29 have lost more than 90 percent of their forest cover. Forest systems regulate 57 percent of total water runoff, ensuring some or all of the water supply for about 4.6 billion people. From 1990 to 2000, temperate forests increased by almost 3 million hectares annually; however, tropical deforestation exceeded 12 million hectares annually. About 40 percent of forest area has been lost during the industrial era, and forests continue to be lost in many regions. Some of the pressure to clear forests in the future, according to the MA, will be alleviated by the expanding role of plantations in timber supply.

Global timber production has increased by 60 percent in the past four decades. Most of the increase is attributed to plantations, which produced 35 percent of the global roundwood harvest in the year 2000. This proportion, according to the MA, is expected to increase to 44 percent by 2020. The most rapid expansion of plantations is expected to occur in the mid-latitudes, where yields are higher and costs are lower.

Under the MA scenarios, which run from 1970 to 2050, forest area is expected to increase in industrial regions and decrease in developing ones.[b] Global deforestation in three of the four scenarios is projected to be approximately equal to historic rates (approximately 0.4 percent annually between 1970 and 1995). The fourth scenario projects a deforestation rate of 0.6 percent per year. Particular ecosystems, such as tropical forests, could be subject to higher than average deforestation rates.

Cultivated Systems

In the MA, cultivated systems include predominantly cropped areas, agroforestry, and aquaculture. In the past two decades, one of the areas with the greatest expansion of cropland was the U.S. Great Plains, and one of the areas with the greatest contraction of cropland was the southeastern United States. While the intensification of cultivated systems has met the increase in food needs over the past 50 years and reduced the pressure to convert natural ecosystems into cropland, this, according to the MA, has come at the cost of greater pressure on inland water ecosystems, generally reduced biodiversity within agricultural landscapes, and higher energy inputs in the form of mechanization and the production of chemical fertilizers. Although cultivated systems provide only 16 percent of global water runoff, they tend to be close to

(continued on page 79)

[a]For an overview of the Millennium Ecosystem Assessment, see web site www.millenniumassessment.org/en/about.overview.aspx. At the time this chapter was written, subglobal assessments were not available. This summary is based on the synthesis report, with an emphasis on the United States.

[b]Scenarios are story lines that envision different future worlds. As with climate change analysis, models are run, and their outputs are described for several possible future scenarios. Each scenario encapsulates a broad set of socioeconomic, political, and ecological assumptions. The four scenarios used in the assessment focused on global conditions in 2050. For more details on the scenarios analyzed, see Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Synthesis* (Washington, DC: Island Press, 2005), web site www.millenniumassessment.org/en/Products.Synthesis.aspx.

Millennium Ecosystem Assessment: Forest and Cultivated Systems (continued)

human populations, and their nutrient and industrial water runoff affects about 5 billion people.

The absence of new suitable land for cultivation and the increased productivity of agricultural lands are reducing the need for agricultural expansion. Consequently, more of the land in cultivated systems is actually being cultivated, with increased intensity of cultivation, shorter fallows, and a shift from monocultures to polycultures. Farmers in North America and other areas increasingly are adopting appropriate soil conservation practices that reduce erosion, such as minimum tillage. Since 1950, one of the areas where cropland has stabilized is North America. The table below summarizes some current characteristics of cropland and forest ecosystems as reported by the MA, including the relative proportions of potential and actual areas in each system, indicated as the "share of area transformed."

Synergies

The MA approach attempts to look beyond the confines of particular systems and stresses a broad interconnected view of the costs and benefits of ecosystem conversions. Because of the connections among ecosystems, the degradation of one can have negative synergistic effects on others; however, the same connections can be harnessed through properly designed human interventions to produce positive synergistic effects. According to the MA, increasing food production in cultivated systems can have negative effects on biodiversity and water regulation, as well as increasing agricultural pollutants in the runoff; however, the interactions between human and natural systems can also have positive synergies. Agroforestry systems, if properly designed, can provide food and fuel, restore soils, and contribute to biodiversity conservation.

Characteristics of Forest Systems and Cultivated Systems Worldwide

System and Subsystem	Area (Million Square Kilometers)	Share of Terrestrial Surface of Earth (Percent)	Mean Net Primary Production[a] (Kilograms Carbon per Square Meter per Year)	Share of System Covered by Protected Areas[b] (Percent)	Share of Area Transformed[c] (Percent)
Forest/Woodland	**41.9**	**28.4**	**0.68**	**10**	**42**
Tropical/Subtropical	23.3	15.8	0.95	11	34
Temperate	6.2	4.2	0.45	16	67
Boreal	12.4	8.4	0.29	4	25
Cultivated	**35.3**	**23.9**	**0.52**	**6**	**47**
Pasture	0.1	0.1	0.64	4	11
Cropland	8.3	5.7	0.49	4	62
Mixed (Crop and Other)	26.9	18.2	0.60	6	43

[a]Net primary productivity (NPP) measures the rate at which carbon is fixed by plants, minus carbon lost through plant respiration.

[b]Protected areas in the International Union for the Conservation of Nature (IUCN) categories I through VI.

[c]For forest/woodland systems, the share of area transformed is the percentage difference between the forest types that could exist on the lands (forested biomes of the World Wildlife Fund's ecoregions land classification) and those that actually exist, as indicated by the Global Land Cover land classification system of the European Commission's Joint Research Center. For cultivated systems, the share of area transformed is the area indicated as such in the Global Land Cover land classification system.

Source: Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Synthesis* (Washington, DC: Island Press, 2005), web site www.millenniumassessment.org/en/Products.Synthesis.aspx.

carbon accumulated in forest ecosystems.[130] Land management activities affect both the stocks of carbon that can be stored in land-based carbon sinks, such as forests and soils, and the fluxes of carbon between land-based sinks and the atmosphere.

The components or "pools" of forest carbon analyzed by the EPA for its most recent inventory include above-ground biomass, below-ground biomass, dead wood, litter, soil organic carbon, harvested wood products in use, and harvested wood products in landfills. As a

[130]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

result of natural biogeochemical processes occurring in forests, as well as anthropogenic activities, carbon is constantly cycling through these components and between the forest and the atmosphere. The net change in overall forest carbon may not always be equal to the net flux between forests and the atmosphere, because timber harvests may not necessarily result in an instant return of carbon to the atmosphere. Timber harvesting transfers carbon from one of the five "forest carbon pools" to one of the two "wood products carbon pools." Once carbon is transferred to a product pool, it is emitted over time as carbon dioxide or methane as the product decays or is combusted. Emission rates vary significantly, depending on the type of product pool that houses the carbon.[131]

In the United States, enhanced forest management, regeneration of formerly cleared forest areas, and timber harvesting have resulted in net annual sequestration of carbon throughout the past decade. Since the 1920s, deforestation for agricultural purposes has become a nearly defunct practice. More recently, managed growth practices have become common in eastern forests, greatly increasing their biomass density over the past 50 years. In the 1970s and 1980s, federally sponsored tree planting and soil conservation programs were embraced. These programs led to the reforestation of formerly harvested lands, improvement in timber management activities, soil erosion abatement, and the conversion of cropland to forests. Forest harvests have also affected carbon sequestration. The majority of harvested timber in the United States is used in wood products. The bulk of the discarded wood products is landfilled, and thus large quantities of the harvested carbon are relocated to long-term storage pools rather than to the atmosphere. The size of this long-term storage pool has increased over the past century.[132]

According to the EPA, carbon sequestration by U.S. forests totaled 753 $MMTCO_2e$ in 2003 (Table 34). Between 1990 and 2003, U.S. forests accounted for an average annual net sequestration of 832 $MMTCO_2e$, resulting from domestic forest growth and increases in forested land area; however, there was a decrease of approximately 21 percent in annual sequestration over the same period.[133]

The overall decline in forest carbon sequestration was driven by a 27-percent reduction in the level of sequestration in the forest carbon pool (739 $MMTCO_2e$ in 1990 versus 537 $MMTCO_2e$ in 2003). The reduction in the forest carbon pool sequestration rate can be attributed primarily to a 110-percent decline in the estimated level of sequestration in forest soils. Not only was there no forest

Table 34. Net Carbon Dioxide Sequestration in U.S. Forests and Harvested Wood Pools, 1990 and 1997-2003
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1997	1998	1999	2000	2001	2002	2003
Forests	**739**	**638**	**599**	**537**	**537**	**537**	**537**	**537**
Above-Ground Biomass	396	457	437	400	400	400	400	400
Below-Ground Biomass	77	89	85	78	78	78	78	78
Dead Wood	74	53	51	45	45	45	45	45
Litter	67	31	28	26	26	26	26	26
Soil Organic Carbon	125	8	-1	-12	-12	-12	-12	-12
Harvested Wood	210	213	206	215	211	214	214	216
Wood Products	48	58	52	62	59	59	59	60
Landfilled Wood	162	155	154	153	152	155	155	155
Total	**949**	**851**	**806**	**752**	**748**	**751**	**751**	**753**

Notes: The sums of the annual net stock changes in this table (shown in the "Total" row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest estimates are based on periodic measurements; harvested wood estimates are based on annual surveys and models. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2005.html.

[131]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003,* EPA-430-R-05-003 (Washington, DC, April 2005), p. 233, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory2005.html.

[132]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003,* EPA-430-R-05-003 (Washington, DC, April 2005), p. 233, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG Emissions USEmissionsInventory2005.html.

[133]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003,* EPA-430-R-05-003 (Washington, DC, April 2005), p. 233, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG Emissions USEmissionsInventory2005.html.

soil sequestration in 2003 (as compared with 125 $MMTCO_2e$ sequestered in 1990), but forest soils became a source with average annual emissions of 12.0 $MMTCO_2e$ during the period 1999-2003. The EPA explains that the decrease in sequestration in this pool is derived from forest inventory data and is a direct consequence of changes in total forest area or changes in forest type.[134]

The EPA points out that net forest growth and increasing forest area, particularly before 1997, contributed to rising sequestration. Since 1997, forest land area has remained relatively constant, and the increase in carbon density (per area) has resulted in net forest carbon sequestration. National estimates of forest land are obtained by summing State surveys for the conterminous United States. Because the State surveys are not completed each year, interpolation between data points is used to provide estimates for years without surveys.

Overall annual sequestration levels in harvested wood carbon stocks increased slightly between 1990 and 2003. The trend in net sequestration amounts has been generally upward, from 210 $MMTCO_2e$ in 1990 to 216 $MMTCO_2e$ in 2003 (Table 34). Annual sequestration levels in landfilled wood declined from 162 $MMTCO_2e$ in 1990 to 155 $MMTCO_2e$ in 2003, but that decline was offset by an increase in carbon sequestration in harvested wood products, from 48 $MMTCO_2e$ in 1990 to 60 $MMTCO_2e$ in 2003.

The EPA has estimated carbon stocks in wood products in use and in landfills from 1910 onward, based on USDA Forest Service historical data and analyses using the North American Pulp and Paper (NAPAP) model,[135] the Timber Assessment Market Model (TAMM),[136] and the Aggregate Timberland Assessment System (ATLAS) model.[137] Carbon decay in harvested wood was analyzed by the EPA for the period 1910 through 2003, using data on annual wood and paper production. The analysis included changes in carbon stocks in wood products, changes in carbon in landfills, and the amount of carbon emitted to the atmosphere (carbon dioxide and methane) both with and without energy recovery. The EPA also followed the "production approach"; that is, carbon stored in imported wood products was not counted, but carbon stored in exports was counted, including logs processed in other countries[138] (see box on page 82).

Croplands Remaining Croplands: Changes in Agricultural Soil Carbon Stocks

The amount of organic carbon in soils depends on the balance between the addition of organic material and the loss of carbon through decomposition. The quantity and quality of organic matter within soils, as well as decomposition rates, are determined by the interaction of climate, soil properties, and land use. Agricultural practices—including clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding—can alter organic matter inputs and decomposition, causing a net flux of carbon to or from soils.

The IPCC methodology, which is used by the EPA to estimate the net flux from agricultural soils (Table 35), is divided into three categories of land-use and land-management activities: (1) agricultural land use and land management activities on mineral soils;[139] (2) agricultural land-use and land-management activities on organic soils;[140] and (3) liming of soils. Of the three activities, the use and management of mineral soils is estimated to be the most significant contributor to total carbon sequestration from 1990 through 2003. Sequestration in mineral soils in 2003 was estimated to be 51.7 $MMTCO_2e$, while emissions from organic soils and liming were estimated at 35.6 and 9.5 $MMTCO_2e$, respectively. Together, these three activities resulted in a

[134]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003,* EPA-430-R-05-003 (Washington, DC, April 2005), p. 233, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG Emissions USEmissionsInventory2005.html.

[135]P.J. Ince, *Recycling and Long-Range Timber Outlook*, USDA Forest Service General Technical Report RM-242 (Fort Collins, CO, February 1994).

[136]U.S. Department of Agriculture, Forest Service, *An Analysis of the Timber Situation in the United States: 1952 to 2050*, General Technical Report PNW-GTR-560 (Portland, OR, February 2003).

[137]J.R. Mills and J.C. Kincaid, *The Aggregate Timberland Assessment System–ATLAS: A Comprehensive Timber Projection Model*, USDA Forest Service General Technical Report PNW-281 (Portland, OR, June 1992).

[138]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003,* EPA-430-R-05-003 (Washington, DC, April 2004), p. 210, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG Emissions USEmissionsInventory2005.html.

[139]Mineral soils are soils consisting predominantly of, and having their properties determined predominantly by, mineral matter. They usually contain less than 200 grams of organic carbon per kilogram of soil (less than 120 to 180 grams per kilogram if saturated with water) but may contain an organic surface layer up to 30 centimeters thick.

[140]Organic soils are soils that, when saturated with water, have 174 grams or more of organic carbon per kilogram of soil if the mineral fraction has 500 grams per kilogram or more of clay, or 116 grams per kilogram organic carbon if the mineral fraction has no clay, or has proportional intermediate contents. If the soil is never saturated with water, organic soils have 203 or more grams per kilogram of organic carbon.

Accounting for Harvested Wood Products in Future Greenhouse Gas Inventories

Harvested wood products (HWP) are defined as "goods manufactured or processed from wood, including lumber and panels for end uses such as housing and furniture, and paper and paperboard for uses such as packaging, printing and writing, and sanitary applications."[a] HWP are an important part of the overall carbon cycle and are thus integral to any greenhouse gas accounting system or inventory.

Preparation of the 2006 guidelines of the Intergovernmental Panel on Climate Change (IPCC) for preparing national greenhouse gas inventories under the United Nations Framewrk Convention on Climate Change (UNFCCC)—including methods for estimating and reporting of HWP—is underway. The issue of accounting for HWP, however, is a complex one, and involves the consideration of factors such as international trade (import-export) of wood products, timing of emissions accounting, determining whether emissions include those from existing wood product pools or solely from harvesting, and establishing how complex or simple the accounting approach should be so as not to create barriers to participation.[b]

Three approaches—stock-change, production, and atmospheric-flow—have been developed and debated, and all three were discussed at a UNFCCC-sponsored workshop held in Norway on August 30 through September 2, 2004.[c] At the Eleventh Conference of the Parties to the UNFCCC in December 2005, the parties agreed to return to this issue at the 24th meeting of the Subsidiary Body for Scientific and Technical Advice.[d]

The first approach under consideration for HWP is the *stock-change approach*. This approach accounts for changes in carbon stock in forests in the country in which the wood is grown, deemed the producing country. Changes in the products pool are accounted for in the country where the products are used, deemed the consuming country. These stock changes are counted within national boundaries, where and when they occur.[b] Under this approach, the HWP stock change in a country may be estimated considering either transfers into and out of the HWP pool, or the difference between HWP carbon stocks at two different set points in time.

The next alternative—the *atmospheric-flow approach*—accounts for emissions or sequestration of carbon to and/or from the atmosphere within national boundaries, both where and when emissions and sequestration occur. The producing country accounts for sequestration of carbon attributed to forest growth, while the consuming country accounts for emissions of carbon to the atmosphere from oxidation of HWP.[b] Under this approach, it is the net flow of carbon dioxide from the pools to the atmosphere that would be reported as the equivalent emission, and the net flow in the opposite direction as the equivalent amount of carbon sequestration.[c]

The third approach for accounting for HWP is the *production approach*. While this approach also reports changes in carbon stock, it is the producing country that reports the stock changes in HWP regardless of the location of the stock (i.e., whether within country boundaries or exported).[c] This approach thus accounts for domestically produced stocks only; that is, stock changes are counted when they occur, regardless of where the stock change occurs.[b]

An additional method that was proposed by one Annex I country—the *simple decay approach*—effectively falls under the production approach. This method assumes that HWP remain a part of the forest in which they were produced until decomposed.[c] This approach is therefore similar to the production approach in that it also estimates the stock changes in HWP when, but not where, they occur if wood products are exported or traded. Both sequestration of carbon from the atmosphere due to forest growth and emissions resulting from harvesting are accounted for in the producing country.[b]

[a]"United States Submission on the Views Related to Carbon Accounting and Wood Products," in United Nations Framework Convention on Climate Change, *Issues Relating to Harvested Wood Products*, Paper No. 7 (May 10, 2004), pp. 42-43, web site http://unfccc.int/resource/docs/2004/sbsta/misc09.pdf.

[b]M. Ward, "Harvested Wood Products, A Beginning Guide to Key Issues," Senior Counsel to the Government of New Zealand (July 2004).

[c]K. Pingoud et al., "Approaches for Inclusion of Harvested Wood Products in Future GHG Inventories Under the UNFCCC, and their Consistency with the Overall UNFCCC Inventory Reporting Framework," *IEA Bioenergy* (July 13, 2004).

[d]International Institute for Sustainable Development, "Summary of the Eleventh Conference of the Parties to the UN Framework Convention on Climate Change and First Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol: 28 November – 10 December 2005," *Earth Negotiations Bulletin*, Vol. 12, No. 291 (December 12, 2005), web site www.iisd.ca/vol12/enb12291e.html.

net 6.6 $MMTCO_2e$ sequestered through agricultural soils in 2003.[141]

Settlements Remaining Settlements

Changes in Urban Tree Carbon Stocks

Urban forests make up a considerable portion of the total tree canopy cover in the United States. Urban areas, which cover 3.5 percent of the continental United States, are estimated to contain about 3.8 billion trees, accounting for approximately 3 percent of total tree cover in the United States. The EPA's carbon sequestration estimates for urban trees are derived from estimates by Nowak and Crane,[142] based on data collected throughout the 1990s and applied to the entire time series in this report. Net carbon dioxide sequestration from urban trees is estimated at 58.7 $MMTCO_2e$ sequestered annually from 1990 through 2003 (Table 33).[143]

Changes in Landfilled Yard Trimming and Food Scrap Carbon Stocks

Carbon stored in landfilled yard trimmings can remain sequestered indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) and food scraps make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings and food scraps collected are discarded in landfills. Both the amount collected annually and the percentage that is landfilled have declined over the past decade. Net carbon dioxide sequestration from landfilled yard trimmings and food scraps has declined accordingly, from 26.0 $MMTCO_2e$ in 1990 to 10.1 $MMTCO_2e$ in 2003 (Table 36).

Since 1990, municipal policies limiting pickup and disposal have led to a 20-percent decrease in yard trimmings collected. In addition, composting of yard trimmings in municipal facilities has increased significantly, reducing the percentage of total yard trimmings placed in landfills from 72 percent in 1990 to 34 percent in 2003. In contrast, the percentage of food scraps disposed of in landfills has decreased only slightly, from 81 percent in 1990 to 77 percent in 2003. The EPA's methodology for estimating carbon storage relies on a life-cycle analysis of greenhouse gas emissions and sinks associated with solid waste management.[144]

Land Use and International Climate Change Negotiations

In past international negotiations on climate change, the United States and many other countries have maintained that the inclusion of LULUCF activities in a binding agreement that limits greenhouse gas emissions is of the utmost importance; however, issues of whether and how terrestrial carbon sequestration could be accepted for meeting various commitments and targets have remained subjects of complex and difficult international negotiations.

Many of the countries involved in climate change negotiations have agreed that implementation of LULUCF

Table 35. Net Carbon Dioxide Sequestration in U.S. Agricultural Soils, 1990 and 1997-2003
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1997	1998	1999	2000	2001	2002	2003
Mineral Soils	52.4[a]	51.7[a]	49.5[b]	48.9[b]	50.0[b]	51.6[b]	51.9[b]	51.7[b]
Organic Soils	-34.8[a]	-35.6[a]	-35.6[b]	-35.6[b]	-35.6[b]	-35.6[b]	-35.6[b]	-35.6[b]
Liming of Soils	-9.5[a]	-8.7[a]	-9.6[a]	-9.1[a]	-8.8[a]	-9.0[a]	-10.1[a]	-9.5[b]
Total	**8.1[a]**	**7.4[a]**	**4.3[b]**	**4.3[b]**	**5.7[b]**	**7.1[b]**	**6.2[b]**	**6.6[b]**

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.
Note: Negative values indicate net emissions.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

[141]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.
[142]D.J. Nowak and D.E. Crane, "Carbon Storage and Sequestration by Urban Trees in the United States," *Environmental Pollution*, Vol. 116, No. 3 (2001), pp. 381-389.
[143]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.
[144]U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov/epaoswer/non-hw/muncpl/ghg/ghg.htm.

activities under an international climate change agreement may be complicated by a lack of clear definitions of "reforestation" and "forest." Further, implementation may be hindered by the lack of effective accounting rules. According to research published by the Pew Center on Global Climate Change,[145] implementation of LULUCF provisions in an international climate change agreement raises many issues, such as:

- What is a direct human-induced activity?
- What is a forest and what is reforestation?
- How will the issues of uncertainty and verifiability be addressed?
- How will the issues of (non) permanence and leakage be addressed?
- Which activities beyond afforestation, reforestation and deforestation (ARD), if any, should be included, and what accounting rules should apply?
- Which carbon pools and which greenhouse gases should be considered?

Uncertainties related to data issues have also slowed international negotiations on climate change.

The Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP-9) was held in Milan, Italy, in December 2003. The parties agreed on some of the rules for carbon sequestration projects under the Clean Development Mechanism (CDM), but the issue of how to treat the non-permanence of carbon sinks projects remained unresolved. Delegates at COP-9 decided to limit the duration of credits generated from carbon sequestration projects and addressed the topics of additionality, leakage, uncertainties, and socioeconomic and environmental impacts.[146]

A year later in Buenos Aires, Argentina, delegates at the Tenth Conference of the Parties (COP-10) did address the issue of small-scale afforestation and reforestation project activities under the CDM. The following decisions were made at COP-10:[147]

- Adopt simplified modalities and procedures for small-scale afforestation and reforestation project activities in the first commitment period.
- Limit the designation of small-scale afforestation and reforestation projects to those with net anthropogenic greenhouse gas removals by sinks that are less than 8,000 metric tons carbon dioxide equivalent per year. For projects that result in greenhouse gas removals of more than this quantity, the excess would be ineligible for temporary or long-term certified emissions reductions.
- Exclude funds obtained through small-scale project activities from the share of proceeds to be used to assist developing countries particularly vulnerable to the adverse impacts of climate change. Such countries shall be entitled to a reduced level of the non-reimbursable fee for requesting registration and a reduced rate of the proceeds to cover administrative expenses of the CDM.

Table 36. Net Carbon Dioxide Sequestration from Landfilled Yard Trimmings and Food Scraps, 1990 and 1997-2003
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1997	1998	1999	2000	2001	2002	2003
Yard Trimmings	**23.2**	**10.4**	**9.6**	**8.5**	**7.2**	**7.4**	**7.5**	**7.5**
Grass	2.5	0.9	0.8	0.7	0.6	0.7	0.7	0.7
Leaves	11.2	5.4	5.1	4.5	4.0	4.0	4.0	4.0
Branches	9.6	4.0	3.7	3.2	2.6	2.7	2.7	2.8
Food Scraps	**2.8**	**2.6**	**2.9**	**2.9**	**3.0**	**2.9**	**2.7**	**2.6**
Total	**26.0**	**12.9**	**12.5**	**11.4**	**10.2**	**10.3**	**10.2**	**10.1**

Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

[145]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA: Pew Center on Global Climate Change, June 2000), p. 5, web site www.pewclimate.org/docUploads/land_use.pdf.
[146]Pew Center on Global Climate Change, "Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change" (Milan, Italy, December 1-12, 2003), web site www.pewclimate.org/what_s_being_done/in_the_world/cop9/index.cfm.
[147]International Institute for Sustainable Development, "Summary of the Tenth Conference of the Parties to the UN Framework Convention on Climate Change: 6-18 December 2004," *Earth Negotiations Bulletin*, Vol. 12, No. 260 (December 20, 2004), web site www.iisd.ca/vol12/enb12260e.html.

Land-Use Data Issues

The EPA's most recent inventory report discusses the uncertainty inherent in the methodology used to estimate forest carbon stocks.[148] The estimates of forest carbon in live biomass, dead wood, and litter are based on USDA forest survey data for the conterminous United States, because no survey data are available for Alaska, Hawaii, and the U.S. Territories. The survey data are statistical samples designed to represent vast areas of land. The USDA mandates that the survey data be accurate to within 3 percent, at a confidence level of 67 percent.[149] An analysis of this methodology for the southeastern United States showed that the uncertainty resulted from sampling errors and not from the regression equations used to calculate tree volume (and thus carbon) from survey statistics such as tree height and diameter. The standard errors of 1 to 2 percent for volumes of growing stock in individual States are insignificant; however those for changes in the volumes of growing stock are much higher, ranging from 12 percent to as much as 139 percent.[150]

Additional uncertainty is associated with the estimates of carbon stocks in other carbon pools, which are based on extrapolations of the relationships among variables in site-specific studies to all forest land. Such extrapolation is needed in the absence of survey data on other carbon pools.[151] The extrapolations bring in uncertainty from modeling errors and conversions between different reporting units. The effect of land-use change and forest management activities (such as harvest) on soil stocks is another large source of uncertainty, with little consensus in the literature.

Global Forest Resources Assessment 2000

The Food and Agriculture Organization of the United Nations (FAO) is the main intergovernmental source of data on global forests. FAO's global forest assessments date back to 1948, with the most recent assessment—*Global Forest Resources Assessment 2000*—published in 2001. The 2000 assessment was the first to include a uniform definition of forests for all regions of the world—that is, areas with at least 10 percent of canopy cover (excluding stands of trees primarily used for agricultural production). Using this new definition, FAO estimated the world's forested area in 2000 at 3.9 billion hectares.

The 2000 assessment reported that the world's forests showed average net annual losses of 9.4 million hectares from 1990 to 2000, with annual losses of 14.6 million hectares due to deforestation and annual gains of 5.2 million hectares due to reforestation, afforestation, and the natural expansion of forests. Net losses for tropical forests were 12.3 million hectares annually, and net gains for non-tropical forests were 2.9 million hectares annually.[a]

The FAO *Global Forest Resources Assessment 2000* draws its forest data for the United States from U.S. Forest Service periodic forest inventories, which cover all forest land in the United States for more than 70 years. The Forest Inventory and Analysis (FIA) traditionally sampled on a 5- to 10-year cycle with an accuracy of ±1 percent per million hectares for forest area estimates. Since 1996, however, the FIA has involved annual sampling in many States. Currently, 46 States are sampled annually. The FAO Assessment for 2000 cites total U.S. forest area at 226 million hectares. The change in U.S. forest area from 1990 to 2000 was 0.4 million hectares per year.[b]

A revised assessment is currently being prepared and will be published in early 2006. *Global Forest Resources Assessment 2005* will involve more sophisticated datasets that result from satellite remote sensing.[c] At the time this chapter was written, the assessment had not yet been published.

[a]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, "Executive Summary," web site www.fao.org/DOCREP/004/Y1997E/y1997e05.htm#bm05.
[b]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, Chapter 34, "North America, Excluding Mexico," web site www.fao.org/DOCREP/004/Y1997E/y1997e13.htm#bm39.
[c]T. Parris, "Global Forest Assessments," *Environment*, Vol. 45, No. 10 (2003), p. 3.

[148]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2005.html.
[149]That is, at least 67 percent of the samples are within 3 percent of the actual forested areas.
[150]The larger errors were found to be attributable to small actual changes in volumes of growing stock, which when over- or underestimated contributed disproportionately to the standard errors for total changes in the volume of growing stock.
[151]Thus, site-specific relationships among variables are used to create models or regression equations, which are then applied to large forested areas.