Data Note:
Emissions (and Sinks) of Carbon from Land-Use Change

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Summary

Estimates of national sources and sinks of carbon resulting from changes in land use are made covering the period 1950 to 2000. They are based a recent global and regional analysis of land-use change by Houghton (2003). In this report the regional fluxes were divided among countries. For tropical regions (Latin America, tropical Asia, and sub-Saharan Africa), each region's flux (from Houghton 2003) was distributed among countries in proportion to the product of change in forest area (1990-2000) and average forest biomass, both reported by the FAO's Forest Resources Assessment 2000 (FAO 2001b). For four regions outside the tropics (Europe, the former USSR, Pacific developed countries, and the region including North Africa and the Middle East), the flux was divided among countries in proportion to annual rates of wood production (harvest) as reported by FAOSTAT (FAO 2001a). The only exception to this method was for European countries between 1975 and 2000. For this interval, the regional sink was distributed among countries by the 1990-2000 change in forest area (similar to the approach for tropical regions). Three of the "regions" (Canada, the United States, and China) provided national estimates directly.

According to these methods, two countries (Indonesia and Brazil, together) account for almost 50% of the global land-use flux of carbon of the 1990s. The top 15 countries account for 90% of emissions. Fully 150 countries (out of this list of 166) contribute less than 1% to the annual emissions of carbon from land-use change.

The errors associated with these national estimates are substantial. Based on recent analyses of tropical deforestation (Achard et al. 2002, DeFries et al. 2002), the emissions of carbon from tropical countries, as determined by Houghton (2003), may be high by a factor of two. If one considers the uncertainty in estimates of carbon stocks in tropical forests, an additional error of ± 50% is possible. Thus, these estimates of national sources and sinks of carbon from land-use change are uncertain on the order of ± 150% for large fluxes, and ± 50 MtC/yr for estimates near zero.

Regional estimates (Houghton 2003)

Briefly, the regional fluxes of carbon calculated by Houghton (2003) include the following types of land-use change and management activities:

- Clearing of natural ecosystems for permanent croplands (cultivation)
- Clearing of natural ecosystems for permanent pastures (no cultivation)
- Abandonment of croplands and pastures with subsequent recovery of carbon stocks to those of the original ecosystem

- Shifting cultivation (swidden agriculture) (repeated clearing, abandonment, and re-clearing of forests in many tropical regions)
- Wood harvest (industrial wood as well as fuel wood). It is important to note that these estimates include the emissions of carbon from wood products (burned, stored in long-term pools, decayed over time).
- For the U.S. only, management of wildfires and woody encroachment

The flux of carbon includes the emissions of carbon from living and dead vegetation disturbed at the time of clearing or harvest, the emissions from wood products (including fuelwood), and the emissions from the oxidation of soil organic matter in the years following initial cultivation. The net flux also includes the sinks of carbon in forests (vegetation and soils) regrowing after agricultural abandonment, harvest, and fire suppression.

The carbon sources and sinks do not explicitly include the indirect or natural effects of climatic change, increased concentrations of CO_2, or nitrogen deposition. Those ecosystems that are not directly affected by human activity (agriculture, forestry) are not included in these estimated sources and sinks.

It is also important to note that the calculated flux of carbon does not explicitly include changes in carbon stocks that may result from various forms of management. Examples of what is not included are agricultural intensification, fertilization, the trend to no-till agriculture, thinning of forests, changes in species or varieties, and other silvicultural practices.

The bookkeeping model used to calculate annual sources and sinks of carbon from changes in land use, and the data used in the analyses, are described in a series of publications documenting the incorporation of new data (Houghton 1986, 1991, 1999, 2003; Houghton and Hackler 1995, 1999, 2000, 2003; Houghton et al. 1983, 1985, 1987, 1991a, 1991b, 1999, 2000).

The regional sources and sinks from the most recent assessment (Houghton 2003) are shown in Table 1 on page 4 (Figure 1 on page 5 shows the annual fluxes from 10 regions from 1950 to 2000). The tropics account for almost all of the global flux (2.2 PgC/yr in the 1990s). Outside the tropics, the net flux is a small sink (0.2 PgC/yr during the 1990s).

Methods for Dividing the Regional Fluxes among Countries

In regions that are primarily tropical (Latin America, tropical Asia, and sub-Saharan Africa) [Note that the term tropical is not strictly correct: some non-tropical countries, such as Uruguay, Chile, Argentina, and South Africa are included] the regional fluxes were divided among countries in proportion to the product of change in forest area (1990-2000) and average forest biomass (FAO 2001b). The change in forest area was from Table 4 in FAO (2001b); the average forest biomass was from Table 7. The same proportions were assumed to apply for all years (1950-2000). Although, in principle, earlier tropical forest assessments by the FAO (FAO/UNEP1981, FAO 1993) might have allowed a more accurate index for the 1970s and 1980s than provided by this assumption, earlier assessments are, in fact, not comparable. Subsequent assessments have used different definitions, different reporting, and improved data; and the FAO reports that some (an unspecified amount) of the apparent changes in forest area result from revisions in earlier estimates rather than real changes on the ground. Furthermore, two recent studies of tropical deforestation find rates that are 23% and 54% lower than the rates reported by FAO (Archard et al. 2002, DeFries et al. 2002). Thus, the changes in forest area in tropical countries are only approximately known, and both the regional estimates and the national estimates of carbon flux calculated here are highly uncertain.

Outside tropical regions, changes in forest area were used to divide the regional flux into national fluxes only in Europe between 1975 and 2000, when Europe is estimated to have been a carbon sink. Before 1976, Europe was a net source, and this source was distributed among countries in proportion to rates of wood harvest (FAO 2001a). Those countries with the highest rates of logging were assigned the highest fluxes. Rates of wood harvest were also used throughout the entire period 1950-2000 to divide into individual countries the regional sources of carbon from the former USSR, Pacific developed countries, North Africa & the Middle East. For the U.S., Canada, and China the regional estimates were equivalent to the national ones.

The errors associated with the regional estimates of carbon flux are substantial. The errors for individual countries are even larger because of the methods used to distribute the regional totals. Uncertainty in the rates of tropical deforestation suggest that the emissions of carbon from tropical countries may be high by a factor of two. If one considers the uncertainty of carbon stocks in tropical forests, an additional error of $\pm$ 50% is possible. Thus, the estimates of the national sources and sinks of carbon from land-use change are uncertain on the order of $\pm$ 150% for large fluxes, and $\pm$ 50 MtC/yr for estimates near zero.

The errors introduced from distributing the regional flux of carbon among countries are probably small relative to the errors associated with FAO's estimates of national changes in forest area and biomass. Nevertheless, there is some additional error introduced from using net changes in forest area as a surrogate for carbon flux. Changes in forest area are not equivalent to changes in carbon stocks, because the sources of carbon from deforestation generally occur over a smaller number of years (more rapidly) than the sinks in recovering forests. Because of lags in regrowth, simultaneous deforestation and reforestation (i.e., no change in area) may, nevertheless, create sources in the short term and sinks in the long-term. Although these asymmetries are captured at the regional level, the methods for partitioning ignore them.

More importantly, the distribution of regional fluxes of carbon among tropical countries on the basis of changes in forest area and biomass does not recognize management effects that may affect forest carbon stocks without changing forest area. Two countries might have similar rates of deforestation, for example, but different rates of logging. Because logging reduces the stocks of carbon in forests (until they recover), differences in longing rates contribute to sources of carbon that are not included in this approach for dividing the regional flux among countries.

Brazil may be used to provide an example of possible errors. The estimate determined here shows Brazil to be a source of ~400 MtC/yr during the 1990s. The estimate is approximately twice that obtained by Houghton et al. (2000) for legal Amazonia. On the other hand, changes in land use in the cerrado (outside legal Amazonia) also contribute to a Brazilian source, and the 400 MtC/yr estimate is probably not high by 100%. Fearnside (1997) estimated a flux of 261 MtC/yr from land-use change in Brazil.

Table 1. Average annual flux of carbon to the atmosphere from changes in land use (PgC/yr) (from Houghton 2003). Negative values indicate an accumulation of carbon on land.

Region	1850-2000	1980-1989	1990-1999
Tropical Asia	48	0.88 ± 0.5	1.09 ± 0.5
Tropical America	37	0.77 ± 0.3	0.75 ± 0.3
Tropical Africa	13	0.28 ± 0.2	0.35 ± 0.2
Subtotal tropics	98	1.93 ± 0.6	2.20 ± 0.6
Canada	5	0.03 ± 0.2	0.03 ± 0.2
U.S.	7	-0.12 ± 0.2	-0.11* ± 0.2
Europe	5	-0.02 ± 0.2	-0.02* ± 0.2
Former Soviet Union	11	0.03 ± 0.2	0.02* ± 0.2
China	23	0.11 ± 0.2	0.03 ± 0.2
Pacific developed	4	0.01 ± 0.2	0.00* ± 0.2
North Africa & Middle East	3	0.02 ± 0.2	0.02* ± 0.2
Subtotal non-tropics	58	0.06 ± 0.5	-0.02 ± 0.5
Global total	156	1.99 ± 0.8	2.18 ± 0.8

* Annual flux through the 1990s assumed to have remained the same as calculated for the year 1990

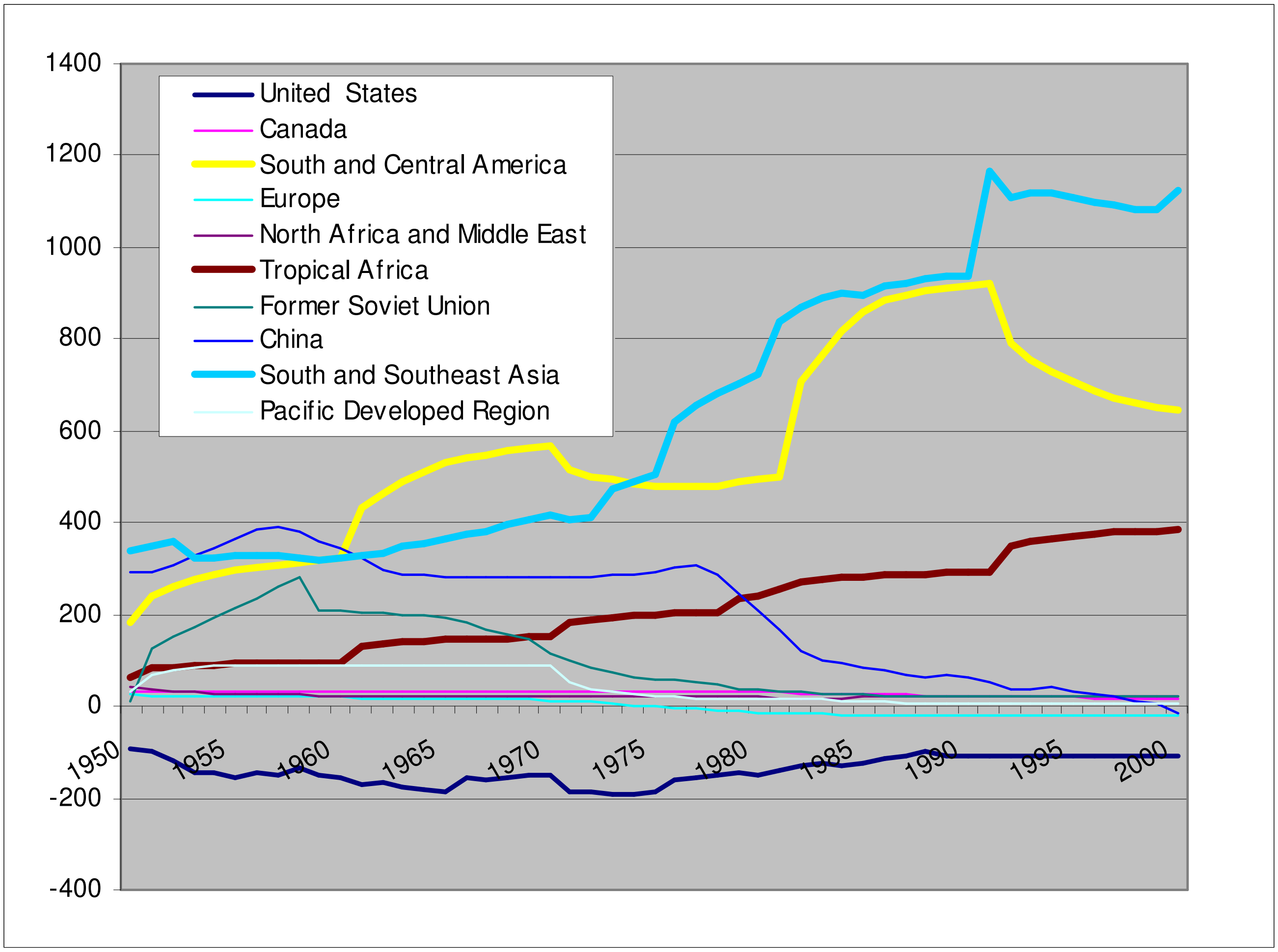

Figure 1. Annual sources (+) and sinks (-) of carbon from the 10 world regions defined in this analysis.

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