Submitted to an Interagency effort focused on the Montreal Process Criteria and Indicators of Sustainable Forest Management. This manuscript, authored by Linda Heath and James Smith, was produced as part of Linda's role as Lead for Criterion 5 (carbon cycle). There are three indicators in Criterion 5. They are being written for the 2003 National Report on Sustainable Forest Management.

Criterion 5, Indicator 27. (Technically reviewed). Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon).

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I. Analysis

A. What is the rationale and guidance for this indicator?

1. Rationale from the Technical Advisory Committee (TAC) for the Montreal Process, as recorded in the Roundtable Report: This indicator assesses the change in total forest ecosystem carbon stocks, as calculated in Indicator 26 (relative to the total carbon budget of the Earth).

Interpretation from the Technical Advisory Committee (TAC) for the Montreal Process, as recorded in the Roundtable Report: This information establishes the significance of information generated through Indicator 26. Refer to comments for Indicator 26.

2. Clarification of the Indicator and additions to rationale.

Refer to clarifications for Indicator 26.

B. What data are used in quantifying this indicator?

This indicator is calculated by taking the difference in carbon pools in successive years, and dividing by the length of the period between the years to produce an average annual net carbon pool change. The carbon pools are estimated using forest inventory data and conversion factors. U.S. forest inventory data come from the USDA Forest Service, Forest Inventory & Analysis

(FIA) Program. Volume, area, and other forest characteristics are compiled in Smith and others (2001) for the years 1953, 1963, 1977, 1987, and 1997. The inventory years begin on the first calendar day of each year. More detailed data are available in databases for 1997. Refer to this section in Indicator 26 for a more complete description of the data used in quantifying this indicator.

All carbon pools, with the exception of soil carbon, are estimated using the FIA inventory data or imputed inventory data, along with inventory-to-carbon relationships, developed with information from ecological studies. Live tree volumes are transformed using equations given in Smith and others (2002) to estimate above- and belowground live tree carbon and standing dead tree carbon. Forest type, forest areas, and age information are used with equations in Smith and Heath (2002) to estimate forest floor carbon. Details about carbon in understory vegetation, soil carbon, and down dead wood can be found in the corresponding section in Indicator 26.

The only additional information presented in this indicator is the partitioning of carbon sequestration in live trees into growth, removals, and mortality. Estimates of these in terms of volumes are taken from inventory data in Smith and others (2001), and transformed into carbon using factors in Birdsey (1992).

C. How should the data be interpreted relative to the rationale from the TAC?

This indicator reports trends in average annual changes in carbon pools, from the first year inventory data were collected using a modern design, 1953, to 1997. The date of the inventory is assigned to be the first day of the year (that is, January 1). Changes in soil carbon are not reported because work to incorporate land use effects into soil carbon calculation has not been completed. Forest carbon pool changes for Alaska and Hawaii are not presented due to limited available data. Carbon is presented in terms of megatonnes of carbon per year (Mt/yr). One megatonne equals one million metric tons.

1. Overview

Average annual net change in non-soil forest ecosystem carbon pools for the period 1953-1997 is 175 Mt/yr being absorbed by forests from the atmosphere. The pattern by period is shown in Figure 27-1. The period 1977-1986 (January 1, 1977 to December 31, 1986) features the largest net increase, about 210 Mt/yr, and the smallest increase occurred during the period 1987-1996. About 77% of the net increase is in live trees, both above- and belowground.

This is a net increase of carbon in forests, not the gross absorption. That is, the increases in forest ecosystem carbon in Figure 27-1 are a net difference between inventories. The net growth of live trees can be thought of as gross growth over the period minus mortality. In the U.S. in 1996, volume removals were about 68% of the volume growth. Thus, harvesting greatly affects the forest carbon budget in the U.S.

Figure 27-2 shows the net growth, removals, and mortality in terms of merchantable tree carbon on unreserved timberland of the U.S. Net growth in terms of merchantable tree carbon has increased 67% over the 1953-1996 (January 1, 1953 to December 31, 1996) period. Carbon in

removals has increased about 37% over the period. A gross increase in merchantable tree carbon can be estimated for 1996 by adding the net annual growth of 153 Mt/yr to mortality, resulting in a gross increase of 193 Mt/yr of C sequestered in trees. This is approximately the gross absorption of merchantable tree carbon on unreserved timberlands. Removals of 105 Mt/yr do not directly become carbon emissions to the atmosphere. This amount transfers into the carbon in harvested wood products reported in Indicator 28, where some of the transferred carbon is held in long-term storage, and some is burned for energy and emitted. Some of the transferred carbon is burned without capturing the energy produced, or decayed. Estimates of these emissions are reported in Indicator 28.

Between 1987-1996 about 135 Mt/yr were added to non-soil forest carbon stocks. About 60 Mt/yr were added to carbon stocks in landfill and wood-in-use categories during 1990 and 1997 (Indicator 28). Adding these two indicators results in 195 Mt/yr, an estimate of net carbon sequestration for the U.S. forest sector for the 1990's, not including soil carbon.

For context, according to the IPCC (2001), the net rate of increased atmospheric carbon dioxide content in terms of carbon was 3200 Mt/yr during 1990 to 1999. Total emissions from burning fossil fuels, along with a small amount from cement production, were estimated to be 6300 Mt/yr. Seventeen hundred Mt/yr was absorbed from the atmosphere by the oceans, and 1400 Mt/yr was estimated to be absorbed from the atmosphere by land-based changes. U.S. forest ecosystems sequester more than 10% of the global total for terrestrial ecosystems.

2. Regional trends

The trends of average annual net changes in non-soil forest carbon pools (Figure 27-3) are presented by period from 1953 to 1996 for all forest land of the conterminous U.S. These trends generally exhibit a pattern of increases in net carbon changes when forest land area and volume increases in the region, and of decreases in net carbon changes when forest land area and volume decreases. If forest land area and volume move in opposite directions, carbon sequestration may increase, decrease, or stay about the same depending on the magnitude of these changes. The North Central (NC) region showed a large consistent amount of carbon sequestration into forests over the entire period. Rocky Mountain (RM) region shows a lower, but also fairly consistent carbon change. The Southeast (SE) and South Central (SC) regions exhibit an increase of carbon in forests over the period, with more carbon being sequestered in the earlier periods than in the later periods. The Pacific Coast regions exhibit little change in net carbon pools over the period. All regions show a continuing increase in the net carbon pool change during the period, 1987-1996.

D. Limitations of data provided

Refer to this section in Indicator 26. The changes in soil carbon are not included in this indicator because the soil carbon estimates are still being developed. The survey data are compiled from a scientifically-based sample, designed to provide reliable volume and area data at a pre-determined level of precision. However, this indicator is a measure of change between inventories, and therefore the estimates feature a greater uncertainty than the estimates of carbon

pools in indicator 26. See Smith and Heath (2001), Smith and Heath (2000), and Heath and Smith (2000) for a discussion of uncertainty in the U.S. forest carbon budget.

E. If current data are not adequate to measure the indicator, what options are available for remedy?

Refer to this section in Indicator 26. The current data and modeling approach are adequate to provide a measure of the indicator. The results seem adequate because other atmosphere-based estimates are generally consistent in terms of the overall flux with the flux derived from land-based estimates (Pacala and others, 2001).

II. Problems related to scientific, social/political, economic, and institutional concerns.

See this section in Indicator 26 for a discussion of institutional problems with more precise surveys.

III. Cross-cutting issues/relationships with other indicators.

See this section in Indicator 26. This indicator is related to many other indicators. It is directly related to the other Criterion 5 indicators, Indicators 26 and 28. Because carbon is related to forest volume changes and area changes, this indicator is related to Indicators 2, 11,12, and 21. Carbon as a productivity issue overlaps with Criterion 2, Maintenance of productive capacity of forest ecosystems, and Criterion 4, Conservation and maintenance of soil and water resources**.** The ability to understand carbon pools depends on knowledge of the carbon cycle, which should be discussed under Indicator 63, Development of scientific understanding of forest ecosystem characteristics and functions. Forest carbon pools should also be a consideration for Indicator 67, Ability to predict impacts on forests of possible climate change. Two other indicators that should be consistent with the information on which Indicator 26 is based are Indicator 60, Availability and extent of up-to-date data, statistics and other information important to measuring or describing indicators associated with criteria 1-7, and Indicator 61, Scope, frequency and statistical reliability of forest inventories, assessments, monitoring and other relevant information.

IV. Suggested guidance on use of the data.

USDA Forest Service FIA data currently available were collected periodically by state over a number of years that do not necessarily correspond to the period of years listed in the figures. Thus, the carbon pool reported for a specific period (such as 1953-1962) may not strictly match that period, but it is the period associated with the compilation of the FIA data. Thus, the estimates should not be interpreted as corresponding exactly with the given periods.

Literature Cited

See this section in Indicator 26 for other relevant citations.

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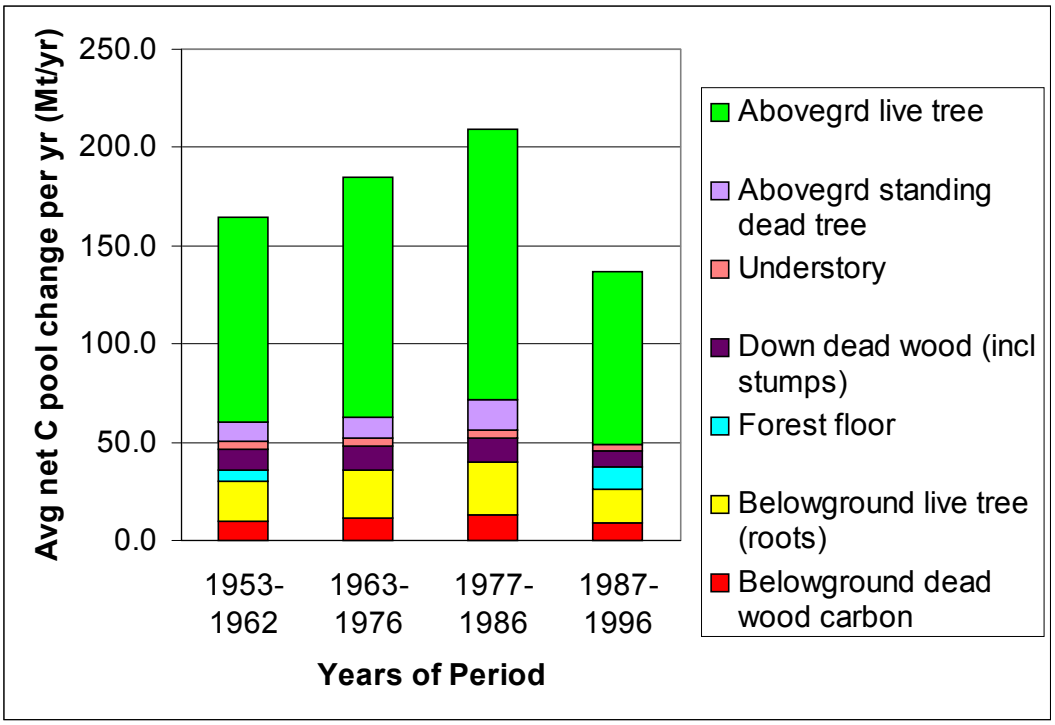
Figure 27-1. Average annual net change in forest ecosystem non-soil carbon pools (Mt/yr) for all forest land of the conterminous U.S., 1953-1997.



NOTE: All net carbon stock changes are positive indicating absorption of carbon from the atmosphere to the forest with one exception. The estimate for aboveground standing dead trees carbon for 1987-1996 is -1.7 Mt/yr. (The negative sign indicates a new decrease in the size of this pool.)

Figure 27-2. Average annual net change in merchantable tree carbon pools (Mt/yr) for unreserved timberland of the conterminous U.S., 1953-1997.

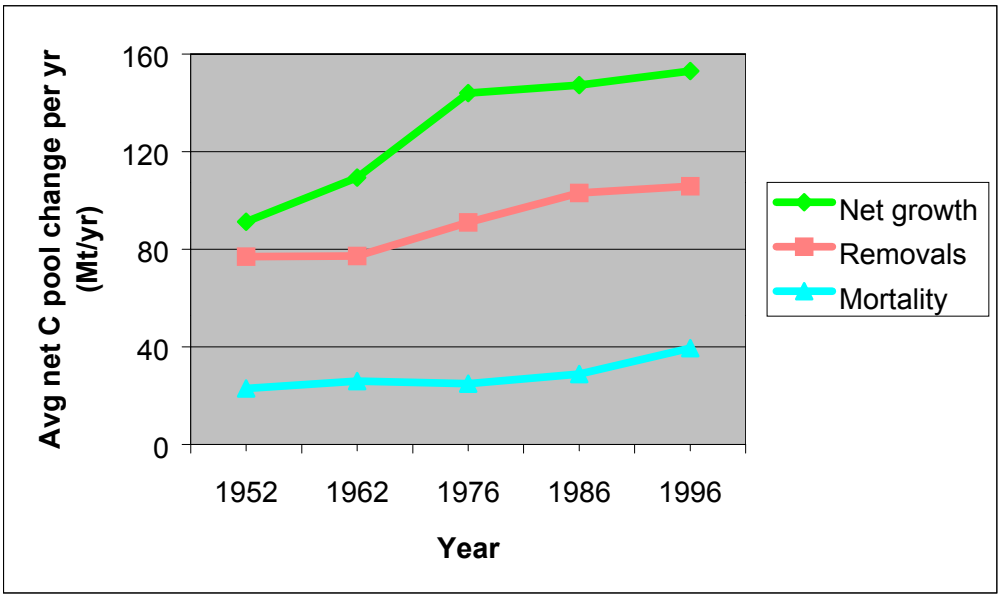
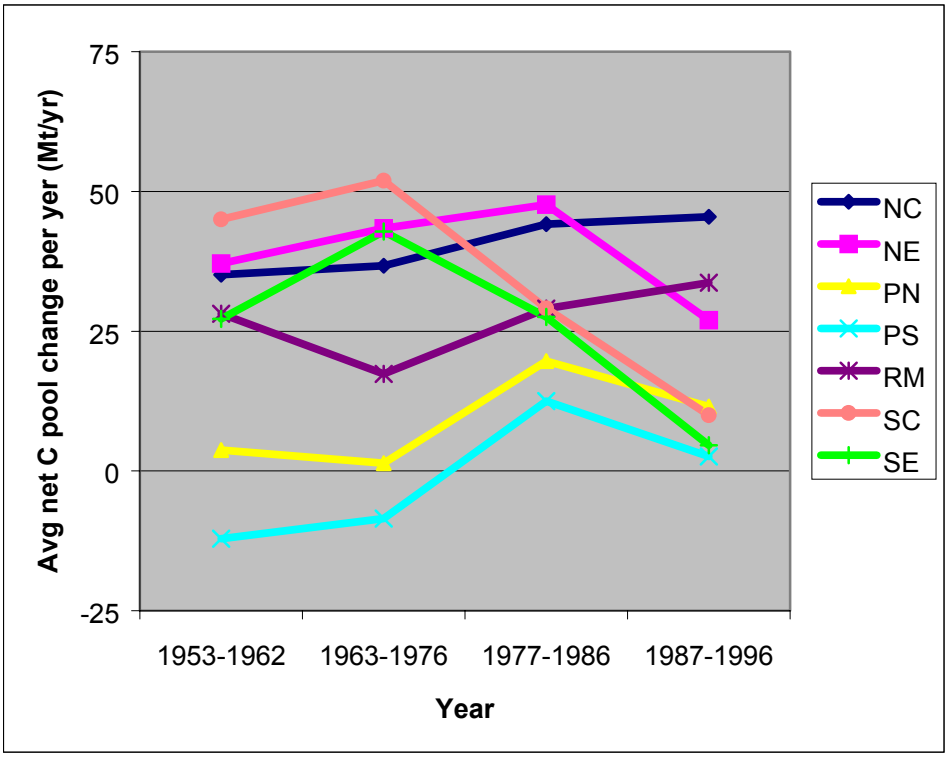


Figure 27-3. Average annual net carbon pool change of all non-soil forest ecosystem components (Mt/yr) by regions for all forest land of the conterminous U.S., 1953-1997.



Regions: NE=Northeast, NC=North Central, PN=Pacific Northwest, PS=Pacific Southwest, RM=Rocky Mountain, SE=Southeast, SC=South Central. Regions follow the regions in Smith and others (2001), with the exception of the States of ND, eastern SD, NB, and KS, which are compiled with the NC region.