Executive Summary

By Zhiliang Zhu, Benjamin M. Sleeter, Ryan R. Reker, Todd J. Hawbaker, Sarah Stackpoole, Brian Bergamaschi, and Shuguang Liu

Executive Summary of

Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Eastern United States

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Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Eastern United States—Executive Summary

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Introduction

This is the third in a series of reports produced by the U.S. Geological Survey (USGS) to fulfill the requirements of section 712 of the Energy Independence and Security Act (EISA) of 2007 and to conduct a comprehensive national assessment of storage and flux (flow) of carbon and the fluxes of other greenhouse gases (GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)). These carbon and GHG variables were examined for major terrestrial ecosystems (forests, grasslands/shrublands, agricultural lands, and wetlands) and aquatic ecosystems (rivers, streams, lakes, estuaries, and coastal waters) in the Eastern United States in two time periods: baseline (from 2001 through 2005) and future (projections from the end of the baseline through 2050). The Great Lakes were not included in this assessment due to a lack of input data. Chapter 1 of this report provides an overview of the general methodology. Topics of this report include the storage and fluxes of carbon estimated based on data included in maps of classes of land-use and land-cover (LULC) change, climate change, land management, and wildland fire. Changes in storage and fluxes of carbon estimated based on potential changes in natural vegetation and future potential vegetation change due to climate change were not included in this report.

This regional assessment was conducted to achieve two primary objectives: (1) to contribute to the EISA mandate for a national assessment of carbon sequestration and GHG fluxes, and (2) to help improve the understanding of carbon cycling at a regional scale by focusing on different ecosystems and their relations with natural and anthropogenic controlling processes (such as climate change, LULC, land management, and wildland fires). To meet the objectives, the assessment was designed to provide answers to such questions as "How much carbon was stored in ecosystems of the Eastern United States and how would storage of carbon change over space and time?" and "How might the stored carbon and carbon fluxes be affected by the natural and anthropogenic processes that affect the region?"

The assessment covered an area of 3.05 million square kilometers in the Eastern United States, which is divided into in seven level II ecoregions (as defined by the U.S. Environmental Protection Agency, 2013): the Mixed Wood Shield, Atlantic Highlands, Mixed Wood Plains, Central USA Plains, Southeastern USA Plains, Ozark, Ouachita-Appalachian Forests, and Mississippi Alluvial and Southeast USA Coastal Plains ecoregions. Further description of the ecoregional framework is provided in detail in chapters 1 and 2. The assessment was based on measured and remotely sensed data collected by the USGS and many other agencies and organizations, combined with statistical methods and simulation models. Specific input data used in different components of the assessment methodology are described in chapters 3 through 7. The major findings are discussed in this executive summary.

Baseline and Projected Future Land-Use and Land-Cover Change

In 2005, the total area of the Eastern United States (3.05 million square kilometers) included the following ecosystems: forests (47.9 percent), agricultural lands (31.2 percent), wetlands (8.9 percent), open water (lakes, reservoirs, rivers, and streams; 5.4 percent), grasslands/shrublands (1.7 percent), and other land types (5 percent). Between 1992 and 2005, changes in land use (such as croplands) and land cover (such as wetlands) in the Eastern United States affected 8.9 percent of that land area (compared with 2.9 percent in the Western United States) and were driven primarily by demands for forest products and urban development.

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The projected changes (to 2050) in both LULC and climate were used in this assessment to support the projection of future potential storage and fluxes of carbon in relation to ecological and economic processes. The projections in LULC were highly variable across the seven ecoregions of the Eastern United States, as were the assumptions that were made. For the Eastern United States as a whole, the total projected change ranged from 17.2 to 22.9 percent between different scenarios, including changes between different LULC categories such as forests, agriculture, and developed lands. The most active ecoregion in terms of projected LULC change was the Southeastern USA Plains ecoregion, averaging 31 percent of change between the different LULC types over the projection years.

Baseline Carbon Storage and Greenhouse Gas Fluxes

Main findings from this assessment for baseline years are described in paragraphs below and are summarized in table E1. The average total storage of carbon in the terrestrial ecosystems of the Eastern United States in 2005 was estimated to be 26,962 teragrams of carbon (TgC), ranging between a low of 25,069 and a high of 28,497 TgC. The total carbon stock was distributed in forests (68.1 percent), wetlands (15.1 percent), agricultural lands (14.7 percent), grasslands/shrublands (0.9 percent), and other lands (1,1 percent). Geographically, the estimated total carbon stocks ranged from 1,499.5 TgC in the Central USA Plains ecoregion to 4,791 TgC in the Ozark, Ouachita-Appalachian Forests ecoregion, and the per-unit-of-area carbon stocks ranged from 6.3 kilograms of carbon per square meter (kgC/m^2) in the Central USA Plains ecoregion to 16.1 kgC/m^2 in the Atlantic Highlands ecoregion. On average, the wetlands maintained the largest stock of carbon per unit of area among all the ecosystems in the Eastern United States with 15 kgC/m^2, followed by forests (12.6 kgC/m^2), grasslands/shrublands (4.7 kgC/m^2), agricultural lands (4.2 kgC/m^2), and other land types (1 kgC/m^2). Overall, live biomass accounted for 42 percent of the total carbon stock, and soil organic carbon (SOC; assessed in the top 20-centimeter-thick layer only) accounted for 43 percent of the total carbon stock; woody debris and other surface carbon pools represented the remaining 15 percent.

The net flux of carbon was calculated as the change of carbon stock between two points in time. A negative number indicates carbon uptake, carbon sequestration, or a carbon sink; a positive number indicates a carbon emission or a carbon source. From 2001 to 2005, an average annual net flux of −279.4 TgC/yr, ranging from a low of −405.5 TgC/yr to a high of −112.5 TgC/yr, was estimated for all the terrestrial ecosystems in the Eastern United States. Most of the net carbon flux in the study area was in forests (81 percent, −154.8 grams of carbon per square meter per year (gC/m^2/yr)), followed by wetlands (12.8 percent, −132.2 gC/m^2/yr), agricultural lands (4.1 percent, −12.1 gC/m^2/yr), and grasslands/shrublands (0.8 percent, −40.9 gC/m^2/yr). Of the total carbon sink, live biomass accounted for 67.6 percent, SOC accounted for 23.4 percent, and dead biomass accounted for 9 percent.

For comparison with the estimated net carbon flux in this study, a recent study found that the net carbon flux from LULC change and forestry was –246.8 TgC in 2011 for the area of the conterminous United States (U.S. Environmental Protection Agency, 2013b). In a separate assessment for the Western United States (Liu and others, 2012), using the same method as described in this report, the per-unit-area net carbon flux for forests was estimated to be –72.1 gC/m^2/yr. Net forest carbon flux was −93 gC/m^2/yr for the United States as a whole (Pan and others, 2011).

Between 2001 and 2008 in the Eastern United States, 875 to 4,842 square kilometers per year was burned, releasing 1.8 to 20.5 teragrams of CO_2-equivalent per year (TgCO_2-eq/yr) (0.5 to 5.6 TgC/yr), mostly along the Atlantic coast in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion, which includes the Everglades and Texas-Louisiana Coastal Plains ecoregions. The average annual GHG emission from the fires was 5.9 TgCO_2-eq/yr (1.6 TgC/yr).

Removal of carbon from forest ecosystems in the Eastern United States was estimated for forest harvesting (clearcutting and partial cutting, with forests remaining as forests) and forests converting to other uses (including agriculture, developed, and other land uses). Carbon removal from forest harvesting was estimated to be an average of 41 TgC/yr from 2001 through 2005, whereas from land use conversions, the average was 7.3 TgC/yr.

Using data collected between the 1970s and the present, rivers and streams throughout the Eastern United States were estimated to transport 36.5 TgC/yr (or an average of 6.4 gC/m^2/yr in yield per unit of area), ranging from 28.1 to 44.8 TgC/yr (or an average of 5 to 7.9 gC/m^2/yr) of dissolved inorganic and total organic carbon from upstream sources to estuaries and the coastal oceans. The emissions of carbon dioxide to the atmosphere from inland waters of the Eastern United States were 51.3 TgC/yr (or an average of 5.2 gC/m^2/yr in yield per unit of area), ranging from 34.3 to 71.4 TgC/yr (or an average of 3.8 to 6.3 gC/m^2/yr in yield per unit of area); 81 percent of the total emissions was from rivers and streams, and 19 percent was from lakes and reservoirs.

The rate of carbon burial (sequestration) in the sediments in the lakes and reservoirs was estimated to be –9.2 TgC/yr (or an average of −3.1 gC/m^2/yr in yield per unit of area), ranging from –4.6 to –13.8 TgC/yr (or an average of –1.6 to –4.7 gC/m^2/yr in yield per unit of area). The estimates of carbon fluxes in aquatic ecosystems were highly variable because of differences in precipitation, topography, lithology, and other controlling processes (Pacala and others, 2001).

Carbon is also stored in coastal waters in the Eastern United States through burial in coastal sediments and through transport of carbon from the surface into the deep ocean. The contribution of terrestrial processes to the total annual rate of carbon storage in coastal waters was estimated to be –7.8 TgC/yr, ranging from –1.8 to –22.4 TgC/yr, similar in the ranges of values of estimated burial of carbon in lakes and

Table E1. Baseline estimates by ecosystems in the Eastern United States.

[gC/m²/yr, grams of carbon per square meter per year; kgC/m², kilograms of carbon per square meter; TgC, teragrams of carbon; TgC/yr, teragrams of carbon per year; $TgCO_2$-eq/yr, teragrams of carbon dioxide-equivalent per year]

Variable	Ecosystem	Mean (range if available)
Total carbon stock	All terrestrial ecosystems	26,961.8 (25,068.8 to 28,497.0) TgC
Per unit area carbon stock	Forests	12.6 kgC/m^2
	Wetlands	15.0 kgC/m^2
	Agricultural lands	4.2 kgC/m^2
Average annual net carbon flux	All terrestrial ecosystems	–279.4 (–405.5 to –112.5) TgC/yr
Per unit area net carbon flux	Forests	–154.8 gC/m^2/yr
	Wetlands	–132.2 gC/m^2/yr
	Agricultural lands	–12.1 gC/m^2/yr
	Grasslands/shrublands	–40.9 gC/m^2/yr
Wildland fire emissions	Forests, wetlands	1.6 (0.5 to 5.6) TgC/yr
Carbon removal from harvest	Forests	41.0 TgC/yr
Carbon removal from forest conversions	Forests converting to nonforest land use	7.3 TgC/yr
Riverine transport	Inland waters	36.5 (28.1 to 44.8) TgC/yr
Emissions (efflux)	Inland waters	51.3 (34.3 to 71.4) TgC/yr
Carbon storage rate	Lakes and reservoirs	–9.2 (–4.6 to –13.8) TgC/yr
Carbon storage rate	Coastal waters	–7.8 (–1.8 to –22.4) TgC/yr
Coastal storage	Coastal waters	15,000 TgC
Total methane emissions	All terrestrial ecosystems	193.0 (191.7 to 195) TgCO2-eq/yr
Total nitrous oxide emissions	All terrestrial ecosystems	174.7 (173.0 to 176.6) TgCO2-eq/yr

reservoirs. However, coastal sediments and deep ocean waters represent an important long-term reservoir for carbon storage, amounting to storage of more than 15,000 TgC over millennial time scales under modeled conditions, or approximately 60 percent of the total terrestrial carbon pool.

In addition to the baseline net terrestrial carbon flux estimates (−279.4 TgC/tr, ranging from −405.5 to −112.5 TgC/yr, or −1,024.6 $TgCO_2$-eq/yr, ranging from –1,487 to –412.9 $TgCO_2$-eq/yr), the baseline flux rates of CH_4 and N_2O were estimated to be relatively low and highly variable among ecosystems and ecoregions. Overall, the estimated flux rate of CH_4 during the baseline years was 193 TgC/yr, ranging from 191.7 to 195 $TgCO_2$-eq/yr. The estimated flux rate of N_2O was 174.7 $TgCO_2$-eq/yr, ranging from 173 to 176.6 $TgCO_2$-eq/yr.

Projected Future Carbon Storage and Greenhouse Gas Fluxes

In order to project the future potential carbon storage amounts and flux rates, combinations of LULC scenarios and climate projections, developed on an annual basis for 2006 through 2050, were used for the assessment along with multiple biogeochemical models. The results of these combinations led to a range of estimates for storage and flux of carbon under a range of projected future conditions. The results of projected future potential stocks and flux of carbon were highly variable among multiple model runs, ecoregions, and ecosystems

The total amount of carbon that potentially could be stored in the terrestrial ecosystems of the Eastern United States in 2050 was projected to be 37,082 TgC, ranging from 25,512 to 46,002 TgC, which is an increase of 10,121 TgC or 37.5 percent in total carbon stock from the stocks stored in the baseline period. Seventy percent of the increase is in forest ecosystems of the study area.

The potential mean annual net carbon flux between 2006 and 2050 was projected to be –224.9 TgC/yr, ranging from –403.7 to 1.4 TgC/yr. When compared with the –279.4 TgC/yr net carbon flux estimates for the baseline period, ranging from −405.5 to −112.5 TgC/yr, the projected rates of future carbon sequestration in the Eastern United States represented a potential decrease of 54.5 TgC/yr, ranging from 1.8 to 113.9 TgC/yr. The projected decrease was largely driven by a potential decrease in the rate of sequestration in forest lands; the rates of carbon sequestration of agricultural lands and wetlands were projected to increase.

Under future projections of climate change, the area burned by wildland fires was projected to increase by 17 to 51 percent, and the GHG combustion emissions from wildland fires were projected to increase by 1 to 41 percent, relative to baseline conditions. Under extreme climate conditions, wildland fire emissions were projected to increase by 43 to 122 percent relative to baseline conditions. Carbon stored in wetlands of the Atlantic coast may be especially vulnerable to wildland-fire emissions because most of the

fire activities were projected to be concentrated in the coastal regions where years of land use have altered some characteristics of hydrologic and fire regimes, such as exposed peat soils, and increased fire frequency.

Rates of carbon storage in coastal and estuarine waters were projected to increase by 19 to 25 percent between 2005 and 2050, largely a result of projected changes in nutrient and sediment supply to coastal waters. The environmental scenario showed the lowest projected change, whereas the economic scenario where energy development was not based on any one particular source (renewable technologies played an equal part in the energy mix as fossil fuels) had the greatest projected change. Nevertheless, the annual rate of coastal carbon storage represents less than 5 percent of those projected for the terrestrial system, so the increased rates projected for coastal waters will do little to offset the decreases seen in the terrestrial estimates.

Limitations of the Assessment Report

The known limitations of the assessment report include the following:

- LULC change was used as the geographic foundation of the assessment, but specific effects of LULC change on stocks and flux of carbon were not fully quantified and analyzed in this report.
- Future climate projections were used to project future ecosystem storage and fluxes of carbon, but the specific effects of the future climate projections on ecosystem carbon balance were not fully quantified and analyzed in this report.
- Wildland-fire combustion emissions were estimated, but the long-term effects of wildland fires on the production of carbon in ecosystems were not analyzed separately in this report.
- Other ecosystem disturbances, such as insect-caused forest mortalities or windstorms were not included in the assessment.
- Fluxes of CH_4 and N_2O were projected to future years based on a set of LULC scenarios without considering the effects of climate projections.
- The baseline carbon fluxes were estimated for the first time for aquatic ecosystems, but the existing carbon storage in the sediments of the aquatic ecosystems was not estimated.
- The SOC pool estimated and mapped in this assessment only represented available data for soil profile up to 20 centimeters deep. These data should not be compared with other SOC results produced at profiles deeper than 20 centimeters.
- Uncertainties from model runs of different components of the assessment were quantified using simple statistical methods to account for the spread of the estimates.

Other sources of uncertainties were described in the report but were not quantified. As a result, the total uncertainty of the assessment is unknown. In addition, there were limitations resulting from the methodology used for the assessment; specifically, the mapping and modeling of major components (such as LULC and wildland fires) of the assessment were not coupled in a completely integrative modeling system.

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