Reference: Heath, L.S., R.A. Birdsey, C. Row, and A.J. Plantinga. 1996 Carbon pools and flux in U.S. forest products. In: Forest Ecosystems, Forest Management, and the Global Carbon Cycle, (M.J. Apps and D.T. Price, eds). NATO ASI Series I: Global Environmental Changes, Volume 40, Springer-Verlag, p. 271-278

CARBON POOLS AND FLUX IN U. S. FOREST PRODUCTS

Linda S. Heath, Richard A. Birdsey, Clark Row, and Andrew J. Plantinga

U.S.D.A. Forest Service
Northeastern Research Station
PO Box 640
Durham NH 03824 USA
lheath@fs.fed.us

INTRODUCTION

Increasing recognition that anthropogenic CO_2 and other greenhouse gas emissions may effect climate change has prompted research studies on global carbon (C) budgets and international agreements for action. At the United Nations Conference on Environment and Development in 1992, world leaders and citizens gathered and initiated the Framework Convention for Climate Change (FCCC), an agreement to address global climate change concerns. Over 160 nations have signed the FCCC, whose ultimate goal is to stabilize the atmospheric concentration of greenhouse gases to prevent significantly negative effects on the climate system. To reach this goal, some nations, including the United States, have committed to reduce greenhouse gas emissions to 1990 levels by the year 2000. Knowledge of the magnitude and processes in C cycles is essential in developing effective strategies to mitigate anthropogenic emissions.

The forest sector C budget is of special interest because it is a large active pool with many components that are difficult to enumerate, and it offers a variety of mitigation options. One pool that is often not included is the amount of C in wood harvested from forests because its size is estimated to be small relative to other pools (Dixon *et al*., 1994). However, Dixon *et al*. (1994) also state that the wood products pool contributes to much of the uncertainty in the forest C budget estimates for mid- and high-latitude forests.

Carbon in wood products has been accounted for in generalized frameworks, such as that of Dewar (1991), who presented an analytical model for forest trees, soil, and wood products, and that of Marland and Marland (1992), who examined the possibility of using harvested trees as fuel to replace fossil fuels. Row and Phelps (1991) calculated percentages of C remaining in various categories of wood products in the U. S. for up to 100 years following harvest under current utilization standards but did not present absolute estimates. In their national C budget for Canada, Kurz *et al*. (1992) developed a forest product submodel using historical harvest rates. Plantinga and Birdsey (1993) and Heath and Birdsey (1993) presented estimates of C in harvested wood from projected future harvests through the year 2040 in the U. S. Neither of these studies includes estimates of C in historical removals. In this paper, we estimate historic (post 1900) and current C pools and flux in wood harvested and removed from forests (removals) in the U.S. We also project C in removals through 2040, and explore how these may be influenced by different assumptions about the future.

Copyright is not claimed for works by employees of the U.S. Government.

METHODS

We compiled historical and projected removals and calculated C in wood products by employing multiplier estimates from the HARVCARB model (Row and Phelps, 1991). The definition of removals is wood that is cut on site and removed for use. We do not consider the fate of logging residue, which is usually modelled as part of the forest ecosystem, not part of the products pool.

HARVCARB

HARVCARB (Version 1) is a model that transforms wood C in several phases: (1) from harvested trees to roundwood, (2) from roundwood to solid wood and finished fiber, and (3) from solid wood and fiber to end uses including products such as construction lumber, paper and newsprint. There are four end-use disposition categories: products, landfills, wood burned for energy, and emissions. The products category includes wood in buildings, repairs and improvements, pallets, and furniture and fixtures. Wood burned to produce energy includes wood used in municipal solid waste incinerators, home heating, wood-burning power plants, and power facilities associated with forest product industries. Changes between end-use categories are included. For example, C may be stored in cardboard five years after harvest, in a landfill ten years later, and decomposed as emissions after twenty additional years. Figure 1 illustrates the possible fates of carbon in the model.

HARVCARB estimates were summarized as percentages of harvested C that remained in each disposition category for five-year time increments following harvest. Separate sets of percentages were developed for each region, hardwood or softwood type, and pulpwood or sawtimber size. Figure 2 shows one example of disposition patterns. Note that summing the percentages across all disposition categories at a given time yields 100%.

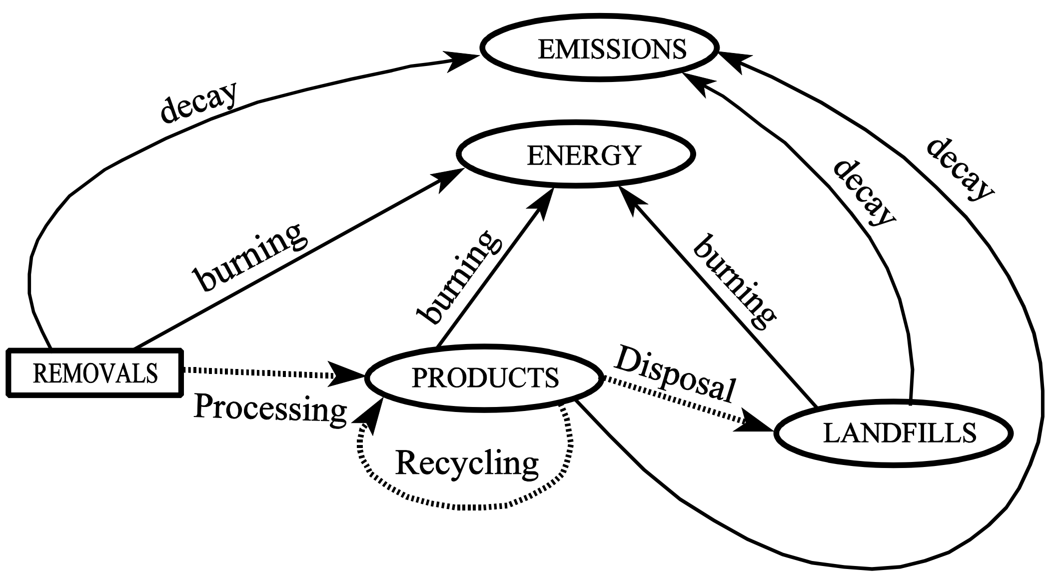

Figure 1. Simulated C pools and flows from removals.

Carbon was tracked over time by multiplying the amount of wood harvested in a given year by the percentages in each disposition category, and accumulating amounts remaining from previous years. HARVCARB estimates were based on current utilization standards, but we assumed that they adequately represented historical standards and projected changes in disposition patterns.

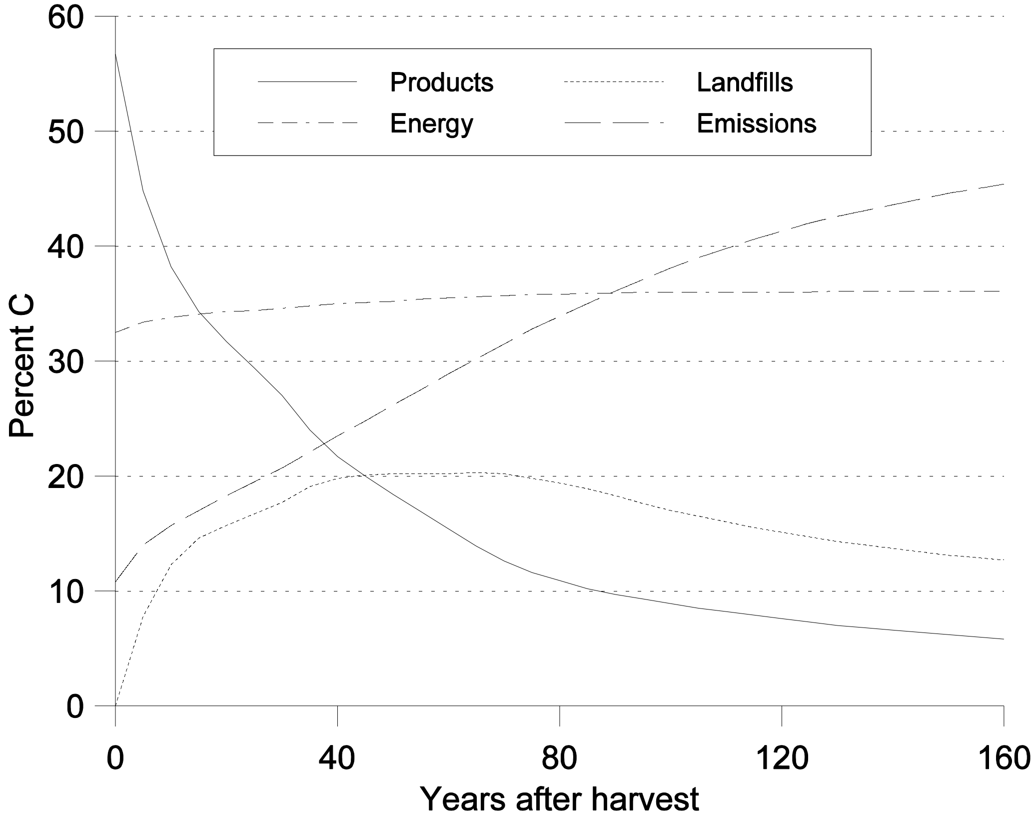

Figure 2. Carbon disposition curves for softwood sawtimber in the southern U.S.

Sources of data for removals

Historical estimates were gathered from a variety of United States Department of Agriculture (USDA) Forest Service publications of summary forest statistics, the latest from Powell *et al.* (1992). There is usually only one annual harvest estimate per decade, so we assumed that this annual estimate was equivalent to the average annual estimate for the period. Projected removals were obtained from the Timber Assessment Market Model (TAMM) (Adams and Haynes, 1980) and the Aggregate Timberland Assessment System (ATLAS) (Mills and Kincaid, 1992). The projections are annual estimates. TAMM projects price, consumption, and production trends in both stumpage and product markets in the U. S. forest sector in conjunction with ATLAS, which projects timber inventories on private lands. Because we calculate C in wood products based on amount of wood removed from U. S. forests only, we do not count C in imports. However, we do include C in exports, even if the logs are processed in other countries. Overall, about 12% of the timber consumed in the U. S. is imported; U.S. exports of roundwood and primary products are about 5% of harvest (Haynes, 1990).

Scenarios

We projected C in wood products from 1990 to 2040 for a base scenario. The base scenario represents current expectations of what will happen in the future; it is a business-as-usual scenario. For specific information about the base, see Haynes *et al*. (1995). We adopted alternate scenarios to investigate the extent to which changes in assumptions affect the results. We looked at four scenarios that affected projections only: increase percent in harvested C in the products category by 50%, decrease percent in harvested C in the products category by 50%, decrease the percent of C in the emissions category by 50%, and stop harvesting in 1990. Because the percentages for the four disposition categories must sum to 100, increasing one category by 50% means the other categories collectively must be reduced by the amount of the increase. We assumed the percent reduction applied equally to the other three categories. These four scenarios were considered to provide an idea of how the magnitudes of carbon flux would vary if large changes occurred in wood use. We ran two other scenarios for a sensitivity analysis, one in which historical harvests (1900-1989) were assumed 25% greater than the base, and a second in which historical harvests were assumed 25% less than the base.

RESULTS AND DISCUSSION

Carbon pools

The cumulative fate of C removed from U.S. forests since 1900 is illustrated in Figure 3. By 1990, about 3.7 Pg of the 10.7 Pg of C removed in harvests during the period 1900-1990 remained sequestered in products and landfills, while another 3.7 Pg was burned for energy. By comparison, in 1987 an estimated 13.8 Pg C was stored in trees in conterminous U.S. forest ecosystems, and 24.7 Pg in soils, forest floor, and understory (Birdsey, 1992). Thus, the amount of C removed was significant when compared to the amount currently stored in trees in forests. The upturn in the estimates after 1990 indicates that consumption of wood products is expected to increase at least through 2040. Emissions and energy pools are greater than the products and landfills pools at the end of the projection period because over time C in products and landfills moves into emissions and energy pools, but C never transfers out.

On a percentage basis, by 1990 approximately 35% of the total C removed is stored in products and landfills, 30% has returned to the atmosphere through decay or burning without energy production, and 35% has been burned for energy, partially offsetting fossil fuel use. Forest products industries contribute to the last end-use by burning virtually all residues used during processing of logs, and wood is burned in power plants, waste incinerators, and the home. This category is often a source of confusion in reporting C in wood products. Because such C is not sequestered in a solid state, it is considered an emission in some accounting frameworks. However, it has helped mitigate increasing atmospheric CO_2 concentration by offsetting fossil fuel use, and in this respect it is not equivalent to emissions from decay. We take the view that it is important to list the amount of carbon burned for energy, but that it should be listed separately.

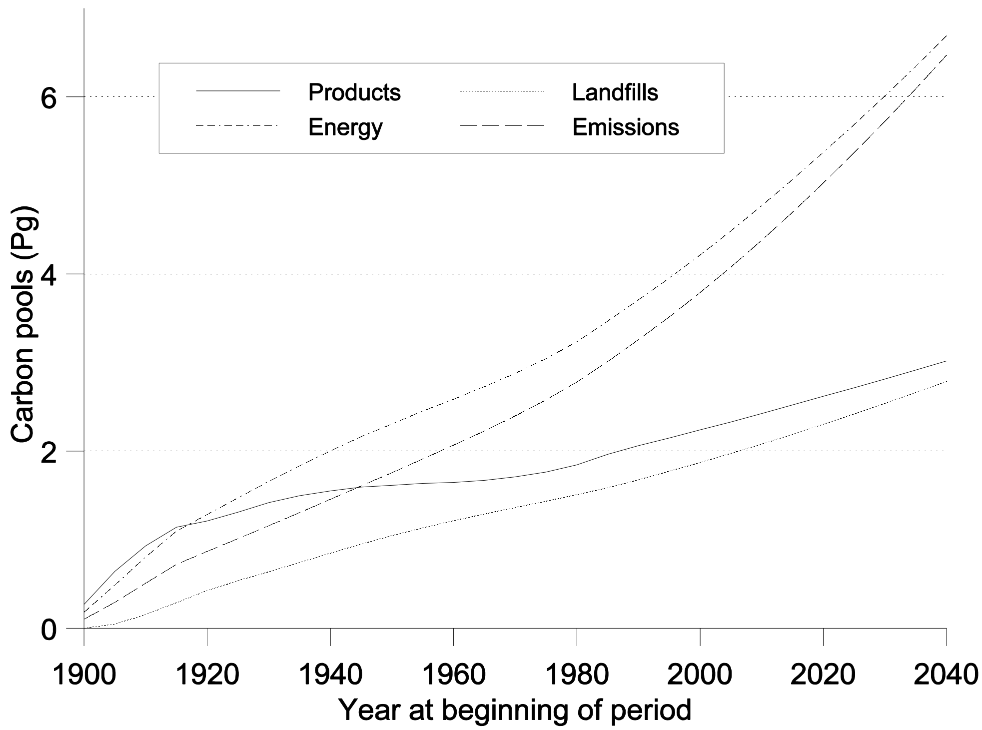

Figure 3. Carbon pool sizes (Pg) for the base scenario.

Carbon fluxes

The net flux of C into each disposition category is displayed in Figure 4. The net current average annual flux into products and landfills is about 37 Tg C yr^{-1}, which is almost 40% of the estimated C flux into the tree component of U. S. forests (Birdsey and Heath, 1995). About 50 Tg C yr^{-1} is emitted when wood is burned for energy. All estimates are positive, indicating that the size of the C pool in each category increases in each successive period. The sizes of these C flux estimates are quite significant considering the United States must reduce its annual emissions by 76 Tg yr^{-1} by the year 2000 to fulfill the FCCC agreement (U. S. Department of Energy, 1994).

Because removals estimates are increasingly unreliable for earlier years, we also performed a sensitivity analysis on the historical estimates (Table 1). Results indicate that even if historical harvest estimates are 25% off from actual harvests, current and future products flux would change by an average of only 5 Tg C yr^{-1}, landfill flux by 0.5 Tg yr^{-1}, wood burned for energy by 0.4 Tg yr^{-1}, and emissions by 5 Tg C yr-1. Thus historical removals contribute most to current and future products and emissions categories, and relatively little to the other two categories. Note that greater harvests in the past produce a smaller future net flux into products and landfills. This occurs by definition; change between pool size (flux) becomes smaller if initial pool size is increased while the next pool size is held constant.

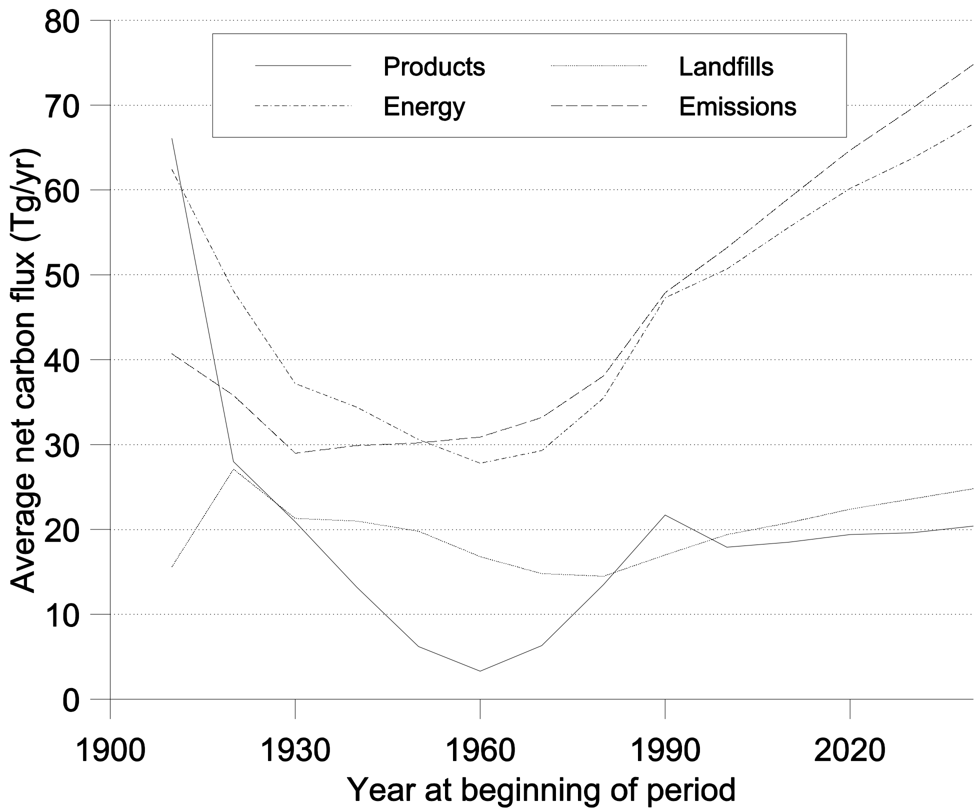

Figure 4. Average annual net C flux (Tg C yr^{-1}) into disposition categories for U. S. timber removals.

Table 1. Projected net C fluxes by disposition category for variations in historical (1900-1989) harvest estimates by +25% and -25%.

Period	Net C Flux by Disposition Category (Tg C yr^{-1})							
	Products		Landfills		Energy		Emissions	
	-25	+25	-25	+25	-25	+25	-25	+25
1990-1999	27	9	17	21	50	51	47	59
2000-2009	24	13	21	20	55	56	54	65
2010-2019	24	15	23	21	60	61	60	70
2020-2029	23	16	25	22	64	64	65	75
2030-2039	23	18	27	23	68	68	70	79

Scenarios

We examined how change in disposition rates may affect flux magnitudes under alternative scenarios (Table 2). The scenario that increased C sequestration most as compared to the base was to decrease percent in emissions by 50% (assuming that percent in the other categories increase proportionally). The scenario to stop harvesting in 1990 is presented only for comparison. If harvesting ceased, emissions and amount in landfills would decline significantly. However, less wood (average 58 Tg yr^{-1}) would offset fossil fuels for energy production, and 40 Tg yr^{-1} on average would not be sequestered in products as compared to the base.

Table 2. Estimated difference between scenario and base case in average annual net C flux into each disposition category during 1990-2040.

Period	Net C Flux by Disposition Category (Tg C yr^{-1})			
	Products	Landfills	Energy	Emissions
Scenario: Increase percent in products by 50%.				
1990-1999	8.8	-2.8	-2.6	-3.4
2000-2009	9.1	-2.7	-3.1	-3.5
2010-2019	9.6	-2.8	-3.3	-3.5
2020-2029	9.7	-2.9	-3.4	-3.5
2030-2039	10.2	-3.0	-3.6	-3.7
Scenario: Decrease percent in products by 50%				
1990-1999	-7.2	3.9	35.2	37.9
2000-2009	-7.9	4.5	39.8	43.6
2010-2019	-8.5	5.4	43.7	48.6
2020-2029	-8.8	6.6	47.1	53.4
2030-2039	-9.4	7.1	50.6	58.0
Scenario: Decrease percent in emissions by 50%				
1990-1999	9.0	8.6	9.0	-26.6
2000-2009	10.0	9.6	10.0	-29.5
2010-2019	10.9	10.6	10.9	-32.3
2020-2029	11.7	11.4	11.7	-34.8
2030-2039	12.6	12.3	12.6	-37.4
Scenario: Stop harvesting in 1990.				
1990-1999	-52.8	-11.4	-48.2	-28.7
2000-2009	-40.7	-22.1	-54.0	-37.1
2010-2019	-37.6	-26.3	-58.9	-43.9
2020-2029	-33.7	-29.8	-62.7	-50.3
2030-2039	-31.6	-32.1	-67.0	-57.2

Comparison to carbon in global harvesting

We can make inferences about carbon in wood products on a global scale through comparison with global wood products statistics. Compared to the rest of the world, in 1990, the U.S. produced 20% of the sawn wood, 25% of wood-based panels, 30% of paper and paperboards, and only about 5% of the fuelwood (Brooks, 1993). Based on these percentages, we can roughly estimate that globally C in wood products (excluding landfills) is currently increasing on the order of 100 Tg yr^{-1}. For global analyses, it may be justifiable to omit the wood products C flux component, as this amount is fairly small compared to an estimated global total net C flux to the atmosphere of 900 Tg yr^{-1} (Dixon *et al*., 1994). However, we found that wood products should be included in C budgets for the U. S. because this component is significant compared to U. S. forest ecosystem flux estimates.

The other pool that is important to examine globally is wood burned for energy. Historically, there has been a tradeoff from the use of wood to fossil fuel as nations become industrialized. As fossil fuel use grows, so do forests as they are harvested less for fuel. The potential for this pattern exists today. In 1989, harvests from tropical zone forests, located mostly in developing countries, were about 36% greater than harvests in temperate zone forests (Brooks, 1993), and about 80% of tropical zone harvests were burned for fuel. With 80% of the total roundwood production of 1.922 x 10^9 m^3 burned for fuel in developing countries, and assuming 234 kg C m^{-3} (Birdsey, 1992), then roughly 360 Tg C yr^{-1} are released to the atmosphere in the tropics alone. If developing nations begin to use more fossil fuels instead of wood for energy, examining only forest ecosystem C budgets would likely show that tropical forests were sequestering more C, although emissions for the entire system might be greater.

CONCLUSIONS

Carbon pools and fluxes from the disposition of C in harvested wood are significant relative to the U.S. forest ecosystem C budget. It is important to include this C when tracking C budgets to compare forest management and utilization policies. Although wood burned for energy is not a pool of C that is physically sequestered, it helps mitigate increasing atmospheric CO2 concentration by offsetting fossil fuel use. The wood for energy flux is larger than the uptake of C in products and landfills in the United States, and we estimate it is larger in proportion in developing countries, particularly those which feature tropical zone forests. Tracking the end-use C pools, including wood burned for energy, along with forest ecosystems C pools would more accurately reflect overall C budget effects.

REFERENCES

Adams D. M. and Haynes R. W. (1980) *The Timber Assessment Market Model: Structure, projections, and policy simulations*. Forest Sci Monog No 22, Society of American Foresters, Bethesda, MD.

Birdsey R. A. (1992) *Carbon storage and accumulation in United States forest ecosystems*. USDA Forest Service, General Technical Report WO-59, Washington, DC.

Birdsey R. A. and Heath L. S. (1995) Carbon changes in U. S. forests. In: *Climate change and the productivity of America's forests* (ed. L. A. Joyce). USDA Forest Service General Technical Report, Rocky Mtn Forest and Range Expt Stn, Fort Collins, CO.

Brooks D. J. (1993) *U.S. forests in a global context*. USDA Forest Service General Technical Report RM-228, Rocky Mtn Forest and Range Expt Stn, Fort Collins, CO, 24 p.

Dewar R. C. (1991) Analytical model of carbon storage in the trees, soils, and wood products of managed forests. *Tree Physiology* 8, 239-258.

Dixon R. K., Brown S., Houghton R. A., Solomon A. M., Trexler M. C. and Wisniewski J. (1994) Carbon pools and flux of global forest ecosystems. *Science* 263, 185-190.

Haynes R. W., Adams D. M. and Mills J. M. (1995) *The 1993 RPA Timber Assessment Update.* USDA Forest Service General Technical Report, Rocky Mtn Forest and Range Expt Stn, Fort Collins, CO.

Haynes R. W. (coord) (1990) *An Analysis of the Timber Situation in the United States: 1989-2040*. USDA Forest Service General Technical Report, Rocky Mtn Forest and Range Expt Stn, Fort Collins, CO. 268 p.

Heath L. S. and Birdsey R. A. (1993) Carbon trends of productive temperate forests of the coterminous United States. *Water, Air and Soil Poll* 70, 279-293.

Kurz W. A., Apps M. J., Webb T. M. and McNamee T. J. (1992) *The carbon budget of the Canadian forest sector: Phase I.* Forestry Canada Information Report NOR-X-236, Northwest Region, Northern Forestry Centre, 93 p.

Marland G. and Marland S. (1992) Should we store carbon in trees? *Water, Air, and Soil Poll* 64, 181-195.

Mill J. R. and Kincaid J. C. (1992) *The Aggregate Timberland Assessment System--ATLAS: A comprehensive timber projection model*, USDA Forest Service General Technical Report PNW-281, Pacific Northwest Research Stn, Portland, OR.

Plantinga A. J. and Birdsey R. A. (1993) Carbon fluxes from U. S. private timberland management. *Climatic Change* 23, 37-53.

Powell D. S., Faulkner J. L., Darr D. R., Zhu Z. and MacCleery D. W. (1993) *Forest resources of the United States, 1992*. USDA Forest Service General Technical Report RM-234, Rocky Mtn Forest and Range Expt Stn, Fort Collins, CO, 132 p.

Row C. and Phelps R. B. (1991) Carbon cycle impacts of future forest products utilization and recycling trends. In: Agriculture in a World of Change, Proceedings of Outlook '91, U. S. Department of Agriculture, Washington, DC.

U. S. Department of Energy, coord. (1994) *The Climate Change Action Plan: Technical Supplement.* U. S. Dept. of Energy, Office of Policy, Planning, and Program Evaluation. Washington, DC, 148 p.