6. Land Use, Land-Use Change, and Forestry

This chapter provides an assessment of the greenhouse gas fluxes resulting from land use and land-use change in the United States.[1] The Intergovernmental Panel on Climate Change's *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) recommends reporting fluxes according to changes within and conversions between all land-use types including: Forest Land, Cropland, Grassland, Wetlands, and Settlements (as well as Other Land).

The greenhouse gas flux from *Forest Land Remaining Forest Land* is reported for all forest ecosystem carbon (C) stocks (i.e., aboveground biomass, belowground biomass, dead wood, litter, and C stock changes from mineral and organic soils), harvested wood pools, and non-carbon dioxide (non-CO_2) emissions from forest fires, the application of synthetic nitrogen fertilizers to forest soils, and the draining of organic soils. Fluxes from *Land Converted to Forest Land* are included for aboveground biomass, belowground biomass, dead wood, litter, and C stock changes from mineral soils.

Fluxes are reported for four agricultural land use/land-use change categories: *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland*, and *Land Converted to Grassland*. The reported greenhouse gas fluxes from these agricultural lands include changes in soil organic C stocks in mineral and organic soils due to land use and management, and for the subcategories of *Forest Land Converted to Cropland* and *Forest Land Converted to Grassland*, the changes in aboveground biomass, belowground biomass, dead wood, and litter C stocks are also reported. The greenhouse gas flux from *Grassland Remaining Grassland* also includes estimates of non-CO_2 emissions from grassland fires.

Fluxes from *Wetlands Remaining Wetlands* include changes in C stocks and methane (CH_4) and nitrous oxide (N_2O) emissions from managed peatlands, as well as aboveground and soil C stock changes in all coastal wetlands, CH_4 emissions from vegetated coastal wetlands, and N_2O emissions from aquaculture in coastal wetlands. Estimates for *Land Converted to Wetlands* include aboveground and soil C stock changes and CH_4 emissions from land converted to vegetated coastal wetlands.

Fluxes from *Settlements Remaining Settlements* include changes in C stocks and N_2O emissions from soils, and CO_2 fluxes from settlement trees and landfilled yard trimmings and food scraps. The reported greenhouse gas flux from *Land Converted to Settlements* includes changes in C stocks in mineral and organic soils due to land use and management for all land use conversions to settlements, and the C stock changes in aboveground biomass, belowground biomass, dead wood, and litter are also included for the subcategory *Forest Land Converted to Settlements*.

The land use, land-use change, and forestry (LULUCF) sector in 2017 resulted in a net increase in C stocks (i.e., net CO_2 removals) of 729.6 MMT CO_2 Eq. (199.0 MMT C).[2] This represents an offset of approximately 11.3 percent of

[1] The term "flux" is used to describe the net emissions of greenhouse gases accounting for both the emissions of CO_2 to and the removals of CO_2 from the atmosphere. Removal of CO_2 from the atmosphere is also referred to as "carbon sequestration."

[2] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland,*

total (i.e., gross) greenhouse gas emissions in 2017. Emissions of CH_4 and N_2O from LULUCF activities in 2017 are 15.5 MMT CO_2 Eq. and represent 0.2 percent of total greenhouse gas emissions.[3]

Total C sequestration in the LULUCF sector decreased by approximately 10.5 percent between 1990 and 2017. This decrease was primarily due to a decline in the rate of net C accumulation in Forest Land and *Cropland Remaining Cropland,* as well as an increase in emissions from *Land Converted to Settlements*.[4] Specifically, there was a net C accumulation in *Settlements Remaining Settlements*, which increased from 1990 to 2017, while the net C accumulation in *Forest Land Remaining Forest Land, Cropland Remaining Cropland*, and *Grassland Remaining Grassland* slowed over this period. Net C accumulation remained steady from 1990 to 2017 in *Land Converted to Forest Land, Wetlands Remaining Wetlands,* and *Land Converted to Wetlands*. Emissions from *Land Converted to Cropland* and *Land Converted to Grassland* decreased during this period. The C stock change from LULUCF is summarized in Table 6-1.

Table 6-1: Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Land-Use Category	1990		2005		2013	2014	2015	2016	2017
Forest Land Remaining Forest Land	**(671.6)**		**(639.4)**		**(616.7)**	**(568.8)**	**(645.2)**	**(628.9)**	**(621.1)**
Changes in Forest Carbon Stocks[a]	(671.6)		(639.4)		(616.7)	(568.8)	(645.2)	(628.9)	(621.1)
Land Converted to Forest Land	**(119.1)**		**(120.0)**		**(120.5)**	**(120.5)**	**(120.6)**	**(120.6)**	**(120.6)**
Changes in Forest Carbon Stocks[b]	(119.1)		(120.0)		(120.5)	(120.5)	(120.6)	(120.6)	(120.6)
Cropland Remaining Cropland	**(40.9)**		**(26.5)**		**(11.4)**	**(12.0)**	**(6.3)**	**(9.9)**	**(10.3)**
Changes in Mineral and Organic Soil Carbon Stocks	(40.9)		(26.5)		(11.4)	(12.0)	(6.3)	(9.9)	(10.3)
Land Converted to Cropland	**75.6**		**66.7**		**66.9**	**66.7**	**66.7**	**67.3**	**66.9**
Changes in all Ecosystem Carbon Stocks[c]	75.6		66.7		66.9	66.7	66.7	67.3	66.9
Grassland Remaining Grassland	**(4.2)**		**5.5**		**(3.7)**	**(7.5)**	**9.6**	**(1.6)**	**(0.1)**
Changes in Mineral and Organic Soil Carbon Stocks	(4.2)		5.5		(3.7)	(7.5)	9.6	(1.6)	(0.1)
Land Converted to Grassland	**8.7**		**5.1**		**8.3**	**7.9**	**9.8**	**8.5**	**8.3**
Changes in all Ecosystem Carbon Stocks[c]	8.7		5.1		8.3	7.9	9.8	8.5	8.3
Wetlands Remaining Wetlands	**(4.0)**		**(5.7)**		**(4.3)**	**(4.3)**	**(4.4)**	**(4.4)**	**(4.4)**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1		1.1		0.8	0.8	0.8	0.7	0.7
Changes in Aboveground and Soil Carbon Stocks in Coastal Wetlands	(5.1)		(6.8)		(5.1)	(5.1)	(5.1)	(5.1)	(5.1)
Land Converted to Wetlands	**(+)**		**(+)**		**(+)**	**(+)**	**(+)**	**(+)**	**(+)**
Changes in Aboveground and Soil Carbon Stocks[d]	(+)		(+)		(+)	(+)	(+)	(+)	(+)
Settlements Remaining Settlements	**(122.1)**		**(127.8)**		**(135.9)**	**(135.8)**	**(135.4)**	**(134.7)**	**(134.5)**
Changes in Organic Soil Carbon Stocks	0.1		0.5		1.3	1.3	1.3	1.3	1.3
Changes in Settlement Tree Carbon Stocks	(96.2)		(116.8)		(125.6)	(125.0)	(124.5)	(123.9)	(123.9)
Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills	(26.0)		(11.4)		(11.7)	(12.1)	(12.3)	(12.1)	(11.9)
Land Converted to Settlements	**62.9**		**86.0**		**86.4**	**86.5**	**86.5**	**86.4**	**86.2**
Changes in all Ecosystem Carbon Stocks[c]	62.9		86.0		86.4	86.5	86.5	86.4	86.2
LULUCF Carbon Stock Change	**(814.8)**		**(756.1)**		**(731.0)**	**(687.8)**	**(739.4)**	**(738.1)**	**(729.6)**

Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements, and *Land Converted to Settlements.*

[3] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[4] Carbon sequestration estimates are net figures. The C stock in a given pool fluctuates due to both gains and losses. When losses exceed gains, the C stock decreases, and the pool acts as a source. When gains exceed losses, the C stock increases, and the pool acts as a sink; also referred to as net C sequestration or removal.

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] Includes the net changes to carbon stocks stored in all forest ecosystem pools and harvested wood products.

[b] Includes the net changes to carbon stocks stored in all forest ecosystem pools (excludes drained organic soils which are included in the flux from *Forest Land Remaining Forest Land* because it is not possible to separate the activity data at this time).

[c] Includes changes in mineral and organic soil carbon stocks for all land use conversions to cropland, grassland, and settlements, respectively. Also includes aboveground/belowground biomass, dead wood, and litter carbon stock changes for conversion of forest land to cropland, grassland, and settlements, respectively.

[d] Includes aboveground and soil carbon stock changes for land converted to vegetated coastal wetlands.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Emissions of CH_4 from LULUCF activities are shown in Table 6-2. Forest fires were the largest source of CH_4 emissions from LULUCF in 2017, totaling 4.9 MMT CO_2 Eq. (194 kt of CH_4). *Coastal Wetlands Remaining Coastal Wetlands* resulted in CH_4 emissions of 3.6 MMT CO_2 Eq. (144 kt of CH_4). Grassland fires resulted in CH_4 emissions of 0.3 MMT CO_2 Eq. (12 kt of CH_4). *Peatlands Remaining Peatlands, Land Converted to Wetlands,* and *Drained Organic Soils* on forest lands resulted in CH_4 emissions of less than 0.05 MMT CO_2 Eq. each.

For N_2O emissions, forest fires were also the largest source from LULUCF in 2017, totaling 3.2 MMT CO_2 Eq. (11 kt of N_2O). Nitrous oxide emissions from fertilizer application to settlement soils in 2017 totaled to 2.5 MMT CO_2 Eq. (8 kt of N_2O). This represents an increase of 72.0 percent since 1990. Additionally, the application of synthetic fertilizers to forest soils in 2017 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt of N_2O). Nitrous oxide emissions from fertilizer application to forest soils have increased by 455.1 percent since 1990, but still account for a relatively small portion of overall emissions. Grassland fires resulted in N_2O emissions of 0.3 MMT CO_2 Eq. (1 kt of N_2O). *Coastal Wetlands Remaining Coastal Wetlands* and *Drained Organic Soils* on forest lands resulted in N_2O emissions of 0.1 MMT CO_2 Eq. each (less than 0.5 kt of N_2O), and *Peatlands Remaining Peatlands* resulted in N_2O emissions of less than 0.05 MMT CO_2 Eq.

Emissions and removals from LULUCF are summarized in Figure 6-1 and Table 6-3 by land-use and category, and Table 6-4 and Table 6-5 by gas in MMT CO_2 Eq. and kt, respectively.

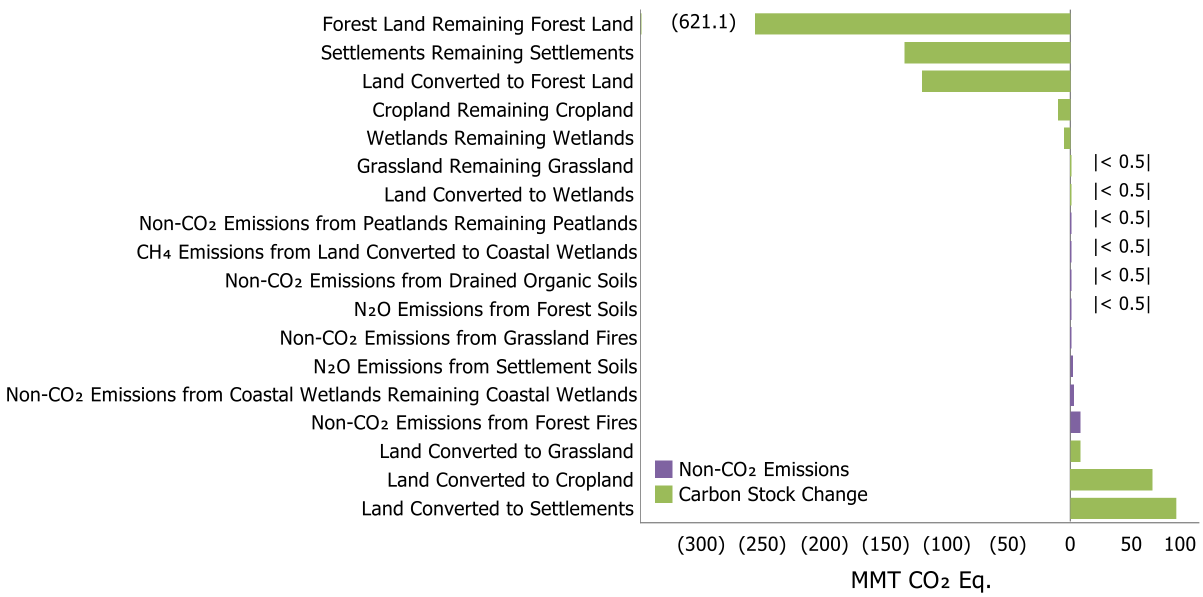
Table 6-2: Emissions from Land Use, Land-Use Change, and Forestry by Gas (MMT CO_2 Eq.)

Gas/Land-Use Sub-Category	1990		2005		2013	2014	2015	2016	2017
CH_4	**5.0**		**9.0**		**9.9**	**10.1**	**16.5**	**8.8**	**8.8**
Forest Land Remaining Forest Land: Forest Fires[a]	1.5		5.2		6.1	6.1	12.6	4.9	4.9
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	3.4		3.5		3.6	3.6	3.6	3.6	3.6
Grassland Remaining Grassland: Grassland Fires[b]	0.1		0.3		0.2	0.4	0.3	0.3	0.3
Land Converted to Wetlands: Land Converted to Coastal Wetlands	+		+		+	+	+	+	+
Forest Land Remaining Forest Land: Drained Organic Soils[c]	+		+		+	+	+	+	+
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+		+		+	+	+	+	+
N_2O	**2.8**		**7.0**		**7.6**	**7.7**	**11.8**	**6.7**	**6.7**
Forest Land Remaining Forest Land: Forest Fires[a]	1.0		3.4		4.0	4.0	8.3	3.2	3.2
Settlements Remaining Settlements: Settlement Soils[d]	1.4		2.5		2.6	2.6	2.5	2.5	2.5
Forest Land Remaining Forest Land: Forest Soils[e]	0.1		0.5		0.5	0.5	0.5	0.5	0.5
Grassland Remaining Grassland: Grassland Fires[b]	0.1		0.3		0.2	0.4	0.3	0.3	0.3
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	0.1		0.2		0.1	0.1	0.1	0.1	0.1
Forest Land Remaining Forest Land: Drained Organic Soils[c]	0.1		0.1		0.1	0.1	0.1	0.1	0.1

	1990	2005	2013	2014	2015	2016	2017
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
LULUCF Emissions	**7.8**	**16.0**	**17.5**	**17.7**	**28.3**	**15.5**	**15.5**

+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] Estimates include emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland*.
[c] Estimates include emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.
[e] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
Note: Totals may not sum due to independent rounding.

Figure 6-1: 2017 LULUCF Chapter Greenhouse Gas Sources and Sinks (MMT CO_2 Eq.)



Note: Parentheses indicate net sequestration.

Table 6-3: Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Land-Use Category	1990	2005	2013	2014	2015	2016	2017
Forest Land Remaining Forest Land	**(669.0)**	**(630.2)**	**(605.9)**	**(558.1)**	**(623.8)**	**(620.3)**	**(612.5)**
Changes in Forest Carbon Stocks[a]	(671.6)	(639.4)	(616.7)	(568.8)	(645.2)	(628.9)	(621.1)
Non-CO_2 Emissions from Forest Fires[b]	2.4	8.6	10.2	10.1	20.8	8.0	8.0
N_2O Emissions from Forest Soils[c]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Non-CO_2 Emissions from Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land Converted to Forest Land	**(119.1)**	**(120.0)**	**(120.5)**	**(120.5)**	**(120.6)**	**(120.6)**	**(120.6)**
Changes in Forest Carbon Stocks[e]	(119.1)	(120.0)	(120.5)	(120.5)	(120.6)	(120.6)	(120.6)
Cropland Remaining Cropland	**(40.9)**	**(26.5)**	**(11.4)**	**(12.0)**	**(6.3)**	**(9.9)**	**(10.3)**
Changes in Mineral and Organic Soil Carbon Stocks	(40.9)	(26.5)	(11.4)	(12.0)	(6.3)	(9.9)	(10.3)
Land Converted to Cropland	**75.6**	**66.7**	**66.9**	**66.7**	**66.7**	**67.3**	**66.9**
Changes in all Ecosystem Carbon Stocks[f]	75.6	66.7	66.9	66.7	66.7	67.3	66.9
Grassland Remaining Grassland	**(4.1)**	**6.2**	**(3.3)**	**(6.7)**	**10.2**	**(1.0)**	**0.6**
Changes in Mineral and Organic Soil Carbon Stocks	(4.2)	5.5	(3.7)	(7.5)	9.6	(1.6)	(0.1)
Non-CO_2 Emissions from Grassland Fires[g]	0.2	0.7	0.4	0.8	0.7	0.6	0.6

Land Converted to Grassland	**8.7**		**5.1**		**8.3**	**7.9**	**9.8**	**8.5**	**8.3**
Changes in all Ecosystem Carbon Stocks[f]	8.7		5.1		8.3	7.9	9.8	8.5	8.3
Wetlands Remaining Wetlands	**(0.5)**		**(2.0)**		**(0.6)**	**(0.6)**	**(0.6)**	**(0.7)**	**(0.7)**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1		1.1		0.8	0.8	0.8	0.7	0.7
Changes in Aboveground and Soil Carbon Stocks in Coastal Wetlands	(5.1)		(6.8)		(5.1)	(5.1)	(5.1)	(5.1)	(5.1)
CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands	3.4		3.5		3.6	3.6	3.6	3.6	3.6
N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands	0.1		0.2		0.1	0.1	0.1	0.1	0.1
Non-CO_2 Emissions from Peatlands Remaining Peatlands	+		+		+	+	+	+	+
Land Converted to Wetlands	**(+)**		**(+)**		**(+)**	**(+)**	**(+)**	**(+)**	**(+)**
Changes in Aboveground and Soil Carbon Stocks	(+)		(+)		(+)	(+)	(+)	(+)	(+)
CH_4 Emissions from Land Converted to Coastal Wetlands	+		+		+	+	+	+	+
Settlements Remaining Settlements	**(120.7)**		**(125.3)**		**(133.3)**	**(133.2)**	**(132.9)**	**(132.2)**	**(132.1)**
Changes in Organic Soil Carbon Stocks	0.1		0.5		1.3	1.3	1.3	1.3	1.3
Changes in Settlement Tree Carbon Stocks	(96.2)		(116.8)		(125.6)	(125.0)	(124.5)	(123.9)	(123.9)
Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills	(26.0)		(11.4)		(11.7)	(12.1)	(12.3)	(12.1)	(11.9)
N_2O Emissions from Settlement Soils[h]	1.4		2.5		2.6	2.6	2.5	2.5	2.5
Land Converted to Settlements	**62.9**		**86.0**		**86.4**	**86.5**	**86.5**	**86.4**	**86.2**
Changes in all Ecosystem Carbon Stocks[f]	62.9		86.0		86.4	86.5	86.5	86.4	86.2
LULUCF Emissions[i]	**7.8**		**16.0**		**17.5**	**17.7**	**28.3**	**15.5**	**15.5**
LULUCF Carbon Stock Change[j]	**(814.8)**		**(756.1)**		**(731.0)**	**(687.8)**	**(739.4)**	**(738.1)**	**(729.6)**
LULUCF Sector Net Total[k]	**(807.0)**		**(740.0)**		**(713.5)**	**(670.0)**	**(711.1)**	**(722.6)**	**(714.1)**

\+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
[a] Includes the net changes to carbon stocks stored in all forest ecosystem pools and harvested wood products.
[b] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*
[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[d] Estimates include emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*
[e] Includes the net changes to carbon stocks stored in all forest ecosystem pools.
[f] Includes changes in mineral and organic soil carbon stocks for all land use conversions to cropland, grassland, and settlements, respectively. Also includes aboveground/belowground biomass, dead wood, and litter carbon stock changes for conversion of forest land to cropland, grassland, and settlements, respectively.
[g] Estimates include emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland.*
[h] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements* because it is not possible to separate the activity data at this time.
[i] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.
[j] LULUCF Carbon Stock Change includes any C stock gains and losses from all land use and land use conversion categories.
[k] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-4: Emissions and Removals from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990		2005		2013	2014	2015	2016	2017
Carbon Stock Change[a]	**(814.8)**		**(756.1)**		**(731.0)**	**(687.8)**	**(739.4)**	**(738.1)**	**(729.6)**
Forest Land Remaining Forest Land	(671.6)		(639.4)		(616.7)	(568.8)	(645.2)	(628.9)	(621.1)
Land Converted to Forest Land	(119.1)		(120.0)		(120.5)	(120.5)	(120.6)	(120.6)	(120.6)
Cropland Remaining Cropland	(40.9)		(26.5)		(11.4)	(12.0)	(6.3)	(9.9)	(10.3)
Land Converted to Cropland	75.6		66.7		66.9	66.7	66.7	67.3	66.9

Gas/Land-Use Category	1990	2005	2013	2014	2015	2016	2017
Grassland Remaining Grassland	(4.2)	5.5	(3.7)	(7.5)	9.6	(1.6)	(0.1)
Land Converted to Grassland	8.7	5.1	8.3	7.9	9.8	8.5	8.3
Wetlands Remaining Wetlands	(4.0)	(5.7)	(4.3)	(4.3)	(4.4)	(4.4)	(4.4)
Land Converted to Wetlands	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Settlements Remaining Settlements	(122.1)	(127.8)	(135.9)	(135.8)	(135.4)	(134.7)	(134.5)
Land Converted to Settlements	62.9	86.0	86.4	86.5	86.5	86.4	86.2
CH_4	**5.0**	**9.0**	**9.9**	**10.1**	**16.5**	**8.8**	**8.8**
Forest Land Remaining Forest Land: Forest Fires[b]	1.5	5.2	6.1	6.1	12.6	4.9	4.9
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	3.4	3.5	3.6	3.6	3.6	3.6	3.6
Grassland Remaining Grassland: Grassland Fires[c]	0.1	0.3	0.2	0.4	0.3	0.3	0.3
Land Converted to Wetlands: Land Converted to Coastal Wetlands	+	+	+	+	+	+	+
Forest Land Remaining Forest Land: Drained Organic Soils[d]	+	+	+	+	+	+	+
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**2.8**	**7.0**	**7.6**	**7.7**	**11.8**	**6.7**	**6.7**
Forest Land Remaining Forest Land: Forest Fires[b]	1.0	3.4	4.0	4.0	8.3	3.2	3.2
Settlements Remaining Settlements: Settlement Soils[e]	1.4	2.5	2.6	2.6	2.5	2.5	2.5
Forest Land Remaining Forest Land: Forest Soils[f]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Grassland Remaining Grassland: Grassland Fires[c]	0.1	0.3	0.2	0.4	0.3	0.3	0.3
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Forest Land Remaining Forest Land: Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
LULUCF Emissions[g]	**7.8**	**16.0**	**17.5**	**17.7**	**28.3**	**15.5**	**15.5**
LULUCF Carbon Stock Change[a]	**(814.8)**	**(756.1)**	**(731.0)**	**(687.8)**	**(739.4)**	**(738.1)**	**(729.6)**
LULUCF Sector Net Total[h]	**(807.0)**	**(740.0)**	**(713.5)**	**(670.0)**	**(711.1)**	**(722.6)**	**(714.1)**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements.*

[b] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[c] Estimates include emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland*.

[d] Estimates include emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[e] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.

[f] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[g] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[h] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-5: Emissions and Removals from Land Use, Land-Use Change, and Forestry (kt)

Gas/Land-Use Category	1990	2005	2013	2014	2015	2016	2017
Carbon Stock Change (CO_2)[a]	**(814,784)**	**(756,056)**	**(730,952)**	**(687,769)**	**(739,378)**	**(738,074)**	**(729,563)**

Forest Land Remaining Forest Land	(671,583)	(639,396)	(616,684)	(568,768)	(645,215)	(628,935)	(621,066)
Land Converted to Forest Land	(119,073)	(119,951)	(120,451)	(120,493)	(120,596)	(120,635)	(120,618)
Cropland Remaining Cropland	(40,940)	(26,544)	(11,367)	(12,018)	(6,321)	(9,941)	(10,280)
Land Converted to Cropland	75,580	66,657	66,945	66,750	66,709	67,314	66,865
Grassland Remaining Grassland	(4,214)	5,492	(3,745)	(7,549)	9,596	(1,621)	(55)
Land Converted to Grassland	8,738	5,124	8,269	7,927	9,786	8,500	8,347
Wetlands Remaining Wetlands	(4,050)	(5,689)	(4,325)	(4,329)	(4,359)	(4,390)	(4,399)
Land Converted to Wetlands	(44)	(32)	(44)	(44)	(44)	(44)	(44)
Settlements Remaining Settlements	(122,119)	(127,755)	(135,916)	(135,793)	(135,409)	(134,680)	(134,524)
Land Converted to Settlements	62,921	86,038	86,366	86,548	86,474	86,358	86,212
CH_4	**199**	**362**	**397**	**402**	**659**	**350**	**352**
Forest Land Remaining Forest Land: Forest Fires[b]	59	208	245	243	502	194	194
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	137	140	142	143	143	144	144
Grassland Remaining Grassland: Grassland Fires[c]	3	13	8	16	13	11	12
Land Converted to Wetlands: Land Converted to Coastal Wetlands	1	+	1	1	1	1	1
Forest Land Remaining Forest Land: Drained Organic Soils[d]	1	1	1	1	1	1	1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**9**	**23**	**25**	**26**	**40**	**22**	**22**
Forest Land Remaining Forest Land: Forest Fires[b]	3	11	14	13	28	11	11
Settlements Remaining Settlements: Settlement Soils[e]	5	8	9	9	9	8	8
Forest Land Remaining Forest Land: Forest Soils[f]	+	2	2	2	2	2	2
Grassland Remaining Grassland: Grassland Fires[c]	+	1	1	1	1	1	1
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	+	1	+	+	+	+	+
Forest Land Remaining Forest Land: Drained Organic Soils[d]	+	+	+	+	+	+	+
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+

+ Absolute value does not exceed 0.5 kt.
[a] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements*.
[b] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*
[c] Estimates include emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland*.
[d] Estimates include emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[e] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.
[f] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Box 6-1: Methodological Approach for Estimating and Reporting U.S. Emissions and Removals

In following the United Nations Framework Convention on Climate Change (UNFCCC) requirement under Article 4.1 to develop and submit national greenhouse gas emission inventories, the gross emissions total presented in this report for the United States excludes emissions and removals from LULUCF. The LULUCF Sector Net Total presented in this report for the United States includes emissions and removals from LULUCF. All emissions and removals estimates are calculated using internationally-accepted methods provided by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)* and the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands*. Additionally, the calculated emissions and removals in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[5] The use of consistent methods to calculate emissions and removals by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. The presentation of emissions and removals provided in this Inventory do not preclude alternative examinations, but rather, this Inventory presents emissions and removals in a common format consistent with how countries are to report Inventories under the UNFCCC. The report itself, and this chapter, follows this standardized format, and provides an explanation of the application of methods used to calculate emissions and removals.

6.1 Representation of the U.S. Land Base

A national land-use representation system that is consistent and complete, both temporally and spatially, is needed in order to assess land use and land-use change status and the associated greenhouse gas fluxes over the Inventory time series. This system should be consistent with IPCC (2006), such that all countries reporting on national greenhouse gas fluxes to the UNFCCC should: (1) describe the methods and definitions used to determine areas of managed and unmanaged lands in the country (Table 6-6), (2) describe and apply a consistent set of definitions for land-use categories over the entire national land base and time series (i.e., such that increases in the land areas within particular land-use categories are balanced by decreases in the land areas of other categories unless the national land base is changing) (Table 6-7), and (3) account for greenhouse gas fluxes on all managed lands. The IPCC (2006, Vol. IV, Chapter 1) considers all anthropogenic greenhouse gas emissions and removals associated with land use and management to occur on managed land, and all emissions and removals on managed land should be reported based on this guidance (See IPCC 2010, Ogle et al. 2018 for further discussion). Consequently, managed land serves as a proxy for anthropogenic emissions and removals. This proxy is intended to provide a practical framework for conducting an inventory, even though some of the greenhouse gas emissions and removals on managed land are influenced by natural processes that may or may not be interacting with the anthropogenic drivers. Guidelines for factoring out natural emissions and removals may be developed in the future, but currently the managed land proxy is considered the most practical approach for conducting an inventory in this sector (IPCC 2010). This section of the Inventory has been developed in order to comply with this guidance.

Three databases are used to track land management in the United States and are used as the basis to classify U.S. land area into the thirty-six IPCC land-use and land-use change categories (Table 6-7) (IPCC 2006). The primary databases are the U.S. Department of Agriculture (USDA) National Resources Inventory (NRI),[6] the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA)[7] Database, and the Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD).[8] For this Inventory, only new FIA data were used to update the time series of land use data in the conterminous United States and Hawaii (i.e., FIA data were not used to update Alaska). A recompilation of activity data of the other land uses and Alaska will occur for the next (i.e., 1990 through 2018) Inventory when new NRI and NLCD data are available.

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[5] See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

[6] NRI data are available at <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[7] FIA data are available at <http://www.fia.fs.fed.us/tools-data/default.asp>.

[8] NLCD data are available at <http://www.mrlc.gov/> and MRLC is a consortium of several U.S. government agencies.

The total land area included in the U.S. Inventory is 936 million hectares across the 50 states.[9] Approximately 890 million hectares of this land base is considered managed and 46 million hectares is unmanaged, which has not changed much over the time series of the Inventory (Table 6-7). In 2017, the United States had a total of 279 million hectares of managed Forest Land (0.4 percent increase compared to 1990). For Cropland, 163 million hectares are estimated (6.5 percent decrease compared to 1990), 339 million hectares of managed Grassland (0 percent change compared to 1990), 43 million hectares of managed Wetlands (1.7 percent decrease compared to 1990), 43 million hectares of Settlements (30 percent increase compared to 1990), and 23 million hectares of managed Other Land (3.8 percent compared to 1990) (Table 6-7). Wetlands are not differentiated between managed and unmanaged, and are reported solely as managed.[10] In addition, C stock changes are not currently estimated for the entire managed land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory (e.g., *Grassland Remaining Grassland* within interior Alaska).[11,12] Planned improvements are under development to estimate C stock changes and greenhouse gas emissions on all managed land and ensure consistency between the total area of managed land in the land-representation description and the remainder of the Inventory.

Dominant land uses vary by region, largely due to climate patterns, soil types, geology, proximity to coastal regions, and historical settlement patterns (Figure 6-2). Forest Land tends to be more common in the eastern United States, mountainous regions of the western United States and Alaska. Cropland is concentrated in the mid-continent region of the United States, and Grassland is more common in the western United States and Alaska. Wetlands are fairly ubiquitous throughout the United States, though they are more common in the upper Midwest and eastern portions of the country, as well as coastal regions. Settlements are more concentrated along the coastal margins and in the eastern states.

Table 6-6: Managed and Unmanaged Land Area by Land-Use Categories for All 50 States (Thousands of Hectares)

Land-Use Categories	1990	2005	2013[a]	2014[a]	2015[a]	2016[a]	2017[a]
Managed Lands	**889,923**	**889,913**	**889,895**	**889,895**	**889,895**	**889,895**	**889,895**
Forest Land	277,653	276,728	278,978	279,072	279,036	278,949	278,889
Croplands	174,427	165,600	163,056	163,056	163,064	163,065	163,065
Grasslands	338,955	341,233	338,881	338,818	338,875	338,970	339,042
Settlements	33,361	40,429	43,308	43,291	43,271	43,270	43,270
Wetlands	45,583	43,338	42,908	42,893	42,874	42,861	42,849
Other Land	21,945	22,585	22,764	22,765	22,775	22,780	22,780
Unmanaged Lands	**46,272**	**46,282**	**46,300**	**46,300**	**46,300**	**46,300**	**46,300**
Forest Land	9,515	8,474	8,601	8,601	8,601	8,601	8,601
Croplands	0	0	0	0	0	0	0
Grasslands	25,953	27,043	26,936	26,936	26,936	26,936	26,936
Settlements	0	0	0	0	0	0	0

[9] The current land representation does not include areas from U.S. Territories, but there are planned improvements to include these regions in future Inventories.

[10] According to the IPCC (2006), wetlands are considered managed if they are created through human activity, such as dam construction, or the water level is artificially altered by human activity. Distinguishing between managed and unmanaged wetlands in the United States is difficult due to limited data availability. Wetlands are not characterized within the NRI with information regarding water table management. As a result, all Wetlands are reported as managed. See the Planned Improvements section of the Inventory for future refinements to the Wetland area estimates.

[11] Other discrepancies between the land use areas in this section and subsequent sections in the LULUCF chapter are primarily due to new activity data that were compiled for *Forest Land Remaining Forest Land* and *Land Converted Forest Land* for this Inventory. These updates led to changes in the land representation data for other land uses through the process of combining FIA data with NRI and NLCD (See section "Approach for Combining Data Sources"). However, an inventory was not compiled for cropland, grassland and settlements in this Inventory, and so the estimates for those land uses are based on the land representation data from the previous Inventory. Also, newly compiled data for *Forest Land Remaining Forest Land* in Alaska were not harmonized with the land representation data in this section, leading to discrepancies with the areas presented for forest land in this section and the later section with the forest land carbon stock data. In addition, discrepancies occur because the coastal wetlands analysis is based on another land use product (NOAA C-CAP) that is not currently incorporated into the land representation analysis for this section. These discrepancies will be rectified in the next (1990 through 2018) Inventory.

[12] These "managed area" discrepancies also occur in the Common Reporting Format (CRF) tables submitted to the UNFCCC.

Wetlands	0	0	0	0	0	0	0
Other Land	10,804	10,765	10,764	10,764	10,764	10,764	10,764
Total Land Areas	**936,195**	**936,195**	**936,195**	**936,195**	**936,195**	**936,195**	**936,195**
Forest Land	287,167	285,202	287,578	287,673	287,637	287,549	287,490
Croplands	174,427	165,600	163,056	163,056	163,064	163,065	163,065
Grasslands	364,908	368,276	365,817	365,754	365,810	365,906	365,978
Settlements	33,361	40,429	43,308	43,291	43,271	43,270	43,270
Wetlands	43,583	43,338	42,908	42,893	42,874	42,861	42,849
Other Land	32,749	33,350	33,528	33,529	33,539	33,544	33,544

[a] The land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. In addition, there were no new data incorporated for Alaska. New activity data for the National Resources Inventory (NRI) and National Land Cover Dataset (NLCD) will be incorporated in the next Inventory.

Table 6-7: Land Use and Land-Use Change for the U.S. Managed Land Base for All 50 States (Thousands of Hectares)

Land-Use & Land-Use Change Categories[a]	1990	2005	2013[b]	2014[b]	2015[b]	2016[b]	2017[b]
Total Forest Land	**277,653**	**276,728**	**278,978**	**279,072**	**279,036**	**278,949**	**278,889**
FF	276,298	275,267	277,444	277,575	277,736	277,674	277,615
CF	205	180	164	162	150	149	149
GF	1,066	1,105	1,172	1,144	973	953	953
WF	15	47	49	48	47	47	47
SF	10	11	16	15	15	14	14
OF	58	117	133	128	117	111	111
Total Cropland	**174,427**	**165,600**	**163,056**	**163,056**	**163,064**	**163,065**	**163,065**
CC	162,058	150,596	149,723	149,725	149,737	149,737	149,737
FC	197	83	75	73	69	69	69
GC	11,754	14,418	12,827	12,827	12,827	12,827	12,827
WC	150	176	128	128	128	128	128
SC	76	85	91	91	91	91	91
OC	192	243	213	213	213	213	213
Total Grassland	**338,955**	**341,233**	**338,881**	**338,818**	**338,875**	**338,970**	**339,042**
GG	329,268	319,686	317,739	317,684	317,750	317,850	317,922
FG	693	3,210	3,225	3,218	3,208	3,204	3,204
CG	8,309	16,825	16,555	16,555	16,555	16,555	16,555
WG	231	429	199	199	199	199	199
SG	53	106	114	114	114	114	114
OG	400	976	1,048	1,048	1,048	1,048	1,048
Total Wetlands	**43,583**	**43,338**	**42,908**	**42,893**	**42,874**	**42,861**	**42,849**
WW	42,824	41,945	41,691	41,677	41,661	41,648	41,636
FW	47	70	72	70	68	68	68
CW	214	378	346	346	346	346	346
GW	452	835	700	700	700	700	700
SW	5	0	1	1	1	1	1
OW	41	110	98	98	98	98	98
Total Settlements	**33,361**	**40,429**	**43,308**	**43,291**	**43,271**	**43,270**	**43,270**
SS	30,471	31,981	35,849	35,850	35,850	35,851	35,851
FS	330	572	607	589	569	568	568
CS	1,247	3,550	2,982	2,982	2,982	2,982	2,982
GS	1,250	4,102	3,653	3,653	3,653	3,653	3,653
WS	6	25	26	26	26	26	26
OS	58	199	190	190	190	190	190
Total Other Land	**21,945**	**22,585**	**22,764**	**22,765**	**22,775**	**22,780**	**22,780**
OO	21,026	20,737	20,771	20,776	20,787	20,793	20,793
FO	51	77	90	86	85	84	84
CO	300	613	679	679	679	679	679
GO	481	982	1,109	1,109	1,109	1,109	1,109
WO	82	168	102	102	102	102	102

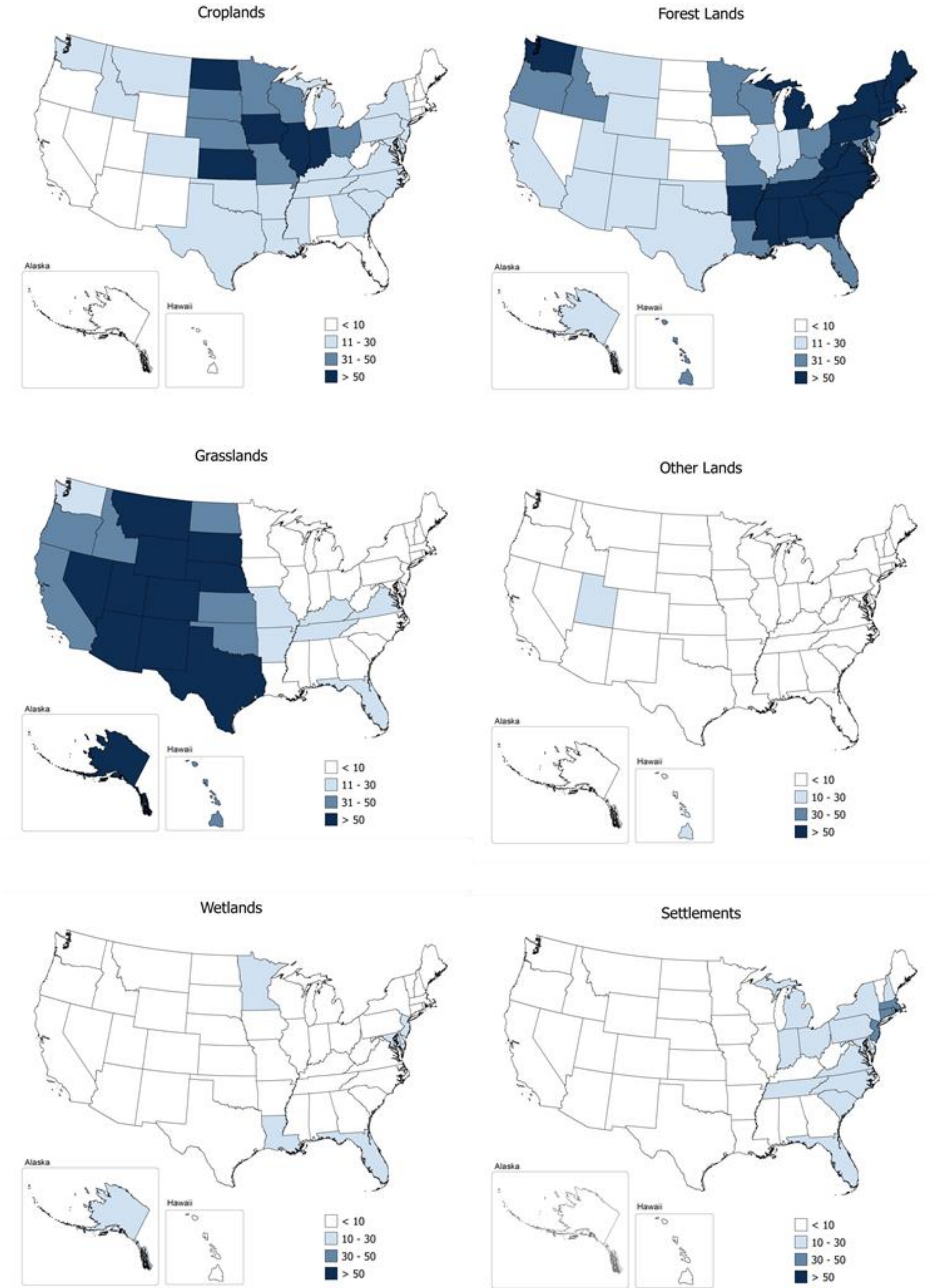
SO	5		9		13	13	13	13	13
Grand Total	**889,923**		**889,913**		**889,895**	**889,895**	**889,895**	**889,895**	**889,895**

[a] The abbreviations are "F" for Forest Land, "C" for Cropland, "G" for Grassland, "W" for Wetlands, "S" for Settlements, and "O" for Other Lands. Lands remaining in the same land-use category are identified with the land-use abbreviation given twice (e.g., "FF" is *Forest Land Remaining Forest Land*), and land-use change categories are identified with the previous land use abbreviation followed by the new land-use abbreviation (e.g., "CF" is *Cropland Converted to Forest Land*).

[b] The land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. In addition, there were no new data incorporated for Alaska. New activity data for the National Resources Inventory (NRI) and National Land Cover Dataset (NLCD will be incorporated for the next (i.e., 1990 through 2018) Inventory.

Notes: All land areas reported in this table are considered managed. A planned improvement is underway to deal with an exception for Wetlands, which based on the definitions for the current U.S. Land Representation Assessment includes both managed and unmanaged lands. U.S. Territories have not been classified into land uses and are not included in the U.S. Land Representation Assessment. See the Planned Improvements section for discussion on plans to include territories in future Inventories. In addition, C stock changes are not currently estimated for the entire land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory.

Figure 6-2: Percent of Total Land Area for Each State in the General Land-Use Categories for 2017



Methodology

IPCC Approaches for Representing Land Areas

IPCC (2006) describes three approaches for representing land areas. Approach 1 provides data on the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. With Approach 1, total net conversions between categories can be detected, but not the individual changes (i.e., additions and/or losses) between the land-use categories that led to those net changes. Approach 2 introduces tracking of individual land-use changes between the categories (e.g., Forest Land to Cropland, Cropland to Forest Land, and Grassland to Cropland), using survey samples or other forms of data, but does not provide spatially-explicit location data. Approach 3 extends Approach 2 by providing spatially-explicit location data, such as surveys with spatially identified sample locations and maps derived from remote sensing products. The three approaches are not presented as hierarchical tiers and are not mutually exclusive.

According to IPCC (2006), the approach or mix of approaches selected by an inventory agency should reflect calculation needs and national circumstances. For this analysis, the NRI, FIA, and the NLCD have been combined to provide a complete representation of land use for managed lands. These data sources are described in more detail later in this section. NRI, FIA and NLCD are Approach 3 data sources that provide spatially-explicit representations of land use and land-use conversions. Lands are treated as remaining in the same category (e.g., *Cropland Remaining Cropland*) if a land-use change has not occurred in the last 20 years. Otherwise, the land is classified in a land-use change category based on the current use and most recent use before conversion to the current use (e.g., *Cropland Converted to Forest Land*).

Definitions of Land Use in the United States

Managed and Unmanaged Land

The United States definition of managed land is similar to the general definition of managed land provided by the IPCC (2006), but with some additional elaboration to reflect national circumstances. Based on the following definitions, most lands in the United States are classified as managed:

- *Managed Land*: Land is considered managed if direct human intervention has influenced its condition. Direct intervention occurs mostly in areas accessible to human activity and includes altering or maintaining the condition of the land to produce commercial or non-commercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or non-commercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community, or societal objectives where these areas are readily accessible to society.[13]
- *Unmanaged Land*: All other land is considered unmanaged. Unmanaged land is largely comprised of areas inaccessible to society due to the remoteness of the locations. Though these lands may be influenced indirectly by human actions such as atmospheric deposition of chemical species produced in industry or CO_2 fertilization, they are not influenced by a direct human intervention.[14]

[13] Wetlands are an exception to this general definition, because these lands, as specified by IPCC (2006), are only considered managed if they are created through human activity, such as dam construction, or the water level is artificially altered by human activity. Distinguishing between managed and unmanaged wetlands in the United States is difficult due to limited data availability. Wetlands are not characterized within the NRI with information regarding water table management. Therefore, unless wetlands are managed for cropland or grassland, it is not possible to know if they are artificially created or if the water table is managed based on the use of NRI data. As a result, all Wetlands are reported as managed, but emissions are only reported for coastal regions and peatlands due to insufficient activity data to estimate emissions and limited resources to improve the inventory. See the Planned Improvements section of the Inventory for future refinements to the Wetland area estimates.

[14] There are some areas, such as Forest Land and Grassland in Alaska that are classified as unmanaged land due to the remoteness of their location.

In addition, land that is previously managed remains in the managed land base for 20 years before re-classifying the land as unmanaged in order to account for legacy effects of management on C stocks. Unmanaged land is also re-classified as managed over time if anthropogenic activity is introduced into the area based on the definition of managed land.

Land-Use Categories

As with the definition of managed lands, IPCC (2006) provides general non-prescriptive definitions for the six main land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. In order to reflect national circumstances, country-specific definitions have been developed, based predominantly on criteria used in the land-use surveys for the United States. Specifically, the definition of Forest Land is based on the FIA definition of forest,[15] while definitions of Cropland, Grassland, and Settlements are based on the NRI.[16] The definitions for Other Land and Wetlands are based on the IPCC (2006) definitions for these categories.

- *Forest Land*: A land-use category that includes areas at least 120 feet (36.6 meters) wide and at least one acre (0.4 hectare) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 m) at maturity in situ. Forest Land includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest Land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (36.6 m) wide or an acre (0.4 ha) in size. However, land is not classified as Forest Land if completely surrounded by urban or developed lands, even if the criteria are consistent with the tree area and cover requirements for Forest Land. These areas are classified as Settlements. In addition, Forest Land does not include land that is predominantly under an agricultural land use (Oswalt et al. 2014).
- *Cropland*: A land-use category that includes areas used for the production of adapted crops for harvest; this category includes both cultivated and non-cultivated lands. Cultivated crops include row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Non-cultivated cropland includes continuous hay, perennial crops (e.g., orchards) and horticultural cropland. Cropland also includes land with agroforestry, such as alley cropping and windbreaks,[17] if the dominant use is crop production, assuming the stand or woodlot does not meet the criteria for Forest Land. Lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides[18]) are also classified as Cropland, as long as these areas do not meet the Forest Land criteria. Roads through Cropland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Cropland area estimates and are, instead, classified as Settlements.
- *Grassland*: A land-use category on which the plant cover is composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing, and includes both pastures and native rangelands. This includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation. Land is also categorized as Grassland with three or fewer years of continuous hay production.[19] Savannas, deserts, and tundra are considered Grassland.[20] Drained wetlands are considered Grassland if the dominant vegetation meets the plant cover

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[15] See <http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2015/Core-FIA-FG-7.pdf>, page 22.

[16] See <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[17] Currently, there is no data source to account for biomass C stock change associated with woody plant growth and losses in alley cropping systems and windbreaks in cropping systems, although these areas are included in the Cropland land base.

[18] A set-aside is cropland that has been taken out of active cropping and converted to some type of vegetative cover, including, for example, native grasses or trees, but is still classified as cropland based on national circumstances.

[19] Areas with four or more years of continuous hay production are Cropland because the land is typically more intensively managed with cultivation, greater amounts of inputs, and other practices.

[20] *2006 IPCC Guidelines* do not include provisions to separate desert and tundra as land-use categories.

criteria for Grassland. Woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also classified as Grassland if they do not meet the criteria for Forest Land. Grassland includes land managed with agroforestry practices, such as silvopasture and windbreaks, if the land is principally grasses, grass-like plants, forbs, and shrubs suitable for grazing and browsing, and assuming the stand or woodlot does not meet the criteria for Forest Land. Roads through Grassland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Grassland and are, instead, classified as Settlements.

- *Wetlands*: A land-use category that includes land covered or saturated by water for all or part of the year, in addition to lakes, reservoirs, and rivers. Managed Wetlands are those where the water level is artificially changed, or were created by human activity. Certain areas that fall under the managed Wetlands definition are included in other land uses based on the IPCC guidance and national circumstances, including lands that are flooded for most or just part of the year in Croplands (e.g., rice cultivation and cranberry production, Grasslands (e.g., wet meadows dominated by grass cover) and Forest Lands (e.g., Riparian Forests near waterways).
- *Settlements*: A land-use category representing developed areas consisting of units of 0.25 acres (0.1 ha) or more that includes residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; parks within urban and built-up areas; and highways, railroads, and other transportation facilities. Also included are tracts of less than 10 acres (4.05 ha) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land, and so are included in the Settlements category. Rural transportation corridors located within other land uses (e.g., Forest Land, Cropland, and Grassland) are also included in Settlements.
- *Other Land*: A land-use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories. Following the guidance provided by the IPCC (2006), C stock changes and non-CO_2 emissions are not estimated for Other Lands because these areas are largely devoid of biomass, litter and soil C pools. However, C stock changes and non-CO_2 emissions are estimated for *Land Converted to Other Land* during the first 20 years following conversion to account for legacy effects.

Land-Use Data Sources: Description and Application to U.S. Land Area Classification

U.S. Land-Use Data Sources

The three main sources for land-use data in the United States are the NRI, FIA, and the NLCD (Table 6-8). These data sources are combined to account for land use in all 50 states. FIA and NRI data are used when available for an area because the surveys contain additional information on management, site conditions, crop types, biometric measurements, and other data that is needed to estimate C stock changes, N_2O, and CH_4 emissions on those lands. If NRI and FIA data are not available for an area, however, then the NLCD product is used to represent the land use.

Table 6-8: Data Sources Used to Determine Land Use and Land Area for the Conterminous United States, Hawaii, and Alaska

	NRI	FIA	NLCD
Forest Land			
Conterminous United States			
Non-Federal		•	
Federal		•	
Hawaii			
Non-Federal	•		
Federal			•
Alaska			
Non-Federal		•	•
Federal		•	•
Croplands, Grasslands, Other Lands, Settlements, and Wetlands			
Conterminous United States			
Non-Federal	•		
Federal			•
Hawaii			
Non-Federal	•		
Federal			•
Alaska			
Non-Federal		•	•
Federal		•	•

National Resources Inventory

For the Inventory, the NRI is the official source of data for land use and land use change on non-federal lands in the conterminous United States and Hawaii (except Forest Land), and is also used to determine the total land base for the conterminous United States and Hawaii. The NRI is a statistically-based survey conducted by the USDA Natural Resources Conservation Service and is designed to assess soil, water, and related environmental resources on non-federal lands. The NRI has a stratified multi-stage sampling design, where primary sample units are stratified on the basis of county and township boundaries defined by the United States Public Land Survey (Nusser and Goebel 1997). Within a primary sample unit (typically a 160 acre [64.75 ha] square quarter-section), three sample points are selected according to a restricted randomization procedure. Each point in the survey is assigned an area weight (expansion factor) based on other known areas and land-use information (Nusser and Goebel 1997). The NRI survey utilizes data derived from remote sensing imagery and site visits in order to provide detailed information on land use and management, particularly for Croplands and Grasslands (i.e., agricultural lands), and is used as the basis to account for C stock changes in agricultural lands (except federal Grasslands). The NRI survey was conducted every 5 years between 1982 and 1997, but shifted to annualized data collection in 1998. The land use between five-year periods from 1982 and 1997 are assumed to be the same for a five-year time period if the land use is the same at the beginning and end of the five-year period (Note: most of the data has the same land use at the beginning and end of the five-year periods). If the land use had changed during a five-year period, then the change is assigned at random to one of the five years. For crop histories, years with missing data are estimated based on the sequence of crops grown during years preceding and succeeding a missing year in the NRI history. This gap-filling approach allows for development of a full time series of land-use data for non-federal lands in the conterminous United States and Hawaii. This Inventory incorporates data through 2012 from the NRI. The land use patterns are assumed to remain the same from 2012 through 2017 for this Inventory, but the time series will be updated when new data are released.

Forest Inventory and Analysis

The FIA program, conducted by the USFS, is another statistically-based survey for the conterminous United States in addition to the southeast and south central coastal Alaska, and the official source of data on Forest Land area and management data for the Inventory. FIA engages in a hierarchical system of sampling, with sampling categorized as Phases 1 through 3, in which sample points for phases are subsets of the previous phase. Phase 1 refers to collection of remotely-sensed data (either aerial photographs or satellite imagery) primarily to classify land into forest or non-forest and to identify landscape patterns like fragmentation and urbanization. Phase 2 is the collection of field data on a network of ground plots that enable classification and summarization of area, tree, and other attributes associated with forest-land uses. Phase 3 plots are a subset of Phase 2 plots where data on indicators of forest health are measured. Data from all three phases are also used to estimate C stock changes for Forest Land. Historically, FIA inventory surveys have been conducted periodically, with all plots in a state being measured at a frequency of every five to 14 years. A new national plot design and annual sampling design was introduced by the FIA program in 1998 and is now used in all states. Annualized sampling means that a portion of plots throughout each state is sampled each year, with the goal of measuring all plots once every five to seven years in the eastern United States and once every ten years in the western United States. See Annex 3.13 to see the specific survey data available by state. The most recent year of available data varies state by state (range of most recent data is from 2012 through 2017; see Table A-219).

National Land Cover Dataset

While the NRI survey sample covers the conterminous United States and Hawaii, land use data are only collected on non-federal lands. In addition, FIA only records data for forest land across the land base in the conterminous United States and a portion of Alaska.[21] Consequently, gaps exist in the land representation when the datasets are combined, such as federal grassland operated by Bureau of Land Management (BLM), USDA, and National Park Service, as well as Alaska.[22] The NLCD is used to account for land use on federal lands in the conterminous United States and Hawaii, in addition to federal and non-federal lands in Alaska.

NLCD products provide land-cover for 1992, 2001, 2006, and 2011 in the conterminous United States (Homer et al. 2007), and also for Alaska in 2001 and 2011 and Hawaii in 2001. For the conterminous United States, the NLCD data have been further processed to derive Land Cover Change Products for 2001, 2006, and 2011 (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). A Land Cover Change Product is also available for Alaska from 2001 to 2011. A NLCD change product is not available for Hawaii because data are only available for one year, i.e., 2001. The NLCD products are based primarily on Landsat Thematic Mapper imagery at a 30-meter resolution, and contain 21 categories of land-cover information, which have been aggregated into the 36 IPCC land-use categories for the conterminous United States and Alaska, and into the six IPCC land-use categories for Hawaii. The land use patterns are assumed to remain the same after the last year of data in the time series, which is 2001 for Hawaii and 2011 for the conterminous United States and Alaska, but the time series will be updated when new data are released.

The aggregated maps of IPCC land-use categories derived from the NLCD products were used in combination with the NRI database to represent land use and land-use change for federal lands, as well as federal and non-federal lands in Alaska. Specifically, NRI survey locations designated as federal lands were assigned a land use/land use change category based on the NLCD maps that had been aggregated into the IPCC categories. This analysis addressed shifts in land ownership across years between federal or non-federal classes as represented in the NRI survey (i.e., the ownership is classified for each survey location in the NRI). The sources of these additional data are discussed in subsequent sections of the report.

Managed Land Designation

Lands are designated as managed in the United States based on the definition provided earlier in this section. In order to apply the definition in an analysis of managed land, the following criteria are used:

- All Croplands and Settlements are designated as managed so only Grassland, Forest Land or Other Lands may be designated as unmanaged land;[23]

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[21] FIA does collect some data on non-forest land use, but these are held in regional databases versus the national database. The status of these data is being investigated.

[22] The NRI survey program does not include U.S. Territories with the exception of non-federal lands in Puerto Rico. The FIA program recently began implementing surveys of forest land in U.S. Territories and those data will be used in the years ahead. Furthermore, NLCD does not include coverage for all U.S. Territories.

[23] All wetlands are considered managed in this Inventory. Distinguishing between managed and unmanaged wetlands in the United States is difficult due to limited data availability. Wetlands are not characterized within the NRI with information regarding water table management. Regardless, a planned improvement is underway to subdivide managed and unmanaged Wetlands.

- All Forest Lands with active fire protection are considered managed;
- All Grassland is considered managed at a county scale if there are grazing livestock in the county;
- Other areas are considered managed if accessible based on the proximity to roads and other transportation corridors, and/or infrastructure;
- Protected lands maintained for recreational and conservation purposes are considered managed (i.e., managed by public and private organizations);
- Lands with active and/or past resource extraction are considered managed; and
- Lands that were previously managed but subsequently classified as unmanaged, remain in the managed land base for 20 years following the conversion to account for legacy effects of management on C stocks.

The analysis of managed lands is conducted using a geographic information system (Ogle et al. 2018). Lands that are used for crop production or settlements are determined from the NLCD (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). Forest Lands with active fire management are determined from maps of federal and state management plans from the National Atlas (U.S. Department of Interior 2005) and Alaska Interagency Fire Management Council (1998). It is noteworthy that all forest lands in the conterminous United States have active fire protection, and are therefore designated as managed regardless of accessibility or other criteria. The designation of grasslands as managed is based on grazing livestock population data at the county scale from the USDA National Agricultural Statistics Service (U.S. Department of Agriculture 2015). Accessibility is evaluated based on a 10-km buffer surrounding road and train transportation networks using the ESRI Data and Maps product (ESRI 2008), and a 10-km buffer surrounding settlements using NLCD. Lands maintained for recreational purposes are determined from analysis of the Protected Areas Database (U.S. Geological Survey 2012). The Protected Areas Database includes lands protected from conversion of natural habitats to anthropogenic uses and describes the protection status of these lands. Lands are considered managed that are protected from development if the regulations allow for extractive or recreational uses or suppression of natural disturbance. Lands that are protected from development and not accessible to human intervention, including no suppression of disturbances or extraction of resources, are not included in the managed land base. Multiple data sources are used to determine lands with active resource extraction: Alaska Oil and Gas Information System (Alaska Oil and Gas Conservation Commission 2009), Alaska Resource Data File (U.S. Geological Survey 2012), Active Mines and Mineral Processing Plants (U.S. Geological Survey 2005), and *Coal Production and Preparation Report* (U.S. Energy Information Administration 2011). A buffer of 3,300 and 4,000 meters is established around petroleum extraction and mine locations, respectively, to account for the footprint of operation and impacts of activities on the surrounding landscape. The buffer size is based on visual analysis of approximately 130 petroleum extraction sites and 223 mines. The resulting managed land area is overlaid on the NLCD to estimate the area of managed land by land use for both federal and non-federal lands. The remaining land represents the unmanaged land base. The resulting spatial product is used to identify NRI survey locations that are considered managed and unmanaged for the conterminous United States and Hawaii,[24] in addition to determining which areas in the NLCD for Alaska are included in the managed land base.

Approach for Combining Data Sources

The managed land base in the United States has been classified into the 36 IPCC land-use/land-use conversion categories using definitions developed to meet national circumstances, while adhering to IPCC (2006).[25] In practice, the land was initially classified into a variety of land-use subcategories within the NRI, FIA, and NLCD datasets, and then aggregated into the 36 broad land use and land-use change categories identified in IPCC (2006). All three datasets provide information on forest land areas in the conterminous United States, but the area data from FIA serve as the official dataset for Forest Land.

Therefore, another step in the analysis is to address the inconsistencies in the representation of the Forest Land among the three databases. NRI and FIA have different criteria for classifying Forest Land in addition to different sampling designs, leading to discrepancies in the resulting estimates of Forest Land area on non-federal land in the conterminous United States. Similarly, there are discrepancies between the NLCD and FIA data for defining and classifying Forest Land on federal lands. Any change in Forest Land Area in the NRI and NLCD also requires a corresponding change in other land use areas because of the dependence between the Forest Land area and the

[24] The exception is cropland and settlement areas in the NRI, which are classified as managed, regardless of the managed land base derived from the spatial analysis described in this section.

[25] Definitions are provided in the previous section.

amount of land designated as other land uses, such as the amount of Grassland, Cropland, and Wetlands (i.e., areas for the individual land uses must sum to the total managed land area of the country).

FIA is the main database for forest statistics, and consequently, the NRI and NLCD are adjusted to achieve consistency with FIA estimates of Forest Land in the conterminous United States. Adjustments are made in the *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, and Forest Land converted to other uses (i.e., Grassland, Cropland, Settlements, Other Lands, and Wetlands). All adjustments are made at the state scale to address the differences in Forest Land definitions and the resulting discrepancies in areas among the land use and land-use change categories. There are three steps in this process. The first step involves adjustments for *Land Converted to Forest Land* (Grassland, Cropland, Settlements, Other Lands, and Wetlands), followed by adjustments in Forest Land converted to another land use (i.e., Grassland, Cropland, Settlements, Other Lands, and Wetlands), and finally adjustments to *Forest Land Remaining Forest Land*.

In the first step, *Land Converted to Forest Land* in the NRI and NLCD are adjusted to match the state-level estimates in the FIA data for non-federal and federal *Land Converted to Forest Land*, respectively. FIA data do not provide specific land-use categories that are converted to Forest Land, but rather a sum of all *Land Converted to Forest Land*. The NRI and NLCD provide information on specific land use conversions, such as *Grassland Converted to Forest Land*. Therefore, adjustments at the state level to NRI and NLCD are made proportional to the amount of specific land use conversions into Forest Land for the state, prior to any adjustments. For example, if 50 percent of land use change to Forest Land is associated with *Grassland Converted to Forest Land* in a state according to NRI or NLCD, then half of the discrepancy with FIA data in the area of *Land Converted to Forest Land* is addressed by increasing or decreasing the area in *Grassland Converted to Forest Land*. Moreover, any increase or decrease in *Grassland Converted to Forest Land* in NRI or NLCD is addressed by a corresponding change in the area of *Grassland Remaining Grassland*, so that the total amount of managed area is not changed within an individual state.

In the second step, state-level areas are adjusted in the NRI and NLCD to address discrepancies with FIA data for Forest Land converted to other uses. Similar to *Land Converted to Forest Land*, FIA does not provide information on the specific land-use changes, and so areas associated with Forest Land conversion to other land uses in NRI and NLCD are adjusted proportional to the amount of area in each conversion class in these datasets.

In the final step, the area of *Forest Land Remaining Forest Land* in a given state according to the NRI and NLCD is adjusted to match the FIA estimates for non-federal and federal land, respectively. It is assumed that the majority of the discrepancy in *Forest Land Remaining Forest Land* is associated with an under- or over-prediction of *Grassland Remaining Grassland* and *Wetland Remaining Wetland* in the NRI and NLCD. This step also assumes that there are no changes in the land use conversion categories. Therefore, corresponding increases or decreases are made in the area estimates of *Grasslands Remaining Grasslands* and *Wetlands Remaining Wetlands* from the NRI and NLCD. This adjustment balances the change in *Forest Land Remaining Forest Land* area, which ensures no change in the overall amount of managed land within an individual state. The adjustments are based on the proportion of land within each of these land-use categories at the state level according to NRI and NLCD (i.e., a higher proportion of Grassland led to a larger adjustment in Grassland area).

The modified NRI data are then aggregated to provide the land-use and land-use change data for non-federal lands in the conterminous United States, and the modified NLCD data are aggregated to provide the land use and land-use change data for federal lands. Data for all land uses in Hawaii are based on NRI for non-federal lands and on NLCD for federal lands. Land use data in Alaska are based on the NLCD data after adjusting this dataset to be consistent with forest land areas in the FIA (Table 6-8). The result is land use and land-use change data for the conterminous United States, Hawaii, and Alaska.

A summary of the details on the approach used to combine data sources for each land use are described below.

- *Forest Land*: Land representation for both non-federal and federal forest lands in the conterminous United States and coastal Alaska are based on the FIA. FIA is used as the basis for both Forest Land area data as well as to estimate C stocks and fluxes on Forest Land in the conterminous United States and Alaska. FIA does have survey plots in Alaska that are used to determine the C stock changes, and the associated area data for this region are harmonized with the NLCD using the methods described above. However, there is insufficient data at this time to address land use change so forest land in this region is based on the 2001 and 2011 NLCD rather than the FIA. NRI is used in the current report to provide Forest Land areas on non-federal lands in Hawaii, and NLCD is used for federal lands. FIA data is being collected in Hawaii and U.S. Territories, however there is insufficient data to make population estimates for this Inventory.

- *Cropland*: Cropland is classified using the NRI, which covers all non-federal lands within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Cropland area data as well as to estimate soil C stocks and fluxes on Cropland. NLCD is used to determine Cropland area and soil C stock changes on federal lands in the conterminous United States and Hawaii. NLCD is also used to determine croplands in Alaska, but C stock changes are not estimated for this region in the current Inventory.
- *Grassland*: Grassland on non-federal lands is classified using the NRI within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Grassland area data as well as to estimate soil C stocks and fluxes on Grassland. Grassland area and soil C stock changes are determined using the classification provided in the NLCD for federal land within the conterminous United States. NLCD is also used to estimate the areas of federal and non-federal grasslands in Alaska, and the federal lands in Hawaii, but the current Inventory does not include C stock changes in these areas.
- *Wetlands*: NRI captures wetlands on non-federal lands within 49 states (excluding Alaska), while the land representation data for federal wetlands and wetlands in Alaska are based on the NLCD.[26]
- *Settlements*: NRI captures non-federal settlement area in 49 states (excluding Alaska). If areas of Forest Land or Grassland under 10 acres (4.05 ha) are contained within settlements or urban areas, they are classified as Settlements (urban) in the NRI database. If these parcels exceed the 10 acre (4.05 ha) threshold and are Grassland, they will be classified as such by NRI. Regardless of size, a forested area is classified as non-forest by FIA if it is located within an urban area. Land representation for settlements on federal lands and Alaska is based on the NLCD.
- *Other Land*: Any land that is not classified into one of the previous five land-use categories, is categorized as Other Land using the NRI for non-federal areas in the conterminous United States and Hawaii and using the NLCD for the federal lands in all regions of the United States and for non-federal lands in Alaska.

Some lands can be classified into one or more categories due to multiple uses that meet the criteria of more than one definition. However, a ranking has been developed for assignment priority in these cases. The ranking process is from highest to lowest priority based on the following order:

Settlements > *Cropland* > *Forest Land* > *Grassland* > *Wetlands* > *Other Land*

Settlements are given the highest assignment priority because they are extremely heterogeneous with a mosaic of patches that include buildings, infrastructure, and travel corridors, but also open grass areas, forest patches, riparian areas, and gardens. The latter examples could be classified as Grassland, Forest Land, Wetlands, and Cropland, respectively, but when located in close proximity to settlement areas, they tend to be managed in a unique manner compared to non-settlement areas. Consequently, these areas are assigned to the Settlements land-use category. Cropland is given the second assignment priority, because cropping practices tend to dominate management activities on areas used to produce food, forage, or fiber. The consequence of this ranking is that crops in rotation with pasture are classified as Cropland, and land with woody plant cover that is used to produce crops (e.g., orchards) is classified as Cropland, even though these areas may meet the definitions of Grassland or Forest Land, respectively. Similarly, Wetlands are considered Croplands if they are used for crop production, such as rice or cranberries. Forest Land occurs next in the priority assignment because traditional forestry practices tend to be the focus of the management activity in areas with woody plant cover that are not croplands (e.g., orchards) or settlements (e.g., housing subdivisions with significant tree cover). Grassland occurs next in the ranking, while Wetlands and then Other Land complete the list.

The assignment priority does not reflect the level of importance for reporting greenhouse gas emissions and removals on managed land, but is intended to classify all areas into a discrete land use category. Currently, the IPCC does not make provisions in the guidelines for assigning land to multiple uses. For example, a wetland is classified

[26] This analysis does not distinguish between managed and unmanaged wetlands, which is a planned improvement for the Inventory.

as Forest Land if the area has sufficient tree cover to meet the stocking and stand size requirements. Similarly, wetlands are classified as Cropland if they are used for crop production, such as rice, or as Grassland if they are composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing. Regardless of the classification, emissions from these areas are included in the Inventory if the land is considered managed, and therefore impacted by anthropogenic activity in accordance with the guidance provided by the IPCC (2006).

QA/QC and Verification

The land base derived from the NRI, FIA, and NLCD was compared to the Topologically Integrated Geographic Encoding and Referencing (TIGER) survey (U.S. Census Bureau 2010). The United States Census Bureau gathers data on the population and economy, and has a database of land areas for the country. The area estimates of land-use categories, based on NRI, FIA, and NLCD, are derived from remote sensing data instead of the land survey approach used by the United States Census Survey. The Census does not provide a time series of land-use change data or land management information, which is needed for reporting greenhouse gas emissions from land use and land use change. Regardless, the Census does provide sufficient information to provide a check on the Inventory data. The Census has about 46 million more hectares of land in the United States land base compared to the total area estimate of 936 million hectares derived from the combined NRI, FIA, and NLCD data. Much of this difference is associated with open waters in coastal regions and the Great Lakes, which is included in the TIGER Survey of the Census, but not included in the land representation using the NRI, FIA and NLCD. There is only a 0.4 percent difference when open water in coastal regions is removed from the TIGER data.

Recalculations Discussion

The land representation data in the current Inventory were recalculated from the previous Inventory by using updated FIA data for 1990 to 2017. These data were used as the basis for the forest areas and harmonized with the other databases as described in the section, “Approach for Combining Data Sources”. This process also leads to changes in the areas of other land uses to ensure the total land base area remains the same. Forest land declined by an average of 4 percent across the time series from 1990 to 2016 based on the new FIA data. Based on the harmonization, Grassland, Other Land and Settlements increased by an average of 3.6 percent, 0.1 percent, and 0.1 percent, respectively. Wetlands decreased by an average of 0.1 percent and Croplands did not change. New data for Alaska were not used this year and will be applied during the next Inventory period along with new NRI and NLCD data.

Planned Improvements

The next (i.e., 1990 through 2018) Inventory will be substantially improved by using new data sets to update the time series for land representation with the latest NRI and NLCD data sets and ensure consistency between the total area of managed land in the land-representation description and the remainder of the Inventory. Coastal wetland areas will also be harmonized with a NOAA data set on coastal wetland land use and land use transitions, as described in more detail below.

Another key planned improvement for the Inventory is to fully incorporate area data by land-use type for U.S. Territories. Fortunately, most of the managed land in the United States is included in the current land-use data, but a complete reporting of all lands in the United States is a key goal for the near future. Preliminary land-use area data for U.S. Territories by land-use category are provided in Box 6-2.

Box 6-2: Preliminary Estimates of Land Use in U.S. Territories

Several programs have developed land cover maps for U.S. Territories using remote sensing imagery, including the Gap Analysis Program, Caribbean Land Cover project, National Land Cover Dataset, USFS Pacific Islands Imagery Project, and the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP). Land-cover data can be used to inform a land-use classification if there is a time series to evaluate the dominate practices. For example, land that is principally used for timber production with tree cover over most of the time series is classified as forest land even if there are a few years of grass dominance following timber harvest. These products were reviewed and evaluated for use in the national Inventory as a step towards implementing a planned improvement to include U.S. Territories in the land representation for the Inventory. Recommendations are to use the NOAA C-CAP Regional Land Cover Database for the smaller island Territories (U.S. Virgin Islands, Guam, Northern Marianas Islands, and American Samoa) because this program is ongoing and therefore will be continually updated. The C-CAP product does not cover the entire territory of Puerto Rico so the NLCD was used for this area. The final selection of a land-cover product for these territories is still under discussion. Results are presented below (in hectares). The total land area of all U.S. Territories is 1.05 million hectares, representing 0.1 percent of the total land base for the United States.

Table 6-9: Total Land Area (Hectares) by Land-Use Category for U.S. Territories

	Puerto Rico	U.S. Virgin Islands	Guam	Northern Marianas Islands	American Samoa	Total
Cropland	19,712	138	236	289	389	20,764
Forest Land	404,004	13,107	24,650	25,761	15,440	482,962
Grasslands	299,714	12,148	15,449	13,636	1,830	342,777
Other Land	5,502	1,006	1,141	5,186	298	13,133
Settlements	130,330	7,650	11,146	3,637	1,734	154,496
Wetlands	24,525	4,748	1,633	260	87	31,252
Total	**883,788**	**38,796**	**54,255**	**48,769**	**19,777**	**1,045,385**

Methods in the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014) have been applied to estimate emissions and removals from coastal wetlands. Specifically, greenhouse gas emissions from coastal wetlands have been developed for the Inventory using the NOAA C-CAP land cover product. The NOAA C-CAP product is not used directly in the land representation analysis, however, so a planned improvement for the next (i.e., 1990 through 2018) Inventory is to reconcile the coastal wetlands data from the C-CAP product with the wetlands area data provided in the NRI. In addition, the current Inventory does not include a classification of managed and unmanaged wetlands. However, implementation of the new guidance will require classification of managed and unmanaged wetlands in the Inventory, and more detailed wetlands datasets will be evaluated and integrated into the analysis to meet this objective.

NOAA C-CAP data for Hawaii were recently released for 2011, and will be used to analyze land use change for this state in the near future. There are also other databases that may need to be integrated into the analysis, particularly for Settlements.

6.2 Forest Land Remaining Forest Land (CRF Category 4A1)

Changes in Forest Carbon Stocks (CRF Category 4A1)

Delineation of Carbon Pools

For estimating carbon (C) stocks or stock change (flux), C in forest ecosystems can be divided into the following five storage pools (IPCC 2006):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 millimeters (mm) diameter.

- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 centimeters (cm) at transect intersection, lying on the ground.
- Soil organic C (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the belowground pools.

In addition, there are two harvested wood pools included when estimating C flux:

- Harvested wood products (HWP) in use.
- HWP in solid waste disposal sites (SWDS).

Forest Carbon Cycle

Carbon is continuously cycled among the previously defined C storage pools and the atmosphere as a result of biogeochemical processes in forests (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere and is also transferred to the litter, dead wood and soil pools by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass C to the atmosphere. Instead, harvesting transfers a portion of the C stored in wood to a "product pool." Once in a product pool, the C is emitted over time as CO_2 in the case of decomposition and as CO_2, CH_4, N_2O, CO, and NO_x when the wood product combusts. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately, and these emissions are reported for information purposes in the Energy sector while the harvest (i.e., the associated reduction in forest C stocks) and subsequent combustion are implicitly estimated in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (i.e., the harvested timber does not enter the HWP pools). Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS. These latter fluxes, with the exception of CH_4 from wood in SWDS, which is included in the Waste sector, are also estimated in the LULUCF sector.

Net Change in Carbon Stocks within Forest Land of the United States

This section describes the general method for quantifying the net changes in C stocks in the five C storage pools and two harvested wood pools (a more detailed description of the methods and data is provided in Annex 3.13). The underlying methodology for determining C stock and stock change relies on data from the national forest inventory (NFI) conducted by the Forest Inventory and Analysis (FIA) program within the USDA Forest Service. The annual NFI is implemented across all U.S. forest lands within the conterminous 48 states and Alaska and inventories have been initiated in Hawaii and some of the U.S. Territories. The methods for estimation and monitoring are continuously improved and these improvements are reflected in the C estimates (Domke et al. 2016; Domke et al. 2017). First, the total C stocks are estimated for each C storage pool, next the net changes in C stocks for each pool are estimated, and then the changes in stocks are summed for all pools to estimate total net flux. The focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Changes in C stocks from disturbances, such natural disturbances (e.g., wildfires, insects/disease, wind) or harvesting, are included in the net changes. For instance, an inventory conducted after fire implicitly includes only the C stocks remaining on the NFI plot. However, changes in C stocks from natural disturbances are highly variable from year to year. The IPCC (2006) recommends estimating changes in C stocks from forest lands according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, with the former being lands that have been forest lands for 20 years or longer and the latter being lands that have been classified as forest lands for less than 20 years. The methods and data used to delineate forest C stock changes by these two categories continue to improve and in order to facilitate this delineation, a combination of modeling approaches for carbon estimation were used in this Inventory.

Forest Area in the United States

Approximately 33 percent of the U.S. land area is estimated to be forested based on the U.S. definition of forest land as provided in the Section 6.1 Representation of the U.S. Land Base. All annual NFI plots included in the public FIA database as of May 2018 (which includes data through 2017) were used in this Inventory. Since area estimates for some land use categories were not updated in the Land Representation in the current Inventory there are differences in the area estimates reported in this section and those reported in Section 6.1 Representation of the U.S. Land Base. The NFIs from each of the conterminous 48 states (CONUS; USDA Forest Service 2018a, 2018b) and Alaska comprise an estimated 272 million hectares of forest land that are considered managed and are included in the current Inventory. Some differences also exist in forest land area estimates from the latest update to the Resources Planning Act (RPA) Assessment (Oswalt et al. 2014) and the forest land area estimates included in this report, which are based on the annual NFI data through 2017 for all states (USDA Forest Service 2018b). Sufficient annual inventory data are not yet available for Hawaii but estimates of these areas are included in Oswalt et al. (2014). While Hawaii and U.S. Territories have relatively small areas of forest land and thus may not substantially influence the overall C budget for forest land, these regions will be added to the forest C estimates as sufficient data become available. Agroforestry systems that meet the definition of forest land are also not currently included in the current Inventory since they are not explicitly inventoried (i.e., classified as an agroforestry system) by either the FIA program or the Natural Resources Inventory (NRI)[27] of the USDA Natural Resources Conservation Service (Perry et al. 2005).

An estimated 77 percent (211 million hectares) of U.S. forests in southeast and southcentral coastal Alaska and the conterminous United States are classified as timberland, meaning they meet minimum levels of productivity and have not been removed from production. Approximately ten percent of southeast and southcentral coastal Alaska forest land and 80 percent of forest land in the conterminous United States are classified as timberland. Of the remaining non-timberland, 30 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 69 million hectares are lower productivity forest lands (Oswalt et al. 2014). Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than the forest land removed from production because it does not meet the minimum level of productivity.

Since the late 1980s, gross forest land area in southeast and southcentral coastal Alaska and the conterminous United States has increased by about 14 million hectares (Oswalt et al. 2014) with the southern region of the United States containing the most forest land (Figure 6-3). A substantial portion of this accrued forest land is from the conversion of abandoned croplands to forest (e.g., Woodall et al. 2015b). Current trends in the estimated forest land area in the CONUS and Alaska represented here show an average annual rate of increase of 0.02 percent. In addition to the increase in forest area, the major influences to the net C flux from forest land across the 1990 to 2017 time series are management activities, natural disturbance, and the ongoing impacts of previous land-use conversions. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems and also the area converted to forest land. For example, intensified management of forests that leads to an increased rate of growth of aboveground biomass (and possible changes to the other C storage pools) may increase the eventual biomass density of the forest, thereby increasing the uptake and storage of C in the aboveground biomass pool.[28] Though harvesting forests removes much of the C in aboveground biomass (and possibly changes C density in other pools), on average, the estimated volume of annual net growth in the conterminous United States is about double the volume of annual removals on timberlands (Oswalt et al. 2014). The net effects of forest management and changes in *Forest Land Remaining Forest Land* are captured in the estimates of C stocks and fluxes presented in this section.

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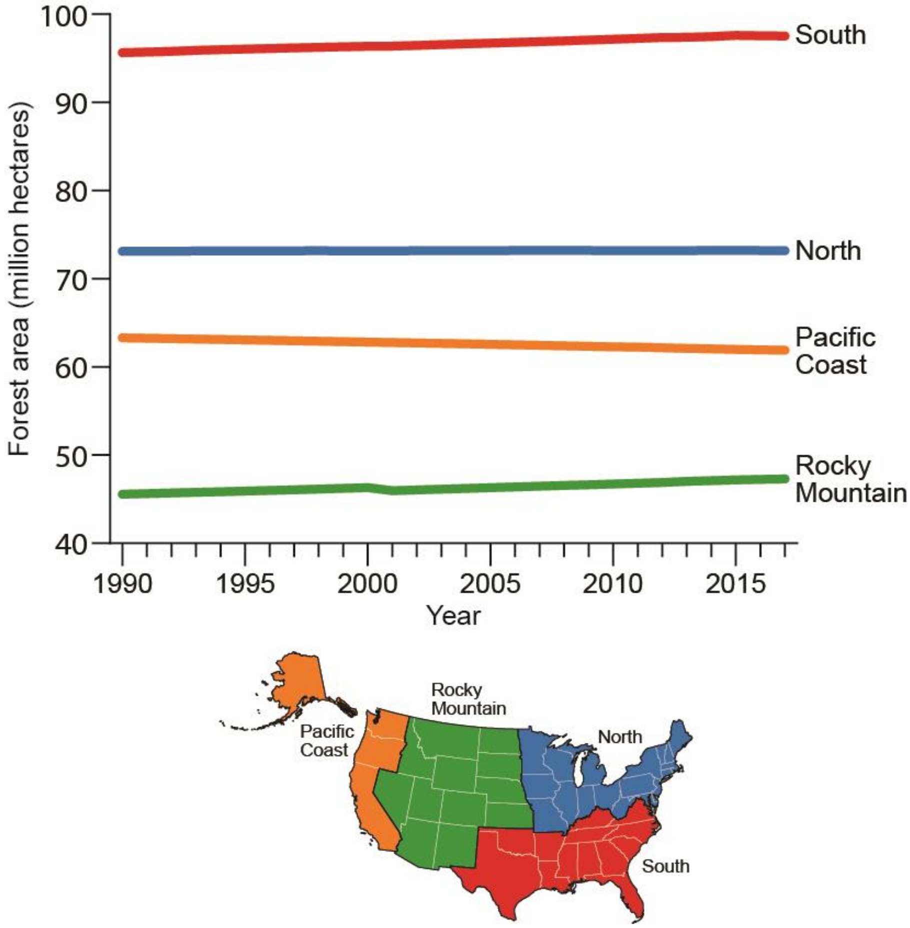
[27] The Natural Resources Inventory of the USDA Natural Resources Conservation Service is described in Section 6.1 Representation of the U.S. Land Base.

[28] The term "biomass density" refers to the mass of live vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is assumed to be 50 percent C by weight.

Figure 6-3: Changes in Forest Area by Region for *Forest Land Remaining Forest Land* in the conterminous United States and Alaska (1990-2017, Million Hectares)



Forest Carbon Stocks and Stock Change

In the United States, forest management practices, the regeneration of forest areas cleared more than 20 years prior to the reporting year, and timber harvesting have resulted in net uptake (i.e., net sequestration or accumulation) of C each year from 1990 through 2017. The rate of forest clearing in the 17th century following European settlement had slowed by the late 19th century. Through the later part of the 20th century many areas of previously forested land in the United States were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still influence C fluxes from these forest lands. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests and natural disturbance have also affected net C fluxes. Because most of the timber harvested from U.S. forest land is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to these long-term storage pools rather than being released rapidly to the atmosphere (Skog 2008). Maintaining current harvesting practices and regeneration activities on these forested lands, along with continued input of harvested products into the HWP pool, C stocks in the *Forest Land Remaining Forest Land* category are likely to continue to increase in the near term, though possibly at a lower rate. Changes in C stocks in the forest ecosystem and harvested wood pools associated with *Forest Land Remaining Forest Land* were estimated to result in net uptake of 621.1 MMT CO_2 Eq. (169.4 MMT C) in 2017 (Table 6-10 and Table 6-11). The estimated net uptake of C in the Forest Ecosystem was 517.8 MMT CO_2 Eq. (141.2 MMT C) in 2017 (Table 6-10 and Table 6-11). The majority of this uptake, 357.1 MMT CO_2 Eq. (97.4 MMT C), was from aboveground biomass in 2017. Overall, estimates of average

C density in forest ecosystems (including all pools) remained stable at approximately 205 MT C ha^{-1} from 1990 to 2017. This was calculated by dividing the Forest Land area estimates by Forest Ecosystem C Stock estimates for every year (see Table 6-12) and then calculating the mean across the entire time series, i.e., 1990 through 2017. The stable forest ecosystem C density when combined with increasing forest area results in net C accumulation over time. These increases may be influenced in some regions by reductions in C density or forest land area due to natural disturbances (e.g., wildfire, weather, insects/disease), particularly in Alaska. Aboveground live biomass is responsible for the majority of net C uptake among all forest ecosystem pools (Figure 6-4).

The estimated net uptake of C in HWP was 103.3 MMT CO_2 Eq. (28.2 MMT C) in 2017 (Table 6-10 and Table 6-11). The majority of this uptake, 67.6 MMT CO_2 Eq. (18.4 MMT C), was from wood and paper in SWDS. Products in use were an estimated 35.7 MMT CO_2 Eq. (9.7 MMT C) in 2017.

Table 6-10: Net CO_2 Flux from Forest Ecosystem Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT CO_2 Eq.)

Carbon Pool	1990	2005	2013	2014	2015	2016	2017
Forest Ecosystem	**(547.8)**	**(531.4)**	**(541.1)**	**(492.4)**	**(549.4)**	**(529.3)**	**(517.8)**
Aboveground Biomass	(378.7)	(361.2)	(379.5)	(361.8)	(377.5)	(371.3)	(357.1)
Belowground Biomass	(90.7)	(86.1)	(89.2)	(84.4)	(88.6)	(87.1)	(83.9)
Dead Wood	(76.0)	(78.9)	(79.4)	(74.5)	(82.6)	(81.9)	(77.4)
Litter	(4.2)	(5.1)	(0.9)	30.0	(3.3)	(1.2)	(3.8)
Soil (Mineral)	1.2	(0.6)	6.8	(1.6)	0.5	9.2	2.3
Soil (Organic)	(0.1)	(0.1)	0.3	(1.0)	1.3	2.2	1.3
Drained Organic Soil[a]	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Harvested Wood	**(123.8)**	**(108.0)**	**(75.6)**	**(76.4)**	**(95.9)**	**(99.6)**	**(103.3)**
Products in Use	(54.8)	(44.6)	(13.0)	(13.7)	(31.4)	(33.5)	(35.7)
SWDS	(69.0)	(63.5)	(62.6)	(62.7)	(64.4)	(66.1)	(67.6)
Total Net Flux	**(671.6)**	**(639.4)**	**(616.7)**	**(568.8)**	**(645.2)**	**(628.9)**	**(621.1)**

[a] These estimates include C stock changes from drained organic soils from both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. See the section below on CO_2, CH_4, and N_2O Emissions from Drained Organic Soils for the methodology used to estimate the CO_2 emissions from drained organic soils. Also, see Table 6-22 and Table 6-23 for non-CO_2 emissions from drainage of organic soils from both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Notes: Forest ecosystem C stocks do not include forest stocks in U.S. Territories, Hawaii, or trees on non-forest land (e.g., agroforestry systems and settlement areas—see Section 6.10 *Settlements Remaining Settlements* for estimates of C stock change from settlement trees). Forest ecosystem C stocks on managed forest land in Alaska were compiled using the gain-loss method as described in Annex 3.13. Parentheses indicate net C uptake (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 6-11: Net C Flux from Forest Ecosystem Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

Carbon Pool	1990	2005	2013	2014	2015	2016	2017
Forest Ecosystem	**(149.4)**	**(144.9)**	**(147.6)**	**(134.3)**	**(149.8)**	**(144.4)**	**(141.2)**
Aboveground Biomass	(103.3)	(98.5)	(103.5)	(98.7)	(102.9)	(101.3)	(97.4)
Belowground Biomass	(24.7)	(23.5)	(24.3)	(23.0)	(24.2)	(23.8)	(22.9)
Dead Wood	(20.7)	(21.5)	(21.7)	(20.3)	(22.5)	(22.3)	(21.1)
Litter	(1.1)	(1.4)	(0.2)	8.2	(0.9)	(0.3)	(1.0)
Soil (Mineral)	0.3	(0.2)	1.9	(0.4)	0.1	2.5	0.6
Soil (Organic)	+	(+)	0.1	(0.3)	0.4	0.6	0.4
Drained Organic Soil[a]	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Harvested Wood	**(33.8)**	**(29.5)**	**(20.6)**	**(20.8)**	**(26.1)**	**(27.2)**	**(28.2)**
Products in Use	(14.9)	(12.2)	(3.5)	(3.7)	(8.6)	(9.1)	(9.7)

SWDS	(18.8)		(17.3)		(17.1)	(17.1)	(17.6)	(18.0)	(18.4)
Total Net Flux	**(183.2)**		**(174.4)**		**(168.2)**	**(155.1)**	**(176.0)**	**(171.5)**	**(169.4)**

+ Absolute value does not exceed 0.05 MMT C

[a] These estimates include carbon stock changes from drained organic soils from both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. See the section below on CO_2, CH_4, and N_2O Emissions from Drained Organic Soils for the methodology used to estimate the C flux from drained organic soils. Also, see Table 6-22 and Table 6-23 for greenhouse gas emissions from non-CO_2 gases changes from drainage of organic soils from *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Notes: Forest C stocks do not include forest stocks in U.S. Territories, Hawaii, or trees on non-forest land (e.g., agroforestry systems and settlement areas—see Section 6.10 *Settlements Remaining Settlements* for estimates of C stock change from settlement trees). Forest ecosystem C stocks on managed forest land in Alaska were compiled using the gain-loss method as described in Annex 3.13. Parentheses indicate net C uptake (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

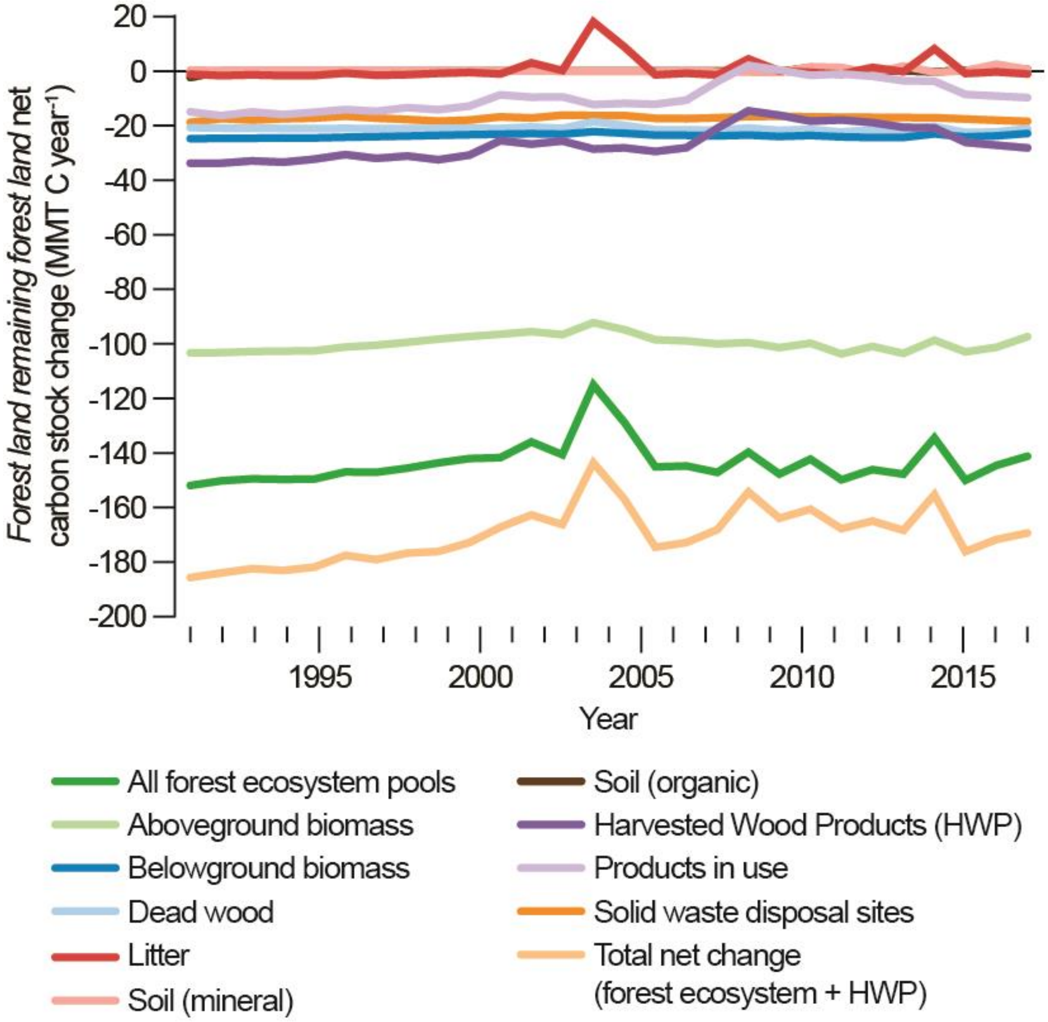
Stock estimates for forest ecosystem and harvested wood C storage pools are presented in Table 6-12. Together, the estimated aboveground biomass and soil C pools account for a large proportion of total forest ecosystem C stocks. Forest land area estimates are also provided in Table 6-12, but these do not precisely match those in Section 6.1 Representation of the U.S. Land Base for *Forest Land Remaining Forest Land*. This is because the forest land area estimates in Table 6-12 only include managed forest land in the conterminous 48 states and Alaska while the area estimates in Section 6.1 include all managed forest land in Hawaii. Differences also exist because forest land area estimates are based on the latest NFI data through 2017 and woodland areas previously included as forest land have been separated and included in the Grassland categories in this Inventory.

Table 6-12: Forest Area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	1990		2005		2013	2014	2015	2016	2017	2018
Forest Area (1,000 ha)	***269,959***		***271,883***		***273,035***	***273,170***	***273,346***	***273,494***	***273,623***	***273,791***
Carbon Pools (MMT C)										
Forest Ecosystem	**53,670**		**55,806**		**56,969**	**57,117**	**57,251**	**57,401**	**57,546**	**57,687**
Aboveground Biomass	11,870		13,357		14,160	14,263	14,362	14,465	14,566	14,664
Belowground Biomass	2,378		2,734		2,924	2,949	2,972	2,996	3,020	3,042
Dead Wood	2,153		2,463		2,636	2,658	2,678	2,700	2,723	2,744
Litter	3,663		3,646		3,645	3,645	3,637	3,638	3,638	3,639
Soil (Mineral)	27,824		27,822		27,821	27,819	27,820	27,820	27,817	27,816
Soil (Organic)	5,783		5,784		5,783	5,782	5,783	5,782	5,782	5,781
Harvested Wood	**1,895**		**2,353**		**2,517**	**2,538**	**2,559**	**2,585**	**2,612**	**2,640**
Products in Use	1,249		1,447		1,476	1,479	1,483	1,492	1,501	1,510
SWDS	646		906		1,042	1,059	1,076	1,093	1,111	1,130
Total C Stock	**55,565**		**58,159**		**59,486**	**59,655**	**59,810**	**59,986**	**60,158**	**60,328**

Notes: Forest area and C stock estimates include all *Forest Land Remaining Forest Land* in the conterminous 48 states and Alaska (million ha). Forest C stocks do not include forest stocks in U.S. Territories, Hawaii, or trees on non-forest land (e.g., agroforestry systems and settlement areas—see Section 6.10 *Settlements Remaining Settlements* for estimates of C stock change from settlement trees). The forest area estimates in this table do not match those in Section 6.1 Representation of the U.S. Land Base, which includes all managed forest land in Hawaii. Differences also exist because forest land area estimates are based on the latest NFI data through 2017 and woodland area previously included as forest land has been separated and included in the Grassland categories in this Inventory. Forest ecosystem C stocks on managed forest land in Alaska were compiled using the gain-loss method as described in Annex 3.13. Harvested wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Population estimates compiled using FIA data are assumed to represent stocks as of January 1 of the Inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2017 requires estimates of C stocks for 2017 and 2018.

Figure 6-4: Estimated Net Annual Changes in C Stocks for All C Pools in *Forest Land Remaining Forest Land* in the Conterminous U.S. and Alaska (1990-2017, MMT C per Year)



Box 6-3: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly includes all C losses due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A forest fire disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forest land already includes CO_2 emissions from forest fires occurring in the conterminous states as well as the portion of managed forest lands in Alaska that are captured in the current Inventory. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these separate estimates are highlighted here. Note that these CO_2 estimates are based on the same methodology as applied for the non-CO_2 greenhouse gas emissions from forest fires that are also quantified in a separate section below as required by IPCC Guidance and UNFCCC Reporting Requirements.

The IPCC (2006) methodology with U.S.-specific data on annual area burned, potential fuel availability, and fire-specific severity and combustion were combined with IPCC default factors as needed to estimate CO_2 emissions from forest fires. It is important to note that a combination of U.S. specific data on area burned, potential fuel available for combustion, and estimates of combustion based on fire severity along with IPCC (2006) default combustion and emission factors were used in this Inventory. This is an improvement over previous Inventories where only the IPCC (2006) defaults have been used to estimate fire emissions and resulted in substantial changes to the estimates provided in this box in comparison to the previous Inventory. The latest information on area burned is used to compile fire emissions for the United States. At the time this Inventory was compiled, fire data for 2017 were not available so estimates from 2016 were used. The 2017 estimates will be updated in subsequent reports as fire data becomes available. Estimated CO_2 emissions for wildfires in the conterminous 48 states and in Alaska as well as prescribed fires in 2017 were estimated to be 64.8 MMT CO_2 per year (Table 6-13). This estimate is an embedded component of the net annual forest C stock change estimates provided previously (i.e., Table 6-11), but this separate approach to estimate emissions is necessary in order to associate a portion of emissions, including estimates of CH_4 and N_2O, with fire. See the discussion in Annex 3.13 for more details on this methodology. Note that the estimates for Alaska provided in Table 6-13 include only managed forest land within the state, which is consistent with C stock change estimates provided above.

Table 6-13: Estimates of CO_2 (MMT per Year) Emissions from Forest Fires in the Conterminous 48 States and Alaska[a]

Year	CO_2 emitted from Wildfires in the Conterminous 48 States (MMT yr^{-1})	CO_2 emitted from Wildfires in Alaska (MMTyr^{-1})	CO_2 emitted from Prescribed Fires (MMTyr^{-1})	Total CO_2 emitted (MMTyr^{-1})
1990	14.5	4.98	0.3	19.58
2005	23.41	44.28	1.6	69.28
2013	58.3	11.9	11.6	81.8
2014	64.8	3.4	12.7	81.0
2015	118.9	41.5	7.2	167.6
2016	51.2	1.7	11.9	64.8
2017[b]	51.2	1.7	11.9	64.8

[a] These emissions have already been included in the estimates of net annual changes in C stocks, which include the amount sequestered minus any emissions, including the assumption that combusted wood may continue to decay through time.

[b] The data for 2017 were unavailable when these estimates were summarized; therefore 2016, the most recent available estimate, is applied to 2017.

Methodology and Data Sources

The methodology described herein is consistent with IPCC (2006). Forest ecosystem C stocks and net annual C stock change were determined according to the stock-difference method for the CONUS, which involved applying C estimation factors to annual forest inventories across time to obtain C stocks and then subtracting between the years to obtain the stock change. The gain-loss method was used to estimate C stocks and net annual C stock changes in Alaska. The approaches for estimating carbon stocks and stock changes on *Forest Land Remaining Forest Land* are described in Annex 3.13. All annual NFI plots available in the public FIA database (USDA Forest Service 2018b) were used in the current Inventory. Additionally, NFI plots established and measured in 2014 as part of a pilot inventory in interior Alaska were also included in this report as were plots established and measured in 2015 and 2016 as part of the operational NFI in interior Alaska. Some of the data from the pilot and operational NFI in interior Alaska are not yet available in the public FIA database. Only plots which meet the definition of forest land (see Section 6.1 Representation of the U.S. Land Base) are measured in the NFI, as part of the pre-field process in the FIA program, all plots or portions of plots (i.e., conditions) are classified into a land use category. This land use information on each forest and non-forest plot was used to estimate forest land area and land converted to and from forest land over the time series. The estimates in this section of the report are based on this land use information from the NFI and they may differ with the other land use categories where area estimates reported in the Land Representation were not updated (see Section 6.1 Representation of the U.S. Land Base). Forest Land conditions in the CONUS were observed on NFI plots at time t_0 and at a subsequent time $t_1=t_0+s$, where s is the time step (time measured in years) and is indexed by discrete (e.g., 5 year) forest age classes. The inventory from t_0 was then projected from t_1 to 2017. This projection approach requires simulating changes in the age-class distribution resulting from forest aging and disturbance events and then applying C density estimates for each age class to obtain population estimates for the nation. Forest land conditions in Alaska were observed on NFI plots from 2004 to 2017. Plot-level data from the NFI were harmonized with auxiliary data describing climate, forest structure, disturbance, and other site-specific conditions to develop non-parametric models to predict carbon stocks by forest ecosystem carbon pool as well as fluxes over the entire inventory period, 1990 to 2017. First, carbon stocks for each forest ecosystem carbon pool were predicted for the year 2016 for all base intensity NFI plot locations (representing approximately 2,403 ha) in coastal southeast and southcentral Alaska and for 1/5 intensity plots in interior Alaska (representing 12,015 ha). Next, the chronosequence of sampled NFI plots and auxiliary information (e.g., climate, forest structure, disturbance, and other site-specific data) were used to predict annual gains and losses by forest ecosystem carbon pool. The annual gains and losses were then combined with the stock estimates and disturbance information to compile plot- and population-level carbon stocks and fluxes for each year from 1990 to 2017. Harvested wood C estimates were based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of the amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). An overview of the different methodologies and data sources used to estimate the C in forest ecosystems and harvested wood products is provided here. See Annex 3.13 for details and additional information related to the methods and data.

Forest Ecosystem Carbon from Forest Inventory

The United States applied the compilation approach described in Woodall et al. (2015a) for the current Inventory which removes the older periodic inventory data, which may be inconsistent with annual inventory data, from the estimation procedures and enables the delineation of forest C accumulation by forest growth, land use change, and natural disturbances such as fire. Development will continue on a system that attributes changes in forest C to disturbances and delineates *Land Converted to Forest Land* from *Forest Land Remaining Forest Land*. As part of this development, C pool science will continue and will be expanded to improve the estimates of C stock transfers from forest land to other land uses and include techniques to better identify land use change (see the Planned Improvements section below).

Unfortunately, the annual FIA inventory system does not extend into the 1990s, necessitating the adoption of a system to estimate carbon stocks prior to the establishment of the annual forest inventory. The estimation of carbon stocks prior to the annual national forest inventory consisted of a modeling framework comprised of a forest dynamics module (age transition matrices) and a land use dynamics module (land area transition matrices). The forest dynamics module assesses forest uptake, forest aging, and disturbance effects (e.g., disturbances such as wind, fire, and floods identified by foresters on inventory plots). The land use dynamics module assesses C stock transfers associated with afforestation and deforestation (Woodall et al. 2015b). Both modules are developed from land use area statistics and C stock change or C stock transfer by age class. The required inputs are estimated from more than 625,000 forest and non-forest observations recorded in the FIA national database (U.S. Forest Service 2018a, b, c). Model predictions prior to the annual inventory period are constructed from the estimation system using the annual estimates. The estimation system is driven by the annual forest inventory system conducted by the FIA program (Frayer and Furnival 1999; Bechtold and Patterson 2005; USDA Forest Service 2018d, 2018a). The FIA program relies on a rotating panel statistical design with a sampling intensity of one 674.5 m^2 ground plot per 2,403 ha of land and water area. A five-panel design, with 20 percent of the field plots typically measured each year within a state, is used in the eastern United States and a ten-panel design, with typically 10 percent of the field plots measured each year within a state, is used in the western United States. The interpenetrating hexagonal design across the U.S. landscape enables the sampling of plots at various intensities in a spatially and temporally unbiased manner. Typically, tree and site attributes are measured with higher sample intensity while other ecosystem attributes such as downed dead wood are sampled during summer months at lower intensities. The first step in incorporating FIA data into the estimation system is to identify annual inventory datasets by state. Inventories include data collected on permanent inventory plots on forest lands and were organized as separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time. Many of the annual inventories reported for states are represented as “moving window” averages, which mean that a portion—but not all—of the previous year’s inventory is updated each year (USDA Forest Service 2018d). Forest C estimates are organized according to these state surveys, and the frequency of surveys varies by state.

Using this FIA data, separate estimates were prepared for the five C storage pools identified by IPCC (2006) and described above. All estimates were based on data collected from the extensive array of permanent, annual forest inventory plots and associated models (e.g., live tree belowground biomass) in the United States (USDA Forest Service 2018b, 2018c). Carbon conversion factors were applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates.

Carbon in Biomass

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at breast height (dbh) of at least 2.54 cm at 1.37 m above the litter. Separate estimates were made for above- and belowground biomass components. If inventory plots included data on individual trees, aboveground and belowground (coarse roots) tree C was based on Woodall et al. (2011a), which is also known as the component ratio method (CRM), and is a function of tree volume, species, and diameter. An additional component of foliage, which was not explicitly included in Woodall et al. (2011a), was added to each tree following the same CRM method.

Understory vegetation is a minor component of biomass, which is defined in the FIA program as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For this Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density were based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). Understory biomass represented over one percent of C in biomass, but its contribution rarely exceeded 2 percent of the total carbon stocks or stock changes across all forest ecosystem C pools each year.

Carbon in Dead Organic Matter

Dead organic matter was initially calculated as three separate pools—standing dead trees, downed dead wood, and litter—with C stocks estimated from sample data or from models as described below. The standing dead tree C pool includes aboveground and belowground (coarse root) biomass for trees of at least 12.7 cm dbh. Calculations followed the basic method applied to live trees (Woodall et al. 2011a) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). Downed dead wood estimates are based on measurement of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008; Woodall et al. 2013). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. A modeling approach, using litter C measurements from FIA plots (Domke et al. 2016) was used to estimate litter C for every FIA plot used in the estimation framework.

Carbon in Forest Soil

Soil carbon is the largest terrestrial C sink with much of that C in forest ecosystems. The FIA program has been consistently measuring soil attributes as part of the annual inventory since 2001 and has amassed an extensive inventory of soil measurement data on forest land in the conterminous United States and coastal Alaska (O'Neill et al. 2005). Observations of mineral and organic soil C on forest land from the FIA program and the International Soil Carbon Monitoring Network were used to develop and implement a modeling approach that enabled the prediction of mineral and organic soil C to a depth of 100 cm from empirical measurements to a depth of 20 cm and included site-, stand-, and climate-specific variables that yield predictions of soil C stocks specific to forest land in the United States (Domke et al. 2017). This new approach allowed for separation of mineral and organic soils, also referred to as Histosols, in the *Forest Land Remaining Forest Land* category. Note that mineral and organic soil C is reported to a depth of 100 cm for *Forest Land Remaining Forest Land* to remain consistent with past reporting in this category, however for consistency across land-use categories mineral (e.g., cropland, grassland, settlements) soil C is reported to a depth of 30 cm in Section 6.3 *Land Converted to Forest Land*. Estimates of C from organic soils in this section (Table 6-10 and Table 6-11) include emissions from drained organic soils and the methods for all estimates can be found in the Drained Organic Soils section below.

Harvested Wood Carbon

Estimates of the HWP contribution to forest C sinks and emissions (hereafter called "HWP contribution") were based on methods described in Skog (2008) using the WOODCARB II model. These methods are based on IPCC (2006) guidance for estimating the HWP contribution. IPCC (2006) provides methods that allow for reporting of HWP contribution using one of several different methodological approaches: Production, stock change and atmospheric flow, as well as a default method that assumes there is no change in HWP C stocks (see Annex 3.13 for more details about each approach). The United States uses the production approach to report HWP contribution. Under the production approach, C in exported wood was estimated as if it remains in the United States, and C in imported wood was not included in the estimates. Though reported U.S. HWP estimates are based on the production approach, estimates resulting from use of the two alternative approaches, the stock change and atmospheric flow approaches, are also presented for comparison (see Annex 3.13). Annual estimates of change were calculated by tracking the annual estimated additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications) and the pool of products held in SWDS. The C loss from harvest is reported here and for information purposes in the Energy sector, but the non-CO_2 emissions associated with biomass energy are included in the Energy sector emissions (see Chapter 3).

Solidwood products include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end uses. There is one product category and one end-use category for paper. Additions to and removals from pools were tracked beginning in 1900, with the exception that additions of softwood lumber to housing, which began in 1800. Solidwood and paper product production and trade data were taken from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census 1976; Ulrich 1985, 1989; Steer 1948; AF&PA 2006a, 2006b; Howard 2003, 2007, 2016, In preparation). Estimates for disposal of products reflected the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that were in sanitary landfills versus dumps.

There are five annual HWP variables that were used in varying combinations to estimate HWP contribution using any one of the three main approaches listed above. These are:

(1A) annual change of C in wood and paper products in use in the United States,

(1B) annual change of C in wood and paper products in SWDS in the United States,

(2A) annual change of C in wood and paper products in use in the United States and other countries where the wood came from trees harvested in the United States,

(2B) annual change of C in wood and paper products in SWDS in the United States and other countries where the wood came from trees harvested in the United States,

(3) C in imports of wood, pulp, and paper to the United States,

(4) C in exports of wood, pulp and paper from the United States, and

(5) C in annual harvest of wood from forests in the United States.

The sum of variables 2A and 2B yielded the estimate for HWP contribution under the production estimation approach. A key assumption for estimating these variables was that products exported from the United States and held in pools in other countries have the same half-lives for products in use, the same percentage of discarded products going to SWDS, and the same decay rates in SWDS as they would in the United States.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis placed bounds on current flux for forest ecosystems through a combination of sample-based and model-based approaches to uncertainty for forest ecosystem CO_2 flux using IPCC Approach 1 (Table 6-14). A Monte Carlo Stochastic Simulation of the Methods described above and probabilistic sampling of C conversion factors were used to determine the HWP uncertainty using IPCC Approach 2. See Annex 3.13 for additional information. The 2017 net annual change for forest C stocks was estimated to be between -922.1 and -341.5 MMT CO_2 Eq. around a central estimate of -621.1 MMT CO_2 Eq. at a 95 percent confidence level. This includes a range of -796.9 to -238.9 MMT CO_2 Eq. around a central estimate of -517.8 MMT CO_2 Eq. for forest ecosystems and -122.1 to -84.5 MMT CO_2 Eq. around a central estimate of -103.3 MMT CO_2 Eq. for HWP.

Table 6-14: Quantitative Uncertainty Estimates for Net CO_2 Flux from *Forest Land Remaining Forest Land*: Changes in Forest C Stocks (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Ecosystem C Pools[a]	CO_2	(517.8)	(796.9)	(238.9)	-53.9%	53.9%
Harvested Wood Products[b]	CO_2	(103.3)	(122.1)	(84.5)	-18.2%	18.2%
Total Forest	**CO_2**	**(621.1)**	**(922.1)**	**(341.5)**	**-45.0%**	**45.0%**

[a] Range of flux estimates predicted through a combination of sample-based and model-based uncertainty for a 95 percent confidence interval, IPCC Approach 1.

[b] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval, IPCC Approach 2.

Note: Parentheses indicate negative values or net uptake.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2018d).

General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the C datasets, which include inventory variables such as areas and volumes, were compared to standard inventory summaries such as the forest resource statistics of Oswalt et al. (2014) or selected population estimates generated from the FIA database, which are available at an FIA internet site (USDA Forest Service 2018b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used.

Estimates of the HWP variables and the HWP contribution under the production estimation approach use data from U.S. Census and USDA Forest Service surveys of production and trade and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census 1976; Ulrich 1985, 1989; Steer 1948; AF&PA 2006a, 2006b; Howard 2003, 2007, 2016, In preparation). Factors to convert wood and paper to units of C are based on estimates by industry and Forest Service published sources (see Annex 3.13). The WOODCARB II model uses estimation methods suggested by IPCC (2006). Estimates of annual C change in solidwood and paper products in use were calibrated to meet two independent criteria. The first criterion is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criterion resulted in an estimated half-life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criterion is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards used in the Waste sector each year over the period 1990 to 2000 (EPA 2006). These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and, to a lesser degree, reduce uncertainty in estimates of annual change in C in products made from wood harvested in the United States. In addition, WOODCARB II landfill decay rates have been validated by ensuring that estimates of CH_4 emissions from landfills based on EPA (2006) data are reasonable in comparison to CH_4 estimates based on WOODCARB II landfill decay rates.

Recalculations Discussion

The methods and data used in the current Inventory to compile estimates for forest ecosystem carbon stocks and stock changes from 1990 through 2017 are consistent with those used in the 1990 through 2016 Inventory for the eastern United States. In this Inventory the regional approach for carbon stock and stock change estimation in the western United States was replaced by the state-level method used in the eastern United States so carbon stocks and stock changes are now estimated consistently for the entire 1990 to 2017 time series in all states with remeasurements in the NFI in the CONUS. This improvement in consistency also improved separation of *Forest Land Remaining Forest Land, Land Converted to Forest Land*, and areas with perennial woody biomass that do not meet the definition of forest land (i.e., woodlands) that are now included in the *Grassland Remaining Grassland* and *Land Converted to Grassland* sections. This resolved approach resulted in a 9 percent decrease in forest area as a result of transferring approximately 23.5 million ha of land previously included in the *Forest Land Remaining Forest Land* to the *Land Converted to Forest Land*, *Grassland Remaining Grassland,* and *Land Converted to Grassland* categories in 2017 and 27.5 million ha on average annually over the time series (Table 6-16). This improvement in consistency also corrected problems with imbalanced area estimates which may have resulted in over or underestimates in carbon stock changes in past Inventories due to different land areas used to calculate stock differences between years, a problem which stemmed from the time when only the *Forest Land Remaining Forest Land* was included in the Inventory and no transfer of carbon between land use categories was estimated. All managed forest land in Alaska, specifically forest land from interior Alaska, was also included for the first time in this Inventory, which added more than 24.5 million ha to the *Forest Land Remaining Forest Land* category (note that estimates for land use conversion to and from forest land are not currently included for Alaska, Table 6-15).

As a result of these improvements, the estimates reported from 1990 through 2016 are not directly comparable to the estimates in this Inventory. To illustrate changes in the current Inventory, Table 6-15 includes forest area and carbon stock estimates for the year 2017 from the previous (1990 to 2016) Inventory and the estimates for 2017 and 2018 from the current Inventory for CONUS and southeast and southcentral coastal Alaska. The forest land area estimates for the year 2017 decreased by more than 23 million ha from the previous Inventory (Table 6-15) and the forest land area decreased by an average of 7.5 million ha over the 1990 to 2016 time series. In most cases this was not a loss of forest land area but rather a reorganization of land into the *Land Converted to Forest Land* category and the transfer of 23.5 million ha of land with perennial woody biomass that does not meet the definition of forest land (i.e., woodlands) into the *Grassland Remaining Grassland* and *Land Converted to Grassland* categories. Despite the reorganization of substantial land area historically included in the *Forest Land Remaining Forest Land* (a 9 percent reduction), there was only a 4 percent decrease in the carbon stocks for the year 2017 between the previous Inventory and the current Inventory (Table 6-15). This is due to increases in carbon stocks from the transition to the state-level method used for the western United States in the current Inventory as well as the relatively minor contribution of the lands reclassified into other land use categories. However, carbon stock changes decreased by 11 percent for the year 2016 in the previous Inventory and the 2016 estimates for the current Inventory (Table 6-16). In particular, the mineral soil carbon stock changes in the year 2016 decreased by 107 percent between the previous Inventory and the current Inventory and this change was consistent over the time series (Table 6-16). This was due, in large part, to the correction of the imbalanced area estimates in the western United States resulting in a substantial decrease in the contribution of soil carbon stock changes from that region. There was also a 111 percent increase in dead wood carbon stock changes and an 83 percent decrease in litter carbon stock changes in the year 2016 between the previous Inventory and the current Inventory. This can be attributed to the incorporation of remeasurements from the NFI in the western United States for the first time in the current Inventory which allowed for using the state-level estimation approach.

While not included in the recalculations described in this section, the inclusion of 24.5 million ha of forest area from interior Alaska contributed an additional 8,604 MMT C stocks, primarily from soil carbon, to the *Forest Land Remaining Forest Land* category in 2018 and this increase was consistent with the additions from interior Alaska over the time series (Table 6-15). The carbon stock changes in interior Alaska were driven, in large part, by wildfires over the time series and contribute, on average over the time series, approximately -2.2 MMT C per year to the sink.

There were no changes in the data or methods used to compile estimates of HWP from 1990 through 2016 so no recalculations were necessary.

Table 6-15: Recalculations of Forest Area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	Previous Estimate for Year 2017, from 2018 Inventory, CONUS+Coastal AK	Current Estimate for Year 2017, from 2019 Inventory, CONUS+Coastal AK	Current Estimate for Year 2018, from 2019 Inventory, CONUS+Coastal AK	Current Estimate for Year 2018, from 2019 Inventory, Interior AK
Forest Area (1,000 ha)	*272,260*	*249,084*	*249,242*	*24,539*
Carbon Pools				
Forest	**51,131**	**48,949**	**49,084**	**8,604**
Aboveground Biomass	14,182	14,090	14,184	480
Belowground Biomass	2,923	2,905	2,924	118
Dead Wood	2,570	2,558	2,578	165
Litter	2,680	2,558	2,589	1,051
Soil (Mineral)	28,422	26,280	26,280	1,536
Soil (Organic)	352	529	528	5,253
Harvested Wood	**2,612**	**2,612**	**2,640**	NA
Products in Use	1,501	1,501	1,510	NA
SWDS	1,111	1,111	1,130	NA
Total Stock	**53,743**	**51,561**	**51,724**	**NA**

NA – Not Applicable

Table 6-16: Recalculations of Net C Flux from Forest Ecosystem Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

Carbon Pool (MMT C)	Previous Estimate for Year 2016, from 2018 Inventory, CONUS+Coastal AK	Current Estimate for Year 2016, from 2019 Inventory, CONUS+Coastal AK	Current Estimate for Year 2017, from 2019 Inventory, CONUS+Coastal AK	Current Estimate for Year 2017, from 2019 Inventory, Interior AK
Forest	**(155.7)**	**(138.9)**	**(134.3)**	**(6.9)**
Aboveground Biomass	(86.0)	(98.6)	(94.2)	(3.2)
Belowground Biomass	(17.9)	(20.3)	(19.5)	(3.4)
Dead Wood	(10.7)	(22.5)	(20.8)	0.4
Litter	(4.4)	(0.7)	(0.6)	0.5
Soil (Mineral)	(36.9)	2.5	(0.3)	0.9
Soil (Organic)	+	0.6	0.8	(0.5)
Drained Organic Soil[a]	0.2	0.2	0.2	NA
Harvested Wood	**(27.2)**	**(27.2)**	**(28.2)**	NA
Products in Use	(9.1)	(9.1)	(9.7)	NA
SWDS	(18.0)	(18.0)	(18.4)	NA
Total Net Flux	**(182.9)**	**(166.1)**	**(162.5)**	**NA**

NA – Not Applicable
+ Absolute value does not exceed 0.05 MMT C
[a] These estimates include carbon stock changes from drained organic soils from both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. See the section below on CO_2, CH_4, and N_2O Emissions from Drained Organic Soils for the methodology used to estimate the C flux from drained organic soils. Also, see Table 6-22 and Table 6-23 for greenhouse gas emissions from non-CO_2 gases changes from drainage of organic soils from *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Planned Improvements

Reliable estimates of forest C stocks and changes across the diverse ecosystems of the United States require a high level of investment in both annual monitoring and associated analytical techniques. Development of improved monitoring/reporting techniques is a continuous process that occurs simultaneously with annual Inventory submissions. Planned improvements can be broadly assigned to the following categories: development of a robust estimation and reporting system, individual C pool estimation, coordination with other land-use categories, and annual inventory data incorporation.

While this Inventory submission includes C change by *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* and C stock changes for all IPCC pools in these two categories, there are many improvements that are still necessary. The estimation approach used for the CONUS in the current Inventory for the forest land category operates at the state scale, whereas previously the western United States and southeast and southcentral coastal Alaska operated at a regional scale. While this is an improvement over previous Inventories and led to improved estimation and separation of land use categories in the current Inventory, research is underway to leverage auxiliary information (i.e., remotely sensed information) to operate at finer spatial and temporal scales. As in past submissions, emissions and removals associated with natural (e.g., wild fire, insects, and disease) and human (e.g., harvesting) disturbances are implicitly included in the report given the design of the annual NFI, but not explicitly estimated. In addition to integrating auxiliary information into the estimation framework, alternative estimators are also being evaluated which will eliminate latency in population estimates from the NFI, improve annual estimation and characterization of interannual variability, facilitate attribution of fluxes to particular activities, and allow for easier harmonization of NFI data with auxiliary data products. The transparency and repeatability of estimation and reporting systems will be improved through the dissemination of open source code (e.g., R programming language) in concert with the public availability of the annual NFI (USDA Forest Service 2018b). Also, several FIA database processes are being institutionalized to increase efficiency and QA/QC in reporting and further improve transparency, completeness, consistency, accuracy, and availability of data used in reporting. Finally, a combination of approaches were used to estimate uncertainty associated with C stock changes in the *Forest Land Remaining Forest Land* category in this report. There is research underway investigating more robust approaches to total uncertainty (Clough et al. 2016), which will be considered in future Inventory reports.

The modeling framework used to estimate downed dead wood within the dead wood C pool will be updated similar to the litter (Domke et al. 2016) and soil C pools (Domke et al. 2017). Finally, components of other pools, such as C in belowground biomass (Russell et al. 2015) and understory vegetation (Russell et al. 2014; Johnson et al. 2017), are being explored but may require additional investment in field inventories before improvements can be realized with the Inventory report.

The foundation of forest C estimation and reporting is the annual NFI. The ongoing annual surveys by the FIA program are expected to improve the accuracy and precision of forest C estimates as new state surveys become available (USDA Forest Service 2018b). With the exception of Wyoming and western Oklahoma, all other states in the CONUS now have sufficient annual NFI data to consistently estimate C stocks and stock changes using the state-level compilation system. The FIA program continues to install permanent plots in Alaska as part of the operational NFI and as more plots are added to the NFI they will be used to improve estimates for all managed forest land in Alaska. The methods used this year to include all managed forest land in Alaska will be used in the years ahead for Hawaii and U.S. Territories as forest C data become available (only a small number of plots from Hawaii are currently available from the annualized sampling design). To that end, research is underway to incorporate all NFI information (both annual and periodic data) and the dense time series of remotely sensed data in multiple inferential frameworks for estimating greenhouse gas emissions and removals as well as change detection and attribution across the entire reporting period and all managed forest land in the United States. Leveraging this auxiliary information will aid not only the interior Alaska effort but the entire inventory system. In addition to fully inventorying all managed forest land in the United States, the more intensive sampling of fine woody debris, litter, and SOC on a subset of FIA plots continues and will substantially improve resolution of C pools (i.e., greater sample intensity; Westfall et al. 2013) as this information becomes available (Woodall et al. 2011b). Increased sample intensity of some C pools and using annualized sampling data as it becomes available for those states currently not reporting are planned for future submissions. The NFI sampling frame extends beyond the forest land use category (e.g., woodlands, which fall into the grasslands category and urban areas, which fall into the settlements category) with inventory-relevant information for these lands which will likely become increasingly available in coming years.

Non-CO_2 Emissions from Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using U.S.-specific data for annual area of forest burned, potential fuel availability, and fire severity as well as the default IPCC (2006) emission factors and some combustion factors applied to the IPCC methodology. In 2017, emissions from this source were estimated to be 4.9 MMT CO_2 Eq. of CH_4 and 3.2 MMT CO_2 Eq. of N_2O (Table 6-17; kt units provided in Table 6-18). The estimates of non-CO_2 emissions from forest fires include wildfires and prescribed fires in the conterminous 48 states and all managed forest land in Alaska.

Table 6-17: Non-CO_2 Emissions from Forest Fires (MMT CO_2 Eq.)[a]

Gas	1990		2005		2013	2014	2015	2016	2017[b]
CH_4	1.5		5.2		6.1	6.1	12.6	4.9	4.9
N_2O	1.0		3.4		4.0	4.0	8.3	3.2	3.2
Total	**2.4**		**8.6**		**10.2**	**10.1**	**20.8**	**8.0**	**8.0**

[a] These estimates include Non-CO_2 Emissions from Forest Fires on *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] The data for 2017 were unavailable when these estimates were developed, therefore 2016, the most recent available estimate, is applied to 2017.

Table 6-18: Non-CO_2 Emissions from Forest Fires (kt)[a]

Gas	1990		2005		2013	2014	2015	2016	2017[b]
CH_4	59		208		245	243	502	194	194
N_2O	3		11		14	13	28	11	11
CO	1,334		4,723		5,574	5,525	11,425	4,425	4,425
NO_x	37		133		157	155	321	124	124

[a] These estimates include Non-CO_2 Emissions from Forest Fires on *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] The data for 2017 were unavailable when these estimates were summarized, therefore 2016, the most recent available estimate, is applied to 2017.

Methodology and Data Sources

Non-CO_2 emissions from forest fires—primarily CH_4 and N_2O emissions—were calculated following IPCC (2006) methodology, which included a combination of U.S.-specific data on area burned, potential fuel available for combustion, and estimates of combustion based on fire severity along with IPCC default combustion and emission factors. The estimates were calculated according to Equation 2.27 of IPCC (2006, Volume 4, Chapter 2), which is:

$$\text{Emissions} = \text{Area burned} \times \text{Fuel available} \times \text{Combustion factor} \times \text{Emission Factor} \times 10^{-3}$$

where forest area burned is based on Monitoring Trends in Burn Severity (MTBS, Eidenshink et al. 2007 and National Land Cover NLCD, Homer et al. 2015) data. Fuel estimates are based on current C density estimates obtained from FIA plot data, combustion is partly a function of burn severity, and emission factors are from IPCC (2006, Volume 4, Chapter 2). See Annex 3.13 for further details.

Uncertainty and Time-Series Consistency

In order to quantify the uncertainties for non-CO_2 emissions from wildfires and prescribed burns, a Monte Carlo (IPCC Approach 2) sampling approach was employed to propagate uncertainty based on the model and data applied for U.S. forest land. See IPCC (2006) and Annex 3.13 for the quantities and assumptions employed to define and propagate uncertainty. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-19. Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2017.

Table 6-19: Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires (MMT CO_2 Eq. and Percent)[a]

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[b] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Non-CO_2 Emissions from Forest Fires	CH_4	4.9	4.1	5.7	-15%	17%

Non-CO_2 Emissions from Forest Fires	N_2O	3.2	2.8	3.6	-12%	14%

[a] These estimates include Non-CO_2 Emissions from Forest Fires on *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[b] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for estimating non-CO_2 emissions from forest fires included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. The QA/QC procedures did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

The methods used in the 1990 through 2017 Inventory to compile estimates of non-CO_2 emissions from forest fires are consistent with those used in the 1990 through 2016 Inventory, but also include some additional steps toward better definition of forest area in Alaska, fuel, and combustion. Modifications in each of these factors affect estimates. Forest within the MTBS defined fire perimeters (MTBS Data Summaries 2018) are estimated according to NLCD spatial datasets (Homer et al. 2015) rather than Ruefenacht et al. (2008) as in the previous report. Fuel estimates are based on the distribution of stand-level carbon pools (USDA Forest Service 2018b, 2018d) classified according to ecological region rather than the state-wide estimates as in the previous report. Combustion estimates are partly a function of the MTBS severity classifications and thus can vary within a fire. The effects of these modifications varied across the time series, but more often lowered the estimates for both CH_4 and N_2O.

Planned Improvements

Continued improvements are planned for developing better fire and site-specific estimates for forest area burned, potential fuel available, and combustion. The goal is to develop easy to apply models based on readily available data to characterize the site and fire for the many fires in the MTBS data. The results will be less reliant on wide regional values or IPCC defaults. Spatially relating potential fuel availability to more localized forest structure is the best example of this. An additional future consideration is to apply the forest inventory data to identify and quantify the likely small additional contribution of fires that are below the minimum size threshold for the MTBS data.

N_2O Emissions from N Additions to Forest Soils

Of the synthetic nitrogen (N) fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropland soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once midway through their life cycle). While the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, the annual application rate is quite low over the entire forest land area.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions. Indirect emissions result from fertilizer N that is transformed and transported to another location in a form other than N_2O (ammonia [NH_3] and nitrogen oxide [NO_x] volatilization, nitrate [NO_3] leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to forest land because the management activity leading to the emissions occurred in forest land.

Direct soil N_2O emissions from *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* in 2017 were 0.3 MMT CO_2 Eq. (1 kt), and the indirect emissions were 0.1 MMT CO_2 Eq. (0.4 kt). Total emissions for 2017 were 0.5 MMT CO_2 Eq. (2 kt) and have increased by 455 percent from 1990 to 2017. Total forest soil N_2O emissions are summarized in Table 6-20.

Table 6-20: N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* (MMT CO_2 Eq. and kt N_2O)

	1990	2005	2013	2014	2015	2016	2017
Direct N_2O Fluxes from Soils							
MMT CO_2 Eq.	0.1	0.3	0.3	0.3	0.3	0.3	0.3
kt N_2O	+	1	1	1	1	1	1
Indirect N_2O Fluxes from Soils							
MMT CO_2 Eq.	0.0	0.1	0.1	0.1	0.1	0.1	0.1
kt N_2O	+	+	+	+	+	+	+
Total							
MMT CO_2 Eq.	**0.1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
kt N_2O	**+**	**2**	**2**	**2**	**2**	**2**	**2**

+ Does not exceed 0.05 MMT CO_2 Eq. or 0.5 kt.
Note: Totals may not sum due to independent rounding.

Methodology and Data Sources

The IPCC Tier 1 approach is used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted are for timber, and about 60 percent of national total harvested forest area is in the southeastern United States. Although southeastern pine plantations represent the majority of fertilized forests in the United States, this Inventory also accounted for N fertilizer application to commercial Douglas-fir stands in western Oregon and Washington. For the Southeast, estimates of direct N_2O emissions from fertilizer applications to forests are based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (Albaugh et al. 2007; Fox et al. 2007). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer is multiplied by the weighted average of the reported range of N fertilization rates (121 lbs. N per acre). Area data for pine plantations receiving fertilizer in the Southeast are not available for 2005 through 2017, so data from 2004 are used for these years. For commercial forests in Oregon and Washington, only fertilizer applied to Douglas-fir is addressed in the inventory because the vast majority (approximately 95 percent) of the total fertilizer applied to forests in this region is applied to Douglas-fir (Briggs 2007). Estimates of total Douglas-fir area and the portion of fertilized area are multiplied to obtain annual area estimates of fertilized Douglas-fir stands. Similar to the Southeast, data are not available for 2005 through 2017, so data from 2004 are used for these years. The annual area estimates are multiplied by the typical rate used in this region (200 lbs. N per acre) to estimate total N applied (Briggs 2007), and the total N applied to forests is multiplied by the IPCC (2006) default emission factor of one percent to estimate direct N_2O emissions.

For indirect emissions, the volatilization and leaching/runoff N fractions for forest land are calculated using the IPCC default factors of 10 percent and 30 percent, respectively. The amount of N volatilized is multiplied by the IPCC default factor of one percent for the portion of volatilized N that is converted to N_2O off-site. The amount of N leached/runoff is multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site. The resulting estimates are summed to obtain total indirect emissions.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from forests depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. IPCC (2006) does not incorporate any of these variables into the default methodology, except variation in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not estimated. However, the total quantity of organic N inputs to soils is included in Section 5.4 Agricultural Soil Management and Section 6.10 *Settlements Remaining Settlements*.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. Fertilization rates are assigned a default level[29] of uncertainty at ±50 percent, and area receiving fertilizer is assigned a ±20 percent according to expert knowledge (Binkley 2004). The uncertainty ranges around the 2004 activity data and emission factor input variables are directly applied to the 2017 emission estimates. IPCC (2006) provided estimates for the uncertainty associated with direct and indirect N_2O emission factor for synthetic N fertilizer application to soils.

Uncertainty is quantified using simple error propagation methods (IPCC 2006). The results of the quantitative uncertainty analysis are summarized in Table 6-21. Direct N_2O fluxes from soils in 2017 are estimated to be between 0.1 and 1.1 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2017 emission estimate of 0.3 MMT CO_2 Eq. Indirect N_2O emissions in 2017 are 0.1 MMT CO_2 Eq. and have a range are between 0.02 and 0.4 MMT CO_2 Eq., which is 86 percent below to 238 percent above the 2017 emission estimate.

Table 6-21: Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
Forest Land Remaining Forest Land			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Direct N_2O Fluxes from Soils	N_2O	0.3	0.1	1.1	-59%	+211%
Indirect N_2O Fluxes from Soils	N_2O	0.1	+	0.4	-86%	+238%

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: Due to rounding the upper and lower bounds may equal the emission estimate in the above table.

The same methods are applied to the entire time series to ensure time-series consistency from 1990 through 2017, and no recalculations have been done from the previous Inventory. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

The spreadsheet tab containing fertilizer applied to forests and calculations for N_2O and uncertainty ranges are checked and verified.

Planned Improvements

Additional data will be compiled to update estimates of forest areas receiving N fertilizer using surrogate data in the next Inventory. Another improvement is to further disaggregate emissions by state for southeastern pine plantations and northwestern Douglas-fir forests to estimate soil N_2O emission. This improvement is contingent on the availability of state-level N fertilization data for forest land. Estimates of the N_2O from mineralization of soil C will also be included in the next Inventory.

CO_2, CH_4, and N_2O Emissions from Drained Organic Soils[30]

Drained organic soils on forest land are identified separately from other forest soils largely because mineralization of the exposed or partially dried organic material results in continuous CO_2 and N_2O emissions (IPCC 2006). In addition, the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*

[29] Uncertainty is unknown for the fertilization rates so a conservative value of ±50 percent is used in the analysis.

[30] Estimates of C and CO_2 emissions from drained organic soils are described in this section but reported in Table 6-10 and Table 6-11 for both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

(IPCC 2014) calls for estimating CH_4 emissions from these drained organic soils and the ditch networks used to drain them.

Organic soils are identified on the basis of thickness of organic horizon and percent organic matter. All organic soils are assumed to have originally been wet, and drained organic soils are further characterized by drainage or the process of artificially lowering the soil water table, which exposes the organic material to drying and the associated emissions described in this section. The land base considered here is drained inland organic soils that are coincident with forest area as identified by the NFI of the USDA Forest Service (USDA Forest Service 2018).

The estimated area of drained organic soils on forest land is 70,849 ha and did not change over the time series based on the data used to compile the estimates in the current Inventory. These estimates are based on permanent plot locations of the NFI (USDA Forest Service 2018) coincident with mapped organic soil locations (STATSGO2 2016), which identifies forest land on organic soils. Forest sites that are drained are not explicitly identified in the data, but for this estimate, planted forest stands on sites identified as mesic or xeric (which are identified in USDA Forest Service 2018) are labeled "drained organic soil" sites.

Land use, region, and climate are broad determinants of emissions as are more site-specific factors such as nutrient status, drainage level, exposure, or disturbance. Current data are limited in spatial precision and thus lack site specific details. At the same time, corresponding emissions factor data specific to U.S. forests are similarly lacking. Tier 1 estimates are provided here following IPCC (2014). Total annual non-CO_2 emissions on forest land with drained organic soils in 2017 are estimated as 0.1 MMT CO_2 Eq. per year (Table 6-22).

The Tier 1 methodology provides methods to estimate C emission as CO_2 from three pathways: direct emissions primarily from mineralization; indirect, or off-site, emissions associated with dissolved organic carbon releasing CO_2 from drainage waters; and emissions from (peat) fires on organic soils. Data about forest fires specifically located on drained organic soils are not currently available; as a result, no corresponding estimate is provided here. Non-CO_2 emissions provided here include CH_4 and N_2O. Methane emissions generally associated with anoxic conditions do occur from the drained land surface but the majority of these emissions originate from ditches constructed to facilitate drainage at these sites. Emission of N_2O can be significant from these drained organic soils in contrast to the very low emissions from wet organic soils.

Table 6-22: Non-CO_2 Emissions from Drained Organic Forest Soils[a,b] (MMT CO_2 Eq.)

Source	1990		2005		2013	2014	2015	2016	2017
CH_4	+		+		+	+	+	+	+
N_2O	0.1		0.1		0.1	0.1	0. 1	0.1	0.1
Total	**0.1**		**0.1**		**0.1**	**0.1**	**0.1**	**0.1**	**0.1**

+ Does not exceed 0.05 MMT CO_2 Eq.
[a] This table includes estimates from *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*
[b] Estimates of C and CO_2 emissions from drained organic soils are described in this section but reported in Table 6-10 and Table 6-11 for both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Table 6-23: Non-CO_2 Emissions from Drained Organic Forest Soils[a,b] (kt)

Source	1990		2005		2013	2014	2015	2016	2017
CH_4	0.6		0.6		0.6	0.6	0.6	0.6	0.6
N_2O	+		+		+	+	+	+	+

+ Does not exceed 0.5 kt.
[a] This table includes estimates from *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*
[b] Estimates of C and CO_2 emissions from drained organic soils are described in this section but reported in Table 6-10 and Table 6-11 for both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Methodology and Data Sources

The Tier 1 methods for estimating CO_2, CH_4 and N_2O emissions from drained inland organic soils on forest lands follow IPCC (2006), with extensive updates and additional material presented in the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014). With the exception of quantifying area of forest on drained organic soils, which is user-supplied, all quantities necessary for Tier 1 estimates are provided in Chapter 2, Drained Inland Organic Soils of IPCC (2014).

Estimated area of drained organic soils on forest land is 70,849 ha based on analysis of the permanent NFI of the USDA Forest Service and did not change over the time series. The most recent plot data per state within the inventories were used in a spatial overlay with the STATSGO2 (2016) soils data, and forest plots coincident with the soil order histosol were selected as having organic soils. Information specific to identifying "drained organic" are not in the inventory data so an indirect approach was employed here. Specifically, artificially regenerated forest stands (inventory field STDORGCD=1) on mesic or xeric sites (inventory field $11 \leq$PHYSCLCD≤ 29) are labeled "drained organic soil" sites. From this selection, forest area and sampling error for forest on drained organic sites are based on the population estimates developed within the inventory data for each state (USDA Forest Service 2018). Eight states, all temperate forests, were identified as having drained organic soils (Table 6-24).

Table 6-24: States identified as having Drained Organic Soils, Area of Forest on Drained Organic Soils, and Sampling Error

State	Forest on Drained Organic Soil (1,000 ha)	Sampling Error (68.3% as ± Percentage of Estimate)
Florida	2.4	79
Georgia	3.7	71
Michigan	18.7	34
Minnesota	30.2	19
North Carolina	1.3	99
Virginia	2.3	102
Washington	2.1	101
Wisconsin	10.1	30
Total	**70.8**	**14**

The Tier 1 methodology provides methods to estimate emissions for three pathways of C emission as CO_2. Note that subsequent mention of equations and tables in the remainder of this section refer to Chapter 2 of IPCC (2014). The first pathway–direct CO_2 emissions–is calculated according to Equation 2.3 and Table 2.1 as the product of forest area and emission factor for temperate drained forest land. The second pathway–indirect, or off-site, emissions–is associated with dissolved organic carbon releasing CO_2 from drainage waters according to Equation 2.4 and Table 2.2, which represent a default composite of the three pathways for this flux: (1) the flux of dissolved organic carbon (DOC) from natural (undrained) organic soil; (2) the proportional increase in DOC flux from drained organic soils relative to undrained sites; and (3) the conversion factor for the part of DOC converted to CO_2 after export from a site. The third pathway–emissions from (peat) fires on organic soils–assumes that the drained organic soils burn in a fire but not any wet organic soils. However, this Inventory currently does not include emissions for this pathway because data on the combined fire and drained organic soils information are not available at this time; this may become available in the future with additional analysis.

Non-CO_2 emissions, according to the Tier 1 method, include methane (CH_4), nitrous oxide (N_2O), and carbon monoxide (CO). Emissions associated with peat fires include factors for CH_4 and CO in addition to CO_2, but fire estimates are assumed to be zero for the current Inventory, as discussed above. Methane emissions generally associated with anoxic conditions do occur from the drained land surface but the majority of these emissions originate from ditches constructed to facilitate drainage at these sites. From this, two separate emission factors are used, one for emissions from the area of drained soils and a second for emissions from drainage ditch waterways. Calculations are according to Equation 2.6 and Tables 2.3 and 2.4, which includes the default fraction of the total area of drained organic soil which is occupied by ditches. Emissions of N_2O can be significant from these drained soils in contrast to the very low emissions from wet organic soils. Calculations are according to Equation 2.7 and Table 2.5, which provide the estimate as kg N per year.

Uncertainty and Time-Series Consistency

Uncertainties are based on the sampling error associated with forest area of drained organic soils and the uncertainties provided in the Chapter 2 (IPCC 2014) emissions factors (Table 6-25). The estimates and resulting quantities representing uncertainty are based on the IPCC Approach 1–error propagation. However, probabilistic sampling of the distributions defined for each emission factor produced a histogram result that contained a mean and 95 percent confidence interval. The primary reason for this approach was to develop a numerical representation of uncertainty with the potential for combining with other forest components. The total non-CO_2 emissions in 2017 from drained organic soils on *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* were estimated to be between 0.07 and 0.2 MMT CO_2 Eq. around a central estimate of 0.1 MMT CO_2 Eq. at a 95 percent confidence level.

Table 6-25: Quantitative Uncertainty Estimates for Non-CO_2 Emissions on Drained Organic Forest Soils (MMT CO_2 Eq. and Percent)[a]

Source	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
CH_4	+	+	+	-76%	76%
N_2O	0.1	+	0.2	-124%	124%
Total	**0.1**	**0.07**	**0.2**	**-108%**	**108%**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Range of flux estimates predicted through a combination of sample-based and IPCC defaults for a 95 percent confidence interval, IPCC Approach 1.

QA/QC and Verification

IPCC (2014) guidance cautions of a possibility of double counting some of these emissions. Specifically, the off-site emissions of dissolved organic C from drainage waters may be double counted if soil C stock and change is based on sampling and this C is captured in that sampling. Double counting in this case is unlikely since plots identified as drained were treated separately in this chapter. Additionally, some of the non-CO_2 emissions may be included in either the Wetlands or sections on N_2O emissions from managed soils. These paths to double counting emissions are unlikely here because these issues are taken into consideration when developing the estimates and this chapter is the only section directly including such emissions on forest land.

Planned Improvements

Additional data will be compiled to update estimates of forest areas on drained organic soils as new reports are made available and new geospatial products become available.

6.3 Land Converted to Forest Land (CRF Category 4A2)

The C stock change estimates for *Land Converted to Forest Land* that are provided in this Inventory include all forest land in an inventory year that had been in another land use(s) during the previous 20 years.[31] For example, cropland or grassland converted to forest land during the past 20 years would be reported in this category. Converted lands are in this category for 20 years as recommended in the *2006 IPCC Guidelines* (IPCC 2006), after which they

[31] The annual NFI data used to compile estimates of carbon transfer and uptake in this section are based on 5- to 10-yr remeasurements so the exact conversion period was limited to the remeasured data over the time series.

are classified as *Forest Land Remaining Forest Land*. Estimates of C stock changes from all pools (i.e., aboveground and belowground biomass, dead wood, litter and soils), as recommended by IPCC (2006), are included in the *Land Converted to Forest Land* category of this Inventory.

Area of Land Converted to Forest in the United States[32]

Land conversion to and from forests has occurred regularly throughout U.S. history. The 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. Recent analyses suggest that net accumulation of forest area continues in areas of the United States, in particular the northeastern United States (Woodall et al. 2015b). Specifically, the annual conversion of land from other land-use categories (i.e., Cropland, Grassland, Wetlands, Settlements, and Other Lands) to Forest Land resulted in a fairly continuous net annual accretion of Forest Land area from over the time series at an average rate of 1.1 million ha year^{-1}.

Over the 20-year conversion period used in the *Land Converted to Forest Land* category, the conversion of cropland to forest land resulted in the largest source of C transfer and uptake, accounting for approximately 40 percent of the uptake annually. Estimated C uptake has remained relatively stable over the time series across all conversion categories (see Table 6-26). The net flux of C from all forest pool stock changes in 2017 was -120.6 MMT CO_2 Eq. (-32.9 MMT C) (Table 6-26 and Table 6-27).

Mineral soil C stocks are increasing slightly in the early 1990s with *Land Converted Forest Land*, but this trend reverses in the early 2000's through the remainder of the time series. The small gains in the early part of the time series are driven by *Cropland Converted to Forest Land* during the 1990s. Much of this conversion is from annual crop production, which has a lower mineral soils C stock than Forest Land. In contrast, *Grassland Converted to Forest Land* dominates the trend starting in the early 2000s. Managed pasture to Forest Land is the most common conversion. This leads to a loss of soil C because pastures are mostly improved in the United States with fertilization and/or irrigation, which enhances C input to soils relative to typical forest management activities.

Table 6-26: Net CO_2 Flux from Forest C Pools in *Land Converted to Forest Land* by Land Use Change Category (MMT CO_2 Eq.)

Land Use/Carbon Pool	1990		2005		2013	2014	2015	2016	2017
Cropland Converted to Forest Land	**(47.4)**		**(47.8)**		**(48.0)**	**(48.1)**	**(48.0)**	**(48.0)**	**(48.0)**
Aboveground Biomass	(26.7)		(27.0)		(27.2)	(27.2)	(27.2)	(27.2)	(27.2)
Belowground Biomass	(5.3)		(5.4)		(5.4)	(5.4)	(5.4)	(5.4)	(5.4)
Dead Wood	(6.1)		(6.2)		(6.2)	(6.2)	(6.2)	(6.2)	(6.2)
Litter	(9.0)		(9.1)		(9.1)	(9.1)	(9.1)	(9.1)	(9.1)
Mineral Soil	(0.4)		(0.2)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Grassland Converted to Forest Land	**(11.0)**		**(11.0)**		**(10.9)**	**(11.0)**	**(11.1)**	**(11.1)**	**(11.2)**
Aboveground Biomass	(5.6)		(5.7)		(5.7)	(5.7)	(5.7)	(5.7)	(5.7)
Belowground Biomass	(0.9)		(0.9)		(0.9)	(0.9)	(0.9)	(0.9)	(0.9)
Dead Wood	(0.7)		(0.7)		(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
Litter	(4.1)		(4.1)		(4.1)	(4.1)	(4.1)	(4.1)	(4.1)
Mineral Soil	0.3		0.4		0.5	0.5	0.3	0.3	0.3
Other Land Converted to Forest Land	**(18.1)**		**(18.2)**		**(18.3)**	**(18.3)**	**(18.3)**	**(18.3)**	**(18.3)**
Aboveground Biomass	(9.1)		(9.2)		(9.2)	(9.2)	(9.2)	(9.2)	(9.2)
Belowground Biomass	(1.7)		(1.7)		(1.7)	(1.7)	(1.7)	(1.7)	(1.7)
Dead Wood	(2.4)		(2.4)		(2.4)	(2.4)	(2.4)	(2.4)	(2.4)
Litter	(4.9)		(4.9)		(5.0)	(5.0)	(5.0)	(5.0)	(5.0)
Mineral Soil	+		+		+	+	+	+	+
Settlements Converted to Forest Land	**(41.1)**		**(41.4)**		**(41.7)**	**(41.7)**	**(41.7)**	**(41.7)**	**(41.7)**
Aboveground Biomass	(24.7)		(24.9)		(25.0)	(25.1)	(25.1)	(25.1)	(25.1)
Belowground Biomass	(4.8)		(4.9)		(4.9)	(4.9)	(4.9)	(4.9)	(4.9)

[32] The estimates reported in this section only include the 48 conterminous states in the US. Land use conversion to forest in Alaska and Hawaii were not included.

Dead Wood	(4.8)	(4.8)	(4.8)	(4.8)	(4.8)	(4.8)	(4.8)
Litter	(6.7)	(6.7)	(6.7)	(6.7)	(6.7)	(6.7)	(6.7)
Mineral Soil	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Wetlands Converted to Forest Land	**(1.4)**	**(1.5)**	**(1.5)**	**(1.5)**	**(1.5)**	**(1.5)**	**(1.5)**
Aboveground Biomass	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
Belowground Biomass	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Dead Wood	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Litter	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
Mineral Soil	+	+	+	+	+	+	+
Total Aboveground Biomass Flux	**(66.8)**	**(67.5)**	**(67.8)**	**(67.9)**	**(67.9)**	**(67.9)**	**(67.9)**
Total Belowground Biomass Flux	**(12.9)**	**(13.0)**	**(13.1)**	**(13.1)**	**(13.1)**	**(13.1)**	**(13.1)**
Total Dead Wood Flux	**(14.1)**	**(14.2)**	**(14.3)**	**(14.3)**	**(14.3)**	**(14.3)**	**(14.3)**
Total Litter Flux	**(25.0)**	**(25.3)**	**(25.4)**	**(25.5)**	**(25.5)**	**(25.5)**	**(25.5)**
Total Mineral Soil Flux	**(0.2)**	**0.1**	**0.2**	**0.2**	**0.1**	**+**	**0.1**
Total Flux	**(119.1)**	**(120.0)**	**(120.5)**	**(120.5)**	**(120.6)**	**(120.6)**	**(120.6)**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net uptake. These estimates only include land conversions in the CONUS–land conversions in Alaska and Hawaii were not included in this Inventory.

Table 6-27: Net C Flux from Forest C Pools in *Land Converted to Forest Land* by Land Use Change Category (MMT C)

Land Use/Carbon Pool	1990	2005	2013	2014	2015	2016	2017
Cropland Converted to Forest Land	**(12.9)**	**(13.0)**	**(13.1)**	**(13.1)**	**(13.1)**	**(13.1)**	**(13.1)**
Aboveground Biomass	(7.3)	(7.4)	(7.4)	(7.4)	(7.4)	(7.4)	(7.4)
Belowground Biomass	(1.4)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)
Dead Wood	(1.7)	(1.7)	(1.7)	(1.7)	(1.7)	(1.7)	(1.7)
Litter	(2.4)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)
Mineral Soil	(0.1)	(0.1)	+	+	+	+	+
Grassland Converted to Forest Land	**(3.0)**	**(3.0)**	**(3.0)**	**(3.0)**	**(3.0)**	**(3.0)**	**(3.0)**
Aboveground Biomass	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)
Belowground Biomass	(0.2)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
Dead Wood	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Litter	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)
Mineral Soil	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other Land Converted to Forest Land	**(4.9)**	**(5.0)**	**(5.0)**	**(5.0)**	**(5.0)**	**(5.0)**	**(5.0)**
Aboveground Biomass	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)
Belowground Biomass	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
Dead Wood	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)
Litter	(1.3)	(1.3)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)
Mineral Soil	+	+	+	+	+	+	+
Settlements Converted to Forest Land	**(11.2)**	**(11.3)**	**(11.4)**	**(11.4)**	**(11.4)**	**(11.4)**	**(11.4)**
Aboveground Biomass	(6.7)	(6.8)	(6.8)	(6.8)	(6.8)	(6.8)	(6.8)
Belowground Biomass	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)
Dead Wood	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)
Litter	(1.8)	(1.8)	(1.8)	(1.8)	(1.8)	(1.8)	(1.8)
Mineral Soil	+	+	(0.1)	+	+	+	+
Wetlands Converted to Forest Land	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**
Aboveground Biomass	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Belowground Biomass	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Dead Wood	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Litter	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Mineral Soil	+	+	+	+	+	+	+
Total Aboveground Biomass Flux	**(18.2)**	**(18.4)**	**(18.5)**	**(18.5)**	**(18.5)**	**(18.5)**	**(18.5)**
Total Belowground Biomass Flux	**(3.5)**	**(3.5)**	**(3.6)**	**(3.6)**	**(3.6)**	**(3.6)**	**(3.6)**
Total Dead Wood Flux	**(3.8)**	**(3.9)**	**(3.9)**	**(3.9)**	**(3.9)**	**(3.9)**	**(3.9)**
Total Litter Flux	**(6.8)**	**(6.9)**	**(6.9)**	**(6.9)**	**(6.9)**	**(6.9)**	**(6.9)**
Total Mineral Soil Flux	**(0.1)**	**+**	**+**	**0.1**	**+**	**+**	**+**
Total Flux	**(32.5)**	**(32.7)**	**(32.9)**	**(32.9)**	**(32.9)**	**(32.9)**	**(32.9)**

+ Absolute value does not exceed 0.05 MMT C.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net uptake. These estimates only include land conversions in the CONUS–land conversions in Alaska and Hawaii were not included in this Inventory.

Methodology

The following section includes a description of the methodology used to estimate stock changes in all forest C pools for *Land Converted to Forest Land*. National Forest Inventory data and IPCC (2006) defaults for reference C stocks were used to compile separate estimates for the five C storage pools. Estimates for Aboveground and Belowground Biomass, Dead Wood and Litter were based on data collected from the extensive array of permanent, annual NFI plots and associated models (e.g., live tree belowground biomass estimates) in the United States (USDA Forest Service 2018b, 2018c). Carbon conversion factors were applied at the individual plot and then appropriately expanded to population estimates. To ensure consistency in the *Land Converted to Forest Land* category where C stock transfers occur between land-use categories, all soil estimates are based on methods from Ogle et al. (2003, 2006) and IPCC (2006).

The methods used for estimating carbon stocks and stock changes in the *Land Converted to Forest Land* are consistent with those used for *Forest Land Remaining Forest Land*. For land use conversion, IPCC (2006) default biomass C stocks removed due to land use conversion from Croplands and Grasslands were used in the year of conversion on individual plots. All annual NFI plots available through May 2018 were used in this Inventory. This may result in inconsistencies with the other land use categories and the area estimates reported in the Land Representation since new area activity data were not compiled for the other land use categories in this Inventory (see Section 6.1 Representation of the U.S. Land Base). Forest Land conditions were observed on NFI plots at time t_0 and at a subsequent time $t_1=t_0+s$, where s is the time step (time measured in years) and is indexed by discrete (e.g., 5 year) forest age classes. The inventory from t_0 was then projected from t_1 to 2017. This projection approach requires simulating changes in the age-class distribution resulting from forest aging and disturbance events and then applying C density estimates for each age class to obtain population estimates for the nation.

Carbon in Biomass

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at breast height (dbh) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates were made for above and belowground biomass components. If inventory plots included data on individual trees, above- and belowground tree C was based on Woodall et al. (2011a), which is also known as the component ratio method (CRM), and is a function of volume, species, and diameter. An additional component of foliage, which was not explicitly included in Woodall et al. (2011a), was added to each tree following the same CRM method.

Understory vegetation is a minor component of biomass and is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For the current Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density were based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). Understory biomass represented over one percent of C in biomass, but its contribution rarely exceeded 2 percent of the total.

Biomass losses associated with conversion from Grassland and Cropland to Forest Land were assumed to occur in the year of conversion. To account for these losses, IPCC (2006) defaults for aboveground and belowground biomass on Grasslands and aboveground biomass on Croplands were subtracted from sequestration in the year of the conversion. For all other land use (i.e., Other Lands, Settlements, Wetlands) conversions to Forest Land no biomass loss data were available and no IPCC (2006) defaults currently exist to include transfers, losses, or gains of carbon in the year of the conversion so none were incorporated for these conversion categories. As defaults or country-specific data become available for these conversion categories they will be incorporated.

Carbon in Dead Organic Matter

Dead organic matter was initially calculated as three separate pools—standing dead trees, downed dead wood, and litter—with C stocks estimated from sample data or from models. The standing dead tree C pool includes aboveground and belowground (coarse root) biomass for trees of at least 12.7 cm dbh. Calculations followed the basic method applied to live trees (Woodall et al. 2011a) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). Downed dead wood estimates are based on measurement of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008; Woodall et al. 2013). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. A modeling approach, using litter C measurements from FIA plots (Domke et al. 2016) was used to estimate litter C for every FIA plot used in the estimation framework.

Mineral Soil Carbon Stock Changes

A Tier 2 method is applied to estimate mineral soil C stock changes for *Land Converted to Forest Land* (Ogle et al. 2003, 2006; IPCC 2006). For this method, land is stratified by climate, soil types, land use, and land management activity, and then assigned reference carbon levels and factors for the forest land and the previous land use. The difference between the stocks is reported as the stock change under the assumption that the change occurs over 20 years. Reference C stocks have been estimated from data in the National Soil Survey Characterization Database (USDA-NRCS 1997), and U.S.-specific stock change factors have been derived from published literature (Ogle et al. 2003, 2006). Land use and land use change patterns are determined from a combination of the Forest Inventory and Analysis Dataset (FIA), the 2012 National Resources Inventory (NRI) (USDA-NRCS 2013), and National Land Cover Dataset (NLCD) (Homer et al. 2007). See Annex 3.12 (Methodology for Estimating N_2O Emissions, CH_4 Emissions and Soil Organic C Stock Changes from Agricultural Soil Management) for more information about this method. Note that soil C in this Inventory has historically been reported to a depth of 100 cm in the Forest Land Remaining Forest Land category (Domke et al. 2017) while other land-use categories report soil C to a depth of 20 or 30 cm. To ensure consistency in the Land Converted to Forest Land category "where C stock transfers occur between land-use categories, all soil C estimates were obtained using methods from Ogle et al. (2003, 2006) and IPCC (2006), which are also used in the Cropland, Grasslands and Settlements land use categories in this Inventory.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis placed bounds on the flux estimates for *Land Converted to Forest Land* through a combination of sample-based and model-based approaches to uncertainty for forest ecosystem CO_2 Eq. flux (IPCC Approach 1). Uncertainty estimates for forest pool C stock changes were developed using the same methodologies as described in the *Forest Land Remaining Forest Land* section for aboveground and belowground biomass, dead wood, and litter. The exception was when IPCC default estimates were used for reference C stocks in certain conversion categories (i.e., *Cropland Converted to Forest Land* and *Grassland Converted to Forest Land*). In those cases, the uncertainties associated with the IPCC (2006) defaults were included in the uncertainty calculations. IPCC Approach 2 was used for mineral soils and is described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-28 for each land conversion category and C pool. Uncertainty estimates were obtained using a combination of sample-based and model-based approaches for all non-soil C pools (IPCC Approach 1) and a Monte Carlo approach (IPCC Approach 2) was used for mineral soil. Uncertainty estimates were combined using the error propagation model (IPCC Approach 1). The combined uncertainty for all C stocks in *Land Converted to Forest Land* ranged from 9 percent below to 9 percent above the 2017 C stock change estimate of -120.6 MMT CO_2 Eq.

Table 6-28: Quantitative Uncertainty Estimates for Forest C Pool Stock Changes (MMT CO_2 Eq. per Year) in 2017 from *Land Converted to Forest Land* by Land Use Change

Land Use/Carbon Pool	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Range[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Forest Land	**(48.0)**	**(56.8)**	**(39.2)**	**-18%**	**18%**
Aboveground Biomass	(27.2)	(35.8)	(18.6)	-32%	32%
Belowground Biomass	(5.4)	(6.5)	(4.3)	-20%	20%

Dead Wood	(6.2)	(7.4)	(5.0)	-19%	20%
Litter	(9.1)	(10.2)	(8.1)	-12%	12%
Mineral Soils	(0.1)	(0.2)	+	-164%	159%
Grassland Converted to Forest Land	**(11.2)**	**(13.5)**	**(8.8)**	**21%**	**21%**
Aboveground Biomass	(5.7)	(7.1)	(4.3)	-25%	25%
Belowground Biomass	(0.9)	(1.2)	(0.6)	-31%	31%
Dead Wood	(0.7)	(0.8)	(0.5)	-22%	22%
Litter	(4.1)	(4.7)	(3.6)	-13%	13%
Mineral Soils	0.2	0.1	0.5	-73%	78%
Other Lands Converted to Forest Land	**(18.3)**	**(20.6)**	**(16.0)**	**-13%**	**13%**
Aboveground Biomass	(9.2)	(11.3)	(7.1)	-23%	23%
Belowground Biomass	(1.7)	(2.2)	(1.3)	-25%	25%
Dead Wood	(2.4)	(2.9)	(1.8)	-24%	24%
Litter	(5.0)	(5.6)	(4.3)	-13%	13%
Mineral Soils	+	+	+	-85%	98%
Settlements Converted to Forest Land	**(41.7)**	**(48.2)**	**(35.2)**	**-16%**	**16%**
Aboveground Biomass	(25.1)	(31.2)	(18.9)	-25%	25%
Belowground Biomass	(4.9)	(6.2)	(3.6)	-27%	27%
Dead Wood	(4.8)	(6.0)	(3.7)	-24%	24%
Litter	(6.7)	(7.6)	(5.8)	-14%	14%
Mineral Soils	(0.2)	(0.2)	(0.1)	-23%	20%
Wetlands Converted to Forest Land	**(1.5)**	**(1.7)**	**(1.3)**	**-11%**	**11%**
Aboveground Biomass	(0.7)	(0.9)	(0.6)	-20%	20%
Belowground Biomass	(0.1)	(0.2)	(0.1)	-22%	22%
Dead Wood	(0.2)	(0.2)	(0.1)	-27%	27%
Litter	(0.5)	(0.5)	(0.4)	-13%	13%
Mineral Soils	+	+	+	-84%	95%
Total: Aboveground Biomass	**(67.9)**	**(78.8)**	**(57.0)**	**-16%**	**16%**
Total: Belowground Biomass	**(13.1)**	**(14.9)**	**(11.3)**	**-14%**	**14%**
Total: Dead Wood	**(14.3)**	**(16.1)**	**(12.5)**	**-12%**	**12%**
Total: Litter	**(25.5)**	**(27.1)**	**(23.8)**	**-6%**	**6%**
Total: Mineral Soils	**0.1**	**(0.2)**	**0.3**	**-358%**	**372%**
Total: Lands Converted to Forest Lands	**(120.6)**	**(131.9)**	**(109.3)**	**-9%**	**9%**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
[a] Range of flux estimate for 95 percent confidence interval
Note: Parentheses indicate net uptake.

QA/QC and Verification

See QA/QC and Verification sections under *Forest land Remaining Forest Land* and for mineral soil estimates *Cropland Remaining Cropland.*

Recalculations Discussion

The approach for estimating carbon stock changes in *Land Converted to Forest Land* is consistent with the methods used for *Forest Land Remaining Forest Land* and is described in Annex 3.13. The *Land Converted to Forest Land* estimates in this Inventory are based on the land use change information in the annual NFI. All conversions are based on empirical estimates compiled using plot remeasurements from the NFI, IPCC (2006) default biomass C stocks removed from Croplands and Grasslands in the year of conversion on individual plots and the Tier 2 method for estimating mineral soil C stock changes (Ogle et al. 2003, 2006; IPCC 2006). All annual NFI plots available through May 2018 were used in this Inventory. This may result in inconsistencies with other land use categories reported in the Land Representation since new area activity data were not compiled for the current Inventory (see Section 6.1 Representation of the U.S. Land Base). This is the first year that remeasurement data from the annual NFI were available throughout the CONUS (with the exception of Wyoming and western Oklahoma) to estimate land use conversion. The availability of remeasurement data from the annual NFI allowed for consistent plot-level estimation of C stocks and stock changes for *Forest Land Remaining Forest Land* and the *Land Converted to Forest Land* categories. Estimates in the previous Inventory were based on state-level carbon density estimates and a combination of NRI data and NFI data in the eastern U.S. The refined analysis in this Inventory resulted in changes in the *Land Converted to Forest Land* categories. Overall, the *Land Converted to Forest Land* C stock changes increased by 38 percent in 2016 between the previous Inventory and the current Inventory (Table 6-29). This increase is directly attributed to the incorporation of annual NFI data into the compilation system. In the previous Inventory, *Grasslands Converted to Forest* Land represented the largest transfer and uptake of C across the land use conversion categories. In this Inventory, *Cropland Converted to Forest Land* represented the largest transfer and uptake of C across the land use change categories followed by *Settlements Converted to Forest Land* (Table 6-29).

Table 6-29: Recalculations of the Net C Flux from Forest C Pools in Land Converted to Forest Land by Land Use Change Category (MMT C)

Conversion category and Carbon pool (MMT C)	2016 Estimate, Previous Inventory	2016 Estimate, Current Inventory	2017 Estimate, Current Inventory
Cropland Converted to Forest Land	**(3.2)**	**(13.1)**	**(13.1)**
Aboveground Biomass	(1.3)	(7.4)	(7.4)
Belowground Biomass	(0.1)	(1.5)	(1.5)
Dead Wood	(0.7)	(1.7)	(1.7)
Litter	(1.1)	(2.5)	(2.5)
Mineral soil	+	+	+
Grassland Converted to Forest Land	**(13.7)**	**(3.0)**	**(3.0)**
Aboveground Biomass	(7.0)	(1.5)	(1.5)
Belowground Biomass	1.6	(0.3)	(0.3)
Dead Wood	(3.1)	(0.2)	(0.2)
Litter	(5.2)	(1.1)	(1.1)
Mineral soil	+	0.1	0.1
Other Land Converted to Forest Land	**(2.5)**	**(5.0)**	**(5.0)**
Aboveground Biomass	(1.1)	(2.5)	(2.5)
Belowground Biomass	(0.2)	(0.5)	(0.5)
Dead Wood	(0.4)	(0.6)	(0.6)
Litter	(0.7)	(1.4)	(1.4)
Mineral soil	+	+	+
Settlements Converted to Forest Land	**(0.5)**	**(11.4)**	**(11.4)**
Aboveground Biomass	(0.2)	(6.8)	(6.8)
Belowground Biomass	(0.0)	(1.3)	(1.3)
Dead Wood	(0.1)	(1.3)	(1.3)
Litter	(0.1)	(1.8)	(1.8)
Mineral soil	+	+	+
Wetlands Converted to Forest Land	**(0.6)**	**(0.4)**	**(0.4)**
Aboveground Biomass	(0.28)	(0.19)	(0.19)
Belowground Biomass	(0.05)	(0.04)	(0.04)
Dead Wood	(0.09)	(0.04)	(0.04)
Litter	(0.19)	(0.13)	(0.13)
Mineral soil	+	+	+
Total Aboveground Biomass Flux	**(9.9)**	**(18.5)**	**(18.5)**
Total Belowground Biomass Flux	**1.2**	**(3.6)**	**(3.6)**
Total Dead Wood Flux	**(4.3)**	**(3.9)**	**(3.9)**
Total Litter Flux	**(7.4)**	**(6.9)**	**(6.9)**
Total SOC (mineral) Flux	**+**	**+**	**+**
Total Flux	**(20.5)**	**(32.9)**	**(32.9)**

\+ Absolute value does not exceed 0.05 MMT C.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net uptake.

Planned Improvements

There are many improvements necessary to improve the estimation of carbons stock changes associated with land use conversion to forest land over the entire time series. First, soil C has historically been reported to a depth of 100 cm in the *Forest Land Remaining Forest Land* category (Domke et al. 2017) while other land-use categories (e.g., Grasslands and Croplands) report soil carbon to a depth of 20 or 30 cm. To ensure greater consistency in the *Land*

Converted to Forest Land category where C stock transfers occur between land-use categories, all mineral soil estimates in the *Land Converted to Forest Land* category in this Inventory are based on methods from Ogle et al. (2003, 2006) and IPCC (2006). Methods have recently been developed (Domke et al. 2017) to estimate soil C to depths of 20, 30, and 100 cm in the Forest Land category using in situ measurements from the Forest Inventory and Analysis program within the USDA Forest Service and the International Soil Carbon Network. In subsequent Inventories, a common reporting depth will be defined for all land use conversion categories and Domke et al. (2017) will be used in the *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* categories to ensure consistent reporting across all forest land. Third, due to the 5 to 10-year remeasurement periods within the FIA program and limited land use change information available over the entire time series, estimates presented in this section may not reflect the entire 20-year conversion history. Work is underway to integrate the dense time series of remotely sensed data into a new estimation system, which will facilitate land conversion estimation over the entire time series. A section on N_2O emissions from forest soils that includes estimates of the N_2O from mineralization of soil C will be provided in the next Inventory.

6.4 Cropland Remaining Cropland (CRF Category 4B1)

Carbon (C) in cropland ecosystems occurs in biomass, dead organic matter, and soils. However, C storage in cropland biomass and dead organic matter is relatively ephemeral and may not need to be reported according to the IPCC (2006), with the exception of C stored in perennial woody crop biomass, such as citrus groves and apple orchards, and the biomass, downed wood and dead organic matter in agroforestry systems. Within soils, C is found in organic and inorganic forms of C, but soil organic C (SOC) is the main source and sink for atmospheric CO_2 in most soils. IPCC (2006) recommends reporting changes in SOC stocks due to agricultural land-use and management activities on both mineral and organic soils.[33]

Well-drained mineral soils typically contain from 1 to 6 percent organic C by weight, whereas mineral soils with high water tables for substantial periods during the year may contain significantly more C (NRCS 1999). Conversion of mineral soils from their native state to agricultural land uses can cause up to half of the SOC to be lost to the atmosphere due to enhanced microbial decomposition. The rate and ultimate magnitude of C loss depends on subsequent management practices, climate and soil type (Ogle et al. 2005). Agricultural practices, such as clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, application of biosolids (i.e., sewage sludge) and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net C stock change (Parton et al. 1987; Paustian et al. 1997a; Conant et al. 2001; Ogle et al. 2005). Eventually, the soil can reach a new equilibrium that reflects a balance between C inputs (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and C loss through microbial decomposition of organic matter (Paustian et al. 1997b).

Organic soils, also referred to as *Histosols*, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999; Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that results in minimal decomposition of plant residues. When organic soils are prepared for crop production, they are drained and tilled, leading to aeration of the soil that accelerates both the decomposition rate and CO_2 emissions.[34] Due to the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time, which varies depending on climate and composition (i.e., decomposability) of the organic matter (Armentano and Menges 1986). Due to deeper drainage and more intensive management practices, the use of organic soils for annual crop production (and also settlements) leads to higher C loss rates than drainage of organic soils in grassland or forests (IPCC 2006).

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[33] Carbon dioxide emissions associated with liming and urea application are also estimated but are included in the Agriculture chapter of the report.

[34] N_2O emissions from soils are included in the Agricultural Soil Management section.

Cropland Remaining Cropland includes all cropland in an Inventory year that has been cropland for a continuous time period of at least 20 years according to the 2012 United States Department of Agriculture (USDA) National Resources Inventory (NRI) land-use survey for non-federal lands (USDA-NRCS 2015) or according to the National Land Cover Dataset for federal lands (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015). Cropland includes all land used to produce food and fiber, in addition to forage that is harvested and used as feed (e.g., hay and silage), and cropland that has been enrolled in the Conservation Reserve Program (CRP) (i.e., considered reserve cropland). Cropland in Alaska is not included in the Inventory, but is a relatively small amount of U.S. cropland area (approximately 28,700 hectares). Some miscellaneous croplands are also not included in the Inventory due to limited understanding of greenhouse gas emissions from these management systems (e.g., aquaculture). This leads to a small discrepancy between the total amount of managed area in *Cropland Remaining Cropland* (see Section 6.1 Representation of the U.S. Land Base) and the cropland area included in the Inventory analysis.[35] Improvements are underway to include croplands in Alaska as part of future C inventories.

Carbon dioxide emissions and removals[36] due to changes in mineral soil C stocks are estimated using a Tier 3 method for the majority of annual crops (Ogle et al. 2010). A Tier 2 IPCC method is used for the remaining crops not included in the Tier 3 method (see Methodology section for a list of crops in the Tier 2 and 3 methods) (Ogle et al. 2003, 2006). In addition, a Tier 2 method is used for very gravelly, cobbly, or shaley soils (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles, or shale, regardless of crop). Emissions from organic soils are estimated using a Tier 2 IPCC method. While a combination of Tier 2 and 3 methods are used to estimate C stock changes across most of the time series, a surrogate data method has been applied to estimate stock changes in the last few years of the Inventory. Stock change estimates based on surrogate data will be recalculated in a future Inventory report using the Tier 2 and 3 methods.

Land-use and land management of mineral soils are the largest contributor to total net C stock change, especially in the early part of the time series (see Table 6-30 and Table 6-31). In 2017, mineral soils are estimated to sequester 40.0 MMT CO_2 Eq. from the atmosphere (10.9 MMT C). This rate of C storage in mineral soils represents about a 44 percent decrease in the rate since the initial reporting year of 1990. Carbon dioxide emissions from organic soils are 29.7 MMT CO_2 Eq. (8.1 MMT C) in 2017, which is a 2 percent decrease compared to 1990. In total, United States agricultural soils in *Cropland Remaining Cropland* sequestered approximately 10.3 MMT CO_2 Eq. (2.8 MMT C) in 2017.

Table 6-30: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT CO_2 Eq.)

Soil Type	1990		2005		2013	2014	2015	2016	2017
Mineral Soils	(71.2)		(56.2)		(41.5)	(41.7)	(36.3)	(39.7)	(40.0)
Organic Soils	30.3		29.7		30.1	29.7	30.0	29.8	29.7
Total Net Flux	**(40.9)**		**(26.5)**		**(11.4)**	**(12.0)**	**(6.3)**	**(9.9)**	**(10.3)**

Note: Parentheses indicate net sequestration.

Table 6-31: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT C)

Soil Type	1990		2005		2013	2014	2015	2016	2017
Mineral Soils	(19.4)		(15.3)		(11.3)	(11.4)	(9.9)	(10.8)	(10.9)
Organic Soils	8.3		8.1		8.2	8.1	8.2	8.1	8.1
Total Net Flux	**(11.2)**		**(7.2)**		**(3.1)**	**(3.3)**	**(1.7)**	**(2.7)**	**(2.8)**

[35] For the U.S. land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for croplands through the process of combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for croplands with the new land representation data so the area estimates in this section are based on the land representation data from the previous Inventory. This has created additional discrepancies with the reported cropland areas in the "Representation of the U.S. Land Base" section.

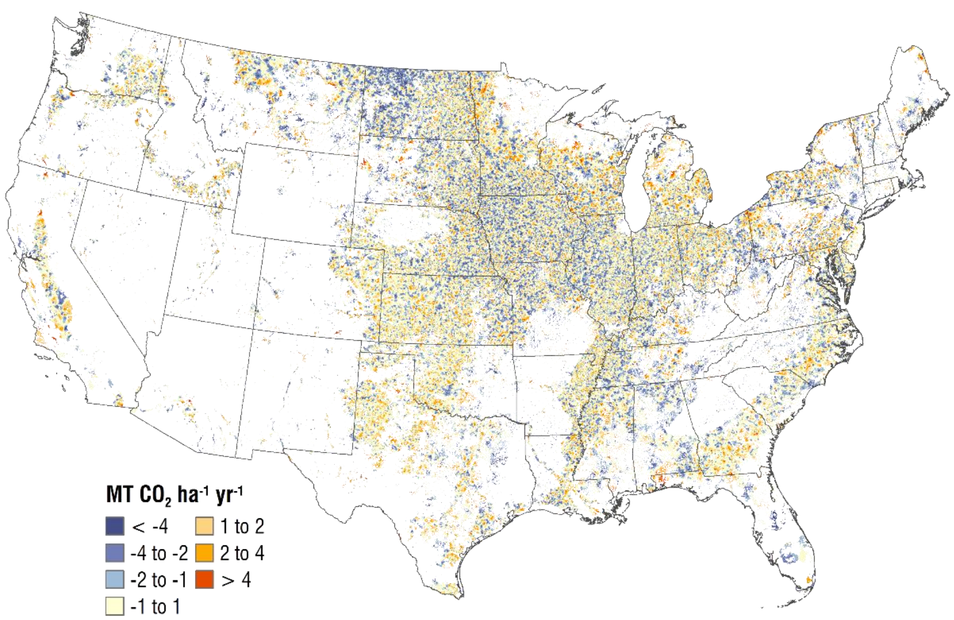
[36] Removals occur through uptake of CO_2 into crop and forage biomass that is later incorporated into soil C pools.

Note: Parentheses indicate net sequestration.

Soil C stocks increase in *Cropland Remaining Cropland* largely due to sequestration in lands enrolled in CRP (i.e., set-aside program), as well as from conversion of land into hay production, adoption of conservation tillage (i.e., reduced- and no-till practices), and intensification of crop production by limiting the use of bare-summer fallow in semi-arid regions. However, there is a decline in the net amount of C sequestration (i.e., 2017 is 44 percent less than 1990), and this decline is largely due to lower sequestration rates and less annual cropland enrolled in the CRP[37] that was initiated in 1985. Soil C losses from drainage of organic soils are relatively stable across the time series with a small decline associated with the land base declining by 7 percent (based on 2012 estimates) for *Cropland Remaining Cropland* on organic soils since 1990.

The spatial variability in the 2012 annual soil C stock changes[38] are displayed in Figure 6-5 and Figure 6-6 for mineral and organic soils, respectively. Isolated areas with high rates of C accumulation occur throughout the agricultural land base in the United States, but there are more concentrated areas with gains in the northern Great Plains, which has high rates of CRP enrollment. High rates of net C accumulation in mineral soils also occurred in the Corn Belt region, which is the region with the largest amounts of conservation tillage, along with moderate rates of CRP enrollment. The regions with the highest rates of emissions from drainage of organic soils occur in the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and isolated areas along the Pacific Coast (particularly California), which coincides with the largest concentrations of organic soils in the United States that are used for agricultural production.

Figure 6-5: Total Net Annual Soil C Stock Changes for Mineral Soils under Agricultural Management within States, 2012, *Cropland Remaining Cropland*



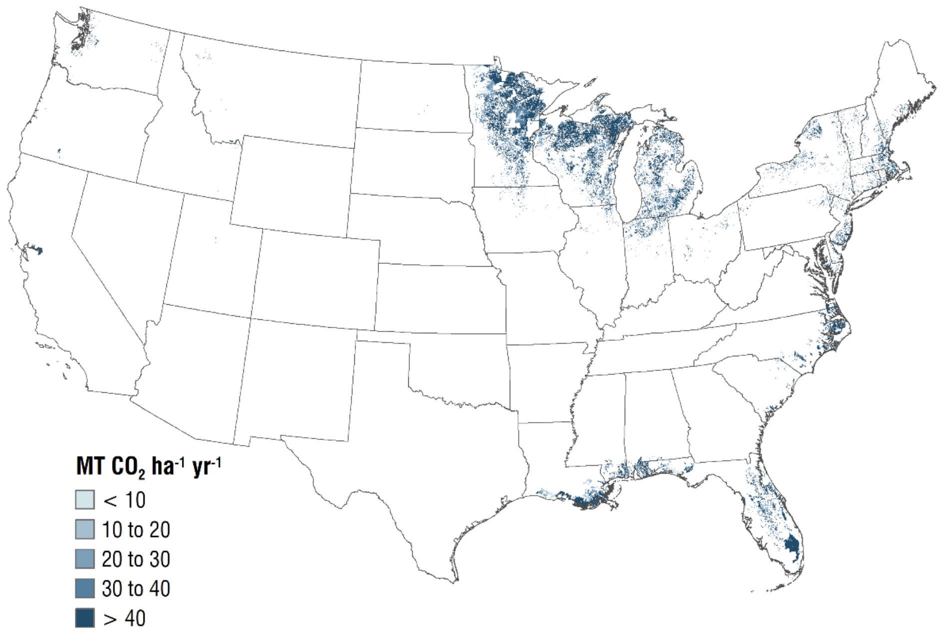
Note: Only national-scale soil C stock changes are estimated for 2013 to 2017 in the current Inventory using a surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from

[37] The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10 to 15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat.

[38] Only national-scale emissions are estimated for 2013 to 2017 in this Inventory using the surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from 2012.

2012. Negative values represent a net increase in soil C stocks, and positive values represent a net decrease in soil C stocks.

Figure 6-6: Total Net Annual Soil C Stock Changes for Organic Soils under Agricultural Management within States, 2012, *Cropland Remaining Cropland*



Note: Only national-scale soil C stock changes are estimated for 2013 to 2017 in the current Inventory using a surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from 2012.

Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks for *Cropland Remaining Cropland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils.

Soil C stock changes on non-federal lands are estimated for *Cropland Remaining Cropland* (as well as agricultural land falling into the IPCC categories *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*) according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2015). The NRI is a statistically-based sample of all non-federal land, and includes approximately 609,211 survey locations in agricultural land for the conterminous United States and Hawaii. Each survey location is associated with an "expansion factor" that allows scaling of C stock changes from NRI survey locations to the entire country (i.e., each expansion factor represents the amount of area with the same land-use/management history as the sample point). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning from 1982 through 1997. For cropland, data had been collected for 4 out of 5 years during each survey cycle (i.e., 1979 through 1982, 1984 through 1987, 1989 through 1992, and 1994 through 1997). In 1998, the NRI program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). NRI survey locations are classified as *Cropland Remaining Cropland* in a given year between 1990 and 2012 if the land use had been cropland for a continuous time period of at least 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an overestimation of *Cropland Remaining Cropland* in the early part of the time series to the extent that some areas are converted to cropland between 1971 and 1978.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, lentils, oats, onions, peanuts, peas, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tobacco, tomatoes, and wheat, but is not applied to estimate C stock changes from other crops or rotations with other crops. The model-based approach uses the DAYCENT biogeochemical model (Parton et al. 1998; Del Grosso et al. 2001, 2011) to estimate soil C stock changes and soil nitrous oxide (N_2O) emissions from agricultural soil management. Carbon and N dynamics are linked in plant-soil systems through the biogeochemical processes of microbial decomposition and plant production (McGill and Cole 1981). Coupling the two source categories (i.e., agricultural soil C and N_2O) in a single inventory analysis ensures that there is a consistent treatment of the processes and interactions between C and N cycling in soils.

The remaining crops on mineral soils are estimated using an IPCC Tier 2 method (Ogle et al. 2003), including some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops. The Tier 2 method is also used for very gravelly, cobbly, or shaley soils (greater than 35 percent by volume), and soil C stock changes on federal croplands. Mineral SOC stocks are estimated using a Tier 2 method for these areas because the DAYCENT model, which is used for the Tier 3 method, has not been fully tested for estimating C stock changes associated with these crops and rotations, as well as cobbly, gravelly, or shaley soils. In addition, there is insufficient information to simulate croplands on federal lands using DAYCENT. Further elaboration on the methodology and data used to estimate stock changes from mineral soils are described below and in Annex 3.12.

A surrogate data method is used to estimate soil C stock changes from 2013 to 2017 at the national scale for land areas included in the Tier 2 and Tier 3 methods. Specifically, linear regression models with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) are used to estimate the relationship between surrogate data and the 1990 to 2012 stock change data that are derived using the Tier 2 and 3 methods. Surrogate data for these regression models include corn and soybean yields from USDA-NASS statistics,[39] and weather data from the PRISM Climate Group (PRISM 2015). See Box 6-4 for more information about the surrogate data method. Stock change estimates for 2013 to 2017 will be recalculated in future inventories when new NRI data are available.

Box 6-4: Surrogate Data Method

Time series extension is needed because there are typically gaps at the end of the time series. This is mainly because the NRI, which provides critical data for estimating greenhouse gas emissions and removals, does not release data every year.

A surrogate data method has been used to impute missing emissions at the end of the time series for soil C stock changes in *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. A linear regression model with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) is used to estimate the relationship between the surrogate data and the modeled 1990 to 2012 emissions data that has been compiled using the inventory methods described in this section. The model to extend the time series is given by

$$Y = X\beta + \varepsilon,$$

where Y is the response variable (e.g., soil organic carbon), $X\beta$ contains specific surrogate data depending on the response variable, and ε is the remaining unexplained error. Models with a variety of surrogate data were tested, including commodity statistics, weather data, or other relevant information. Parameters are estimated from the emissions data for 1990 to 2012 using standard statistical techniques, and these estimates are used to predict the missing emissions data for 2013 to 2017.

A critical issue in using splicing methods, is to adequately account for the additional uncertainty introduced by predicting emissions with related information without compiling the full inventory. Specifically, uncertainty will increase for years with imputed estimates based on the splicing methods, compared to those years in which the full inventory is compiled. This added uncertainty is quantified within the model framework using a Monte Carlo approach. The approach requires estimating parameters for results in each Monte Carlo simulation for the full

[39] See <https://quickstats.nass.usda.gov/>.

inventory (i.e., the surrogate data model is refit with the emissions estimated in each Monte Carlo iteration from the full inventory analysis with data from 1990 to 2012), estimating emissions from each model and deriving confidence intervals, which propagates uncertainties through the calculations from the original inventory and the surrogate data method.

Tier 3 Approach. Mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical[40] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), which is able to simulate cycling of C, N, and other nutrients in cropland, grassland, forest, and savanna ecosystems. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. The modeling approach uses daily weather data as an input, along with information about soil physical properties. Input data on land use and management are specified at a daily resolution and include land-use type, crop/forage type, and management activities (e.g., planting, harvesting, fertilization, manure amendments, tillage, irrigation, and grazing). The model simulates net primary productivity (NPP) using the NASA-CASA production algorithm MODIS Enhanced Vegetation Index (EVI) products, MOD13Q1 and MYD13Q1, for most croplands[41] (Potter et al. 1993, 2007). The model also simulates soil temperature, and water dynamics, in addition to turnover, stabilization, and mineralization of soil organic matter C and nutrients (N, P, K, S). This method is more accurate than the Tier 1 and 2 approaches provided by the IPCC (2006) because the simulation model treats changes as continuous over time as opposed to the simplified discrete changes represented in the default method (see Box 6-5 for additional information).

Box 6-5: Tier 3 Approach for Soil C Stocks Compared to Tier 1 or 2 Approaches

A Tier 3 model-based approach is used to estimate soil C stock changes on the majority of agricultural land on mineral soils. This approach results in a more complete and accurate accounting of soil C stock changes and entails several fundamental differences from the IPCC Tier 1 or 2 methods, as described below.

(1) The IPCC Tier 1 and 2 methods are simplified approaches for estimating soil C stock changes and classify land areas into discrete categories based on highly aggregated information about climate (six regions), soil (seven types), and management (eleven management systems) in the United States. In contrast, the Tier 3 model incorporates the same variables (i.e., climate, soils, and management systems) with considerably more detail both temporally and spatially, and captures multi-dimensional interactions through the more complex model structure.

(2) The IPCC Tier 1 and 2 methods have a coarser spatial resolution in which data are aggregated to soil types in climate regions, of which there about 30 of combinations in the United States. In contrast, the Tier 3 model simulates soil C dynamics at more than 300,000 individual NRI survey locations in individual fields.

(3) The IPCC Tier 1 and 2 methods use a simplified approach to estimating changes in C stocks that assumes a step-change from one equilibrium level of the C stock to another equilibrium level. In contrast, the Tier 3 approach simulates a continuum of C stock changes that may reach a new equilibrium over an extended period of time depending on the environmental conditions (i.e., a new equilibrium often requires hundreds to thousands of years to reach). More specifically, the DAYCENT model (i.e., daily time-step version of the Century model) simulates soil C dynamics (and CO_2 emissions and uptake) on a daily time step based on C emissions and removals from plant production and decomposition processes. These changes in soil C stocks are influenced by multiple factors that affect primary production and decomposition, including changes in land use and management, weather variability and secondary feedbacks between management activities, climate, and soils.

[40] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

[41] NPP is estimated with the NASA-CASA algorithm for most of the cropland that is used to produce major commodity crops in the central United States from 2000 to 2012. Other regions and years prior to 2000 are simulated with a method that incorporates water, temperature and moisture stress on crop production (see Metherell et al. 1993), but does not incorporate the additional information about crop condition provided with remote sensing data.

Historical land-use patterns and irrigation histories are simulated with DAYCENT based on the 2012 USDA NRI survey (USDA-NRCS 2015). Additional sources of activity data are used to supplement the land-use information from the NRI. The Conservation Technology Information Center (CTIC 2004) provided annual data on tillage activity at the county level for the conterminous United States between 1989 and 2004, and these data are adjusted for long-term adoption of no-till agriculture (Towery 2001). No-till adoption is assumed to remain constant from 2005 through 2012 due to lack of data, but there is a planned improvement to update the tillage histories with a dataset that was recently released by the USDA (Conservation Effects Assessment Program Data, See Planned Improvements section). Information on fertilizer use and rates by crop type for different regions of the United States are obtained primarily from the USDA Economic Research Service. The data collection program was known as the Cropping Practices Surveys through 1995 (USDA-ERS 1997), and then became the Agricultural Resource Management Surveys (ARMS) (USDA-ERS 2015). Additional data are compiled through other sources particularly the National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to cropland for 1997 are estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 are used to adjust the area amended with manure (see Annex 3.12 for further details). Greater availability of managed manure N relative to 1997 is assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 is assumed to reduce the amended area. Data on the county-level N available for application are estimated for managed systems based on the total amount of N excreted in manure minus N losses during storage and transport, and include the addition of N from bedding materials. Nitrogen losses include direct N_2O emissions, volatilization of ammonia and NO_x, N runoff and leaching, and the N in poultry manure used as a feed supplement. More information on livestock manure production is available in Section 5.2 Manure Management and Annex 3.11.

Daily weather data are another input to the model simulations. These data are based on a 4 kilometer gridded product from the PRISM Climate Group (2015). Soil attributes are obtained from the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2016). The C dynamics at each NRI point are simulated 100 times as part of the uncertainty analysis, yielding a total of over 18 million simulation runs for the analysis. Uncertainty in the C stock estimates from DAYCENT associated with parameterization and model algorithms are adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values (Ogle et al. 2007, 2010). Carbon stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2012 using the NRI survey data (which is available through 2012). However, the areas may have changed through the process in which the NRI survey data are reconciled with the Forest Inventory and Analysis (FIA) survey data and the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015). This process ensures that the areas of *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* are consistent in all three datasets, and leads to some modification of other lands use areas to ensure the total land area of the United States does not change. For example, if the FIA estimate less *Cropland Converted to Forest Land* than the NRI, then the amount of area for this land use conversion is reduced in the NRI dataset and re-classified as *Cropland Remaining Cropland* (See Section 6.1, Representation of the U.S. Land Base for more information).

Soil C stock changes from 2013 to 2017 are estimated using a surrogate data method that is described in Box 6-4. Future Inventories will be updated with new NRI activity data when the data are made available, and the time series from 2013 to 2017 will be recalculated.

Tier 2 Approach. In the IPCC Tier 2 method, data on climate, soil types, land-use, and land management activity are used to classify land area and apply appropriate soil C stock change factors (Ogle et al. 2003, 2006). Reference C stocks are estimated using the National Soil Survey Characterization Database (NRCS 1997) with cultivated cropland as the reference condition, rather than native vegetation as used in IPCC (2006). Soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (NRCS 1997) than are soils under a native condition, and therefore cultivated cropland provided a more robust sample for estimating the reference condition. U.S.-specific C stock change factors are derived from published literature to determine the impact of management practices on SOC storage (Ogle et al. 2003, 2006). The factors include changes in tillage, cropping rotations, intensification, and land-use change between cultivated and uncultivated conditions. U.S. factors associated with organic matter amendments are not estimated due to an insufficient number of studies in the United States to analyze the impacts. Instead, factors from IPCC (2006) are used to estimate the effect of those activities.

Climate zones in the United States are classified using mean precipitation and temperature (1950 to 2000) variables from the WorldClim data set (Hijmans et al. 2005) and potential evapotranspiration data from the Consortium for Spatial Information (CGIAR-CSI) (Zomer et al. 2008, 2007) (Figure A-9). IPCC climate zones are then assigned to NRI point locations.

Activity data are primarily based on the historical land-use/management patterns recorded in the 2012 NRI (USDA-NRCS 2015). Each NRI point is classified by land use, soil type, climate region, and management condition. Survey locations on federal lands are included in the NRI, but land use and cropping history are not compiled at these locations in the survey program (i.e., NRI is restricted to data collection on non-federal lands). Land-use patterns at the NRI survey locations on federal lands are based on the National Land Cover Database (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). Classification of cropland area by tillage practice is based on data from the Conservation Technology Information Center (CTIC 2004; Towery 2001) as described in the Tier 3 approach above. Activity data on wetland restoration of Conservation Reserve Program land are obtained from Euliss and Gleason (2002). Manure N amendments over the inventory time period are based on application rates and areas amended with manure N from Edmonds et al. (2003), in addition to the managed manure production data discussed in the methodology subsection for the Tier 3 approach. Utilizing information from these data sources, SOC stocks for mineral soils are estimated 50,000 times for 1990 through 2012, using a Monte Carlo stochastic simulation approach and probability distribution functions for U.S.-specific stock change factors, reference C stocks, and land-use activity data (Ogle et al. 2002; Ogle et al. 2003; Ogle et al. 2006).

Soil C stock changes from 2013 to 2017 are estimated using a surrogate data method that is described in Box 6-4. As with the Tier 3 method, future Inventories will be updated with new NRI activity data when the data are made available, and the time series will be recalculated (see Planned Improvements section).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Cropland Remaining Cropland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo Stochastic Simulation with 50,000 iterations. Emissions are based on the annual data for drained organic soils from 1990 to 2012 for *Cropland Remaining Cropland* areas in the 2012 NRI (USDA-NRCS 2015). A surrogate data method is used to estimate annual C emissions from organic soils from 2013 to 2017 as described in Box 6-4 of this section. Estimates for 2013 to 2017 will be recalculated in future Inventories when new NRI data are available.

Uncertainty and Time-Series Consistency

Uncertainty associated with the *Cropland Remaining Cropland* land-use category is addressed for changes in agricultural soil C stocks (including both mineral and organic soils). Uncertainty estimates are presented in Table 6-32 for each subsource (mineral soil C stocks and organic soil C stocks) and the methods that are used in the Inventory analyses (i.e., Tier 2 and Tier 3). Uncertainty for the Tier 2 and 3 approaches is derived using a Monte Carlo approach (see Annex 3.12 for further discussion). For 2013 to 2017, there is additional uncertainty propagated through the Monte Carlo Analysis associated with the surrogate data method. Soil C stock changes from the Tier 2 and 3 approaches are combined using the simple error propagation method provided by the IPCC (2006). The combined uncertainty is calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Cropland Remaining Cropland* ranged from 423 percent below to 423 percent above the 2017 stock change estimate of -10.3 MMT CO_2 Eq. The large relative uncertainty around the 2017 stock change estimate is partly due to variation in soil C stock changes that are not explained by the surrogate data method, leading to high prediction error with this splicing method. The estimate is also near zero for the total emissions and the Tier 3 Inventory with a lower bound below zero and an upper bound above zero, leading to large relative uncertainty.

Table 6-32: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Cropland Remaining Cropland* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 3 Inventory Methodology	(36.5)	(79.8)	6.8	-119%	119%
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	(3.5)	(6.9)	(0.1)	-96%	96%
Organic Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	29.7	26.5	32.9	-11%	11%
Combined Uncertainty for Flux associated with Agricultural Soil Carbon Stock Change in Cropland Remaining Cropland	**(10.3)**	**(53.8)**	**33.2**	**-423%**	**423%**

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation with a 95 percent confidence interval.
Note: Parentheses indicate net sequestration.

Uncertainty is also associated with lack of reporting of agricultural woody biomass and dead organic matter C stock changes. The IPCC (2006) does not recommend reporting of annual crop biomass in *Cropland Remaining Cropland* because all of the biomass senesces each year and so there is no long-term storage of C in this pool. For woody plants, biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations. There will be some removal and replanting of tree crops each year, but the net effect on biomass C stock changes is probably minor because the overall area and tree density is relatively constant across time series. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may be significantly changing biomass C stocks over the Inventory time series, at least in some regions of the United States, but there are currently no datasets to evaluate the trends. Changes in litter C stocks are also assumed to be negligible in croplands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons. However, this trend may change in the future, particularly if crop residue becomes a viable feedstock for bioenergy production.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data are properly handled throughout the inventory process. Inventory reporting forms and text are reviewed and revised as needed to correct transcription errors. Results from the DAYCENT model are compared to field measurements, and a statistical relationship has been developed to assess uncertainties in the predictive capability of the model. The comparisons include 92 long-term experiments, representing about 908 combinations of management treatments across all of the sites (see Ogle et al. 2007 and Annex 3.12 for more information).

Planned Improvements

New land representation data have not been compiled for the current Inventory, and a surrogate data method has been applied to estimate emissions in the latter part of the time series, which introduces additional uncertainty in the emissions data. Therefore, a key improvement for a future Inventory will be to recalculate the time series for soil C stock changes by applying the Tier 2 and 3 methods with the latest land use data from the National Resources Inventory and related management statistics compiled through the Conservation Effects Assessment Program (discussed below).

There are several other planned improvements underway. The DAYCENT model will be refined to simulate soil organic C stock changes to a depth of at least 30 cm (currently at 20 cm). Improvements are also underway to more accurately simulate plant production. Crop parameters associated with temperature effects on plant production will be further improved in DAYCENT with additional model calibration. Senescence events following grain filling in crops, such as wheat, are being modified based on recent model algorithm development, and will be incorporated. Experimental study sites will continue to be added for quantifying model structural uncertainty.

There is an effort underway to update the time series of management data with information from the USDA-NRCS Conservation Effects Assessment Program (CEAP). This improvement will fill several gaps in the management data including more specific data on fertilizer rates, updated tillage practices, and more information on planting and harvesting dates for crops.

Improvements are underway to simulate crop residue burning in the DAYCENT model based on the amount of crop residues burned according to the data that are used in the Field Burning of Agricultural Residues source category (see Section 5.7). This improvement will more accurately represent the C inputs to the soil that are associated with residue burning.

In the future, the Inventory will include an analysis of C stock changes in Alaska for cropland and managed grassland, using the Tier 2 method for mineral and organic soils that is described earlier in this section. This analysis will initially focus on land use change, which typically has a larger impact on soil C stock changes, but will be further refined over time to incorporate more of the management data that drive C stock changes on long-term cropland.

Many of these improvements are expected to be completed for the next 1990 through 2018 Inventory (i.e., 2020 submission to the UNFCCC). However, the time line may be extended if there are insufficient resources to fund all or part of these planned improvements.

6.5 Land Converted to Cropland (CRF Category 4B2)

Land Converted to Cropland includes all cropland in an inventory year that had been in another land use(s) during the previous 20 years (USDA-NRCS 2015), and used to produce food or fiber, or forage that is harvested and used as feed (e.g., hay and silage). For example, grassland or forest land converted to cropland during the past 20 years would be reported in this category. Recently converted lands are retained in this category for 20 years as recommended by IPCC (2006). This Inventory includes all croplands in the conterminous United States and Hawaii, but does not include a minor amount of *Land Converted to Cropland* in Alaska. Some miscellaneous croplands are also not included in the Inventory due to limited understanding of greenhouse gas dynamics in management systems (e.g., aquaculture) or climate zones (e.g., boreal climates). Consequently, there is a discrepancy between the total amount of managed area in *Land Converted to Cropland* (see Section 6.1 Representation of the U.S. Land Base) and the cropland area included in the Inventory.[42] Improvements are underway to include croplands in Alaska and miscellaneous croplands in future C inventories.

Land use change can lead to large losses of C to the atmosphere, particularly conversions from forest land (Houghton et al. 1983). Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally (Schimel 1995), although this source may be declining according to a recent assessment (Tubiello et al. 2015).

The *2006 IPCC Guidelines* recommend reporting changes in biomass, dead organic matter and soil organic carbon (SOC) stocks with land use change. All SOC stock changes are estimated and reported for *Land Converted to*

[42] For the U.S. land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for croplands through the process of combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for croplands with the new land representation data so the area estimates in this section are based on the land representation data from the previous Inventory. This has created additional discrepancies with the reported cropland areas in the "Representation of the U.S. Land Base" section.

Cropland, but reporting of C stock changes for aboveground and belowground biomass, dead wood and litter pools is limited to *Forest Land Converted to Cropland*.[43]

Forest Land Converted to Cropland is the largest source of emissions from 1990 to 2017, accounting for approximately 70 percent of the average total loss of C among all of the land use conversions in *Land Converted to Cropland*. The pattern is due to the large losses of biomass and dead organic matter C for *Forest land Converted to Cropland*. The next largest source of emissions is *Grassland Converted to Cropland* with the majority of the loss occurring in the mineral soil C, accounting for approximately 28 percent of the total emissions (Table 6-33 and Table 6-34).

The net change in total C stocks for 2017 led to CO_2 emissions to the atmosphere of 66.9 MMT CO_2 Eq. (18.2 MMT C), including 27.2 MMT CO_2 Eq. (7.4 MMT C) from aboveground biomass C losses, 5.4 MMT CO_2 Eq. (1.5 MMT C) from belowground biomass C losses, 6.0 MMT CO_2 Eq. (1.6 MMT C) from dead wood C losses, 8.4 MMT CO_2 Eq. (2.3 MMT C) from litter C losses, 16.4 MMT CO_2 Eq. (4.5 MMT C) from mineral soils and 3.5 MMT CO_2 Eq. (0.9 MMT C) from drainage and cultivation of organic soils. Emissions in 2017 are 12 percent lower than the emissions in the initial reporting year of 1990, largely due to a reduction in the losses from *Grassland Converted to Cropland* and *Forest Land Converted to Cropland*.

Table 6-33: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes in *Land Converted to Cropland* by Land Use Change Category (MMT CO_2 Eq.)

	1990	2005	2013	2014	2015	2016	2017
Grassland Converted to Cropland	**24.5**	**17.3**	**18.0**	**17.9**	**17.8**	**18.4**	**18.0**
Mineral Soils	21.9	13.9	15.2	15.1	15.0	15.6	15.1
Organic Soils	2.5	3.3	2.9	2.8	2.8	2.8	2.8
Forest Land Converted to Cropland	**50.0**	**48.2**	**47.1**	**47.1**	**47.1**	**47.1**	**47.1**
Aboveground Live Biomass	28.9	27.9	27.3	27.2	27.2	27.2	27.2
Belowground Live Biomass	5.8	5.6	5.5	5.4	5.4	5.4	5.4
Dead Wood	6.3	6.1	6.0	6.0	6.0	6.0	6.0
Litter	8.8	8.5	8.4	8.4	8.4	8.4	8.4
Mineral Soils	0.2	0.1	+	+	+	0.1	0.1
Organic Soils	0.1	+	+	+	+	+	+
Other Lands Converted to Cropland	**0.3**	**0.3**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Mineral Soils	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Organic Soils	0.1	0.1	+	+	+	+	+
Settlements Converted to Cropland	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Mineral Soils	0.1	0.1	+	+	+	+	+
Organic Soils	+	+	0.1	0.1	0.1	0.1	0.1
Wetlands Converted to Cropland	**0.7**	**0.8**	**1.6**	**1.6**	**1.7**	**1.6**	**1.6**
Mineral Soils	0.1	0.1	1.2	1.2	1.2	1.1	1.1
Organic Soils	0.6	0.7	0.4	0.5	0.5	0.5	0.5
Aboveground Live Biomass	**28.9**	**27.9**	**27.2**	**27.2**	**27.2**	**27.2**	**27.2**
Belowground Live Biomass	**5.8**	**5.6**	**5.5**	**5.4**	**5.4**	**5.4**	**5.4**
Dead Wood	**6.3**	**6.1**	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
Litter	**8.8**	**8.5**	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**
Total Mineral Soil Flux	**22.5**	**14.4**	**16.4**	**16.3**	**16.3**	**16.9**	**16.4**
Total Organic Soil Flux	**3.4**	**4.2**	**3.4**	**3.4**	**3.4**	**3.4**	**3.5**
Total Net Flux	**75.6**	**66.7**	**66.9**	**66.7**	**66.7**	**67.3**	**66.9**

+ Does not exceed 0.05 MMT CO_2 Eq.

[43] Changes in biomass C stocks are not currently reported for other land use conversions (other than forest land) to cropland, but this is a planned improvement for a future inventory. Note: changes in dead organic matter are assumed to negligible for other land use conversions (i.e., other than forest land) to cropland.

Table 6-34: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes in *Land Converted to Cropland* (MMT C)

	1990	2005	2013	2014	2015	2016	2017
Grassland Converted to Cropland	**6.7**	**4.7**	**4.9**	**4.9**	**4.9**	**5.0**	**4.9**
Mineral Soils	6.0	3.8	4.1	4.1	4.1	4.3	4.1
Organic Soils	0.7	0.9	0.8	0.8	0.8	0.8	0.8
Forest Land Converted to Cropland	**13.6**	**13.1**	**12.9**	**12.8**	**12.8**	**12.8**	**12.9**
Aboveground Live Biomass	7.9	7.6	7.4	7.4	7.4	7.4	7.4
Belowground Live Biomass	1.6	1.5	1.5	1.5	1.5	1.5	1.5
Dead Wood	1.7	1.7	1.6	1.6	1.6	1.6	1.6
Litter	2.4	2.3	2.3	2.3	2.3	2.3	2.3
Mineral Soils	0.1	+	+	+	+	+	+
Organic Soils	+	+	+	+	+	+	+
Other Lands Converted to Cropland	**0.1**	**0.1**	**+**	**+**	**+**	**+**	**+**
Mineral Soils	+	0.1	+	+	+	+	+
Organic Soils	+	+	+	+	+	+	+
Settlements Converted to Cropland	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Mineral Soils	+	+	+	+	+	+	+
Organic Soils	+	+	+	+	+	+	+
Wetlands Converted to Cropland	**0.2**	**0.2**	**0.4**	**0.4**	**0.5**	**0.4**	**0.4**
Mineral Soils	+	+	0.3	0.3	0.3	0.3	0.3
Organic Soils	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Aboveground Live Biomass	**7.9**	**7.6**	**7.4**	**7.4**	**7.4**	**7.4**	**7.4**
Belowground Live Biomass	**1.6**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
Dead Wood	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**
Litter	**2.4**	**2.3**	**2.3**	**2.3**	**2.3**	**2.3**	**2.3**
Total Mineral Soil Flux	**6.1**	**3.9**	**4.5**	**4.5**	**4.4**	**4.6**	**4.5**
Total Organic Soil Flux	**0.9**	**1.1**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**
Total Net Flux	**20.6**	**18.2**	**18.3**	**18.2**	**18.2**	**18.4**	**18.2**

+ Does not exceed 0.05 MMT C.

Methodology

The following section includes a description of the methodology used to estimate C stock changes for *Land Converted to Cropland*, including (1) loss of aboveground and belowground biomass, dead wood and litter C with conversion of forest lands to croplands, as well as (2) the impact from all land use conversions to cropland on mineral and organic soil C stocks.

Biomass, Dead Wood and Litter Carbon Stock Changes

A Tier 2 method is applied to estimate biomass, dead wood, and litter C stock changes for *Forest Land Converted to Cropland*. Estimates are calculated in the same way as those for *Forest Land Remaining Forest Land* using data from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (USDA Forest Service 2018). However, a default estimate is used for amount of biomass C in cropland (IPCC 2006), and litter and dead wood C stocks were assumed to be zero since no reference C density estimates exist for croplands. The difference between the stocks is reported as the stock change under the assumption that the change occurred in the year of the conversion. If FIA plots include data on individual trees, aboveground and belowground C density estimates are based on Woodall et al. (2011). Aboveground and belowground biomass estimates also include live understory which is a minor component of biomass defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For this Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density are based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). If FIA plots include data on standing dead trees, standing dead tree C density is estimated following the basic method applied to live trees (Woodall et al. 2011) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). If FIA plots include data on downed dead wood, downed dead wood C density is estimated based on measurements of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. If FIA plots include litter material, a modeling approach using litter C measurements from FIA plots is used to estimate litter C density (Domke et al. 2016). See Annex 3.13 for more information about reference C density estimates for forest land and the compilation system used to estimate carbon stock changes from forest land.

Soil Carbon Stock Changes

SOC stock changes are estimated for *Land Converted to Cropland* according to land-use histories recorded in the 2012 USDA NRI survey for non-federal lands (USDA-NRCS 2015). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) had been collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, which are currently available through 2012 (USDA-NRCS 2015). NRI survey locations are classified as *Land Converted to Cropland* in a given year between 1990 and 2012 if the land use is cropland but had been another use during the previous 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998, which may have led to an underestimation of *Land Converted to Cropland* in the early part of the time series to the extent that some areas are converted to cropland from 1971 to 1978. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes from 1990 to 2012 for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, lentils, oats, onions, peanuts, peas, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tobacco, tomatoes, and wheat. SOC stock changes on the remaining mineral soils are estimated with the IPCC Tier 2 method (Ogle et al. 2003), including land used to produce some vegetables and perennial/horticultural crops and crops rotated with these crops; land on very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted from another land use or federal ownership.[44]

For the years 2013 to 2017, a surrogate data method is used to estimate soil C stock changes at the national scale for land areas included in the Tier 2 and Tier 3 methods. Specifically, linear regression models with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) are used to estimate the relationship between surrogate data and the 1990 to 2012 stock change data from the Tier 2 and 3 methods. Surrogate data for these regression models include corn and soybean yields from USDA-NASS statistics,[45] and weather data from the PRISM Climate Group (PRISM 2015). See Box 6-4 in the Methodology Section of *Cropland Remaining Cropland* for more information about the surrogate data method. Stock change estimates for 2013 to 2017 will be recalculated in future inventories when new NRI data are available.

Tier 3 Approach. For the Tier 3 method, mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical model (Parton et al. 1998; Del Grosso et al. 2001, 2011). The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. National estimates are obtained by using the model to simulate historical land-use change patterns as recorded in the USDA NRI (USDA-NRCS 2015). Carbon stocks and

[44] Federal land is not a land use, but rather an ownership designation that is treated as grassland for purposes of these calculations. The specific land use on federal lands is not identified in the NRI survey (USDA-NRCS 2015).

[45] See <https://quickstats.nass.usda.gov/>.

95 percent confidence intervals are estimated for each year between 1990 and 2012. See the *Cropland Remaining Cropland* section for additional discussion of the Tier 3 methodology for mineral soils.

Soil C stock changes from 2013 to 2017 are estimated using the surrogate data method described in Box 6-4 of the Methodology Section in *Cropland Remaining Cropland*. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (See Planned Improvements section in *Cropland Remaining Cropland*).

Tier 2 Approach. For the mineral soils not included in the Tier 3 analysis, SOC stock changes are estimated using a Tier 2 Approach, as described in the Tier 2 Approach for mineral soils in *Cropland Remaining Cropland*. This includes application of the surrogate data method that is described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. As with the Tier 3 method, future inventories will be updated with new NRI activity data when the data are made available, and the time series will be recalculated.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Cropland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils. This includes application of the surrogate data method that is described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. Estimates will be recalculated in future Inventories when new NRI data are available.

Uncertainty and Time-Series Consistency

The uncertainty analysis for biomass, dead wood and litter C losses with *Forest Land Converted to Cropland* is conducted in the same way as the uncertainty assessment for forest ecosystem C flux associated with *Forest Land Remaining Forest Land*. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006) by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. For additional details, see the Uncertainty Analysis in Annex 3.13. The uncertainty analyses for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described for *Cropland Remaining Cropland*. The uncertainty for annual C emission estimates from drained organic soils in *Land Converted to Cropland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section. For 2013 to 2017, there is additional uncertainty propagated through the Monte Carlo Analysis associated with a surrogate data method, which is also described in *Cropland Remaining Cropland*.

Uncertainty estimates are presented in Table 6-35 for each subsource (i.e., biomass C stocks, dead wood C stocks, litter C stocks, mineral soil C stocks and organic soil C stocks) and the method applied in the Inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates for the total C stock changes for biomass, dead organic matter and soils are combined using the simple error propagation methods provided by the IPCC (2006), as discussed in the previous paragraph. The combined uncertainty for total C stocks in *Land Converted to Cropland* ranged from 60 percent below to 60 percent above the 2017 stock change estimate of 66.9 MMT CO_2 Eq. The large relative uncertainty around the 2017 stock change estimate is partly due to large uncertainties in biomass and dead organic matter C losses with *Forest Land Conversion to Cropland*. The large relative uncertainty is also associated with variation in soil C stock change that is not explained by the surrogate data method, leading to high prediction error with the splicing method.

Table 6-35: Approach 2 Quantitative Uncertainty Estimates for Soil, Dead Organic Matter and Biomass C Stock Changes occurring within *Land Converted to Cropland* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Grassland Converted to Cropland	**18.0**	**4.4**	**31.6**	**-76%**	**76%**
Mineral Soil C Stocks: Tier 3	14.1	0.6	27.7	-96%	96%
Mineral Soil C Stocks: Tier 2	1.0	0.3	1.7	-71%	71%

Organic Soil C Stocks: Tier 2	2.8	1.9	3.8	-34%	34%
Forest Land Converted to Cropland	**47.1**	**9.5**	**84.8**	**-80%**	**80%**
Aboveground Live Biomass	27.2	-7.4	61.8	-127%	127%
Belowground Live Biomass	5.4	-1.5	12.4	-127%	127%
Dead Wood	6.0	-1.6	13.5	-127%	127%
Litter	8.4	-2.3	19.1	-127%	127%
Mineral Soil C Stocks: Tier 2	0.1	-0.4	0.5	-592%	592%
Organic Soil C Stocks: Tier 2	+	0.0	0.1	-100%	197%
Other Lands Converted to Cropland	**0.1**	**+**	**0.1**	**-105%**	**104%**
Mineral Soil C Stocks: Tier 2	0.1	+	0.1	-105%	104%
Organic Soil C Stocks: Tier 2	+	+	+	0%	0%
Settlements Converted to Cropland	**0.1**	**+**	**0.1**	**-57%**	**57%**
Mineral Soil C Stocks: Tier 2	+	+	+	-214%	210%
Organic Soil C Stocks: Tier 2	0.1	+	0.1	-56%	56%
Wetlands Converted to Croplands	**1.6**	**0.7**	**2.6**	**-60%**	**60%**
Mineral Soil C Stocks: Tier 2	1.1	0.2	2.0	-83%	83%
Organic Soil C Stocks: Tier 2	0.5	0.2	0.9	-67%	67%
Total: Land Converted to Cropland	**66.9**	**26.8**	**106.9**	**-60%**	**60%**
Aboveground Live Biomass	**27.2**	**(7.4)**	**61.8**	**-127%**	**127%**
Belowground Live Biomass	**5.4**	**(1.5)**	**12.4**	**-127%**	**127%**
Dead Wood	**6.0**	**(1.6)**	**13.5**	**-127%**	**221%**
Litter	**8.4**	**(2.3)**	**19.1**	**-127%**	**127%**
Mineral Soil C Stocks: Tier 3	**14.1**	**0.6**	**27.7**	**-96%**	**96%**
Mineral Soil C Stocks: Tier 2	**2.3**	**1.0**	**3.5**	**-55%**	**55%**
Organic Soil C Stocks: Tier 2	**3.5**	**2.4**	**4.5**	**-30%**	**30%**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Methodological recalculations are applied from 2013 to 2016 using the surrogate data method developed for soil C stock change and from 1990 to 2016 for biomass and dead organic matter C estimates, ensuring consistency across the time series. Details on the emission trends through time are described in more detail in the Methodology section.

Uncertainty is also associated with lack of reporting of agricultural biomass and dead organic matter C stock changes. Biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations, given the small amount of change in land used to produce these commodities in the United States. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may have led to significant changes in biomass C stocks, at least in some regions of the United States. However, there are currently no datasets to evaluate the trends. Changes in dead organic matter C stocks are assumed to be negligible with conversion of land to croplands with the exception of forest lands, which are included in this analysis. This assumption will be further explored in a future analysis.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland* for information on QA/QC steps.

Recalculations Discussion

Methodological recalculations are associated with extending the time series from 2013 through 2016 for mineral and organic soils using a surrogate data method, and from 1990 to 2016 for biomass and dead organic matter C associated with *Forest Land Converted to Cropland*. No other recalculations have been implemented in the current Inventory. Carbon stock change losses increased by an average of 141 percent from 1990 through 2016 based on the recalculation. This change is almost entirely attributed to the update of biomass and dead organic matter losses for *Forest Land Converted to Cropland* with newly available re-measurement data for the western United States. Stock changes were re-estimated at the plot-level with the new data consistent with the compilation methods described for *Forest Land Remaining Forest Land*. In the previous Inventory, state-level averages from the plot data had been used to approximate the losses of C with *Forest Land Converted to Cropland* due to a lack of re-measurement data.

Planned Improvements

Soil C stock changes with *Forest Land Converted to Cropland* are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and croplands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to cropland. Additional planned improvements are discussed in the *Cropland Remaining Cropland* section.

6.6 Grassland Remaining Grassland (CRF Category 4C1)

Carbon (C) in grassland ecosystems occurs in biomass, dead organic matter, and soils. Soils are the largest pool of C in grasslands, and have the greatest potential for longer-term storage or release of C. Biomass and dead organic matter C pools are relatively ephemeral compared to the soil C pool, with the exception of C stored in tree and shrub biomass, that occurs in grasslands. The *2006 IPCC Guidelines* recommend reporting changes in biomass, dead organic matter and soil organic C (SOC) stocks with land use and management, but there is currently no reporting of C stock changes for aboveground and belowground biomass, dead wood and litter pools.[46] For SOC, the *2006 IPCC Guidelines* (IPCC 2006) recommend reporting changes due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[47]

Grassland Remaining Grassland includes all grassland in an Inventory year that had been grassland for a continuous time period of at least 20 years (USDA-NRCS 2015). Grassland includes pasture and rangeland that are primarily, but not exclusively used for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. The current Inventory includes all privately-owned and federal grasslands in the conterminous United States and Hawaii, but does not include approximately 50 million hectares of *Grassland Remaining Grassland* in Alaska. This leads to a discrepancy with the total amount of managed area in *Grassland Remaining Grassland* (see Section 6.1 Representation of the U.S. Land Base) and the grassland area included in the Inventory analysis (CRF Category 4C1—Section 6.6)[48].

In *Grassland Remaining Grassland*, there has been considerable variation in soil C stocks between 1990 and 2017. These changes are driven by variability in weather patterns and associated interaction with land management activity. Moreover, changes are small on a per hectare rate basis across the time series even in the years with a larger total change in stocks. Land use and management generally increased soil C in mineral soils for *Grassland Remaining Grassland* between 1990 and 2017. In contrast, organic soils lose a relatively constant amount of C annually from 1990 through 2017. In 2017, soil C stocks are a net sink, sequestering 0.1 MMT CO_2 Eq. (0.0 MMT C), with an increase of 5.6 MMT CO_2 Eq. (1.5 MMT C) in mineral soils, and a loss of 5.6 MMT CO_2 Eq. (1.5 MMT C) from organic soils (Table 6-36 and Table 6-37). Soil C stock changes are 99 percent lower in 2017 compared to 1990, but stock changes are highly variable from 1990 to 2017, with an average annual sequestration of 5.0 MMT

[46] There are planned improvements to address all C pools in the future, with an initial effort focused on biomass C.

[47] CO_2 emissions associated with liming and urea fertilization are also estimated but included in the Agriculture chapter of the report.

[48] For the U.S. land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for grasslands through the process of combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for grasslands with the new land representation data so the area estimates in this section are based on the land representation data from the previous Inventory. This has created additional discrepancies with the reported grassland areas in the "Representation of the U.S. Land Base" section.

CO_2 Eq. (1.4 MMT C). However, the large inter-annual variability leads to years in which *Grassland Remaining Grassland* is a net sink and others in which it is a net source of CO_2 emissions.

Table 6-36: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT CO_2 Eq.)

Soil Type	1990	2005	2013	2014	2015	2016	2017
Mineral Soils	(11.4)	(0.5)	(9.3)	(13.1)	4.1	(7.2)	(5.6)
Organic Soils	7.2	6.0	5.5	5.5	5.5	5.5	5.6
Total Net Flux	**(4.2)**	**5.5**	**(3.7)**	**(7.5)**	**9.6**	**(1.6)**	**(0.1)**

Note: Parentheses indicate net sequestration.

Table 6-37: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT C)

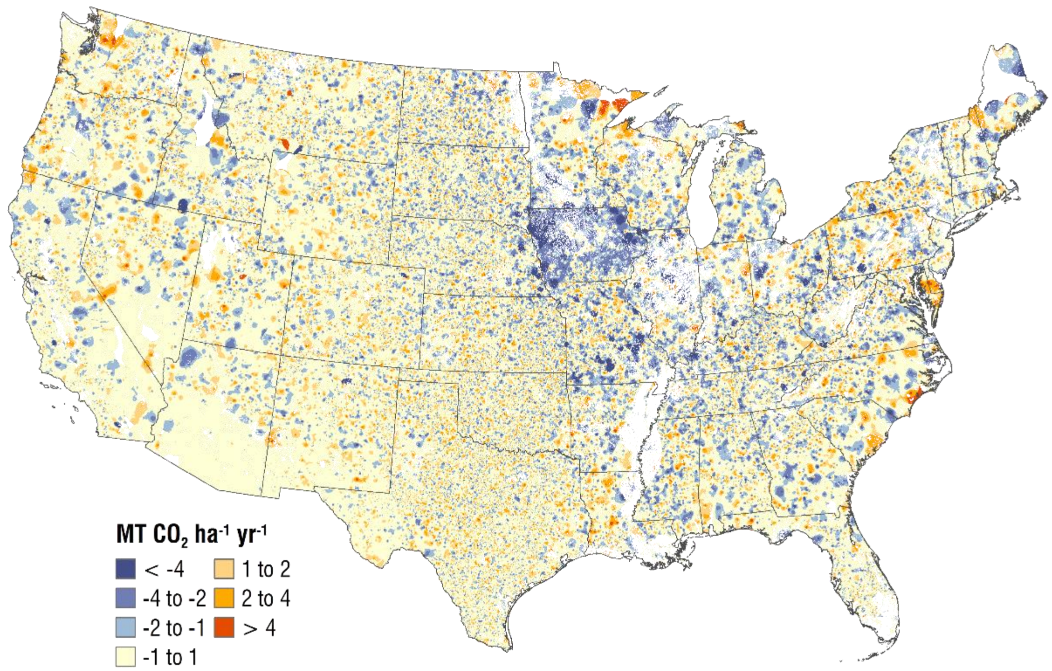
Soil Type	1990	2005	2013	2014	2015	2016	2017
Mineral Soils	(3.1)	(0.1)	(2.5)	(3.6)	1.1	(2.0)	(1.5)
Organic Soils	2.0	1.6	1.5	1.5	1.5	1.5	1.5
Total Net Flux	**(1.1)**	**1.5**	**(1.0)**	**(2.1)**	**2.6**	**(0.4)**	**+**

+ Absolute value does not exceed 0.05 MMT C
Note: Parentheses indicate net sequestration.

The spatial variability in the 2012 annual soil C stock changes[49] associated with mineral soils is displayed in Figure 6-7 and organic soils in Figure 6-8. Although relatively small on a per-hectare basis, grassland soils gained C in isolated areas throughout the country, with a larger concentration of grasslands sequestering soil C in Iowa. For organic soils, the regions with the highest rates of emissions coincide with the largest concentrations of organic soils used for managed grassland, including the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast, and a few isolated areas along the Pacific Coast.

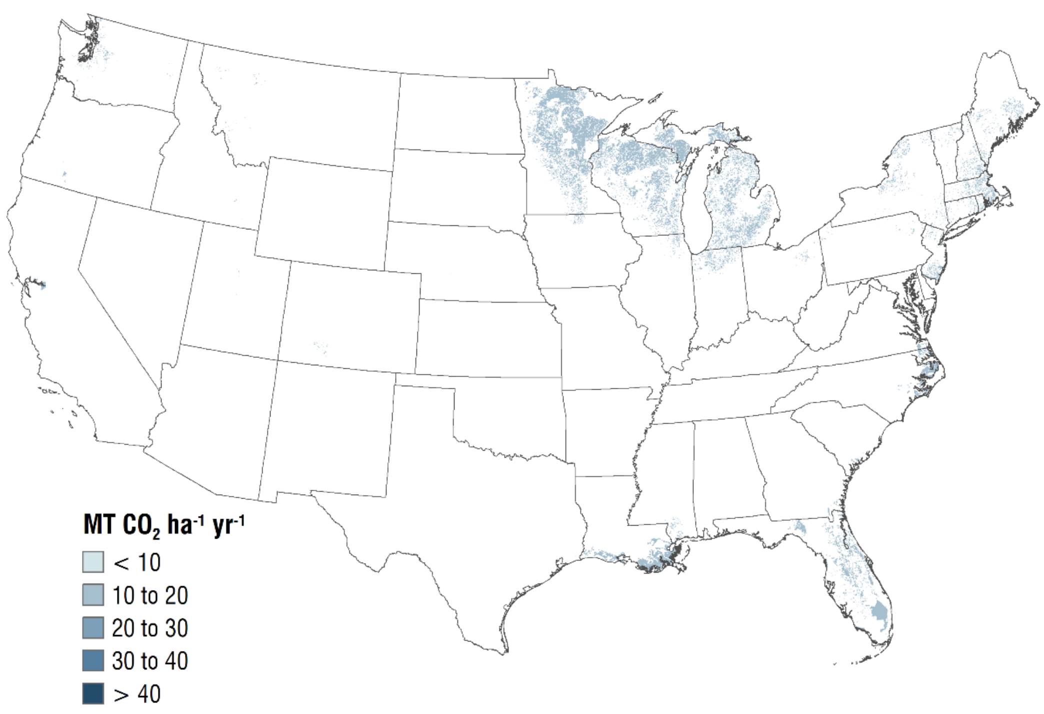
[49] Only national-scale emissions are estimated for 2013 to 2017 in the current Inventory using the surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from 2012.

Figure 6-7: Total Net Annual Soil C Stock Changes for Mineral Soils under Agricultural Management within States, 2012, *Grassland Remaining Grassland*



Note: Only national-scale soil C stock changes are estimated for 2013 to 2017 in the current Inventory using a surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from 2012. Negative values represent a net increase in soil C stocks, and positive values represent a net decrease in soil C stocks.

Figure 6-8: Total Net Annual Soil C Stock Changes for Organic Soils under Agricultural Management within States, 2012, *Grassland Remaining Grassland*



Note: Only national-scale soil carbon stock changes are estimated for 2013 to 2017 in the current Inventory using a surrogate data method, and therefore the fine-scale emission patterns in this map are based on inventory data from 2012.

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks for *Grassland Remaining Grassland*, including: (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Soil C stock changes are estimated for *Grassland Remaining Grassland* on non-federal lands according to land use histories recorded in the 2012 USDA NRI survey (USDA-NRCS 2015). Land-use and some management information (e.g., grass type, soil attributes, and irrigation) were originally collected for each NRI survey location on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). NRI survey locations are classified as *Grassland Remaining Grassland* in a given year between 1990 and 2012 if the land use had been grassland for 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an overestimation of *Grassland Remaining Grassland* in the early part of the time series to the extent that some areas are converted to grassland between 1971 and 1978. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes from 1990 to 2012 for most mineral soils in *Grassland Remaining Grassland*. The C stock changes for the remaining soils are estimated with an IPCC Tier 2 method (Ogle et al. 2003), including gravelly, cobbly, or shaley soils (greater than 35 percent by volume) and additional stock changes associated with biosolids (i.e., sewage sludge) amendments. SOC stock changes on the remaining soils are estimated with the IPCC Tier 2 method (Ogle et al. 2003), including land used to produce some vegetables and perennial/horticultural crops and crops rotated with these crops; land on very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted from another land use or federal ownership.[50]

A surrogate data method is used to estimate soil C stock changes from 2013 to 2017 at the national scale for land areas included in the Tier 2 and Tier 3 methods. Specifically, linear regression models with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) are used to estimate the relationship between surrogate data and the 1990 to 2012 emissions data from the Tier 2 and 3 methods. Surrogate data for these regression models includes weather data from the PRISM Climate Group (PRISM 2015). See Box 6-4 in the Methodology section of *Cropland Remaining Cropland* for more information about the surrogate data method. Stock change estimates for 2013 to 2017 will be recalculated in future inventories when new NRI data are available.

Tier 3 Approach. Mineral SOC stocks and stock changes for *Grassland Remaining Grassland* are estimated using the DAYCENT biogeochemical[51] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), as described in *Cropland Remaining Cropland*. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land-use patterns and irrigation histories are simulated with DAYCENT based on the 2012 USDA NRI survey (USDA-NRCS 2015). Frequency and rates of manure application to grassland during 1997 are estimated from data compiled by the USDA Natural Resources Conservation Service (NRCS) (Edmonds, et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 are used

[50] Federal land is not a land use, but rather an ownership designation that is treated as grassland for purposes of these calculations. The specific land use on federal lands is not identified in the NRI survey (USDA-NRCS 2015).

[51] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

to adjust the area amended with manure (see *Cropland Remaining Cropland* section and Annex 3.12 for further details). Greater availability of managed manure nitrogen (N) relative to 1997 is assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 is assumed to reduce the amended area.

The amount of manure produced by each livestock type is calculated for managed and unmanaged waste management systems based on methods described in Section 5.2 Manure Management and Annex 3.11. Manure N deposition from grazing animals (i.e., PRP manure) is an input to the DAYCENT model, and the remainder is deposited on federal lands (i.e., the amount that is not included in DAYCENT simulations is assumed to be applied on federal grasslands). Carbon stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2012 using the NRI survey data.

Soil C stock changes from 2013 to 2017 are estimated using a surrogate data method described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (See Planned Improvements section in *Cropland Remaining Cropland*).

Tier 2 Approach. The Tier 2 approach is based on the same methods described in the Tier 2 portion of *Cropland Remaining Cropland* section for mineral soils, with the exception of the land use and management data that are used in the Inventory for federal grasslands. The NRI (USDA-NRCS 2015) provides land use and management histories for all non-federal lands, and is the basis for the Tier 2 analysis for these areas. However, NRI does not provide land use information on federal lands. The land use data for federal lands is based on the National Land Cover Database (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). In addition, the Bureau of Land Management (BLM) manages some of the federal grasslands, and compiles information on grassland condition through the BLM Rangeland Inventory (BLM 2014). To estimate soil C stock changes from federal grasslands, rangeland conditions in the BLM data are aligned with IPCC grassland management categories of nominal, moderately degraded, and severely degraded in order to apply the appropriate emission factors. As with the non-federal lands, the time series for federal lands has been extended from 2013 to 2017 using a surrogate data method described in Box 6-4 of the Methodology Section in *Cropland Remaining Cropland*. Further elaboration on the Tier 2 methodology and data used to estimate C stock changes from mineral soils are described in Annex 3.12.

Additional Mineral C Stock Change Calculations

A Tier 2 method is used to adjust annual C stock change estimates for mineral soils between 1990 and 2017 to account for additional C stock changes associated with biosolid (i.e., sewage sludge) amendments. Estimates of the amounts of biosolids N applied to agricultural land are derived from national data on biosolids generation, disposition, and N content (see Section 7.2, Wastewater Treatment for a detailed discussion of the methodology for estimating sewage sludge available for land application application). Although biosolids can be added to land managed for other land uses, it is assumed that agricultural amendments only occur in *Grassland Remaining Grassland*. Total biosolids generation data for 1988, 1996, and 1998, in dry mass units, are obtained from EPA (1999) and estimates for 2004 are obtained from an independent national biosolids survey (NEBRA 2007). These values are linearly interpolated to estimate values for the intervening years, and linearly extrapolated to estimate values for years since 2004. N application rates from Kellogg et al. (2000) are used to determine the amount of area receiving biosolids amendments. The soil C storage rate is estimated at 0.38 metric tons C per hectare per year for biosolids amendments to grassland as described above. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.12 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Grassland Remaining Grassland* are estimated using the Tier 2 method provided in IPCC (2006), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. A surrogate data method is used to estimate annual C emissions from organic soils from 2013 to 2017 as described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. Estimates for 2013 to 2017 will be updated in future Inventories when new NRI data are available. For more information, see the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described in the *Cropland Remaining Cropland* section. The uncertainty for annual C emission estimates from drained organic soils in *Grassland Remaining Grassland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section. For 2013 to 2017, there is additional uncertainty propagated through the Monte Carlo Analysis associated with the surrogate data method.

Uncertainty estimates are presented in Table 6-38 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and the method applied in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Grassland Remaining Grassland* ranges from more than 1,000 percent below and above the 2017 stock change estimate of -0.1 MMT CO_2 Eq. The large relative uncertainty is primarily due to the small estimated change in soil C stocks, which is almost zero for 2017.

Table 6-38: Approach 2 Quantitative Uncertainty Estimates for C Stock Changes Occurring Within *Grassland Remaining Grassland* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks Grassland Remaining Grassland, Tier 3 Methodology	(4.0)	(44.4)	36.5	-1,016%	1,016%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	(1.5)	(2.9)	+	-100%	100%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology (Change in Soil C due to Biosolids [i.e., Sewage Sludge] Amendments)	(0.2)	(0.2)	(0.1)	-50%	50%
Organic Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	5.6	5.0	6.1	-10%	10%
Combined Uncertainty for Flux Associated with Agricultural Soil Carbon Stock Change in Grassland Remaining Grassland	**(0.1)**	**(40.5)**	**40.4**	**-74,245%**	**74,245%**

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
+ Does not exceed 0.05 MMT CO_2 Eq.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Details on the emission trends through time are described in more detail in the Methodology section.

Uncertainty is also associated with a lack of reporting on biomass and litter C stock changes. Biomass C stock changes may be significant for managed grasslands with woody encroachment despite not having attained enough tree cover to be considered forest lands. Changes in dead organic matter C stocks are assumed to be negligible in grasslands on an annual basis, although there are certainly significant changes at sub-annual time scales across seasons.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland*.

Planned Improvements

Grasslands in Alaska are not currently included in the Inventory. This is a significant planned improvement and estimates are expected to be available in a future Inventory contingent on funding availability. Another key planned improvement is to estimate woody biomass C stock changes for grasslands (See Box 6-6). For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland*.

Box 6-6: Grassland Woody Biomass Analysis

An initial analysis of woodland biomass has been conducted for regions in the western United States. Woodlands are areas with trees in a matrix of grass vegetation that do not reach the thresholds for tree cover, diameter at breast height, and/or tree height to be considered forest land. For this pilot effort, carbon stock densities and stock changes are estimated using woodland plots in the Forest Inventory and Analysis (FIA) database. The full set of woodland plots cover 12 states in the western United States, and include two FIA forest type groups, pinyon-juniper and woodland hardwoods. The results suggest that woodlands are sequestering approximately 20 MMT CO_2 Eq. in biomass, dead wood, and litter pools. The analysis will be expanded to the entire time series and reported in a future Inventory.

Non-CO_2 Emissions from Grassland Fires (CRF Source Category 4C1)

Fires are common in grasslands, and are thought to have been a key feature shaping the evolution of the grassland vegetation in North America (Daubenmire 1968; Anderson 2004). Fires can occur naturally through lightning strikes, but are also an important management practice to remove standing dead vegetation and improve forage for grazing livestock. Woody and herbaceous biomass will be oxidized in a fire, although currently the focus is primarily on herbaceous biomass in this section.[52] Biomass burning emits a variety of trace gases including non-CO_2 greenhouse gases, CH_4 and N_2O, as well as CO and NO_x that can become greenhouse gases when they react with other gases in the atmosphere (Andreae and Merlet 2001). IPCC (2006) recommends reporting non-CO_2 greenhouse gas emissions from all wildfires and prescribed burning occurring in managed grasslands.

Biomass burning in grassland of the United States is a relatively small source of emissions, but it has increased by over 300 percent since 1990. In 2017, CH_4 and N_2O emissions from biomass burning in grasslands were 0.3 MMT CO_2 Eq. (12 kt) and 0.3 MMT CO_2 Eq. (1 kt), respectively. Annual emissions from 1990 to 2017 have averaged approximately 0.3 MMT CO_2 Eq. (12 kt) of CH_4 and 0.3 MMT CO_2 Eq. (1 kt) of N_2O (see Table 6-39 and Table 6-40).

Table 6-39: CH_4 and N_2O Emissions from Biomass Burning in Grassland (MMT CO_2 Eq.)

	1990		2005		2013	2014	2015	2016	2017
CH_4	0.1		0.3		0.2	0.4	0.3	0.3	0.3
N_2O	0.1		0.3		0.2	0.4	0.3	0.3	0.3
Total Net Flux	**0.2**		**0.7**		**0.4**	**0.8**	**0.7**	**0.6**	**0.6**

Note: Totals may not sum due to independent rounding.

Table 6-40: CH_4, N_2O, CO, and NO_x Emissions from Biomass Burning in Grassland (kt)

	1990		2005		2013	2014	2015	2016	2017
CH_4	3		13		8	16	13	11	12
N_2O	+		1		1	1	1	1	1
CO	84		358		217	442	356	324	345
NO_x	5		21		13	27	21	19	21

+ Does not exceed 0.5 kt

[52] A planned improvement is underway to incorporate woodland tree biomass into the Inventory.

Methodology

The following section includes a description of the methodology used to estimate non-CO_2 greenhouse gas emissions from biomass burning in grassland, including (1) determination of the land base that is classified as managed grassland; (2) assessment of managed grassland area that is burned each year, and (3) estimation of emissions resulting from the fires. For this Inventory, the IPCC Tier 1 method is applied to estimate non-CO_2 greenhouse gas emissions from biomass burning in grassland from 1990 to 2014 (IPCC 2006). A data splicing method is used to estimate the emissions in 2015 to 2017, which is discussed later in this section.

The land area designated as managed grassland is based primarily on the 2012 National Resources Inventory (NRI) (Nusser and Goebel 1997; USDA-NRCS 2015). NRI has survey locations across the entire United States, but does not classify land use on federally-owned areas. These survey locations are designated as grassland using land cover data from the National Land Cover Dataset (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015) (see Section 6.1 Representation of the U.S. Land Base).

The area of biomass burning in grasslands (*Grassland Remaining Grassland* and *Land Converted to Grassland*) is determined using 30-m fire data from the Monitoring Trends in Burn Severity (MTBS) program for 1990 through 2014.[53] NRI survey locations on grasslands are designated as burned in a year if there is a fire within a 500 m of the survey point according to the MTBS fire data. The area of biomass burning is estimated from the NRI spatial weights and aggregated to the country (Table 6-41).

Table 6-41: Thousands of Grassland Hectares Burned Annually

Year	Thousand Hectares
1990	317
2005	1,343
2013	815
2014	1,659
2015	NE
2016	NE
2017	NE

Notes: Burned area are not estimated (NE) for 2015 to 2017 but will be updated in a future Inventory.

For 1990 to 2014, the total area of grassland burned is multiplied by the IPCC default factor for grassland biomass (4.1 tonnes dry matter per ha) (IPCC 2006) to estimate the amount of combusted biomass. A combustion factor of 1 is assumed in this Inventory, and the resulting biomass estimate is multiplied by the IPCC default grassland emission factors for CH_4 (2.3 g CH_4 per kg dry matter), N_2O (0.21 g CH_4 per kg dry matter), CO (65 g CH_4 per kg dry matter) and NO_x (3.9 g CH_4 per kg dry matter) (IPCC 2006). The Tier 1 analysis is implemented in the Agriculture and Land Use National Greenhouse Gas Inventory (ALU) software (Ogle et al. 2016).[54]

A linear extrapolation of the trend in the time series is applied to estimate the emissions for 2015 to 2017 because new activity data have not been compiled for the current Inventory. Specifically, a linear regression model with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) is used to estimate the trend in emissions over time from 1990 to 2014, and the trend is used to approximate the 2015 to 2017 emissions. The Tier 1 method described previously will be applied to recalculate the 2015 to 2017 emissions in a future Inventory.

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[53] See <http://www.mtbs.gov/nationalregional/burnedarea.html>.

[54] See <http://www.nrel.colostate.edu/projects/ALUsoftware/>.

Uncertainty and Time-Series Consistency

Emissions are estimated using a linear regression model with ARMA errors for 2015 to 2017. The linear regression ARMA model produced estimates of the upper and lower bounds of the emission estimate and the results are summarized in Table 6-42. Methane emissions from Biomass Burning in Grassland for 2017 are estimated to be between 0.0 and 0.7 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 100 percent below and 139 percent above the 2017 emission estimate of 0.3 MMT CO_2 Eq. Nitrous oxide emissions are estimated to be between 0.0 and 0.8 MMT CO_2 Eq., or approximately 100 percent below and 140 percent above the 2017 emission estimate of 0.3 MMT CO_2 Eq.

Table 6-42: Uncertainty Estimates for Non-CO_2 Greenhouse Gas Emissions from Biomass Burning in Grassland (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Grassland Burning	CH_4	0.3	0.0	0.7	-100%	139%
Grassland Burning	N_2O	0.3	0.0	0.8	-100%	140%

[a] Range of emission estimates predicted by linear regression time-series model for a 95 percent confidence interval.

Uncertainty is also associated with lack of reporting of emissions from biomass burning in grassland of Alaska. Grassland burning emissions could be relatively large in this region of the United States, and therefore extending this analysis to include Alaska is a planned improvement for the Inventory. There is also uncertainty due to lack of reporting combustion of woody biomass, and this is another planned improvement.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data are properly handled throughout the inventory process. Inventory reporting forms and text are reviewed and revised as needed to correct transcription errors. Quality control identified problems with input data for common reporting format tables in the spreadsheets, which have been corrected.

Planned Improvements

A splicing data method is applied to estimate emissions in the latter part of the time series, which introduces additional uncertainty in the emissions data. Therefore, a key improvement for the next Inventory will be to update the time series with new activity data and recalculate the emissions for 2015 to 2017.

Two other planned improvements have been identified for this source category, including a) incorporation of country-specific grassland biomass factors, and b) extending the analysis to include Alaska. In the current Inventory, biomass factors are based on a global default for grasslands that is provided by the IPCC (2006). There is considerable variation in grassland biomass, however, which would affect the amount of fuel available for combustion in a fire. Alaska has an extensive area of grassland and includes tundra vegetation, although some of the areas are not managed. There has been an increase in fire frequency in boreal forest of the region (Chapin et al. 2008), and this may have led to an increase in burning of neighboring grassland areas. There is also an effort under development to incorporate grassland fires into DAYCENT model simulations. Both improvements are expected to reduce uncertainty and lead to more accurate estimates of non-CO_2 greenhouse gas emissions from grassland burning.

6.7 Land Converted to Grassland (CRF Category 4C2)

Land Converted to Grassland includes all grassland in an Inventory year that had been in another land use(s) during the previous 20 years (USDA-NRCS 2015).[55] For example, cropland or forest land converted to grassland during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended by IPCC (2006). Grassland includes pasture and rangeland that are used primarily but not exclusively for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. This Inventory includes all grasslands in the conterminous United States and Hawaii, but does not include *Land Converted to Grassland* in Alaska. Consequently, there is a discrepancy between the total amount of managed area for *Land Converted to Grassland* (see Section 6.1 Representation of the U.S. Land Base) and the grassland area included in the inventory analysis (CRF Category 4C2—Section 6.7)[56].

Land use change can lead to large losses of C to the atmosphere, particularly conversions from forest land (Houghton et al. 1983). Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally (Schimel 1995), although this source may be declining according to a recent assessment (Tubiello et al. 2015).

IPCC (2006) recommends reporting changes in biomass, dead organic matter, and soil organic C (SOC) stocks due to land use change. All soil C stock changes are estimated and reported for *Land Converted to Grassland*, but there is limited reporting of other pools in this Inventory. Losses of aboveground and belowground biomass, dead wood and litter C from *Forest Land Converted to Grassland* are reported, but these C stock changes are not estimated for other land use conversions to grassland.[57]

The largest C losses with *Land Converted to Grassland* are associated with aboveground biomass, belowground biomass, dead wood and litter C losses from *Forest Land Converted to Grassland* (see Table 6-43 and Table 6-44). These four pools led to net emissions in 2017 of 12.6, 2.4, -0.9, and 4.8 MMT CO_2 Eq. (3.4, 0.7, -0.3, and 1.3 MMT C), respectively. Land use and management of mineral soils in *Land Converted to Grassland* led to an increase in soil C stocks, estimated at 12.2 MMT CO_2 Eq. (3.3 MMT C) in 2017, while drainage of organic soils for grassland management led to CO_2 emissions to the atmosphere of 1.6 MMT CO_2 Eq. (0.4 MMT C). The total net C stock change in 2017 for *Land Converted to Grassland* is estimated as a loss of 8.3 MMT CO_2 Eq. (2.3 MMT C), which is a 3 percent decrease in emissions compared to the initial reporting year of 1990.

Table 6-43: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes for *Land Converted to Grassland* (MMT CO_2 Eq.)

	1990		2005		2013	2014	2015	2016	2017
Cropland Converted to Grassland	**(7.5)**		**(11.5)**		**(8.1)**	**(8.4)**	**(6.2)**	**(7.5)**	**(7.6)**

[55] NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 2001. This may have led to an underestimation of *Land Converted to Grassland* in the early part of the time series to the extent that some areas are converted to grassland between 1971 and 1978.

[56] For the U.S. land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for grasslands through the process of combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for grasslands with the new land representation data so the area estimates in this section are based on the land representation data from the previous Inventory. This has created additional discrepancies with the reported grassland areas in the "Representation of the U.S. Land Base" section.

[57] Changes in biomass C stocks are not currently reported for other conversions to grassland (other than forest land), but this is a planned improvement for a future Inventory. Note: changes in dead organic matter are assumed to negligible for other land use conversions (i.e., other than forest land) to grassland based on the Tier 1 method in IPCC (2006).

	1990		2005		2013	2014	2015	2016	2017
Mineral Soils	(8.0)		(12.7)		(9.3)	(9.5)	(7.4)	(8.6)	(8.7)
Organic Soils	0.5		1.1		1.1	1.1	1.1	1.1	1.1
Forest Land Converted to Grassland	**17.0**		**18.0**		**16.3**	**16.1**	**15.9**	**15.9**	**15.8**
Aboveground Live Biomass	12.6		12.6		12.6	12.6	12.6	12.6	12.6
Belowground Live Biomass	2.5		2.5		2.4	2.4	2.4	2.4	2.4
Dead Wood	(1.6)		(1.3)		(1.0)	(0.9)	(0.9)	(0.9)	(0.9)
Litter	4.3		4.6		4.8	4.8	4.8	4.8	4.8
Mineral Soils	(0.8)		(0.5)		(2.7)	(2.9)	(3.1)	(3.1)	(3.2)
Organic Soils	+		0.1		0.1	0.1	0.1	0.1	0.1
Other Lands Converted Grassland	**(0.5)**		**(1.0)**		**+**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**
Mineral Soils	(0.5)		(1.1)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Organic Soils	+		+		+	+	+	+	+
Settlements Converted Grassland	**(0.1)**		**(0.1)**		**+**	**+**	**+**	**+**	**+**
Mineral Soils	(0.1)		(0.1)		+	+	+	+	+
Organic Soils	+		+		+	+	+	+	+
Wetlands Converted Grassland	**(0.2)**		**(0.2)**		**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
Mineral Soils	(0.3)		(0.4)		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic Soils	0.1		0.3		0.3	0.3	0.3	0.3	0.3
Aboveground Live Biomass	**12.6**		**12.6**		**12.6**	**12.6**	**12.6**	**12.6**	**12.6**
Belowground Live Biomass	**2.5**		**2.5**		**2.4**	**2.4**	**2.4**	**2.4**	**2.4**
Dead Wood	**(1.6)**		**(1.3)**		**(1.0)**	**(0.9)**	**(0.9)**	**(0.9)**	**(0.9)**
Litter	**4.3**		**4.6**		**4.8**	**4.8**	**4.8**	**4.8**	**4.8**
Total Mineral Soil Flux	**(9.7)**		**(14.8)**		**(12.3)**	**(12.6)**	**(10.8)**	**(12.0)**	**(12.2)**
Total Organic Soil Flux	**0.7**		**1.5**		**1.7**	**1.6**	**1.7**	**1.6**	**1.6**
Total Net Flux	**8.7**		**5.1**		**8.3**	**7.9**	**9.8**	**8.5**	**8.3**

+ Does not exceed 0.05 MMT CO_2 Eq.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Table 6-44: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes for *Land Converted to Grassland* (MMT C)

	1990		2005		2013	2014	2015	2016	2017
Cropland Converted to Grassland	**(2.0)**		**(3.1)**		**(2.2)**	**(2.3)**	**(1.7)**	**(2.0)**	**(2.1)**
Mineral Soils	(2.2)		(3.5)		(2.5)	(2.6)	(2.0)	(2.3)	(2.4)
Organic Soils	0.1		0.3		0.3	0.3	0.3	0.3	0.3
Forest Land Converted to Grassland	**4.6**		**4.9**		**4.4**	**4.4**	**4.3**	**4.3**	**4.3**
Aboveground Live Biomass	3.4		3.4		3.4	3.4	3.4	3.4	3.4
Belowground Live Biomass	0.7		0.7		0.7	0.7	0.7	0.7	0.7
Dead Wood	(0.4)		(0.3)		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
Litter	1.2		1.3		1.3	1.3	1.3	1.3	1.3
Mineral Soils	(0.2)		(0.1)		(0.7)	(0.8)	(0.8)	(0.9)	(0.9)
Organic Soils	+		+		+	+	+	+	+
Other Lands Converted Grassland	**(0.1)**		**(0.3)**		**+**	**+**	**+**	**+**	**+**
Mineral Soils	(0.1)		(0.3)		+	+	+	+	+
Organic Soils	+		+		+	+	+	+	+
Settlements Converted Grassland	**+**		**+**		**+**	**+**	**+**	**+**	**+**
Mineral Soils	+		+		+	+	+	+	+
Organic Soils	+		+		+	+	+	+	+
Wetlands Converted Grassland	**(0.1)**		**+**		**+**	**+**	**+**	**+**	**+**
Mineral Soils	(0.1)		(0.1)		+	+	(0.1)	(0.1)	(0.1)
Organic Soils	+		0.1		0.1	0.1	0.1	0.1	0.1
Aboveground Live Biomass	**3.4**		**3.4**		**3.4**	**3.4**	**3.4**	**3.4**	**3.4**
Belowground Live Biomass	**0.7**		**0.7**		**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Dead Wood	**(0.4)**		**(0.3)**		**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**
Litter	**1.2**		**1.3**		**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Total Mineral Soil Flux	**(2.6)**		**(4.0)**		**(3.3)**	**(3.4)**	**(2.9)**	**(3.3)**	**(3.3)**
Total Organic Soil Flux	**0.2**		**0.4**		**0.5**	**0.4**	**0.5**	**0.4**	**0.4**
Total Net Flux	**2.4**		**1.4**		**2.3**	**2.2**	**2.7**	**2.3**	**2.3**

+ Does not exceed 0.05 MMT C. Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Methodology

The following section includes a description of the methodology used to estimate C stock changes for *Land Converted to Grassland*, including (1) loss of aboveground and belowground biomass, dead wood and litter C with conversion of *Forest Land Converted to Grassland*, as well as (2) the impact from all land use conversions to grassland on mineral and organic soil C stocks.

Biomass, Dead Wood and Litter Carbon Stock Changes

A Tier 2 method is applied to estimate biomass, dead wood and litter C stock changes for *Forest Land Converted to Grassland*. Estimates are calculated in the same way as those in the *Forest Land Remaining Forest Land* category using data from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (USDA Forest Service 2018). The difference between the stocks is reported as the stock change under the assumption that the change occurred in the year of the conversion.

The amount of biomass C that is lost abruptly with *Forest Land Converted to Grasslands* is estimated based on the amount of C before conversion and the amount of C following conversion according to re-measurements in the FIA program. This approach is consistent with IPCC (2006) that assumes there is an abrupt change during the first year, but does not necessarily capture the slower change over the years following conversion until a new steady is reached. It was determined that using an IPCC Tier I approach, which assumes all carbon is lost in the year of conversion for *Forest Land Converted to Grasslands*, in the West and Great Plains states does not accurately characterize the transfer of carbon in woody biomass during abrupt or gradual land use change. To estimate this transfer of carbon in woody biomass, state-specific carbon densities for woody biomass remaining on these former forest lands following conversion to grasslands were developed and included in the estimation of carbon stock changes from *Forest Land Converted to Grasslands*. A review of the literature in grassland and rangeland ecosystems (Asner et al. 2003, Huang et al. 2009, Tarhouni et al. 2016), as well as an analysis of FIA data, suggests that a conservative estimate of 50 percent of the woody biomass carbon density was lost during conversion from forest land to grassland. This estimate was used to develop state-specific carbon density estimates for biomass, dead wood, and litter for grasslands in the West and Great Plains states and these state-specific carbon densities were applied in the compilation system to estimate the carbon losses associated with conversion from forest land to grassland in the West and Great Plains states. In addition, losses from forest land to what are often characterized as woodlands are included in this category using FIA plot re-measurements and the methods and models described hereafter. If FIA plots include data on individual trees, aboveground and belowground C density estimates are based on Woodall et al. (2011). In the Eastern United States, there is limited data on grassland carbon stocks following conversion to grassland so only default biomass estimates (IPCC 2006) for grasslands were used to estimate carbon stock changes (litter and dead wood carbon stocks were assumed to be zero since no reference C density estimates exist for grassland in the Eastern United States).

Aboveground and belowground biomass estimates also include live understory which is a minor component of biomass defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For this Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density are based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003).

Estimates are also derived for changes in dead organic matter with *Forest Land Converted to Grassland*. If FIA plots include data on standing dead trees, standing dead tree C density is estimated following the basic method applied to live trees (Woodall et al. 2011) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). If FIA plots include data on downed dead wood, downed dead wood C density is estimated based on measurements of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. If FIA plots include litter material, a modeling approach using litter C measurements from FIA plots is used to estimate litter C density (Domke et al. 2016). See Annex 3.13 for more information about reference C density estimates for forest land.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Land Converted to Grassland* according to land use histories recorded in the 2012 USDA NRI survey for non-federal lands (USDA-NRCS 2015). Land use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI survey locations on a 5-year cycle beginning in 1982. In 1998, the NRI Program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). NRI survey locations are classified as *Land Converted to Grassland* in a given year between 1990 and 2012 if the land use is grassland but had been classified as another use during the previous 20 years. NRI survey locations are classified according to land use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an underestimation of *Land Converted to Grassland* in the early part of the time series to the extent that some areas are converted to grassland between 1971 and 1978. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for *Land Converted to Grassland* on most mineral soils that are classified in this land use change category. C stock changes on the remaining soils are estimated with an IPCC Tier 2 approach (Ogle et al. 2003), including prior cropland used to produce vegetables, tobacco, and perennial/horticultural crops; land areas with very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted to grassland from another land use other than cropland.

A surrogate data method is used to estimate soil C stock changes from 2013 to 2017 at the national scale for land areas included in the Tier 2 and Tier 3 methods. Specifically, linear regression models with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) are used to estimate the relationship between surrogate data and the 1990 to 2012 emissions data that are derived using the Tier 2 and 3 methods. Surrogate data for these regression models include weather data from the PRISM Climate Group (PRISM 2015). See Box 6-4 in the Methodology section of *Cropland Remaining Cropland* for more information about the surrogate data method. Stock change estimates for 2013 to 2017 will be recalculated in future inventories when new NRI data are available.

Tier 3 Approach. Mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical[58] model (Parton et al. 1998; Del Grosso et al. 2001, 2011). The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land use patterns and irrigation histories are simulated with DAYCENT based on the 2012 USDA NRI survey (USDA-NRCS 2015). C stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2012. See the *Cropland Remaining Cropland* section and Annex 3.12 for additional discussion of the Tier 3 methodology for mineral soils.

Soil C stock changes from 2013 to 2017 are estimated using a surrogate data method described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (See Planned Improvements section in *Cropland Remaining Cropland*).

Tier 2 Approach. For the mineral soils not included in the Tier 3 analysis, SOC stock changes are estimated using a Tier 2 Approach, as described in the Tier 2 Approach for mineral soils in *Grassland Remaining Grassland*. This includes application of the surrogate data method that is described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. As with the Tier 3 method, future Inventories will be updated with new NRI activity data when the data are made available, and the time series will be recalculated.

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[58] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Grassland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils. A surrogate data method is used to estimate annual C emissions from organic soils from 2013 to 2017 as described in Box 6-4 of the Methodology section in *Cropland Remaining Cropland*. Estimates for 2013 to 2017 will be recalculated in future Inventories when new NRI data are available.

Uncertainty and Time-Series Consistency

The uncertainty analysis for biomass, dead wood and litter C losses with *Forest Land Converted to Grassland* is conducted in the same way as the uncertainty assessment for forest ecosystem C flux in the *Forest Land Remaining Forest Land* category. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006), by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. For additional details see the Uncertainty Analysis in Annex 3.13. The uncertainty analyses for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described in the *Cropland Remaining Cropland* section. The uncertainty for annual C emission estimates from drained organic soils in *Land Converted to Grassland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section. For 2013 to 2017, there is additional uncertainty propagated through the Monte Carlo Analysis associated with a surrogate data method, which is also described in *Cropland Remaining Cropland*.

Uncertainty estimates are presented in Table 6-45 for each subsource (i.e., biomass C stocks, mineral soil C stocks and organic soil C stocks) and the method applied in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), as discussed in the previous paragraph. The combined uncertainty for total C stocks in *Land Converted to Grassland* ranges from 214 percent below to 214 percent above the 2017 stock change estimate of 8.3 MMT CO_2 Eq. The large relative uncertainty around the 2017 stock change estimate is partly due to large uncertainties in biomass and dead organic matter C losses with *Forest Land Conversion to Grassland*. The large relative uncertainty is also associated with variation in soil C stock change that is not explained by the surrogate data method, leading to high prediction error with the splicing method.

Table 6-45: Approach 2 Quantitative Uncertainty Estimates for Soil, Dead Organic Matter and Biomass C Stock Changes occurring within *Land Converted to Grassland* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate[a] (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Grassland	**(7.6)**	**(16.3)**	**1.2**	**-116%**	**116%**
Mineral Soil C Stocks: Tier 3	(8.6)	(17.4)	0.1	-102%	102%
Mineral Soil C Stocks: Tier 2	(0.1)	(0.3)	0.1	-333%	333%
Organic Soil C Stocks: Tier 2	1.1	0.8	1.4	-29%	29%
Forest Land Converted to Grassland	**15.8**	**0.3**	**31.4**	**-98%**	**98%**
Aboveground Live Biomass	12.6	(0.6)	25.7	-104%	104%
Belowground Live Biomass	2.4	(0.1)	4.9	-105%	104%
Dead Wood	(0.9)	(6.6)	4.7	-597%	599%
Litter	4.8	(0.2)	9.9	-105%	104%
Mineral Soil C Stocks: Tier 2	(3.2)	(5.4)	(1.0)	-70%	70%
Organic Soil C Stocks: Tier 2	0.1	0.1	0.2	-43%	43%
Other Lands Converted to Grassland	**(0.1)**	**(0.3)**	**0.1**	**-250%**	**251%**
Mineral Soil C Stocks: Tier 2	(0.1)	(0.3)	0.1	-160%	160%
Organic Soil C Stocks: Tier 2	+	+	0.1	-37%	37%
Settlements Converted to Grassland	**+**	**+**	**+**	**-79%**	**79%**
Mineral Soil C Stocks: Tier 2	+	+	+	-575%	550%
Organic Soil C Stocks: Tier 2	+	+	+	-51%	53%
Wetlands Converted to Grasslands	**0.1**	**(0.1)**	**0.3**	**-174%**	**173%**

Mineral Soil C Stocks: Tier 2	(0.2)	(0.4)	+	-83%	83%
Organic Soil C Stocks: Tier 2	0.3	0.2	0.4	-42%	42%
Total: Land Converted to Grassland	**8.3**	**(9.5)**	**26.2**	**-214%**	**214%**
Aboveground Live Biomass	**12.6**	**(0.6)**	**25.7**	**-104%**	**104%**
Belowground Live Biomass	**2.4**	**(0.1)**	**4.9**	**-105%**	**104%**
Dead Wood	**(0.9)**	**(6.6)**	**4.7**	**-597%**	**599%**
Litter	**4.8**	**(0.2)**	**9.9**	**-105%**	**104%**
Mineral Soil C Stocks: Tier 3	**(8.6)**	**(17.4)**	**0.1**	**-102%**	**102%**
Mineral Soil C Stocks: Tier 2	**(3.6)**	**(5.8)**	**(1.3)**	**-63%**	**63%**
Organic Soil C Stocks: Tier 2	**1.6**	**1.3**	**2.0**	**-22%**	**22%**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Methodological recalculations are applied from 2013 to 2017 using the surrogate data method developed using the C stock change estimates from 1990 to 2012, ensuring consistency across the time series. Details on the emission trends through time are described in more detail in the introductory section, above.

Uncertainty is also associated with a lack of reporting on biomass and dead organic matter C stock changes for *Land Converted to Grassland* with the exception of forest land conversion. Biomass C stock changes may be significant for managed grasslands with woody encroachment despite not having attained enough tree cover to be considered forest lands. Changes in dead organic matter C stocks are assumed to be negligible with conversion of land to grasslands with the exception of forest lands, which are included in this analysis. This assumption will be further explored in a future Inventory.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland* for information on QA/QC steps.

Recalculations Discussion

Methodological recalculations are associated with extending the time series from 2013 through 2016 for mineral and organic soils using a surrogate data method, and from 1990 to 2016 for biomass and dead organic matter C associated with *Forest Land Converted to Grassland*. No other recalculations have been implemented in the current Inventory. C stock change losses decreased by an average of 67 percent from 1990 through 2016 based on the recalculation. This change is almost entirely attributed to the update of biomass and dead organic matter losses for *Forest Land Converted to Grassland* with newly available re-measurement data for the western United States. Stock changes were re-estimated at the plot-level with the new data consistent with the compilation methods described for *Forest Land Remaining Forest Land*. In the previous Inventory, state-level averages from the plot data had been used to approximate the losses of C with *Forest Land Converted to Grassland* due to a lack of re-measurement data.

Planned Improvements

The amount of biomass C that is lost abruptly or the slower changes that continue to occur over a decade or longer with *Forest Land Converted to Grasslands* will be further refined in a future Inventory. The current values are estimated based on the amount of C before conversion and an estimated level of C left after conversion based on limited plot data from the FIA and published literature for the Western United States and Great Plains Regions. The amount of C left after conversion will be further investigated with additional data collection, particularly in the Western United States and Great Plains, including tree biomass, understory biomass, dead wood and litter C pools.

Soil C stock changes with land use conversion from forest land to grassland are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and grasslands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to grassland. In addition, biomass C stock changes will be estimated for *Cropland Converted to Grassland*, and other land use conversions to grassland, to the extent that data are available. One additional planned improvement for the *Land Converted to Grassland* category is to develop an inventory of C stock changes for grasslands in Alaska. For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland* and *Grassland Remaining Grassland*.

6.8 Wetlands Remaining Wetlands (CRF Category 4D1)

Wetlands Remaining Wetlands includes all wetland in an Inventory year that had been classified as wetland for the previous 20 years, and in this Inventory includes Peatlands and Coastal Wetlands.

Peatlands Remaining Peatlands

Emissions from Managed Peatlands

Managed peatlands are peatlands that have been cleared and drained for the production of peat. The production cycle of a managed peatland has three phases: land conversion in preparation for peat extraction (e.g., clearing surface biomass, draining), extraction (which results in the emissions reported under *Peatlands Remaining Peatlands*), and abandonment, restoration, or conversion of the land to another use.

Carbon dioxide emissions from the removal of biomass and the decay of drained peat constitute the major greenhouse gas flux from managed peatlands. Managed peatlands may also emit CH_4 and N_2O. The natural production of CH_4 is largely reduced but not entirely shut down when peatlands are drained in preparation for peat extraction (Strack et al. 2004 as cited in the *2006 IPCC Guidelines*). Drained land surface and ditch networks contribute to the CH_4 flux in peatlands managed for peat extraction. Methane emissions were considered insignificant under the IPCC Tier 1 methodology (IPCC 2006), but are included in the emissions estimates for *Peatlands Remaining Peatlands* consistent with the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013). Nitrous oxide emissions from managed peatlands depend on site fertility. In addition, abandoned and restored peatlands continue to release greenhouse gas emissions. Although methodologies are provided for rewetted organic soils (which includes rewetted/restored peatlands) in IPCC (2013) guidelines, information on the areal extent of rewetted/restored peatlands in the United States is currently unavailable. The current Inventory estimates CO_2, CH_4 and N_2O emissions from peatlands managed for peat extraction in accordance with IPCC (2006 and 2013) guidelines.

CO_2, N_2O, and CH_4 Emissions from Peatlands Remaining Peatlands

IPCC (2014) recommends reporting CO_2, N_2O, and CH_4 emissions from lands undergoing active peat extraction (i.e., *Peatlands Remaining Peatlands*) as part of the estimate for emissions from managed wetlands. Peatlands occur where plant biomass has sunk to the bottom of water bodies and water-logged areas and exhausted the oxygen supply below the water surface during the course of decay. Due to these anaerobic conditions, much of the plant matter does not decompose but instead forms layers of peat over decades and centuries. In the United States, peat is extracted for horticulture and landscaping growing media, and for a wide variety of industrial, personal care, and other products. It has not been used for fuel in the United States for many decades. Peat is harvested from two types of peat deposits in the United States: sphagnum bogs in northern states (e.g., Minnesota) and wetlands in states further south (e.g., Florida). The peat from sphagnum bogs in northern states, which is nutrient-poor, is generally corrected for acidity and mixed with fertilizer. Production from more southerly states is relatively coarse (i.e., fibrous) but nutrient-rich.

IPCC (2006 and 2014) recommend considering both on-site and off-site emissions when estimating CO_2 emissions from *Peatlands Remaining Peatlands* using the Tier 1 approach. Current methodologies estimate only on-site N_2O and CH_4 emissions, since off-site N_2O estimates are complicated by the risk of double-counting emissions from nitrogen fertilizers added to horticultural peat, and off-site CH_4 emissions are not relevant given the non-energy uses of peat, so methodologies are not provided in IPCC (2014) guidelines.

On-site emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. As this occurs, some peat deposit is lost and CO_2 is emitted from the oxidation of the peat. Since N_2O emissions from saturated ecosystems tend to be low unless there is an exogenous source of nitrogen, N_2O emissions from drained peatlands are dependent on nitrogen mineralization and therefore on soil fertility. Peatlands located on highly fertile soils contain significant amounts of organic nitrogen in inactive form. Draining land in preparation for peat extraction allows bacteria to convert the nitrogen into nitrates which leach to the surface where they are reduced to N_2O, and contributes to the activity of methanogens and methanotrophs that result in CH_4 emissions (Blodau 2002; Treat et al. 2007 as cited in IPCC 2014). Drainage ditches, which are constructed to drain the land in preparation for peat extraction, also contribute to the flux of CH_4 through in situ production and lateral transfer of CH_4 from the organic soil matrix (IPCC 2014).

Off-site CO_2 emissions from managed peatlands occur from waterborne carbon losses and the horticultural and landscaping use of peat. Dissolved organic carbon from water drained off peatlands reacts within aquatic ecosystems and is converted to CO_2, which is then emitted to the atmosphere (Billet et al. 2004 as cited in IPCC 2014). During the horticultural and landscaping use of peat, nutrient-poor (but fertilizer-enriched) peat tends to be used in bedding plants and in greenhouse and plant nursery production, whereas nutrient-rich (but relatively coarse) peat is used directly in landscaping, athletic fields, golf courses, and plant nurseries. Most (nearly 94 percent) of the CO_2 emissions from peat occur off-site, as the peat is processed and sold to firms which, in the United States, use it predominantly for the aforementioned horticultural and landscaping purposes.

Total emissions from *Peatlands Remaining Peatlands* were estimated to be 0.7 MMT CO_2 Eq. in 2017 (see Table 6-46) comprising 0.7 MMT CO_2 Eq. (734 kt) of CO_2, 0.004 MMT CO_2 Eq. (0.15 kt) of CH_4 and 0.0005 MMT CO_2 Eq. (0.002 kt) of N_2O. Total emissions in 2017 were about 0.11 percent greater than total emissions in 2016.

Total emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.7 and 1.3 MMT CO_2 Eq. across the time series with a decreasing trend from 1990 until 1993, followed by an increasing trend until reaching peak emissions in 2000. After 2000, emissions generally decreased until 2006 and then increased until 2009. The trend reversed in 2009 and total emissions have generally decreased between 2009 and 2017. Carbon dioxide emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.7 and 1.3 MMT CO_2 across the time series, and these emissions drive the trends in total emissions. Methane and N_2O emissions remained close to zero across the time series. Nitrous oxide emissions showed a decreasing trend from 1990 until 1995, followed by an increasing trend through 2001. Nitrous oxide emissions decreased between 2001 and 2006, followed by a leveling off between 2008 and 2010, and a general decline between 2011 and 2017. Methane emissions decreased from 1990 until 1995, followed by an increasing trend through 2000, a period of fluctuation through 2010, and a general decline between 2010 and 2017.

Table 6-46: Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq.)

Gas	1990		2005		2013	2014	2015	2016	2017
CO_2	**1.1**		**1.1**		**0.8**	**0.8**	**0.8**	**0.7**	**0.7**
Off-site	1.0		1.0		0.7	0.7	0.7	0.7	0.7
On-site	0.1		0.1		+	0.1	+	+	+
CH_4 (On-site)	+		+		+	+	+	+	+
N_2O (On-site)	+		+		+	+	+	+	+
Total	**1.1**		**1.1**		**0.8**	**0.8**	**0.8**	**0.7**	**0.7**

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Totals may not sum due to independent rounding.

Table 6-47: Emissions from *Peatlands Remaining Peatlands* (kt)

Gas	1990		2005		2013	2014	2015	2016	2017
CO_2	**1,055**		**1,101**		**770**	**775**	**755**	**733**	**734**
Off-site	985		1,030		720	725	706	686	687
On-site	70		71		50	50	49	47	47
CH_4 (On-site)	+		+		+	+	+	+	+
N_2O (On-site)	+		+		+	+	+	+	+

+ Does not exceed 0.5 kt
Note: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Totals may not sum due to independent rounding.

Methodology

Off-Site CO_2 Emissions

Carbon dioxide emissions from domestic peat production were estimated using a Tier 1 methodology consistent with IPCC (2006). Off-site CO_2 emissions from *Peatlands Remaining Peatlands* were calculated by apportioning the annual weight of peat produced in the United States (Table 6-48) into peat extracted from nutrient-rich deposits and peat extracted from nutrient-poor deposits using annual percentage-by-weight figures. These nutrient-rich and nutrient-poor production values were then multiplied by the appropriate default C fraction conversion factor taken from IPCC (2006) in order to obtain off-site emission estimates. For the lower 48 states, both annual percentages of peat type by weight and domestic peat production data were sourced from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Commodity Summaries* from the U.S. Geological Survey (USGS 1991 through 2016; USGS 2018). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying domestic peat producers. On average, about 75 percent of the peat operations respond to the survey; and USGS estimates data for non-respondents on the basis of prior-year production levels (Apodaca 2011).

The Alaska estimates rely on reported peat production from the annual *Alaska's Mineral Industry* reports (DGGS 1993 through 2015). Similar to the U.S. Geological Survey, the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGS) solicits voluntary reporting of peat production from producers for the *Alaska's Mineral Industry* report. However, the report does not estimate production for the non-reporting producers, resulting in larger inter-annual variation in reported peat production from Alaska depending on the number of producers who report in a given year (Szumigala 2011). In addition, in both the lower 48 states and Alaska, large variations in peat production can also result from variations in precipitation and the subsequent changes in moisture conditions, since unusually wet years can hamper peat production. The methodology estimates Alaska emissions separately from lower 48 emissions because the state conducts its own mineral survey and reports peat production by volume, rather than by weight (Table 6-49). However, volume production data were used to calculate off-site CO_2 emissions from Alaska applying the same methodology but with volume-specific C fraction conversion factors from IPCC (2006).[59] Peat production was not reported for 2015 in *Alaska's Mineral Industry 2014* report (DGGS 2015); and reliable data are not available beyond 2012, so Alaska's peat production in 2013 through 2017 (reported in cubic yards) was assumed to be equal to the 2012 value.

Consistent with IPCC (2014) guidelines, off-site CO_2 emissions from dissolved organic carbon were estimated based on the total area of peatlands managed for peat extraction, which is calculated from production data using the methodology described in the On-Site CO_2 Emissions section below. Carbon dioxide emissions from dissolved organic C were estimated by multiplying the area of peatlands by the default emission factor for dissolved organic C provided in IPCC (2014).

The *apparent consumption* of peat, which includes production plus imports minus exports plus the decrease in stockpiles, in the United States is over time the amount of domestic peat production. However, consistent with the Tier 1 method whereby only domestic peat production is accounted for when estimating off-site emissions, off-site CO_2 emissions from the use of peat not produced within the United States are not included in the Inventory. The United States has largely imported peat from Canada for horticultural purposes; from 2011 to 2014, imports of sphagnum moss (nutrient-poor) peat from Canada represented 97 percent of total U.S. peat imports (USGS 2016). Most peat produced in the United States is reed-sedge peat, generally from southern states, which is classified as nutrient-rich by IPCC (2006). Higher-tier calculations of CO_2 emissions from apparent consumption would involve

[59] Peat produced from Alaska was assumed to be nutrient poor; as is the case in Canada, "where deposits of high-quality [but nutrient poor] sphagnum moss are extensive" (USGS 2008).

consideration of the percentages of peat types stockpiled (nutrient-rich versus nutrient-poor) as well as the percentages of peat types imported and exported.

Table 6-48: Peat Production of Lower 48 States (kt)

Type of Deposit	1990		2005		2013	2014	2015	2016	2017
Nutrient-Rich	595.1		657.6		418.5	416.5	405.0	388.1	374.0
Nutrient-Poor	55.4		27.4		46.5	51.5	50.1	52.9	66.0
Total Production	**692.0**		**685.0**		**465.0**	**468.0**	**455.0**	**441.0**	**440.0**

Sources: United States Geological Survey (USGS) (1991–2016) *Minerals Yearbook: Peat (1994–2016);* United States Geological Survey (USGS) (2018) *Mineral Commodity Summaries: Peat (2018).*

Table 6-49: Peat Production of Alaska (Thousand Cubic Meters)

	1990		2005		2013	2014	2015	2016	2017
Total Production	49.7		47.8		93.1	93.1	93.1	93.1	93.1

Sources: Division of Geological & Geophysical Surveys (DGGS), Alaska Department of Natural Resources (1997–2015) *Alaska's Mineral Industry Report (1997–2014).*

On-site CO_2 Emissions

IPCC (2006) suggests basing the calculation of on-site emission estimates on the area of peatlands managed for peat extraction differentiated by the nutrient type of the deposit (rich versus poor). Information on the area of land managed for peat extraction is currently not available for the United States, but consistent with IPCC (2006), an average production rate for the industry was applied to derive an area estimate. In a mature industrialized peat industry, such as exists in the United States and Canada, the vacuum method can extract up to 100 metric tons per hectare per year (Cleary et al. 2005 as cited in IPCC 2006).[60] The area of land managed for peat extraction in the lower 48 states of the United States was estimated using nutrient-rich and nutrient-poor production data and the assumption that 100 metric tons of peat are extracted from a single hectare in a single year. The annual land area estimates were then multiplied by the IPCC (2014) default emission factor in order to calculate on-site CO_2 emission estimates. Production data are not available by weight for Alaska. In order to calculate on-site emissions resulting from *Peatlands Remaining Peatlands* in Alaska, the production data by volume were converted to weight using annual average bulk peat density values, and then converted to land area estimates using the same assumption that a single hectare yields 100 metric tons.

The estimated areas of land managed for peat extraction are presented in Table 6-50. The total area of peat production is used to calculate off-site CO_2 emissions from dissolved organic carbon and on-site CO_2 emissions. The total area of peat production is also used to calculate on-site CH_4 emissions, as described in the *On-Site CH_4 Emissions* section. The area of nutrient-rich peat production is used to estimate on-site N_2O emissions, as described in the *On-Site N_2O Emissions* section.

Table 6-50: Peat Production Area (Hectares)

	1990		2005		2013	2014	2015	2016	2017
Total Area of Peat Production	7,206		6,954		4,860	4,884	4,759	4,611	4,601
Area of Nutrient-Rich Production	554		274		465	515	501	529	660

The IPCC (2006) on-site emissions equation also includes a term which accounts for emissions resulting from the change in C stocks that occurs during the clearing of vegetation prior to peat extraction. Area data on land undergoing conversion to peatlands for peat extraction is also unavailable for the United States. However, USGS records show that the number of active operations in the United States has been declining since 1990; therefore, it

[60] The vacuum method is one type of extraction that annually "mills" or breaks up the surface of the peat into particles, which then dry during the summer months. The air-dried peat particles are then collected by vacuum harvesters and transported from the area to stockpiles (IPCC 2006).

seems reasonable to assume that no new areas are being cleared of vegetation for managed peat extraction. Other changes in C stocks in living biomass on managed peatlands are also assumed to be zero under the Tier 1 methodology (IPCC 2006 and 2014).

On-site N_2O Emissions

IPCC (2006) suggests basing the calculation of on-site N_2O emission estimates on the area of nutrient-rich peatlands managed for peat extraction. These area data are not available directly for the United States, but the on-site CO_2 emissions methodology above details the calculation of area data from production data. In order to estimate N_2O emissions, the area of nutrient-rich *Peatlands Remaining Peatlands* was multiplied by the appropriate default emission factor taken from IPCC (2014).

On-site CH_4 Emissions

IPCC (2014) also suggests basing the calculation of on-site CH_4 emission estimates on the total area of peatlands managed for peat extraction. Area data is derived using the calculation from production data described in the On-site CO_2 Emissions section above. In order to estimate CH_4 emissions from drained land surface, the area of *Peatlands Remaining Peatlands* was multiplied by the emission factor for direct CH_4 emissions taken from IPCC (2014). In order to estimate CH_4 emissions from drainage ditches, the total area of peatland was multiplied by the default fraction of peatland area that contains drainage ditches, and the appropriate emission factor taken from IPCC (2014).

Uncertainty and Time-Series Consistency

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the uncertainty of CO_2, CH_4, and N_2O emissions from *Peatlands Remaining Peatlands* for 2017, using the following assumptions:

- The uncertainty associated with peat production data was estimated to be ± 25 percent (Apodaca 2008) and assumed to be normally distributed.
- The uncertainty associated with peat production data stems from the fact that the USGS receives data from the smaller peat producers but estimates production from some larger peat distributors. The peat type production percentages were assumed to have the same uncertainty values and distribution as the peat production data (i.e., ± 25 percent with a normal distribution).
- The uncertainty associated with the reported production data for Alaska was assumed to be the same as for the lower 48 states, or ± 25 percent with a normal distribution. It should be noted that the DGGS estimates that around half of producers do not respond to their survey with peat production data; therefore, the production numbers reported are likely to underestimate Alaska peat production (Szumigala 2008).
- The uncertainty associated with the average bulk density values was estimated to be ± 25 percent with a normal distribution (Apodaca 2008).
- IPCC (2006 and 2014) gives uncertainty values for the emissions factors for the area of peat deposits managed for peat extraction based on the range of underlying data used to determine the emission factors. The uncertainty associated with the emission factors was assumed to be triangularly distributed.
- The uncertainty values surrounding the C fractions were based on IPCC (2006) and the uncertainty was assumed to be uniformly distributed.
- The uncertainty values associated with the fraction of peatland covered by ditches was assumed to be ± 100 percent with a normal distribution based on the assumption that greater than 10 percent coverage, the upper uncertainty bound, is not typical of drained organic soils outside of The Netherlands (IPCC 2014).

The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-51. Carbon dioxide emissions from *Peatlands Remaining Peatlands* in 2017 were estimated to be between 0.6 and 0.8 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 15 percent below to 15 percent above the 2017 emission estimate of 0.7 MMT CO_2 Eq. Methane emissions from *Peatlands Remaining Peatlands* in 2017 were estimated to be between 0.002 and 0.007 MMT CO_2 Eq. This indicates a range of 57 percent below to 79 percent above the 2017 emission estimate of 0.004 MMT CO_2 Eq. Nitrous oxide emissions from *Peatlands Remaining Peatlands* in 2017 were estimated to be between 0.0002 and 0.0008 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 53 percent below to 54 percent above the 2017 emission estimate of 0.0005 MMT CO_2 Eq.

Table 6-51: Approach 2 Quantitative Uncertainty Estimates for CO_2, CH_4, and N_2O Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Peatlands Remaining Peatlands	CO_2	0.7	0.6	0.8	-15%	15%
Peatlands Remaining Peatlands	CH_4	+	+	+	-57%	79%
Peatlands Remaining Peatlands	N_2O	+	+	+	-53%	54%

+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

QA/QC and Verification

A QA/QC analysis was performed to review input data and calculations, and no issues were identified. In addition, the emission trends were analyzed to ensure they reflected activity data trends.

Recalculations Discussion

The emissions estimates for *Peatlands Remaining Peatlands* were updated for 2017 using the Peat section of the *Mineral Commodity Summaries 2017* and *Mineral Commodity Summaries 2018*. The 2018 edition provided 2016 data and updated 2015 data for the lower 48 states. The 2017 edition provided peat type production estimates for 2016. Although Alaska peat production data for 2017 were unavailable, 2014 data are available in the *Alaska's Mineral Industry 2014* report. However, the reported values represented an apparent 98 percent decrease in production since 2012. Due to the uncertainty of the most recent data, 2013, 2014, 2015, 2016, and 2017 values were assumed to be equal to the 2012 value. If updated data are available for the next inventory cycle, this will result in a recalculation in the next Inventory report.

Planned Improvements

In order to further improve estimates of CO_2, N_2O, and CH_4 emissions from *Peatlands Remaining Peatlands*, future efforts will investigate if improved data sources exist for determining the quantity of peat harvested per hectare and the total area undergoing peat extraction.

Efforts will also be made to find a new source for Alaska peat production. The current source has not been reliably updated since 2012 and future publication of these data may discontinue.

The implied emission factors will be calculated and included in this chapter for future inventories. The N_2O emissions calculation uses different land areas than the CO_2 and CH_4 emission calculations, so estimating the implied emission factor per total land area is not appropriate and are not generated in the CRF tables. The inclusion of implied emission factors in this chapter will provide another method of QA/QC and verification.

The *2006 IPCC Guidelines* do not cover all wetland types; they are restricted to peatlands drained and managed for peat extraction, conversion to flooded lands, and some guidance for drained organic soils. They also do not cover all of the significant activities occurring on wetlands (e.g., rewetting of peatlands). Since this inventory only includes *Peatlands Remaining Peatlands*, additional wetland types and activities found in the *2013 IPCC Supplement* will be reviewed to determine if they apply to the United States. For those that do, available data will be investigated to allow for the estimation of greenhouse gas fluxes in future inventory years.

Coastal Wetlands Remaining Coastal Wetlands

This Inventory recognizes Wetlands as a "land-use that includes land covered or saturated for all or part of the year, in addition to areas of lakes, reservoirs and rivers." Consistent with ecological definitions of wetlands,[61] the United States has historically included under the category of Wetlands those coastal shallow water areas of estuaries and bays that lie within the extent of the Land Representation.

Additional guidance on quantifying greenhouse gas emissions and removals on Coastal Wetlands is provided in the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement),* which recognizes the particular importance of vascular plants in sequestering CO_2 from the atmosphere within biomass and building soil carbon stocks. Thus, the *Wetlands Supplement* provides specific guidance on quantifying emissions on organic and mineral soils that are covered or saturated for part of the year by tidal fresh, brackish or saline water and are vegetated by vascular plants and may extend seaward to the maximum depth of vascular plant vegetation.

The United States recognizes both Vegetated Wetlands and Unvegetated Open Water as Coastal Wetlands. Per guidance provided by the *Wetlands Supplement*, sequestration of carbon into biomass and soil carbon pools is recognized only in Vegetated Coastal Wetlands and not to occur in Unvegetated Open Water Coastal Wetlands. The United States takes the additional step of recognizing that stock losses occur when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands.

This Inventory includes all privately-owned and publicly-owned coastal wetlands along the oceanic shores on the conterminous U.S., but does not include *Coastal Wetlands Remaining Coastal Wetlands* in Alaska or Hawaii. Seagrasses are not currently included within the Inventory due to insufficient data on distribution, change through time and carbon (C) stocks or C stock changes as a result of anthropogenic influence.

Under the *Coastal Wetlands Remaining Coastal Wetlands* category, the following emissions and removals are quantified in this chapter:

1) Carbon stock changes and CH_4 emissions on *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands*,
2) Carbon changes on *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands*,
3) Carbon stock changes on *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands*, and
4) *Nitrous Oxide Emissions from Aquaculture in Coastal Wetlands*.

Vegetated coastal wetlands hold C in all five C pools (i.e., aboveground, belowground, dead organic matter [DOM; dead wood and litter], and soil) though typically soil C and, to a lesser extent aboveground and belowground biomass, are the dominant pools, depending on wetland type (i.e., forested vs. marsh). Vegetated Coastal Wetlands are net accumulators of C as soils accumulate C under anaerobic soil conditions and in plant biomass. Emissions from soil C and biomass stocks occur when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands (i.e., when managed Vegetated Coastal Wetlands are lost due to subsidence), but are still recognized as Coastal Wetlands in this Inventory. These C emissions resulting from conversion to Unvegetated Open Water Coastal Wetlands can cause the release of many years of accumulated soil C, as well as the standing stock of biomass C. Conversion of Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands initiates the building of C stocks within soils and biomass. In applying the *2013 IPCC Wetlands Supplement* methodologies for CH_4 emissions, coastal wetlands in salinity conditions less than half that of sea water are sources of CH_4 as result of slow decomposition of organic matter under lower salinity brackish and freshwater, anaerobic conditions. Conversion of Vegetated Coastal Wetlands to or from Unvegetated Open Water Coastal Wetlands do not result in a change in salinity condition and are assumed to have no impact on CH_4 emissions. The *2013 IPCC Wetlands Supplement* provides methodologies to estimate N_2O emissions on coastal wetlands that occur due to aquaculture. While N_2O emissions can also occur due to anthropogenic N loading from the watershed and atmospheric deposition, these emissions are not reported here to avoid double-counting of indirect N_2O emissions with the Agricultural Soils Management, Forest Land and Settlements categories. The N_2O emissions from

[61] See <https://water.usgs.gov/nwsum/WSP2425/definitions.html>.

aquaculture result from the N derived from consumption of the applied food stock that is then excreted as N load available for conversion to N_2O.

The *Wetlands Supplement* provides procedures for estimating C stock changes and CH_4 emissions from mangroves, tidal marshes and seagrasses. Depending upon their height and area, stock changes from managed mangroves may be reported under the Forest Land category or under Coastal Wetlands. All non-drained, intact coastal marshes are intended to be reported under Coastal Wetlands.

Because of human use and level of regulatory oversight, all coastal wetlands within the conterminous United States are included within the managed land area described in Section 6.1, and as such all estimates of C stock changes, emissions of CH_4, and N_2O from aquaculture are included in this Inventory. At the present stage of inventory development, Coastal Wetlands are not explicitly shown in the Land Representation analysis while work continues to harmonize data from NOAA's Coastal Change Analysis Program[62] with National Resources Inventory (NRI) data used to compile the Land Representation. However, a check was undertaken to confirm that Coastal Wetlands recognized by C-CAP represented a subset of Wetlands recognized by the NRI for marine coastal states.

Emissions and Removals from Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands

The conterminous United States hosts 2.9 million hectares of intertidal *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* comprised of tidally influenced palustrine emergent marsh (602,652 ha), palustrine scrub shrub (140,602 ha) and estuarine emergent marsh (1,838,461 ha), estuarine scrub shrub (97,231 ha) and estuarine forest (192,011 ha). Mangroves fall under both estuarine forest and estuarine scrub shrub categories depending upon height. Dwarf mangroves, found in Texas, do not attain the height status to be recognized as Forest Land, and are therefore always classified within Vegetated Coastal Wetlands. *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* are found in cold temperate (52,405 ha), warm temperate (899,026 ha), subtropical (1,863,204 ha) and Mediterranean (56,322 ha) climate zones.

Soils are the largest C pool in *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands*, reflecting long-term removal of atmospheric CO_2 by vegetation and transfer into the soil pool in the form of decaying organic matter. Soil C emissions are not assumed to occur in coastal wetlands that remain vegetated. This Inventory, for the first time, includes changes in aboveground biomass C stocks along with soils. Currently, insufficient data exist on C stock changes in belowground biomass, DOM and litter. Methane emissions from decomposition of organic matter in anaerobic conditions are significant at salinity less than half that of sea water. Mineral and organic soils are not differentiated in terms of C stock changes or CH_4 emissions.

Table 6-52 through Table 6-54 below summarize nationally aggregated aboveground biomass and soil C stock changes and CH_4 emissions on Vegetated Coastal Wetlands. Intact *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* hold a relatively small aboveground biomass C stock (9 MMT); however, wetlands maintain a large C stock in soil (estimated to be 870 MMT C (3,190 MMT CO_2 Eq.)) within the top 1 meter of soil to which C is accumulated at a yearly rate of 9.9 MMT CO_2 Eq. over the past five years. Recent yearly CH_4 emissions of 3.6 of MMT CO_2 Eq. offset C removals resulting in an annual net C removal rate of 6.5 MMT CO_2 Eq. Due to federal regulatory protection, loss of Vegetated Coastal Wetland area slowed considerably in the 1970s and the current rates of C stock change and CH_4 emissions are relatively constant over time. Losses of Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands (described later in this chapter) and to other land uses do occur, which, because of the depth to which soil C stocks are impacted, have a significant impact on the net stock changes in Coastal Wetlands.

Table 6-52: CO_2 Flux from C Stock Changes in *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* (MMT CO_2 Eq.)

Year	1990	2005	2013	2014	2015	2016	2017
Soil Flux	(9.9)	(10.0)	(9.9)	(9.9)	(9.9)	(9.9)	(9.9)

[62] See <https://coast.noaa.gov/digitalcoast/tools/lca>.

Aboveground Biomass Flux	(0.02)	0.04	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Total C Stock Change	**(9.9)**	**(9.9)**	**(9.9)**	**(9.9)**	**(9.9)**	**(9.9)**	**(9.9)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Table 6-53: CO_2 Flux from C Stock Changes in *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* (MMT C)

Year	1990	2005	2013	2014	2015	2016	2017
Soil Flux	(2.7)	(2.7)	(2.7)	(2.7)	(2.7)	(2.7)	(2.7)
Aboveground Biomass Flux	(0.01)	0.01	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Total C Stock Change	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**	**(2.7)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Table 6-54: CH_4 Emissions from *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* (MMT CO_2 Eq. and kt CH_4)

Year	1990	2005	2013	2014	2015	2016	2017
Methane Emissions (MMT CO_2 Eq.)	3.4	3.5	3.6	3.6	3.6	3.6	3.6
Methane Emissions (kt CH_4)	137	140	142	143	143	144	144

Methodology

The following section includes a description of the methodology used to estimate changes in aboveground biomass C stocks, soil C stocks and emissions of CH_4 for *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands*.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* for both mineral and organic soils on wetlands below the elevation of high tides (taken to be mean high water spring tide elevation) and as far seawards as the extent of intertidal vascular plants according to the national LiDAR dataset, the national network of tide gauges and land use histories recorded in the 1996, 2001, 2005 and 2010 NOAA C-CAP surveys.[63] Federal and non-federal lands are represented. Trends in land cover change are extrapolated to 1990 and 2017 from these datasets. Based upon NOAA C-CAP, coastal wetlands are subdivided into freshwater (palustrine) and saline (estuarine) classes and further subdivided into emergent marsh, scrub shrub and forest classes.[64] Soil C stock changes, stratified by climate zones and wetland classes, are derived from a synthesis of peer-reviewed literature (Lynch 1989; Orson et al. 1990; Kearny & Stevenson 1991; Roman et al. 1997; Craft et al. 1998; Orson et al. 1998; Merrill 1999; Hussein et al. 2004; Church et al. 2006; Köster et al. 2007; Callaway et al. 2012 a & b; Bianchi et al. 2013; Crooks et al. 2014; Weston et al. 2014; Villa & Mitsch 2015; Marchio et al. 2016; Noe et al. 2016). To estimate soil C stock changes, no differentiation is made between organic and mineral soils.

Tier 2 level estimates of soil C removal associated with annual soil C accumulation from managed *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* were developed with country-specific soil C removal factors multiplied by activity data of land area for *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands*. The methodology follows Eq. 4.7, Chapter 4 of the *Wetlands Supplement*, and is applied to the area of *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* on an annual basis. A single soil emission factor was used based on Holmquist et al. (2018). The authors found no statistical support to disaggregate soil C removal factors by climate region, vegetation type, or salinity range (estuarine or palustrine).

Aboveground Biomass Carbon Stock Changes

Aboveground biomass C Stocks for Palustrine and Estuarine marshes are estimated for *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands*. Biomass is not sensitive to soil organic content but is differentiated based

63 See <https://coast.noaa.gov/digitalcoast/tools/lca.html>.

64 See <https://coast.noaa.gov/digitalcoast/tools/lca.html>.

on climate zone. Data are derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al., 2017; Byrd, et al., 2018). Trends in land cover change are derived from the NOAA C-CAP dataset and extrapolated to cover the entire 1990 to 2017 time series. Aboveground biomass stock changes per year for wetlands remaining wetlands were determined by calculating the difference in area between that year and the previous year to calculate gain/loss of area for each climate type, which was multiplied by the mean biomass for that climate type. Currently, a nationwide dataset for belowground biomass has not been assembled.

Soil Methane Emissions

Tier 1 estimates of CH_4 emissions for *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* are derived from the same wetland map used in the analysis of wetland soil C fluxes, produced from C-CAP, LiDAR and tidal data, in combination with default CH_4 emission factors provided in Table 4.14 of the *Wetlands Supplement.* The methodology follows Eq. 4.9, Chapter 4 of the *Wetlands Supplement*, and is applied to the area of *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* on an annual basis.

Uncertainty and Time-Series Consistency

Underlying uncertainties in estimates of soil and aboveground biomass C stock changes and CH_4 include uncertainties associated with Tier 2 literature values of soil C stocks, aboveground biomass C stocks and CH_4 flux, assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* include differentiation of palustrine and estuarine community classes, which determines the soil C stock and CH_4 flux applied. Soil C stocks and CH_4 fluxes applied are determined from vegetation community classes across the coastal zone and identified by NOAA C-CAP. Community classes are further subcategorized by climate zones and growth form (forest, shrub-scrub, marsh). Aboveground biomass classes were subcategorized by climate zones. Uncertainties for soil and aboveground biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgement about the most appropriate assignment of a C stock to a disaggregation of a community class. Because mean soil and aboveground biomass C stocks for each available community class are in a fairly narrow range, the same overall uncertainty was assigned to each, respectively (i.e., applying approach for asymmetrical errors, where the largest uncertainty for any one soil C stock referenced using published literature values for a community class; uncertainty approaches provide that if multiple values are available for a single parameter, the highest uncertainty value should be applied to the propagation of errors; IPCC 2000). Uncertainties for CH_4 flux are the Tier 1 default values reported in the *Wetlands Supplement*. Overall uncertainty of the NOAA C-CAP remote sensing product is 15 percent. This is in the range of remote sensing methods (±10-15 percent; IPCC 2003). However, there is significant uncertainty in salinity ranges for tidal and non-tidal estuarine wetlands and activity data used to apply CH_4 flux emission factors (delineation of an 18 ppt boundary) will need significant improvement to reduce uncertainties.

Table 6-55: Approach 1 Quantitative Uncertainty Estimates for C Stock Changes and CH_4 Emissions occurring within *Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands* (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Estimate (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock Change	CO_2	(9.9)	(11.7)	(8.1)	-29.5%	29.5%
Aboveground Biomass C Stock Change	CO_2	(0.02)	(0.03)	(0.02)	-16.5%	16.5%
CH_4 emissions	CH_4	3.6	2.5	4.7	-29.8%	29.8%
Total Flux		**(6.3)**	**(8.8)**	**(3.9)**	**-38.5%**	**38.5%**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

QA/QC and Verification

NOAA provided National LiDAR Dataset, tide data, and C-CAP land cover and land cover change mapping, all of which are subject to agency internal QA/QC assessment. Acceptance of final datasets into archive and dissemination are contingent upon the product compilation being compliant with mandatory QA/QC requirements (McCombs et al. 2016). QA/QC and verification of soil C stock datasets have been provided by the Smithsonian Environmental Research Center and Coastal Wetland Inventory team leads who reviewed summary tables against reviewed sources. Aboveground biomass C stocks are derived from peer-review literature and reviewed by the U.S. Geological Survey prior to publishing, by the peer-review process during publishing, and by the Coastal Wetland Inventory team leads before inclusion in the inventory. A team of two evaluated and verified there were no computational errors within the calculation worksheets. Soil and aboveground biomass C stock change data are based upon peer-reviewed literature and CH_4 emission factors derived from the IPCC Wetlands Supplement.

Recalculations Discussion

Methodological recalculations are associated with the extension of C-CAP data extrapolation through 2017. Soil reference carbon sequestration rates were expanded and reanalyzed based upon geometric means; upper and lower 95 percent confidence intervals were calculated and the larger of the two was used (Lu and Megonigal 2017). Recalculation of carbon sequestration lowered annual removals from 12.1 MMT CO_2 Eq. to 9.9 MMT CO_2 Eq. per year over the past five years. New data on aboveground biomass carbon stocks were added that were derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al. 2017; Byrd, et al. 2018).

Planned Improvements

Administered by the Smithsonian Environmental Research Center, the Coastal Wetland Carbon Research Coordination Network has established a U.S. country-specific database of soil C stock and aboveground biomass for coastal wetlands.[65] This dataset will be updated periodically. Refined error analysis combining land cover change and C stock estimates will be provided as new data are incorporated. Through this work, a model is in development to represent changes in soil C stocks for estuarine emergent wetlands. The C-CAP dataset for 2015 is currently under development with planned release 2019. Additional data products for years 2003, 2008 and 2013 are also planned for release. Once complete, land use change for 1990 through 2017 will be recalculated with this updated dataset.

Emissions from Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands

Conversion of intact Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands is a source of emissions from both soil and biomass C stocks. It is estimated that 4,828 ha of Vegetated Coastal Wetlands were converted to Unvegetated Open Water Coastal Wetlands in 2017. The Mississippi Delta represents more than 40 percent of the total coastal wetland of the United States, and over 90 percent of the conversion of Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands. The drivers of coastal wetlands loss include legacy human impacts on sediment supply through rerouting river flow, direct impacts of channel cutting on hydrology, salinity and sediment delivery, and accelerated subsidence from aquafer extraction. Each of these drivers directly contributes to wetland erosion and subsidence, while also reducing the resilience of the wetland to build with sea-level rise or recover from hurricane disturbance. Over recent decades, the rate of Mississippi Delta wetland loss has slowed, though episodic mobilization of sediment occurs during hurricane events (Couvillion et al. 2011; Couvillion et al. 2016). The most recent land cover analysis recorded by the C-CAP surveys of 2005 and 2010 coincides with two such events, hurricanes Katrina and Rita both in 2005.

Shallow nearshore open water within the U.S. Land Representation is recognized as falling under the Wetlands category within the U.S. Inventory. While high resolution mapping of coastal wetlands provides data to support Tier 2 approaches for tracking land cover change, the depth to which sediment is lost is less clear. This Inventory adopts the Tier 1 methodological guidance from the *Wetlands Supplement* for estimating emissions following the methodology for excavation (see Methodology section, below) when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands, assuming a 1 m depth of disturbed soil. This 1 m depth of disturbance is

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[65] See <https://serc.si.edu/coastalcarbon>.

consistent with estimates of wetland C loss provided in the literature (Crooks et al. 2009; Couvillion et al. 2011; Delaune and White 2012; IPCC 2013). A Tier 1 assumption is also adopted that all mobilized C is immediately returned to the atmosphere (as assumed for terrestrial land use categories), rather than redeposited in long-term C storage. The science is currently under evaluation to adopt more refined emissions factors for mobilized coastal wetland C based upon the geomorphic setting of the depositional environment.

Table 6-56: CO_2 Flux from C Stock Changes in *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands* (MMT CO_2 Eq.)

Year	1990		2005		2013	2014	2015	2016	2017
Soil Flux	4.8		3.1		4.8	4.8	4.8	4.8	4.8
Aboveground Biomass Flux	0.04		0.03		0.04	0.04	0.04	0.04	0.04
Total C Stock Change	**4.8**		**3.1**		**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Note: Totals may not sum due to independent rounding.

Table 6-57: CO_2 Flux from C Stock Changes in *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands* (MMT C)

Year	1990		2005		2013	2014	2015	2016	2017
Soil Flux	1.3		0.8		1.3	1.3	1.3	1.3	1.3
Aboveground Biomass Flux	0.01		0.01		0.01	0.01	0.01	0.01	0.01
Total C Stock Change	**1.3**		**0.9**		**1.3**	**1.3**	**1.3**	**1.3**	**1.3**

Note: Totals may not sum due to independent rounding.

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil and aboveground biomass C stocks for *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands*.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands* on lands below the elevation of high tides (taken to be mean high water spring tide elevation) within the U.S. Land Representation according to the national LiDAR dataset, the national network of tide gauges and land use histories recorded in the 1996, 2001, 2005 and 2010 NOAA C-CAP surveys. Publicly-owned and privately-owned lands are represented. Trends in land cover change are extrapolated to 1990 and 2017 from these datasets. C-CAP provides peer reviewed country-specific mapping to support IPCC Approach 3 quantification of coastal wetland distribution, including conversion to and from open water. Country-specific soil C stocks were updated in 2018 based upon analysis of an assembled dataset of 1,959 cores from across the conterminous United States (Holmquist et al. 2018). This analysis demonstrated that it was not justified to stratify C stocks based upon mineral or organic soil classification, climate zone, nor wetland classes. Following the Tier 1 approach for estimating CO_2 emissions with extraction provided within the *Wetlands Supplement*, soil C loss with conversion of Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands is assumed to affect soil C stock to one-meter depth (Holmquist et al. 2018) with all emissions occurring in the year of wetland conversion, and multiplied by activity data of land area for managed coastal wetlands. The methodology follows Eq. 4.6 in the *Wetlands Supplement*.

Aboveground Biomass Carbon Stock Changes

Aboveground biomass C stocks for palustrine and estuarine marshes are estimated for *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands*. Biomass C stock is not sensitive to soil organic content but is differentiated based on climate zone. Aboveground biomass C stock data are derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al., 2017; Byrd, et al., 2018). Trends in land cover change are derived from the NOAA C-CAP dataset and extrapolated to cover the entire 1990-2017 time series. Conversion to open water results in emissions of all aboveground biomass C stocks during the year of conversion; therefore, emissions are calculated by multiplying the C-CAP derived area lost that year in each climate zone by its mean aboveground biomass. Currently, a nationwide dataset for belowground biomass has not been assembled.

Soil Methane Emissions

A Tier 1 assumption has been applied that salinity conditions are unchanged and hence methane emissions are assumed to be zero with conversion of Vegetated Coastal Wetlands to Unvegetated Open Water Coastal Wetlands.

Uncertainty and Time-Series Consistency

Underlying uncertainties in estimates of soil and aboveground biomass C stock changes are associated with country-specific (Tier 2) literature values of these stocks. Assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data are also included in this uncertainty assessment. Uncertainty specific to coastal wetlands include differentiation of palustrine and estuarine community classes, which determines the soil C stock applied. Soil C stocks applied are determined from vegetation community classes across the coastal zone and identified by NOAA C-CAP. Community classes are further subcategorized by climate zones and growth form (forest, shrub-scrub, marsh). Soil and aboveground biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgement about the most appropriate assignment of a soil and aboveground biomass C stock to a disaggregation of a community class. Because mean soil and aboveground biomass C stocks for each available community class are in a fairly narrow range, the same overall uncertainty was assigned to each (i.e., applying approach for asymmetrical errors, where the largest uncertainty for any one soil C stock referenced using published literature values for a community class; uncertainty approaches provide that if multiple values are available for a single parameter, the highest uncertainty value should be applied to the propagation of errors; IPCC 2000). For aboveground biomass C stocks, the mean standard error was very low and largely influenced by error in estimated map area (Byrd et al. 2018). Overall uncertainty of the NOAA C-CAP remote sensing product is 15 percent. This is in the range of remote sensing methods (±10-15 percent; IPCC 2003).

Table 6-58: Approach 1 Quantitative Uncertainty Estimates for CO_2 Flux Occurring within *Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock	4.8	4.1	5.5	-41.7%	+41.7%
Aboveground Biomass C Stock	0.04	0.03	0.05	-16.5%	+16.5%
Total Flux	**4.8**	**3.0**	**6.7**	**-24.4%**	**+24.4%**

Note: Totals may not sum due to independent rounding.

The C-CAP dataset, consisting of a time series of four time intervals, each five years in length, and two major hurricanes striking the Mississippi Delta in the most recent time interval (2006 to 2010), creates a challenge in utilizing it to represent the annual rate of wetland loss and for extrapolation to 1990 and 2017. Uncertainty in the defining the long-term trend will be improved with release of the 2015 survey, expected in 2019.

More detailed research is in development that provides a longer term assessment and more highly refined rates of wetlands loss across the Mississippi Delta (e.g., Couvillion et al. 2016), which could provide a more refined regional Approach 2-3 for assessing wetland loss and support the national-scale assessment provided by C-CAP.

Based upon the IPCC Tier 1 methodological guidance in the *Wetlands Supplement* for estimating emissions with excavation in coastal wetlands, it has been assumed that a 1-meter column of soil has been remobilized with erosion and the C released immediately to the atmosphere as CO_2. This depth of disturbance is a simplifying assumption that is commonly applied in the scientific literature to gain a first-order estimate of scale of emissions (e.g., Delaune and White 2012). It is also a simplifying assumption that all that C is released back to the atmosphere immediately and future development of the country-specific estimate may refine the emissions both in terms of scale and rate. Given that erosion has been ongoing for multiple decades the assumption that the C eroded is released to the atmosphere the year of erosion is a reasonable simplification, but one that could be further refined.

QA/QC and Verification

Data provided by NOAA (i.e., National LiDAR Dataset, NOS Tide Data, and C-CAP land cover and land cover change mapping) undergo internal agency QA/QC procedures. Acceptance of final datasets into archive and dissemination are contingent upon assurance that the data product is compliant with mandatory NOAA QA/QC requirements (McCombs et al. 2016). QA/QC and Verification of the soil C stock dataset have been provided by the Smithsonian Environmental Research Center and by the Coastal Wetlands project team leads who reviewed the estimates against primary scientific literature. Aboveground biomass C stocks are derived from peer-review literature and reviewed by the U.S. Geological Survey prior to publishing, by the peer-review process during publishing, and by the Coastal Wetland Inventory team leads before inclusion in the Inventory. Land cover estimates were assessed to ensure that the total land area did not change over the time series in which the inventory was developed, and were verified by a second QA team. A team of two evaluated and verified there were no computational errors within the calculation worksheets. Two biogeochemists at the USGS, in addition to members of the NASA Carbon Monitoring System Science Team, corroborated the assumption that where salinities are unchanged CH_4 emissions are constant with conversion of *Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands*.

Recalculations Discussion

Methodological recalculations are associated with the extension of C-CAP data extrapolation through 2017. Reference soil carbon stocks were modified to 270 t C ha^{-1} to all vegetated intertidal coastal wetland classes and for all climatic zones, reflecting analysis by Holmquist et al. (2018). This resulted in an increase in soil carbon emissions due wetland erosions: 1.3 MMT CO_2 Eq. per year over the period of 2011 to 2016. New data on aboveground biomass carbon stocks were added, broken down by climate zone, that were derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al. 2017; Byrd, et al. 2018), increasing emissions further by 0.04 MMT CO_2 Eq. per year.

Planned Improvements

A refined uncertainty analysis and efforts to improve times series consistency are planned for the 1990 through 2018 Inventory (i.e., 2020 submission to the UNFCCC). An approach for calculating the fraction of remobilized coastal wetland soil C returned to the atmosphere as CO_2 is currently under review and may be included in future reports. Research by USGS is investigating higher resolution mapping approaches to quantify conversion of coastal wetlands is also underway. Such approaches may form the basis of an Approach 3 land representation assessment in future years.

The C-CAP dataset for 2015 is currently under development with a planned release in 2019. Additional data products for years 2003, 2008, and 2013 are also planned for release. Once complete, land use change for 1990 through 2018 will be recalculated with this updated dataset. C-CAP data harmonization with the National Land Cover Dataset (NLCD) will be incorporated into a future iteration of the inventory.

Stock Changes from Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands

Open Water within the U.S. land base, as described in the Land Representation, is recognized as Coastal Wetlands within the Inventory. The appearance of vegetated tidal wetlands on lands previously recognized as open water reflects either the building of new vegetated marsh through sediment accumulation or the transition from other lands uses through an intermediary open water stage as flooding intolerant plants are displaced and then replaced by wetland plants. Biomass and soil C accumulation on *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands* begins with vegetation establishment.

Within the United States, conversion of *Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands* is predominantly due to engineered activities, which include active restoration of wetlands (e.g., wetlands restoration in San Francisco Bay), dam removals or other means to reconnect sediment supply to the nearshore (e.g., Atchafalaya Delta, Louisiana, Couvillion et al., 2011). Wetlands restoration projects have been ongoing in the

United States since the 1970s. Early projects were small, a few hectares in size. By the 1990s, restoration projects, each hundreds of hectares in size, were becoming common in major estuaries. In a number of coastal areas e.g., San Francisco Bay, Puget Sound, Mississippi Delta and south Florida, restoration activities are in planning and implementation phases, each with the goal of recovering tens of thousands of hectares of wetlands.

During wetland restoration, Unvegetated Open Water Coastal Wetland is a common intermediary phase bridging land use transitions from Cropland or Grassland to Vegetated Coastal Wetlands. The period of open water may last from five to 20 years depending upon management. The conversion of these other land uses to Unvegetated Open Water Coastal Wetland will result in reestablishment of wetland biomass and soil C sequestration and may result in cessation of emissions from drained organic soil. Only changes in soil and aboveground biomass C stocks are reported in the Inventory at this time, but improvements are being evaluated to include changes from other C pools.

Table 6-59: CO_2 Flux from C Stock Changes from *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands* (MMT CO_2 Eq.)

Year	1990		2005		2013	2014	2015	2016	2017
Soil C Flux	(0.004)		(0.002)		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Aboveground Biomass C Flux	(0.01)		(0.004)		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Total C Stock Change	**(0.02)**		**(0.01)**		**(0.02)**	**(0.02)**	**(0.02)**	**(0.02)**	**(0.02)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Table 6-60: CO_2 Flux from C Stock Changes from *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands* (MMT C)

Year	1990		2005		2013	2014	2015	2016	2017
Soil C Flux	(0.001)		(0.001)		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Aboveground Biomass C Flux	(0.003)		(0.001)		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Total C Stock Change	**(0.005)**		**(0.002)**		**(0.005)**	**(0.005)**	**(0.005)**	**(0.005)**	**(0.005)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks and CH_4 emissions for *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands*.

Soil Carbon Stock Change

Soil C stock changes are estimated for *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands* on lands below the elevation of high tides (taken to be mean high water spring tide elevation) according to the national LiDAR dataset, the national network of tide gauges and land use histories recorded in the 1996, 2001, 2005 and 2010 NOAA C-CAP surveys. Privately-owned and publicly-owned lands are represented. Trends in land cover change are extrapolated to 1990 and 2017 from these datasets. C-CAP provides peer reviewed country-level mapping of coastal wetland distribution, including conversion to and from open water. Country-specific soil C stock change associated with soil C accretion, stratified by climate zones and wetland classes, are derived from a synthesis of peer-reviewed literature and updated this year based upon refined review of the dataset (Lynch 1989; Orson et al. 1990; Kearny & Stevenson 1991; Roman et al. 1997; Craft et al. 1998; Orson et al. 1998; Merrill 1999; Hussein et al. 2004; Church et al. 2006; Koster et al. 2007; Callaway et al. 2012 a & b; Bianchi et al. 2013; Crooks et al. 2014; Weston et al. 2014; Villa & Mitsch 2015; Marchio et al. 2016; Noe et al. 2016). Soil C stock changes are stratified based upon wetland class (Estuarine, Palustrine) and subclass (Emergent Marsh, Scrub Shrub). For soil C stock change no differentiation is made for soil type (i.e., mineral, organic).

Tier 2 level estimates of C stock changes associated with annual soil C accumulation in managed Vegetated Coastal Wetlands were developed using country-specific soil C removal factors multiplied by activity data on land area for managed coastal wetlands. The methodology follows Eq. 4.7, Chapter 4 of the *Wetlands Supplement*, and is applied to the area of managed Vegetated Coastal Wetlands on an annual basis. Emission factors were developed from literature references that provided soil C removal factors disaggregated by climate region and vegetation type by salinity range (estuarine or palustrine) as identified using NOAA C-CAP as described above.

Aboveground Biomass Carbon Stock Changes

Quantification of regional coastal wetland aboveground biomass C stock changes for palustrine and estuarine marsh vegetation are presented this year for *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands.* Biomass C stock is not sensitive to soil organic content but differentiated based on climate zone. Data are derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al., 2017; Byrd, et al., 2018). Trends in land cover change are derived from the NOAA C-CAP dataset and extrapolated to cover the entire 1990-2017 time series. Conversion of open water to Vegetated Coastal Wetlands results in the establishment of a standing biomass C stock; therefore, stock changes that occur are calculated by multiplying the C-CAP derived area gained that year in each climate zone by its mean aboveground biomass. Currently, a nationwide dataset for belowground biomass has not been assembled.

Soil Methane Emissions

A Tier 1 assumption has been applied that salinity conditions are unchanged and hence methane emissions are assumed to be zero with conversion of Vegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands.

Uncertainty and Time-Series Consistency

Underlying uncertainties in estimates of soil and aboveground biomass C stock changes include uncertainties associated with country-specific (Tier 2) literature values of these C stocks and assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to coastal wetlands include differentiation of palustrine and estuarine community classes that determines the soil C stock applied. Soil C stocks applied are determined from vegetation community classes across the coastal zone and identified by NOAA C-CAP. Community classes are further subcategorized by climate zones and growth form (forest, shrub-scrub, marsh). Soil and aboveground biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgement about the most appropriate assignment of a soil C stock to a disaggregation of a community class. Because mean soil and aboveground biomass C stocks for each available community class are in a fairly narrow range, the same overall uncertainty was applied to each, respectively (i.e., applying approach for asymmetrical errors, where the largest uncertainty for any one soil C stock referenced using published literature values for a community class; uncertainty approaches provide that if multiple values are available for a single parameter, the highest uncertainty value should be applied to the propagation of errors; IPCC 2000). For aboveground biomass C stocks, the mean standard error was very low and largely influenced by error in estimated map area (Byrd et al. 2018). Overall uncertainty of the NOAA C-CAP remote sensing product is 15 percent. This is in the range of remote sensing methods (±10 to 15 percent; IPCC 2003).

Table 6-61: Approach 1 Quantitative Uncertainty Estimates for C Stock Changes Occurring within *Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range (MMT CO_2 Eq.)		Relative to Flux Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock Flux	(0.004)	(0.005)	(0.004)	-29.5%	29.5%
Aboveground Biomass C Stock Flux	(0.01)	(0.01)	(0.01)	-16.5%	16.5%
Total Flux	**(0.02)**	**(0.02)**	**(0.01)**	**-38.6%**	**38.6%**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

QA/QC and Verification

NOAA provided data (i.e., National LiDAR Dataset, NOS Tide Data, and C-CAP land cover and land cover change mapping), which undergo internal agency QA/QC assessment procedures. Acceptance of final datasets into the archive for dissemination are contingent upon assurance that the product is compliant with mandatory NOAA QA/QC requirements (McCombs et al. 2016). QA/QC and Verification of soil C stock dataset has been provided by the Smithsonian Environmental Research Center and Coastal Wetlands project team leads who reviewed produced summary tables against primary scientific literature. Aboveground biomass C reference stocks are derived from an analysis by the Blue Carbon Monitoring project and reviewed by US Geological Survey prior to publishing, the peer-review process during publishing, and the Coastal Wetland Inventory team leads before inclusion in the inventory. Land cover estimates were assessed to ensure that the total land area did not change over the time series in which the inventory was developed, and verified by a second QA team. A team of two evaluated and verified there were no computational errors within calculation worksheets. Two biogeochemists at the USGS, also members of the NASA Carbon Monitoring System Science Team, corroborated the simplifying assumption that where salinities are unchanged CH_4 emissions are constant with conversion of *Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands*.

Recalculations Discussion

Methodological recalculations are associated with the extension of C-CAP data extrapolation through 2017. Soil reference carbon sequestration rates were updated based on recalculation by Lu and Megonigal (2017), which decreased net removals to soil by 0.01 MMT CO_2 Eq. per year. New data on aboveground biomass carbon stocks were added, broken down by climate zone, that were derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al., 2017; Byrd, et al., 2018). This resulted in an increase in net removal by 0.01 MMT CO_2 Eq. per year.

Planned Improvements

Administered by the Smithsonian Environmental Research Center, the Coastal Wetland Carbon Research Coordination Network have established a U.S. country-specific database of published data quantifying soil C stock and aboveground biomass in coastal wetlands. Reference values for soil and aboveground biomass C stocks will be updated as new data emerge. Refined error analysis combining land cover change and soil and aboveground biomass C stock estimates will be updated at those times.

The C-CAP dataset for 2015 is currently under development with a planned release in 2019. Additional data products for years 2003, 2008, and 2013 are also planned for release. Once complete, land use change for 1990 through 2017 will be recalculated and extended to 2018 with this updated dataset. C-CAP data harmonization with the NLCD is an ongoing process and will occur in future iterations of the inventory.

N_2O Emissions from Aquaculture in Coastal Wetlands

Shrimp and fish cultivation in coastal areas increases nitrogen loads resulting in direct emissions of N_2O. Nitrous oxide is generated and emitted as a byproduct of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification (Hu et al. 2012). Nitrous oxide emissions can be readily estimated from data on fish production (IPCC 2013 *Wetlands Supplement*).

Overall, aquaculture production in the United States has fluctuated slightly from year to year, increasing from 0.1 in 1990 to upwards of 0.2 MMT CO_2 Eq. between 1992 and 2010. Levels have essentially remained consistent since 2011; however, data for 2016 and 2017 are not yet available and in this analysis are held constant with 2015 emissions of 0.1 MMT CO_2 Eq.

Table 6-62: N_2O Emissions from Aquaculture in Coastal Wetlands (MMT CO_2 Eq.)

Year	1990	2005	2013	2014	2015	2016	2017
Emissions (MMT CO_2 Eq.)	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Emissions (kt N_2O)	0.4	0.6	0.5	0.5	0.5	0.5	0.5

Methodology

The methodology to estimate N_2O emissions from Aquaculture in Coastal Wetlands follows guidance in the *2013 IPCC Wetlands Supplement* by applying country-specific fisheries production data and the IPCC Tier 1 default emission factor.

Each year NOAA Fisheries document the status of U.S. marine fisheries in the annual report of *Fisheries of the United States* (National Marine Fisheries Service, 2016), from which activity data for this analysis is derived.[66] The fisheries report has been produced in various forms for more than 100 years, primarily at the national level, on U.S. recreational catch and commercial fisheries landings and values. In addition, data are reported on U.S. aquaculture production, the U.S. seafood processing industry, imports and exports of fish-related products, and domestic supply and per capita consumption of fisheries products. Within the aquaculture chapter, mass of production for Catfish, Striped bass, Tilapia, Trout, Crawfish, Salmon and Shrimp are reported. While some of these fisheries are produced on land and some in open water cages, all have data on the quantity of food stock produced, which is the activity data that is applied to the IPCC Tier 1 default emissions factor to estimate emissions of N_2O from aquaculture. It is not apparent from the data as to the amount of aquaculture occurring above the extent of high tides on river floodplains. While some aquaculture likely occurs on coastal lowland floodplains, this is likely a minor component of tidal aquaculture production because of the need for a regular source of water for pond flushing. The estimation of N_2O emissions from aquaculture is not sensitive to salinity using IPCC approaches and as such the location of aquaculture ponds on the landscape does not influence the calculations.

Other open water shellfisheries for which no food stock is provided, and thus no additional N inputs, are not applicable for estimating N_2O emissions (e.g., Clams, Mussels and Oysters) and have not been included in the analysis. The IPCC Tier 1 default emissions factor of 0.00169 kg N_2O-N per kg of fish produced (95 percent confidence interval – 0, 0.0038) is applied to the activity data to calculate total N_2O emissions.

Uncertainty and Time-Series Consistency

Uncertainty estimates are based upon the Tier 1 default 95 percent confidence interval provided within the *Wetlands Supplement* for N_2O emissions. Uncertainties in N_2O emissions from aquaculture are based on expert judgement for the NOAA *Fisheries of the United States* fisheries production data (± 100 percent) multiplied by default uncertainty level for N_2O emissions found in Table 4.15, chapter 4 of the *Wetlands Supplement*. Given the overestimate of fisheries production from coastal wetland areas due to the inclusion of fish production in non-coastal wetland areas, this is a reasonable initial first approximation for an uncertainty range.

Table 6-63: Approach 1 Quantitative Uncertainty Estimates for N_2O Emissions for Aquaculture Production in Coastal Wetlands (MMT CO_2 Eq. and Percent)

Source	2017 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Combined Uncertainty for N_2O Emissions for Aquaculture Production in Coastal Wetlands	0.1	0.00	0.31	-116%	116%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

QA/QC and Verification

NOAA provided internal QA/QC review of reported fisheries data. The Coastal Wetlands Inventory team consulted with the Coordinating Lead Authors of the Coastal Wetlands chapter of the *2013 IPCC Wetlands Supplement* to assess which fisheries production data to include in estimating emissions from aquaculture. It was concluded that N_2O emissions estimates should be applied to any fish production to which food supplement is supplied be they pond or open water and that salinity conditions were not a determining factor in production of N_2O emissions.

[66] See <https://www.st.nmfs.noaa.gov/st1/publications.html>.

6.9 Land Converted to Wetlands (CRF Category 4D2)

Emissions and Removals from Land Converted to Vegetated Coastal Wetlands

Land Converted to Vegetated Coastal Wetlands occurs as a result of inundation of unprotected low-lying coastal areas with gradual sea-level rise, flooding of previously drained land behind hydrological barriers, and through active restoration and creation of coastal wetlands through removal of hydrological barriers. All other land categories (i.e., Forest Land, Cropland, Grassland, Settlements and Other Lands) are identified as having some area converting to Vegetated Coastal Wetlands. Between 1990 and 2017 the rate of annual transition for *Land Converted to Vegetated Coastal Wetlands* ranged from 2,619 ha/year to 5,316 ha/year. Conversion rates were higher during the period 2010 through 2017 than during the earlier part of the time series.

At the present stage of Inventory development, Coastal Wetlands are not explicitly shown in the Land Representation analysis while work continues harmonizing data from NOAA's Coastal Change Analysis Program[67] with NRI data used to compile the Land Representation.

Following conversion to Vegetated Coastal Wetlands there are increases in plant biomass and soil C storage. Additionally, at salinities less than half that of seawater, the transition from upland dry soils to wetland soils results in CH_4 emissions. In this Inventory analysis, soil and aboveground biomass C stock changes as well as CH_4 emissions are quantified. Estimates of emissions and removals are based on emission factor data that have been applied to assess changes in soil and aboveground biomass C stocks and CH_4 emissions for *Land Converted to Vegetated Coastal Wetlands*.

Table 6-64: CO_2 Flux from C Stock Changes in *Land Converted to Vegetated Coastal Wetlands* (MMT CO_2 Eq.)

Year	1990		2005		2013	2014	2015	2016	2017
Soil Flux	(0.01)		(0.01)		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Aboveground Biomass Flux	(0.03)		(0.02)		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Total C Stock Change	**(0.04)**		**(0.03)**		**(0.04)**	**(0.04)**	**(0.04)**	**(0.04)**	**(0.04)**

Table 6-65: CO_2 Flux from C Stock Changes in *Land Converted to Vegetated Coastal Wetlands* (MMT C)

Year	1990		2005		2013	2014	2015	2016	2017
Soil Flux	(0.004)		(0.002)		(0.005)	(0.004)	(0.004)	(0.004)	(0.004)
Aboveground Biomass Flux	(0.01)		(0.01)		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Total C Stock Change	**(0.01)**		**(0.01)**		**(0.01)**	**(0.01)**	**(0.01)**	**(0.01)**	**(0.01)**

Table 6-66: CH_4 Emissions from *Land Converted to Vegetated Coastal Wetlands* (MMT CO_2 Eq. and kt CH_4)

Year	1990		2005		2013	2014	2015	2016	2017
Methane Emissions (MMT CO_2 Eq.)	0.01		0.01		0.01	0.01	0.01	0.01	0.01
Methane Emissions (kt CH_4)	0.6		0.5		0.6	0.6	0.6	0.6	0.6

[67] See <https://coast.noaa.gov/digitalcoast/tools/lca>.

Methodology

The following section includes a description of the methodology used to estimate changes in soil and aboveground biomass C stock changes and CH_4 emissions for *Land Converted to Vegetated Coastal Wetlands*.

Soil Carbon Stock Changes

Soil C removals are estimated for *Land Converted to Vegetated Coastal Wetlands* for land below the elevation of high tides (taken to be mean high water spring tide elevation) and as far seawards as the extent of intertidal vascular plants within the U.S. Land Representation according to the national LiDAR dataset, the national network of tide gauges and land use histories recorded in the 1996, 2001, 2005 and 2010 NOAA C-CAP surveys.[68] As a QC step, a check was undertaken to confirm that Coastal Wetlands recognized by C-CAP represented a subset of Wetlands recognized by the NRI for marine coastal states. Delineating Vegetated Coastal Wetlands from ephemerally flooded upland Grasslands represents a particular challenge in remote sensing. Moreover, at the boundary between wetlands and uplands, which may be gradual on low lying coastlines, the presence of wetlands may be ephemeral depending upon weather and climate cycles and as such impacts on the emissions and removals will vary over these time frames. Federal and non-federal lands are represented. Trends in land cover change are extrapolated to 1990 and 2017 from these datasets. Based upon NOAA C-CAP, wetlands are subdivided into freshwater (Palustrine) and saline (Estuarine) classes and further subdivided into emergent marsh, scrub shrub and forest classes. Soil C stock changes, stratified by climate zones and wetland classes, are derived from a synthesis of peer-reviewed literature (Lynch 1989; Orson et al. 1990; Kearny & Stevenson 1991; Roman et al. 1997; Craft et al. 1998; Orson et al. 1998; Merrill 1999; Hussein et al. 2004; Church et al. 2006; Koster et al. 2007; Callaway et al. 2012 a & b; Bianchi et al. 2013; Crooks et al. 2014; Weston et al. 2014; Villa & Mitsch 2015; Marchio et al. 2016; Noe et al. 2016). To estimate soil C stock changes no differentiation is made for soil type (i.e., mineral, organic).

Tier 2 level estimates of soil C removal associated with annual soil C accumulation from *Land Converted to Vegetated Coastal Wetlands* were developed using country-specific soil C removal factors multiplied by activity data of land area for *Land Converted to Vegetated Coastal Wetlands*. The methodology follows Eq. 4.7, Chapter 4 of the *IPCC Wetlands Supplement*, and applied to the area of *Land Converted to Vegetated Coastal Wetlands* on an annual basis. Emission factors were developed from literature references that provided soil C removal factors disaggregated by climate region, vegetation type by salinity range (estuarine or palustrine) as identified using NOAA C-CAP as described above.

Aboveground Biomass Carbon Stock Changes

Aboveground biomass C Stocks for palustrine and estuarine marshes are estimated for *Lands Converted to Vegetated Coastal Wetlands*. Biomass is not sensitive soil organic content but differentiated based on climate zone. Data are derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al., 2017; Byrd, et al., 2018). Trends in land cover change are derived from the NOAA C-CAP dataset and extrapolated to cover the entire 1990-2017 time series. Stock changes that occur by converting lands to vegetated wetlands are calculated by multiplying the C-CAP derived area gained that year in each climate zone by its mean aboveground biomass. Currently, a nationwide dataset for belowground biomass has not been assembled.

Soil Methane Emissions

Tier 1 estimates of CH_4 emissions for *Land Converted to Vegetated Coastal Wetlands* are derived from the same wetland map used in the analysis of wetland soil C fluxes, produced from C-CAP, LiDAR and tidal data, in combination with default CH_4 emission factors provided in Table 4.14 of the *IPCC Wetlands Supplement.* The methodology follows Eq. 4.9, Chapter 4 of the *IPCC Wetlands Supplement*, and is applied to the total area of *Land Converted to Vegetated Coastal Wetlands* on an annual basis.

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[68] See <https://coast.noaa.gov/digitalcoast/tools/lca>.

Uncertainty and Time-Series Consistency

Underlying uncertainties in estimates of soil C removal factors, aboveground biomass change, and CH_4 emissions include error in uncertainties associated with Tier 2 literature values of soil C removal estimates, aboveground biomass stocks, and IPCC default CH_4 emission factors, uncertainties linked to interpretation of remote sensing data, as well as assumptions that underlie the methodological approaches applied.

Uncertainty specific to coastal wetlands include differentiation of palustrine and estuarine community classes which determines the soil C removal and CH_4 flux applied. Soil C removal and CH_4 fluxes applied are determined from vegetation community classes across the coastal zone and identified by NOAA C-CAP. Community classes are further subcategorized by climate zones and growth form (forest, shrub-scrub, marsh). Aboveground biomass classes were subcategorized by climate zones. Soil and aboveground biomass C removal data for all subcategories are not available and thus assumptions were applied using expert judgement about the most appropriate assignment of a soil and aboveground biomass C removal factor to a disaggregation of a community class. Because mean soil and aboveground biomass C removal for each available community class are in a fairly narrow range, the same overall uncertainty was assigned to each, respectively (i.e., applying approach for asymmetrical errors, the largest uncertainty for any soil C stock value should be applied in the calculation of error propagation; IPCC 2000). Uncertainties for CH_4 flux are the Tier 1 default values reported in the *IPCC Wetlands Supplement*. Overall uncertainty of the NOAA C-CAP remote sensing product is 15 percent. This is in the range of remote sensing methods (±10-15 percent; IPCC 2003). However, there is significant uncertainty in salinity ranges for tidal and non-tidal estuarine wetlands and activity data used to estimate the CH_4 flux (e.g., delineation of an 18 ppt boundary), which will need significant improvement to reduce uncertainties.

Table 6-67: Approach 1 Quantitative Uncertainty Estimates for C Stock Changes occurring within *Land Converted to Vegetated Coastal Wetlands* (MMT CO_2 Eq. and Percent)

Source	2017 Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock Change	(0.01)	(0.01)	(0.01)	-29.5%	29.5%
Aboveground Biomass C Stock Change	(0.03)	(0.03)	(0.03)	-16.5%	16.5%
Methane Emissions	0.01	0.01	0.02	-29.8%	29.8%
Total Uncertainty	**(0.03)**	**(0.04)**	**(0.02)**	**-38.5%**	**38.5%**

[a] Range of flux estimates based on error propagation at 95 percent confidence interval.

Note: Totals may not sum due to independent rounding.

QA/QC and Verification

NOAA provided National LiDAR Dataset, tide data, and C-CAP land cover and land cover change mapping, all of which are subject to agency internal mandatory QA/QC assessment (McCombs et al. 2016). QA/QC and verification of soil C stock dataset has been provided by the Smithsonian Environmental Research Center and Coastal Wetland Inventory team leads. Aboveground biomass C stocks are derived from peer-review literature, reviewed by US Geological Survey prior to publishing, by the peer-review process during publishing, and by the Coastal Wetland Inventory team leads prior to inclusion in the inventory. Land cover estimates were assessed to ensure that the total land area did not change over the time series in which the inventory was developed, and verified by a second QA team. A team of two evaluated and verified there were no computational errors within the calculation worksheets. Soil C stock, emissions/removals data where based upon peer-reviewed literature and CH_4 emission factors derived from the *IPCC Wetlands Supplement*.

Recalculations Discussion

Methodological recalculations are associated with the extension of C-CAP data extrapolation through 2017. Soil reference carbon sequestration rates were updated based recalculation by Lu and Megonigal (2017). New data on aboveground biomass carbon stocks were added, broken down by climate zone, that were derived from a national assessment combining field plot data and aboveground biomass mapping by remote sensing (Byrd et al. 2017; Byrd et al. 2018). A minor transcription error in calculation of *Lands Converted to Wetlands* for the Mediterranean climate zone (years 2011 through 2016) was fixed. An error was corrected in aggregating state level activity data to national level for *Land Converted to Vegetated Coastal Wetlands* emergent and scrub shrub wetlands (2011 through 2016), decreasing wetland area by 4,345 ha, which reduced net carbon removals to soil by 0.01 MMT CO_2 Eq.

Planned Improvements

Administered by the Smithsonian Environmental Research Center, the Coastal Wetland Carbon Research Coordination Network has established a U.S. country-specific database of soil C stocks and aboveground biomass for coastal wetlands.[69] This dataset will be updated periodically. Refined error analysis combining land cover change and C stock estimates will be provided as new data are incorporated. Through this work, a model is in development to represent changes in soil C stocks

The C-CAP dataset for 2015 is currently under development with a planned release in early 2019. Additional data products for years 2003, 2008, and 2013 are also planned for release. Once complete, land use change for 1996 through 2018 will be recalculated with this updated dataset. Currently, biomass from lands converted to wetlands are only tracked for one year due to lack of available data. In 2019, data harmonization of C-CAP with the National Land Cover dataset (NLCD) will occur that will enable 20-year tracking of biomass as per IPCC guidance.

6.10 Settlements Remaining Settlements (CRF Category 4E1)

Soil Carbon Stock Changes (CRF Category 4E1)

Soil C stock changes for *Settlements Remaining Settlements* occur in both mineral and organic soils. The United States does not, however, estimate changes in soil organic C stocks for mineral soils in *Settlements Remaining Settlements*, which is consistent with the assumption of the Tier 1 method in the *2006 IPCC Guidelines* (IPCC 2006). This assumption may be re-evaluated in the future if funding and resources are available to conduct an analysis of soil C stock changes for mineral soils in *Settlements Remaining Settlements*. Drainage of organic soils is common when wetland areas have been developed for settlements. Organic soils, also referred to as *Histosols*, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999, Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that results in minimal decomposition of plant residues. Drainage of organic soils leads to aeration of the soil that accelerates decomposition rate and CO_2 emissions.[70] Due to the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time, which varies depending on climate and composition (i.e., decomposability) of the organic matter (Armentano and Menges 1986).

Settlements Remaining Settlements includes all areas that have been settlements for a continuous time period of at least 20 years according to the 2012 United States Department of Agriculture (USDA) National Resources Inventory (NRI) (USDA-NRCS 2015)[71] or according to the National Land Cover Dataset (NLCD) for federal lands (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015). The Inventory includes settlements on privately-owned lands in the conterminous United States and Hawaii. Alaska and the small amount of settlements on federal lands are not included in this Inventory even though these areas are part of the U.S. managed land base. This leads to a discrepancy with the total amount of managed area in *Settlements Remaining Settlements* (see Section 6.1

[69] See <https://serc.si.edu/coastalcarbon>.

[70] N_2O emissions from soils are included in the N_2O Emissions from Settlement Soils section.

[71] NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an overestimation of *Settlements Remaining Settlements* in the early part of the time series to the extent that some areas are converted to settlements between 1971 and 1978.

Representation of the U.S. Land Base) and the settlements area included in the Inventory analysis[72]. There is a planned improvement to include settlements on drained organic soils in these areas as part of a future Inventory.

CO_2 emissions from drained organic soils in settlements are 1.3 MMT CO_2 Eq. (0.3 MMT C) in 2017. Although the flux is relatively small, the amount has increased by over 800 percent since 1990.

Table 6-68: Net CO_2 Flux from Soil C Stock Changes in *Settlements Remaining Settlements* (MMT CO_2 Eq.)

Soil Type	1990		2005		2013	2014	2015	2016	2017
Organic Soils	0.1		0.5		1.3	1.3	1.3	1.3	1.3

Table 6-69: Net CO_2 Flux from Soil C Stock Changes in *Settlements Remaining Settlements* (MMT C)

Soil Type	1990		2005		2013	2014	2015	2016	2017
Organic Soils	+		0.1		0.4	0.4	0.4	0.4	0.3

+ Does not exceed 0.05 MMT C

Methodology

An IPCC Tier 2 method is used to estimate soil organic C stock changes for organic soils in *Settlements Remaining Settlements* (IPCC 2006). Organic soils in *Settlements Remaining Settlements* are assumed to be losing C at a rate similar to croplands due to deep drainage, and therefore emission rates are based on country-specific values for cropland (Ogle et al. 2003).

The land area designated as settlements is based primarily on the 2012 NRI (USDA 2015) with additional information from the NLCD (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). It is assumed that all settlement area on organic soils is drained, and those areas are provided in Table 6-70 (See Section 6.1, Representation of the U.S. Land Base for more information). The area of drained organic soils is estimated from the NRI spatial weights and aggregated to the country (Table 6-70). The area of land on organic soils in *Settlements Remaining Settlements* has increased from 3 thousand hectares in 1990 to over 28 thousand hectares in 2012. The area of land on organic soils are not currently available from NRI for *Settlements Remaining Settlements* after 2012.

Table 6-70: Thousands of Hectares of Drained Organic Soils in *Settlements Remaining Settlements*

Year	Area (Thousand Hectares)
1990	3
2005	10
2012	28
2013	ND
2014	ND
2015	ND
2016	ND
2017	ND

Note: No NRI data are available after 2012. ND (No data)

[72] For the land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for settlements through the process of combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for settlements in this Inventory, but rather the emissions and removals are based on a surrogate data method. Therefore, the area estimates in this section are based on the land representation data from the previous Inventory.

To estimate CO_2 emissions from drained organic soils across the time series from 1990 to 2012, the total area of organic soils in *Settlements Remaining Settlements* is multiplied by the country-specific emission factors for *Cropland Remaining Cropland* under the assumption that there is deep drainage of the soils. The emission factors are 11.2 MT C per ha in cool temperate regions, 14.0 MT C per ha in warm temperate regions, and 14.3 MT C per ha in subtropical regions (see Annex 3.12 for more information).

A linear extrapolation of the trend in the time series is applied to estimate the emissions from 2013 to 2017 because NRI activity data are not available for these years to determine the area of drained organic soils in *Settlements Remaining Settlements*. Specifically, a linear regression model with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) is used to estimate the trend in emissions over time from 1990 to 2012, and in turn, the trend is used to approximate the 2013 to 2017 emissions. The Tier 2 method described previously will be applied in future inventories to recalculate the estimates beyond 2012 as activity data becomes available.

Uncertainty and Time-Series Consistency

Uncertainty for the Tier 2 approach is derived using a Monte Carlo approach, along with additional uncertainty propagated through the Monte Carlo Analysis for 2013 to 2017 based on the linear time series model. The results of the Approach 2 Monte Carlo uncertainty analysis are summarized in Table 6-71. Soil C losses from drained organic soils in *Settlements Remaining Settlements* for 2017 are estimated to be between 0.8 and 1.8 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 40 percent below and 40 percent above the 2017 emission estimate of 1.3 MMT CO_2 Eq.

Table 6-71: Uncertainty Estimates for CO_2 Emissions from Drained Organic Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Organic Soils	CO_2	1.3	0.8	1.8	-40%	40%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations are applied from 2013 to 2017 using the linear time series model described above. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data are properly handled throughout the inventory process. Inventory reporting forms and text are reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

Methodological recalculations are associated with extending the time series from 2013 through 2017 using a linear time series model. The recalculation had a minor effect on the time series overall with C losses from drainage of organic soils increasing by less than 1 percent on average.

Planned Improvements

This source will be extended to include CO_2 emissions from drainage of organic soils in settlements of Alaska and federal lands in order to provide a complete inventory of emissions for this category. New land representation data will also be compiled, and the time series will be recalculated for the latter years that are estimated using the data splicing method in the current Inventory.

Changes in Carbon Stocks in Settlement Trees (CRF Source Category 4E1)

Settlements are land uses where human populations and activities are concentrated. In these areas, the anthropogenic impacts on tree growth, stocking and mortality are particularly pronounced (Nowak 2012) in comparison to forest lands where non-anthropogenic forces can have more significant impacts. Previous assessments of carbon stock changes in settlements trees in the Inventory used urban areas as a proxy for settlement area. The past definition of urban areas was based on population density as delimited by the U.S. Census Bureau. This assessment changes this approach and uses the settlement areas from Section 6.1 Representation of the U.S. Land Base and tree cover in U.S. developed land from the NLCD as a proxy for tree cover in settlements, which results in a close, but not precise alignment with the settlement areas shown in Section 6.1 of this Inventory.

Trees in settlement areas of the United States are estimated to account for an average annual net sequestration of 113.7 MMT CO_2 Eq. (31.0 MMT C) over the period from 1990 through 2017. Net C flux from settlement trees in 2017 is estimated to be -123.9 MMT CO_2 Eq. (-33.8 MMT C). Dominant factors affecting carbon flux trends for settlement trees are changes in the amount of settlement area (increasing sequestration due to more land and trees) and net changes in tree cover (e.g., tree losses vs tree gains through planting and natural regeneration), which has been trending downward recently and increasing emissions. In addition, changes in species composition, tree sizes and tree densities affect base C flux estimates. Annual estimates of CO_2 flux (Table 6-72) were developed based on estimates of annual settlement area and tree cover derived from developed land. Developed land, which was used to estimate tree cover in settlement areas, is about seven percent higher than the area categorized as *Settlements* in the Representation of the U.S. Land Base developed for this report. Developed land is likely a better proxy for tree cover in settlement areas than urban areas as urban land areas were about 36 percent smaller than settlement areas in 2011.

Carbon flux estimates per unit tree cover for settlement areas are derived from available data on tree cover and C sequestration in U.S. cities. Percent tree cover in settlement areas was derived from NLCD tree cover data from developed land, which were adjusted based on photo-interpretation of tree cover in developed land. Photo-interpretation also includes changes in tree cover in developed lands based on paired photo-interpretation points between c. 2011 and 2016. Annual sequestration increased by 29 percent between 1990 and 2017 due to increases in settlement area and changes in tree cover.

Trees in settlements often grow faster than forest trees because of their relatively open structure (Nowak and Crane 2002). Because tree density in settlements is typically much lower than in forested areas, the C storage per hectare of land is in fact smaller for settlement areas than for forest areas. Also, percent tree cover in settlement areas are less than in forests and this tree cover varies significantly across the United States (e.g., Nowak and Greenfield 2018a). To quantify the C stored in settlement trees, the methodology used here requires analysis per unit area of tree cover, rather than per unit of total land area (as is done for *Forest Lands).*

Table 6-72: Net C Flux from Settlement Trees (MMT CO_2 Eq. and MMT C)

Year	MMT CO_2 Eq.	MMT C
1990	(96.2)	(26.2)
2005	(116.8)	(31.9)
2013	(125.6)	(34.2)
2014	(125.0)	(34.1)
2015	(124.5)	(33.9)
2016	(123.9)	(33.8)
2017	(123.9)	(33.8)

Note: Parentheses indicate net sequestration.

Methodology

To estimate net carbon sequestration in settlement areas, three types of data are required by state:

1. Settlement area
2. Percent tree cover in settlement areas
3. Carbon sequestration density per unit of tree cover

Settlement Area

Settlements area is defined in Section 6.1 Representation of the U.S. Land Base as a land-use category representing developed areas. However, as the data used to estimate settlement area comes from the NRI and there hasn't been an update to this data since 2012, the decision was made to utilize the settlement area data from the previous 1990 through 2016 Inventory for this analysis, while also holding the 2017 value constant with the 2016 value. As a result, the settlement areas used in this assessment are slightly different from the time series shown in Section 6.1 Representation of the U.S. Land Base (less than 0.24 percent on average over the years).

Percent Tree Cover in Settlement Areas

Percent tree cover in settlement area is needed to convert settlement land area to settlement tree cover area. Converting to tree cover area is essential as tree cover, and thus carbon estimates, can vary widely among states in settlement areas due to variations in the amount of tree cover (e.g., Nowak and Greenfield 2018a). However, since the specific geography of settlement area is unknown because they are based on NRI sampling methods, NLCD developed land was used to estimate the percent tree cover to be used in settlement areas. NLCD developed classes 21-24 (developed, open space (21), low intensity (22), medium intensity (23), and high intensity (24)) were used to estimate percent tree cover in settlement area by state (U.S. Department of Interior 2018, MRLC 2013).

a) "Developed, Open Space – areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes." Plots designated as either park, recreation, cemetery, open space, institutional or vacant land were classified as Developed Open Space.

b) "Developed, Low Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 to 49 percent of total cover. These areas most commonly include single-family housing units." Plots designated as single family or low-density residential land were classified as Developed, Low Intensity.

c) "Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. These areas most commonly include single-family housing units." Plots designated as medium density residential, other urban or mixed urban were classified as Developed, Medium Intensity.

d) "Developed High Intensity – highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover." Plots designated as either commercial, industrial, high density residential, downtown, multi-family residential, shopping, transportation or utility were classified as Developed, High Intensity.

As NLCD is known to underestimate tree cover (Nowak and Greenfield 2010), photo-interpretation of tree cover within NLCD developed lands was conducted for the years of c. 2011 and 2016 using 1,000 random points to determine an average adjustment factor for NLCD tree cover estimates in developed land and determine recent tree cover changes. This photo-interpretation of change followed methods detailed in Nowak and Greenfield (2018b). Percent tree cover (%TC) in settlement areas by state was estimated as:

%TC in state = state NLCD %TC x national photo-interpreted %TC / national NLCD %TC

Percent tree cover in settlement areas by year was set as follows:

- 1990 to 2011: used 2011 NLCD tree cover adjusted with 2011 photo-interpreted values
- 2012 to 2015: used 2011 NLCD tree cover adjusted with photo-interpreted values, which were interpolated from values between 2011 and 2016
- 2016 to 2017: used 2011 NLCD tree cover adjusted with 2016 photo-interpreted values

Carbon Sequestration Density per Unit of Tree Cover

Methods for quantifying settlement tree biomass, C sequestration, and C emissions from tree mortality and decomposition were taken directly from Nowak et al. (2013), Nowak and Crane (2002), and Nowak (1994). In general, net C sequestration estimates followed three steps, each of which is explained further in the paragraphs below. First, field data from cities and urban areas within entire states were used to estimate C in tree biomass from field data on measured tree dimensions. Second, estimates of annual tree growth and biomass increment were generated from published literature and adjusted for tree condition, crown competition, and growing season to generate estimates of gross C sequestration in settlement trees for all 50 states and the District of Columbia. Third, estimates of C emissions due to mortality and decomposition were subtracted from gross C sequestration estimates to obtain estimates of net C sequestration. Carbon storage, gross and net sequestration estimates were standardized per unit tree cover based on tree cover in the study area.

Settlement tree carbon estimates are based on published literature (Nowak et al. 2013; Nowak and Crane 2002; Nowak 1994) as well as newer data from the i-Tree database[73] and Forest Service urban forest inventory data (e.g., Nowak et al. 2016, 2017) (Table 6-73). These data are based on collected field measurements in several U.S. cities between 1989 and 2017. Carbon storage and sequestration in these cities were estimated using the U.S. Forest Service's i-Tree Eco model (Nowak et al. 2008). This computer model uses standardized field data from randomly located plots, along with local hourly air pollution and meteorological data to quantify urban forest structure, values of the urban forest, and environmental effects, including total C stored and annual C sequestration (Nowak et al. 2013).

In each city, a random sample of plots were measured to assess tree stem diameter, tree height, crown height and crown width, tree location, species, and canopy condition. The data for each tree were used to estimate total dry-weight biomass using allometric models, a root-to-shoot ratio to convert aboveground biomass estimates to whole tree biomass, and wood moisture content. Total dry weight biomass was converted to C by dividing by two (50 percent carbon content). An adjustment factor of 0.8 was used for open grown trees to account for settlement trees having less aboveground biomass for a given stem diameter than predicted by allometric models based on forest trees (Nowak 1994). Carbon storage estimates for deciduous trees include only C stored in wood. Estimated C storage was divided by tree cover in the area to estimate carbon storage per square meter of tree cover.

Table 6-73: Carbon Storage (kg C/m^2 tree cover), Gross and Net Sequestration (kg C/m^2 tree cover/year) and Tree Cover (percent) among Sampled U.S. Cities (see Nowak et al. 2013).

City	Storage	SE	Sequestration Gross	SE	Net	SE	Ratio[a]	Tree Cover	SE
Adrian, MI	12.17	1.88	0.34	0.04	0.13	0.07	0.36	22.1	2.3
Albuquerque, NM	5.61	0.97	0.24	0.03	0.20	0.03	0.82	13.3	1.5
Arlington, TX	6.37	0.73	0.29	0.03	0.26	0.03	0.91	22.5	0.3
Atlanta, GA	6.63	0.54	0.23	0.02	0.18	0.03	0.76	53.9	1.6
Austin, TX	3.57	0.25	0.17	0.01	0.13	0.01	0.73	30.8	1.1
Baltimore, MD	10.30	1.24	0.33	0.04	0.20	0.04	0.59	28.5	1.0
Boise, ID	7.33	2.16	0.26	0.04	0.16	0.06	0.64	7.8	0.2
Boston, MA	7.02	0.96	0.23	0.03	0.17	0.02	0.73	28.9	1.5
Camden, NJ	11.04	6.78	0.32	0.20	0.03	0.10	0.11	16.3	9.9
Casper, WY	6.97	1.50	0.22	0.04	0.12	0.04	0.54	8.9	1.0
Chester, PA	8.83	1.20	0.39	0.04	0.25	0.05	0.64	20.5	1.7
Chicago (region), IL	9.38	0.59	0.38	0.02	0.26	0.02	0.70	15.5	0.3
Chicago, IL	6.03	0.64	0.21	0.02	0.15	0.02	0.70	18.0	1.2
Corvallis, OR	10.68	1.80	0.22	0.03	0.20	0.03	0.91	32.6	4.1
El Paso, TX	3.93	0.86	0.32	0.05	0.23	0.05	0.72	5.9	1.0
Freehold, NJ	11.50	1.78	0.31	0.05	0.20	0.05	0.64	31.2	3.3
Gainesville, FL	6.33	0.99	0.22	0.03	0.16	0.03	0.73	50.6	3.1
Golden, CO	5.88	1.33	0.23	0.05	0.18	0.04	0.79	11.4	1.5
Grand Rapids, MI	9.36	1.36	0.30	0.04	0.20	0.05	0.65	23.8	2.0

[73] See <http://www.itreetools.org>.

Hartford, CT	10.89	1.62	0.33	0.05	0.19	0.05	0.57	26.2	2.0
Houston, TX	4.55	0.48	0.31	0.03	0.25	0.03	0.83	18.4	1.0
Indiana[b]	8.80	2.68	0.29	0.08	0.27	0.07	0.92	20.1	3.2
Jersey City, NJ	4.37	0.88	0.18	0.03	0.13	0.04	0.72	11.5	1.7
Kansas[b]	7.42	1.30	0.28	0.05	0.22	0.04	0.78	14.0	1.6
Kansas City (region), MO/KS	7.79	0.85	0.39	0.04	0.26	0.04	0.67	20.2	1.7
Lake Forest Park, WA	12.76	2.63	0.49	0.07	0.42	0.07	0.87	42.4	0.8
Las Cruces, NM	3.01	0.95	0.31	0.14	0.26	0.14	0.86	2.9	1.0
Lincoln, NE	10.64	1.74	0.41	0.06	0.35	0.06	0.86	14.4	1.6
Los Angeles, CA	4.59	0.51	0.18	0.02	0.11	0.02	0.61	20.6	1.3
Milwaukee, WI	7.26	1.18	0.26	0.03	0.18	0.03	0.68	21.6	1.6
Minneapolis, MN	4.41	0.74	0.16	0.02	0.08	0.05	0.52	34.1	1.6
Moorestown, NJ	9.95	0.93	0.32	0.03	0.24	0.03	0.75	28.0	1.6
Morgantown, WV	9.52	1.16	0.30	0.04	0.23	0.03	0.78	39.6	2.2
Nebraska[b]	6.67	1.86	0.27	0.07	0.23	0.06	0.84	15.0	3.6
New York, NY	6.32	0.75	0.33	0.03	0.25	0.03	0.76	20.9	1.3
North Dakota[b]	7.78	2.47	0.28	0.08	0.13	0.08	0.48	2.7	0.6
Oakland, CA	5.24	0.19	NA	NA	NA	NA	NA	21.0	0.2
Oconomowoc, WI	10.34	4.53	0.25	0.10	0.16	0.06	0.65	25.0	7.9
Omaha, NE	14.14	2.29	0.51	0.08	0.40	0.07	0.78	14.8	1.6
Philadelphia, PA	8.65	1.46	0.33	0.05	0.29	0.05	0.86	20.8	1.8
Phoenix, AZ	3.42	0.50	0.38	0.04	0.35	0.04	0.94	9.9	1.2
Roanoke, VA	9.20	1.33	0.40	0.06	0.27	0.05	0.67	31.7	3.3
Sacramento, CA	7.82	1.57	0.38	0.06	0.33	0.06	0.87	13.2	1.7
San Francisco, CA	9.18	2.25	0.24	0.05	0.22	0.05	0.92	16.0	2.6
Scranton, PA	9.24	1.28	0.40	0.05	0.30	0.04	0.74	22.0	1.9
Seattle, WA	9.59	0.98	0.67	0.06	0.55	0.05	0.82	27.1	0.4
South Dakota[b]	3.14	0.66	0.13	0.03	0.11	0.02	0.87	16.5	2.2
Syracuse, NY	9.48	1.08	0.30	0.03	0.22	0.04	0.72	26.9	1.3
Tennessee[b]	6.47	0.50	0.34	0.02	0.30	0.02	0.89	37.7	0.8
Washington, DC	8.52	1.04	0.26	0.03	0.21	0.03	0.79	35.0	2.0
Woodbridge, NJ	8.19	0.82	0.29	0.03	0.21	0.03	0.73	29.5	1.7

SE – Standard Error
NA – Not Available
[a] Ratio of net to gross sequestration
[b] Statewide assessment of urban areas

To determine gross sequestration rates, tree growth rates need to be estimated. Base growth rates were standardized for open-grown trees in areas with 153 days of frost free length based on measured data on tree growth (Nowak et al. 2013). These growth rates were adjusted to local tree conditions based on length of frost free season, crown competition (as crown competition increased, growth rates decreased), and tree condition (as tree condition decreased, growth rates decreased). Annual growth rates were applied to each sampled tree to estimate gross annual sequestration – that is, the difference in C storage estimates between year 1 and year (x + 1) represents the gross amount of C sequestered. These annual gross C sequestration rates for each tree were then scaled up to city estimates using tree population information. Total C sequestration was divided by total tree cover to estimate a gross carbon sequestration density (kg C/m^2 of tree cover/year). The area of assessment for each city or state was defined by its political boundaries; parks and other forested urban areas were thus included in sequestration estimates.

Where gross C sequestration accounts for all C sequestered, net C sequestration for settlement trees takes into account C emissions associated with tree death and removals. The third step in the methodology estimates net C emissions from settlement trees based on estimates of annual mortality, tree condition, and assumptions about whether dead trees were removed from the site. Estimates of annual mortality rates by diameter class and condition class were obtained from a study of street-tree mortality (Nowak 1986). Different decomposition rates were applied to dead trees left standing compared with those removed from the site. For removed trees, different rates were applied to the removed/aboveground biomass in contrast to the belowground biomass (Nowak et al. 2002). The estimated annual gross C emission rates for each plot were then scaled up to city estimates using tree population information.

The full methodology development is described in the underlying literature, and key details and assumptions were made as follows. The allometric models applied to the field data for the Nowak methodology for each tree were taken from the scientific literature (see Nowak 1994, Nowak et al. 2002), but if no allometric model could be found for the particular species, the average result for the genus or botanical relative was used. The adjustment (0.8) to account for less live tree biomass in open-grown urban trees was based on information in Nowak (1994). Measured tree growth rates for street (Frelich 1992; Fleming 1988; Nowak 1994), park (deVries 1987), and forest (Smith and Shifley 1984) trees were standardized to an average length of growing season (153 frost free days) and adjusted for site competition and tree condition. Standardized growth rates of trees of the same species or genus were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Crown light exposure (CLE) measurements (number of sides and/or top of tree exposed to sunlight) were used to represent forest, park, and open (street) tree growth conditions. Local tree base growth rates were then calculated as the average standardized growth rate for open-grown trees multiplied by the number of frost free days divided by 153. Growth rates were then adjusted for CLE. The CLE adjusted growth rate was then adjusted based on tree condition to determine the final growth rate. Assumptions for which dead trees would be removed versus left standing were developed specific to each land use and were based on expert judgment of the authors. Decomposition rates were based on literature estimates (Nowak et al. 2013).

Estimates of gross and net sequestration rates for each of the 50 states and the District of Columbia (Table 6-74) were compiled in units of C sequestration per unit area of tree canopy cover. These rates were used in conjunction with estimates of state settlement area and developed land percent tree cover data to calculate each state's annual net C sequestration by urban trees. This method was described in Nowak et al. (2013) and has been modified here to incorporate developed land percent tree cover data.

Net annual C sequestration estimates were obtained for all 50 states and the District of Columbia by multiplying the gross annual emission estimates by 0.73, the average ratio for net/gross sequestration (Table 6-74). However, state specific ratios were used where available.

State Carbon Sequestration Estimates

The gross and net annual C sequestration values for each state were multiplied by each state's settlement area of tree cover, which was the product of the state's settlement area and the state's tree cover percentage based on NLCD developed land. The model used to calculate the total carbon sequestration amounts for each state, can be written as follows:

Net state annual C sequestration (t C/yr) = Gross state sequestration rate (t C/ha/yr) × Net to Gross state sequestration ratio × state settlement Area (ha) × % state tree cover in settlement area

The results for all 50 states and the District of Columbia are given in Table 6-74. This approach is consistent with the default IPCC Gain-Loss methodology in IPCC (2006), although sufficient field data are not yet available to separately determine interannual gains and losses in C stocks in the living biomass of settlement trees. Instead, the methodology applied here uses estimates of net C sequestration based on modeled estimates of decomposition, as given by Nowak et al. (2013).

Table 6-74: Estimated Annual C Sequestration (Metric Tons C/Year), Tree Cover (Percent), and Annual C Sequestration per Area of Tree Cover (kg C/m²/ year) for settlement areas in United States by State and the District of Columbia (2017)

State	Gross Annual Sequestration	Net Annual Sequestration	Tree Cover	Gross Annual Sequestration per Area of Tree Cover	Net Annual Sequestration per Area of Tree Cover	Net: Gross Annual Sequestration Ratio
Alabama	1,949,043	1,420,218	53.5	0.376	0.274	0.73
Alaska	116,009	84,533	47.4	0.169	0.123	0.73
Arizona	168,252	122,601	4.6	0.388	0.283	0.73
Arkansas	1,205,718	878,576	48.9	0.362	0.264	0.73
California	1,924,163	1,402,089	16.9	0.426	0.311	0.73
Colorado	136,841	99,713	8.0	0.216	0.157	0.73
Connecticut	601,867	438,565	58.7	0.262	0.191	0.73
Delaware	94,692	69,000	24.4	0.366	0.267	0.73
DC	11,995	8,741	25.1	0.366	0.267	0.73
Florida	4,204,004	3,063,350	40.3	0.520	0.379	0.73
Georgia	3,113,443	2,268,687	56.3	0.387	0.282	0.73

Hawaii	301,173	219,457	41.7	0.637	0.464	0.73
Idaho	59,881	43,634	7.4	0.201	0.146	0.73
Illinois	655,998	478,009	15.5	0.310	0.226	0.73
Indiana	465,440	430,373	17.1	0.274	0.254	0.92
Iowa	175,849	128,137	8.6	0.263	0.191	0.73
Kansas	287,496	223,720	10.8	0.310	0.241	0.78
Kentucky	902,579	657,686	36.8	0.313	0.228	0.73
Louisiana	1,445,497	1,053,297	47.0	0.435	0.317	0.73
Maine	369,598	269,316	55.5	0.242	0.176	0.73
Maryland	793,137	577,939	40.1	0.353	0.257	0.73
Massachusetts	940,348	685,208	57.2	0.278	0.203	0.73
Michigan	1,317,348	959,918	34.7	0.241	0.175	0.73
Minnesota	311,422	226,926	13.1	0.251	0.183	0.73
Mississippi	1,406,412	1,024,817	57.3	0.377	0.275	0.73
Missouri	836,547	609,570	23.2	0.313	0.228	0.73
Montana	47,429	34,560	4.9	0.201	0.147	0.73
Nebraska	92,271	77,864	7.3	0.261	0.220	0.84
Nevada	38,516	28,066	4.8	0.226	0.165	0.73
New Hampshire	341,910	249,141	59.3	0.238	0.174	0.73
New Jersey	867,597	632,196	40.7	0.321	0.234	0.73
New Mexico	172,828	125,935	10.2	0.288	0.210	0.73
New York	1,472,194	1,072,751	39.9	0.263	0.192	0.73
North Carolina	2,914,053	2,123,396	54.1	0.341	0.249	0.73
North Dakota	18,021	8,563	1.8	0.244	0.116	0.48
Ohio	1,220,678	889,477	28.2	0.271	0.198	0.73
Oklahoma	687,300	500,818	22.1	0.364	0.265	0.73
Oregon	676,245	492,762	39.9	0.265	0.193	0.73
Pennsylvania	1,708,480	1,244,926	40.2	0.267	0.195	0.73
Rhode Island	120,034	87,466	50.0	0.283	0.206	0.73
South Carolina	1,679,448	1,223,771	53.8	0.370	0.269	0.73
South Dakota	28,803	24,978	2.9	0.258	0.224	0.87
Tennessee	1,520,025	1,359,081	41.1	0.332	0.297	0.89
Texas	3,937,047	2,868,826	28.5	0.403	0.294	0.73
Utah	118,115	86,068	11.7	0.235	0.172	0.73
Vermont	174,444	127,113	50.6	0.234	0.170	0.73
Virginia	1,863,143	1,357,625	52.9	0.321	0.234	0.73
Washington	1,032,079	752,049	37.6	0.282	0.206	0.73
West Virginia	628,574	458,026	64.1	0.264	0.192	0.73
Wisconsin	683,179	497,815	25.9	0.246	0.180	0.73
Wyoming	33,049	24,082	4.7	0.199	0.145	0.73
Total	**45,870,216**	**33,791,433**				

Uncertainty and Time-Series Consistency

Uncertainty associated with changes in C stocks in settlement trees includes the uncertainty associated with settlement area, percent tree cover in developed land and how well it represents percent tree cover in settlement areas, and estimates of gross and net C sequestration for each of the 50 states and the District of Columbia. A 10 percent uncertainty was associated with settlement area estimates based on expert judgment. Uncertainty associated with estimates of percent settlement tree coverage for each of the 50 states was based on standard error associated with the photo-interpretation of national tree cover in developed lands. Uncertainty associated with estimates of gross and net C sequestration for each of the 50 states and the District of Columbia was based on standard error estimates for each of the state-level sequestration estimates (Table 6-75). These estimates are based on field data collected in each of the 50 states and the District of Columbia, and uncertainty in these estimates increases as they are scaled up to the national level.

Additional uncertainty is associated with the biomass models, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there is likely some overlap between the settlement tree C estimates and the forest tree C estimates (e.g., Nowak et al. 2013). Due to data limitations, urban soil flux is not quantified as part of this analysis, while reconciliation of settlement tree and forest tree estimates will be addressed through the land-representation effort described in the Planned Improvements section of this chapter.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate in 2017. The results of this quantitative uncertainty analysis are summarized in Table 6-75. The net C flux from changes in C stocks in urban trees in 2017 was estimated to be between -182.6 and -64.0 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 47 percent more sequestration to 48 percent less sequestration than the 2017 flux estimate of -123.9 MMT CO_2 Eq.

Table 6-75: Approach 2 Quantitative Uncertainty Estimates for Net C Flux from Changes in C Stocks in Settlement Trees (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Settlement Trees	CO_2	(123.9)	(182.6)	(64.0)	-47%	48%

Note: Parentheses indicate negative values or net sequestration.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2017. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for settlement trees included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. Errors that were found during this process were corrected as necessary.

Recalculations Discussion

Past estimates of carbon sequestration in settlement areas used urban land and urban tree cover as proxy for the settlement area estimates. This new approach uses settlement land area and percent tree cover in developed land as a proxy for percent tree cover in settlement area. This approach to estimating tree cover is believed to be a better approach as the land area totals between NLCD developed land and settlements align much closer than do urban land (Table 6-76). Comparing NLCD developed land, urban land (previous method of assessing settlement carbon) and settlement area in the conterminous United States, reveals:

- 2011 settlement area = 42.51 million ha
- 2010 urban area = 27.35 million ha (-36 percent compared to settlement area)
- 2011 NLCD developed land = 45.41 million ha (+6.8 percent compared to settlement area)

Table 6-76: Comparison of Settlement, Developed and Urban Land Area for Conterminous United States

State	Settlement ha (2011)	Developed ha (2011)	Urban ha (2010)
Alabama	962,863	977,171	573,377
Arizona	940,105	695,750	566,051
Arkansas	675,412	826,279	284,638
California	2,659,965	2,772,706	2,130,095
Colorado	789,092	763,913	395,419
Connecticut	388,777	314,105	472,596
Delaware	104,101	96,465	105,296
Florida	1,985,843	2,143,229	1,902,388
Georgia	1,399,213	1,529,610	1,236,321
Idaho	401,565	371,793	129,330

Illinois	1,362,424	1,739,240	1,022,445
Indiana	987,906	1,015,945	653,408
Iowa	776,671	1,089,338	246,630
Kansas	860,579	1,107,665	252,178
Kentucky	778,060	781,755	364,934
Louisiana	702,575	846,643	512,518
Maine	272,418	296,070	92,849
Maryland	557,088	482,788	519,219
Massachusetts	580,120	529,429	767,917
Michigan	1,572,260	1,590,477	934,804
Minnesota	946,863	1,249,080	444,906
Mississippi	646,988	794,063	288,525
Missouri	1,150,921	1,262,346	531,858
Montana	481,111	552,027	76,888
Nebraska	479,506	732,393	135,555
Nevada	349,974	288,438	198,212
New Hampshire	238,170	189,572	166,613
New Jersey	660,640	610,737	757,507
New Mexico	585,252	381,817	214,415
New York	1,393,123	1,176,401	1,063,658
North Carolina	1,549,227	1,397,659	1,193,342
North Dakota	415,797	732,998	47,801
Ohio	1,584,543	1,569,694	1,144,527
Oklahoma	853,953	1,114,380	338,576
Oregon	641,273	681,309	286,589
Pennsylvania	1,571,368	1,444,560	1,220,442
Rhode Island	83,714	83,486	103,555
South Carolina	833,338	770,522	615,517
South Dakota	390,275	572,579	58,759
Tennessee	1,102,701	1,058,201	751,912
Texas	3,400,132	4,450,649	2,260,511
Utah	423,971	372,832	235,230
Vermont	146,658	135,858	40,335
Virginia	1,087,778	1,024,120	691,376
Washington	963,767	1,045,135	615,435
West Virginia	366,579	442,929	165,875
Wisconsin	1,064,980	1,083,778	487,222
Wyoming	350,006	223,165	50,347
Conterminous U.S.	**42,519,645**	**45,411,098**	**27,347,901**

The advantages of this newer approach are that the settlement area is now exact (urban method underestimated the land area as it used urban land instead of settlement land) and percent tree cover is now estimated using areas that more closely align in total with settlement areas (previous approach used percent urban tree cover). It is not known how well percent tree cover from developed land represents tree cover in settlement areas, but given the similarities in definitions and area, the estimate is assumed to be reasonable.

Given that land area now matches with settlement area, the carbon estimates have increased from previous estimates that used a smaller urban land area. In 2016, the net sequestration values increased from 92.9 MMT CO_2 Eq**.** (previous urban based estimate) to 123.9 MMT CO_2 Eq**.** (2016 and 2017 settlement estimates) (+33 percent).

This new approach also added changes in percent tree cover based on paired-point analysis of photo interpretation. Tree cover in developed land dropped from 31.5 percent in c. 2011 to 30.8 percent in c. 2016. This decline in tree cover will reduce net carbon sequestration. As settlement land was held constant since 2012, tree cover decline led to a decrease in net sequestration between 2012 and 2016 (Table 6-76). Once settlement area projections are updated, settlement areas estimates since 2012 should increase and lead to increasing sequestration during this period, but at a lesser rate than if tree cover was held constant. Tree cover is intended to be reinterpreted using the same 1,000 paired points in the coming years to monitor tree cover changes in developed lands.

Planned Improvements

A consistent representation of the managed land base in the United States is discussed in Section 6.1 Representation of the U.S. Land Base, and discusses a planned improvement by the USDA Forest Service to reconcile the overlap between urban forest and non-urban forest greenhouse gas inventories. Estimates for settlements are based on tree cover in settlement areas. What needs to be determined is how much of this settlement area tree cover might also be accounted for "forest" area assessments as some of these forests may fall within settlement areas. For example, "forest" as defined by the USDA Forest Service Forest Inventory and Analysis (FIA) program fall within urban areas. Nowak et al. (2013) estimates that 1.5 percent of forest plots measured by the FIA program fall within land designated as Census urban, suggesting that approximately 1.5 percent of the C reported in the Forest source category might also be counted in the urban areas. The potential overlap with settlement areas is unknown. Future research may also enable more complete coverage of changes in the C stock of trees for all *Settlements* land.

To provide more accurate emissions estimates in the future, the following actions will be taken:

a) Settlement land area will be updated utilizing new data from the most recent National Resources Inventory (NRI) that will be incorporated into the Section 6.1 Representation of the U.S. Land Base. This update will provide new data beyond the current NRI that extends through 2012
b) Photo interpretation of settlement tree cover will be updated bi-annually to update tree cover estimates and trends
c) Areas for photo interpretation of settlement area tree cover will be updated as new NLCD developed land information becomes available
d) Overlap between forest and NLCD developed land (settlement area proxy) will be estimated based on Forest Service Forest Inventory plot data

N_2O Emissions from Settlement Soils (CRF Source Category 4E1)

Of the synthetic N fertilizers applied to soils in the United States, approximately 3.1 percent are currently applied to lawns, golf courses, and other landscaping within settlement areas. Application rates are lower than those occurring on cropland soils, and, therefore, account for a smaller proportion of total U.S. soil N_2O emissions per unit area. In addition to synthetic N fertilizers, a portion of surface applied biosolids (i.e., sewage sludge) is applied to settlement areas, and drained organic soils (i.e., soils with high organic matter content, known as *Histosols*) also contribute to emissions of soil N_2O.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions in the form of synthetic fertilizers and biosolids as well as enhanced mineralization of N in drained organic soils. Indirect emissions result from fertilizer and biosolids N that is transformed and transported to another location in a form other than N_2O (ammonia [NH_3] and nitrogen oxide [NO_x] volatilization, nitrate [NO_3^-] leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to settlements because the management activity leading to the emissions occurred in settlements.

Total N_2O emissions from soils in *Settlements Remaining Settlements*[74] are 2.5 MMT CO_2 Eq. (8 kt of N_2O) in 2017. There is an overall increase of 73 percent from 1990 to 2017 due to an expanding settlement area leading to more synthetic N fertilizer applications. Inter-annual variability in these emissions is directly attributable to variability in total synthetic fertilizer consumption, area of drained organic soils, and biosolids applications in the United States. Emissions from this source are summarized in Table 6-77.

Table 6-77: N_2O Emissions from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and kt N_2O)

	1990		2005		2013	2014	2015	2016	2017
MMT CO_2 Eq.									

[74] Estimates of Soil N_2O for *Settlements Remaining Settlements* include emissions from *Land Converted to Settlements* because it was not possible to separate the activity data.

Direct N_2O Emissions from Soils	**1.1**		**1.9**		**2.0**	**2.0**	**2.0**	**1.9**	**1.9**
Synthetic Fertilizers	0.8		1.6		1.7	1.7	1.6	1.6	1.6
Biosolids	0.2		0.2		0.2	0.2	0.2	0.2	0.2
Drained Organic Soils	0.1		0.1		0.2	0.2	0.2	0.2	0.2
Indirect N_2O Emissions from Soils	**0.4**		**0.6**		**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Total	**1.4**		**2.5**		**2.6**	**2.6**	**2.5**	**2.5**	**2.5**
kt N_2O									
Direct N_2O Emissions from Soils	**4**		**6**		**7**	**7**	**7**	**7**	**6**
Synthetic Fertilizers	3		5		6	6	6	5	5
Biosolids	1		1		1	1	1	1	1
Drained Organic Soils	+		1		1	1	1	1	1
Indirect N_2O Emissions from Soils	1		**2**		**2**	**2**	**2**	**2**	**2**
Total	**5**		**8**		**9**	**9**	**9**	**8**	**8**

+ Does not exceed 0.5 kt

Methodology

For settlement soils, the IPCC Tier 1 approach is used to estimate soil N_2O emissions from synthetic N fertilizer, biosolids additions, and drained organic soils. Estimates of direct N_2O emissions from soils in settlements are based on the amount of N in synthetic commercial fertilizers applied to settlement soils, the amount of N in biosolids applied to non-agricultural land and surface disposal (see Section 7.2, Wastewater Treatment for a detailed discussion of the methodology for estimating biosolids available for non-agricultural land application), and the area of drained organic soils within settlements.

Nitrogen applications to settlement soils are estimated using data compiled by the USGS (Ruddy et al. 2006). The USGS estimated on-farm and non-farm fertilizer use is based on sales records at the county level from 1982 through 2001 (Ruddy et al. 2006). Non-farm N fertilizer is assumed to be applied to settlements and forest lands; values for 2002 through 2012 are based on 2001 values adjusted for annual total N fertilizer sales in the United States because there is no new activity data on application after 2001. Settlement application is calculated by subtracting forest application from total non-farm fertilizer use. Biosolids applications are derived from national data on biosolids generation, disposition, and N content (see Section 7.2, Wastewater Treatment for further detail). The total amount of N resulting from these sources is multiplied by the IPCC default emission factor for applied N (one percent) to estimate direct N_2O emissions (IPCC 2006) for 1990 to 2012. The IPCC (2006) Tier 1 method is also used to estimate direct N_2O emissions due to drainage of organic soils in settlements at the national scale. Estimates of the total area of drained organic soils are obtained from the 2012 NRI (USDA-NRCS 2015) using soils data from the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2011). To estimate annual emissions from 1990 to 2012, the total area is multiplied by the IPCC default emission factor for temperate regions (IPCC 2006). This Inventory does not include soil N_2O emissions from drainage of organic soils in Alaska and federal lands, although this is a planned improvement for a future Inventory.

For indirect emissions, the total N applied from fertilizer and biosolids is multiplied by the IPCC default factors of 10 percent for volatilization and 30 percent for leaching/runoff to calculate the amount of N volatilized and the amount of N leached/runoff. The amount of N volatilized is multiplied by the IPCC default factor of one percent for the portion of volatilized N that is converted to N_2O off-site and the amount of N leached/runoff is multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site. The resulting estimates are summed to obtain total indirect emissions from 1990 to 2012.

A linear extrapolation of the trend in the time series is applied to estimate the direct and indirect N_2O emissions from 2013 to 2017 from synthetic fertilizers and drained organic soils because new activity data for these two sources have not been compiled for the latter part of the time series. Specifically, a linear regression model with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) is used to estimate the trend in emissions over time from 1990 to 2012, and in turn, the trend is used to approximate the 2013 to 2017 emissions. The time series will be recalculated for the years beyond 2012 in a future inventory with the methods described above for 1990 to 2012. This Inventory does incorporate updated activity data on biosolids application in settlements through 2017.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from settlement soils depends not only on N inputs and area of drained organic soils, but also on a large number of variables that can influence rates of nitrification and denitrification, including organic C availability; rate, application method, and timing of N input; oxygen gas partial pressure; soil moisture content; pH; temperature; and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O emissions is complex and highly uncertain. The IPCC default methodology does not explicitly incorporate any of these variables, except variations in the total amount of fertilizer N and biosolids applications. All settlement soils are treated equivalently under this methodology.

Uncertainties exist in both the fertilizer N and biosolids application rates in addition to the emission factors. Uncertainty in fertilizer N application is assigned a default level of ±50 percent.[75] Uncertainty in the area of drained organic soils is based on the estimated variance from the NRI survey (USDA-NRCS 2015). For 2013 to 2017, there is also additional uncertainty associated with the surrogate data method. Uncertainty in the amounts of biosolids applied to non-agricultural lands and used in surface disposal is derived from variability in several factors, including: (1) N content of biosolids; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the biosolids disposal practice distributions to non-agricultural land application and surface disposal. Uncertainty in the direct and indirect emission factors is provided by IPCC (2006).

Uncertainty is propagated through the calculations of N_2O emissions from fertilizer N and drainage of organic soils using a Monte Carlo analysis. The results are combined with the uncertainty in N_2O emissions from the biosolids application using simple error propagation methods (IPCC 2006). The results are summarized in Table 6-78. Direct N_2O emissions from soils in *Settlements Remaining Settlements* in 2017 are estimated to be between 1.3 and 2.7 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 31 percent below to 41 percent above the 2017 emission estimate of 1.9 MMT CO_2 Eq. Indirect N_2O emissions in 2017 are between 0.4 and 0.7 MMT CO_2 Eq., ranging from a -26 percent to 26 percent around the estimate of 0.6 MMT CO_2 Eq.

Table 6-78: Quantitative Uncertainty Estimates of N_2O Emissions from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Emissions (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
Settlements Remaining Settlements			**Lower Bound**	**Upper Bound**	**Lower Bound**	**Upper Bound**
Direct N_2O Emissions from Soils	N_2O	1.9	1.3	2.7	-31%	41%
Indirect N_2O Emissions from Soils	N_2O	0.6	0.4	0.7	-26%	26%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: These estimates include direct and indirect N_2O emissions from *Settlements Remaining Settlements* and *Land Converted to Settlements* because it was not possible to separate the activity data.

Methodological recalculations are applied from 2013 to 2017 using the linear time series model described above. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

The spreadsheet containing fertilizer, drainage of organic soils, and biosolids applied to settlements and calculations for N_2O and uncertainty ranges have been checked and verified.

[75] No uncertainty is provided with the USGS fertilizer consumption data (Ruddy et al. 2006) so a conservative ±50 percent is used in the analysis. Biosolids data are also assumed to have an uncertainty of ±50 percent.

Recalculations Discussion

Methodological recalculations are associated with extending the time series from 2013 through 2017 using a linear time series model. The recalculation had a minor effect on the time series overall with N_2O emissions declining by less than 1 percent on average.

Planned Improvements

This source will be extended to include soil N_2O emissions from drainage of organic soils in settlements of Alaska and federal lands in order to provide a complete inventory of emissions for this category. Updated data on fertilizer amount and area of drained organic soils will be compiled to update emissions estimates for estimates beyond 2012 in a future Inventory.

Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills (CRF Category 4E1)

In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are put in landfills. Carbon (C) contained in landfilled yard trimmings and food scraps can be stored for very long periods.

Carbon storage estimates within the Inventory are associated with particular land uses. For example, harvested wood products are reported under *Forest Land Remaining Forest Land* because these wood products originated from the forest ecosystem. Similarly, C stock changes in yard trimmings and food scraps are reported under *Settlements Remaining Settlements* because the bulk of the C, which comes from yard trimmings, originates from settlement areas. While the majority of food scraps originate from cropland and grassland, in this Inventory they are reported with the yard trimmings in the *Settlements Remaining Settlements* section. Additionally, landfills are considered part of the managed land base under settlements (see Section 6.1 Representation of the U.S. Land Base) and reporting these C stock changes that occur entirely within landfills fits most appropriately within the *Settlements Remaining Settlements* section.

Both the estimated amount of yard trimmings collected annually and the fraction that is landfilled have been declining. In 1990, over 53 million metric tons (wet weight) of yard trimmings and food scraps are estimated to have been generated (i.e., put at the curb for collection to be taken to disposal sites or to composting facilities) (EPA 2018). Since then, programs banning or discouraging yard trimmings disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent estimated 0.8 percent decrease between 1990 and 2017 in the tonnage of yard trimmings generated (i.e., collected for composting or disposal in landfills). At the same time, an increase in the number of municipal composting facilities has reduced the proportion of collected yard trimmings that are discarded in landfills—from 72 percent in 1990 to 31 percent in 2017 The net effect of the reduction in generation and the increase in composting is a 57 percent decrease in the quantity of yard trimmings disposed of in landfills since 1990.

Food scrap generation has grown by an estimated 67 percent since 1990, and while the proportion of total food scraps generated that are eventually discarded in landfills has decreased slightly, from an estimated 82 percent in 1990 to 76 percent in 2017, the tonnage disposed of in landfills has increased considerably (by an estimated 55 percent) due to the increase in food scrap generation. Although the total tonnage of food scraps disposed of in landfills has increased from 1990 to 2017, the difference in the amount of food scraps added from one year to the next generally decreased, and consequently the annual carbon stock *net changes* from food scraps have generally decreased as well (as shown in Table 6-79 and Table 6-80). As described in the Methodology section, the carbon stocks are modeled using data on the amount of food scraps landfilled since 1960. These food scraps decompose over time, producing CH_4 and CO_2. Decomposition happens at a higher rate initially, then decreases. As decomposition decreases, the carbon stock becomes more stable. Because the cumulative carbon stock left in the landfill from previous years is (1) not decomposing as much as the carbon introduced from food scraps in a single more recent year; and (2) is much larger than the carbon introduced from food scraps in a single more recent year, the total carbon stock in the landfill is primarily driven by the more stable ‘older’ carbon stock, thus resulting in less annual change in later years.

Overall, the decrease in the landfill disposal rate of yard trimmings has more than compensated for the increase in food scrap disposal in landfills, and the net result is a decrease in annual *net change* landfill C storage from 26.0 MMT CO_2 Eq. (7.1 MMT C) in 1990 to 11.9 MMT CO_2 Eq. (3.2 MMT C) in 2017 (Table 6-79 and Table 6-80).

Table 6-79: Net Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills (MMT CO_2 Eq.)

Carbon Pool	1990		2005		2013	2014	2015	2016	2017
Yard Trimmings	**(21.0)**		**(7.4)**		**(8.4)**	**(8.3)**	**(8.3)**	**(8.4)**	**(8.4)**
Grass	(1.8)		(0.6)		(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Leaves	(9.0)		(3.3)		(3.9)	(3.8)	(3.8)	(3.9)	(3.9)
Branches	(10.2)		(3.4)		(3.8)	(3.8)	(3.7)	(3.7)	(3.7)
Food Scraps	**(5.0)**		**(4.1)**		**(3.2)**	**(3.8)**	**(3.9)**	**(3.7)**	**(3.5)**
Total Net Flux	**(26.0)**		**(11.4)**		**(11.7)**	**(12.1)**	**(12.3)**	**(12.1)**	**(11.9)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-80: Net Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills (MMT C)

Carbon Pool	1990		2005		2013	2014	2015	2016	2017
Yard Trimmings	**(5.7)**		**(2.0)**		**(2.3)**	**(2.3)**	**(2.3)**	**(2.3)**	**(2.3)**
Grass	(0.5)		(0.2)		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Leaves	(2.5)		(0.9)		(1.1)	(1.0)	(1.0)	(1.1)	(1.1)
Branches	(2.8)		(0.9)		(1.0)	(1.0)	(1.0)	(1.0)	(1.0)
Food Scraps	**(1.4)**		**(1.1)**		**(0.9)**	**(1.0)**	**(1.1)**	**(1.0)**	**(1.0)**
Total Net Flux	**(7.1)**		**(3.1)**		**(3.2)**	**(3.3)**	**(3.3)**	**(3.3)**	**(3.2)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Methodology

When wastes of biogenic origin (such as yard trimmings and food scraps) are landfilled and do not completely decompose, the C that remains is effectively removed from the C cycle. Empirical evidence indicates that yard trimmings and food scraps do not completely decompose in landfills (Barlaz 1998, 2005, 2008; De la Cruz and Barlaz 2010), and thus the stock of C in landfills can increase, with the net effect being a net atmospheric removal of C. Estimates of net C flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled C stocks between inventory years and are based on methodologies presented for the *Land Use, Land-Use Change, and Forestry* sector in IPCC (2003) and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Carbon stock estimates were calculated by determining the mass of landfilled C resulting from yard trimmings and food scraps discarded in a given year; adding the accumulated landfilled C from previous years; and subtracting the mass of C that was landfilled in previous years and has since decomposed and been emitted as CO_2 and CH_4.

To determine the total landfilled C stocks for a given year, the following data and factors were assembled: (1) The composition of the yard trimmings; (2) the mass of yard trimmings and food scraps discarded in landfills; (3) the C storage factor of the landfilled yard trimmings and food scraps; and (4) the rate of decomposition of the degradable C. The composition of yard trimmings was assumed to be 30 percent grass clippings, 40 percent leaves, and 30 percent branches on a wet weight basis (Oshins and Block 2000). The yard trimmings were subdivided, because each component has its own unique adjusted C storage factor (i.e., moisture content and C content) and rate of decomposition. The mass of yard trimmings and food scraps disposed of in landfills was estimated by multiplying the quantity of yard trimmings and food scraps discarded by the proportion of discards managed in landfills. Data on discards (i.e., the amount generated minus the amount diverted to centralized composting facilities) for both yard trimmings and food scraps were taken primarily from *Advancing Sustainable Materials Management: Facts and Figures 2015* (EPA 2018), which provides data for 1960, 1970, 1980, 1990, 2000, 2005, 2010, 2014 and 2015. To provide data for some of the missing years, detailed backup data were obtained from the 2012, 2013, and 2014, and 2015 versions of the *Advancing Sustainable Materials Management: Facts and Figures* reports (EPA 2018), as well as historical data tables that EPA developed for 1960 through 2012 (EPA 2016). Remaining years in the time series for which data were not provided were estimated using linear interpolation. Since the *Advancing Sustainable*

Materials Management: Facts and Figures reports for 2016 and 2017 were unavailable, landfilled material generation, recovery, and disposal data for 2016 and 2017 were set equal to 2015 values.

The amount of C disposed of in landfills each year, starting in 1960, was estimated by converting the discarded landfilled yard trimmings and food scraps from a wet weight to a dry weight basis, and then multiplying by the initial (i.e., pre-decomposition) C content (as a fraction of dry weight). The dry weight of landfilled material was calculated using dry weight to wet weight ratios (Tchobanoglous et al. 1993, cited by Barlaz 1998) and the initial C contents and the C storage factors were determined by Barlaz (1998, 2005, 2008) (Table 6-81).

The amount of C remaining in the landfill for each subsequent year was tracked based on a simple model of C fate. As demonstrated by Barlaz (1998, 2005, 2008), a portion of the initial C resists decomposition and is essentially persistent in the landfill environment. Barlaz (1998, 2005, 2008) conducted a series of experiments designed to measure biodegradation of yard trimmings, food scraps, and other materials, in conditions designed to promote decomposition (i.e., by providing ample moisture and nutrients). After measuring the initial C content, the materials were placed in sealed containers along with methanogenic microbes from a landfill. Once decomposition was complete, the yard trimmings and food scraps were re-analyzed for C content; the C remaining in the solid sample can be expressed as a proportion of the initial C (shown in the row labeled "C Storage Factor, Proportion of Initial C Stored (%)" in Table 6-81).

The modeling approach applied to simulate U.S. landfill C flows builds on the findings of Barlaz (1998, 2005, 2008). The proportion of C stored is assumed to persist in landfills. The remaining portion is assumed to degrade over time, resulting in emissions of CH_4 and CO_2. (The CH_4 emissions resulting from decomposition of yard trimmings and food scraps are reported in the *Waste* chapter.) The degradable portion of the C is assumed to decay according to first-order kinetics. The decay rates for each of the materials are shown in Table 6-81.

The first-order decay rates, *k*, for each refuse type were derived from De la Cruz and Barlaz (2010). De la Cruz and Barlaz (2010) calculate first-order decay rates using laboratory data published in Eleazer et al. (1997), and a correction factor, *f*, is calculated so that the weighted average decay rate for all components is equal to the EPA AP-42 default decay rate (0.04) for mixed MSW for regions that receive more than 25 inches of rain annually (EPA 1995). Because AP-42 values were developed using landfill data from approximately 1990, 1990 waste composition for the United States from EPA's *Characterization of Municipal Solid Waste in the United States: 1990 Update* (EPA 1991) was used to calculate *f*. This correction factor is then multiplied by the Eleazer et al. (1997) decay rates of each waste component to develop field-scale first-order decay rates.

De la Cruz and Barlaz (2010) also use other assumed initial decay rates for mixed MSW in place of the AP-42 default value based on different types of environments in which landfills in the United States are located, including dry conditions (less than 25 inches of rain annually, k=0.02) and bioreactor landfill conditions (moisture is controlled for rapid decomposition, k=0.12). As in the Landfills section of the Inventory (Section 7.1), which estimates CH_4 emissions, the overall MSW decay rate is estimated by partitioning the U.S. landfill population into three categories based on annual precipitation ranges of: (1) Less than 20 inches of rain per year, (2) 20 to 40 inches of rain per year, and (3) greater than 40 inches of rain per year. These correspond to overall MSW decay rates of 0.020, 0.038, and 0.057 $year^{-1}$, respectively.

De la Cruz and Barlaz (2010) calculate component-specific decay rates corresponding to the first value (0.020 $year^{-1}$), but not for the other two overall MSW decay rates. To maintain consistency between landfill methodologies across the Inventory, the correction factors (*f*) were developed for decay rates of 0.038 and 0.057 $year^{-1}$ through linear interpolation. A weighted national average component-specific decay rate was calculated by assuming that decay rates differ for populations that live in differing annual precipitation categories, and waste generation is proportional to population (the same assumption used in the landfill methane emission estimate), based on population data from the 2010 U.S. Census. Population data were broken into three categories: less than 20 inches of rain per year, 20 to 40 inches of rain per year, and greater than 40 inches of rain per year. To calculate the weighted national average for component-specific decay rates, the percentage of the population within each precipitation category was multiplied by the component-specific decay rate for that category, and then summed. The component-specific decay rates are shown in Table 6-81.

For each of the four materials (grass, leaves, branches, food scraps), the stock of C in landfills for any given year is calculated according to Equation 1:

$$LFC_{i,t} = \sum_{n}^{t} W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k(t-n)}]\}$$

where,

t	=	Year for which C stocks are being estimated (year),
i	=	Waste type for which C stocks are being estimated (grass, leaves, branches, food scraps),
$LFC_{i,t}$	=	Stock of C in landfills in year t, for waste i (metric tons),
$W_{i,n}$	=	Mass of waste i disposed of in landfills in year n (metric tons, wet weight),
n	=	Year in which the waste was disposed of (year, where $1960 < n < t$),
MC_i	=	Moisture content of waste i (percent of water),
CS_i	=	Proportion of initial C that is stored for waste i (percent),
ICC_i	=	Initial C content of waste i (percent),
e	=	Natural logarithm, and
k	=	First-order decay rate for waste i, (year^{-1}).

For a given year t, the total stock of C in landfills ($TLFC_t$) is the sum of stocks across all four materials (grass, leaves, branches, food scraps). The annual flux of C in landfills (F_t) for year t is calculated in as the change in C stock compared to the preceding year according to Equation 2:

$$F_t = TLFC_t - TLFC_{(t-1)}$$

Thus, as seen in Equation 1, the C placed in a landfill in year n is tracked for each year t through the end of the inventory period. For example, disposal of food scraps in 1960 resulted in depositing about 1,135,000 metric tons of C in landfills. Of this amount, 16 percent (179,000 metric tons) is persistent; the remaining 84 percent (956,000 metric tons) is degradable. By 1965, more than half of the degradable portion (518,000 metric tons) decomposes, leaving a total of 617,000 metric tons (the persistent portion, plus the remainder of the degradable portion).

Continuing the example, by 2017, the total food scraps C originally disposed of in 1960 had declined to 179,000 metric tons (i.e., virtually all degradable C had decomposed). By summing the C remaining from 1960 with the C remaining from food scraps disposed of in subsequent years (1961 through 2017), the total landfill C from food scraps in 2017 was 45.3 million metric tons. This value is then added to the C stock from grass, leaves, and branches to calculate the total landfill C stock in 2017, yielding a value of 275.5 million metric tons (as shown in Table 6-82). In the same way total net flux is calculated for forest C and harvested wood products, the total net flux of landfill C for yard trimmings and food scraps for a given year (Table 6-80) is the difference in the landfill C stock for that year and the stock in the preceding year. For example, the net change in 2017 shown in Table 6-80 (3.2 MMT C) is equal to the stock in 2017 (275.5 MMT C) minus the stock in 2016 (272.3 MMT C). The C stocks calculated through this procedure are shown in Table 6-82.

Table 6-81: Moisture Contents, C Storage Factors (Proportions of Initial C Sequestered), Initial C Contents, and Decay Rates for Yard Trimmings and Food Scraps in Landfills

Variable	Yard Trimmings			Food Scraps
	Grass	Leaves	Branches	
Moisture Content (% H_2O)	70	30	10	70
C Storage Factor, Proportion of Initial C Stored (%)	53	85	77	16
Initial C Content (%)	45	46	49	51
Decay Rate (year^{-1})	0.313	0.179	0.015	0.151

Note: The decay rates are presented as weighted averages based on annual precipitation categories and population residing in each precipitation category.

Table 6-82: C Stocks in Yard Trimmings and Food Scraps in Landfills (MMT C)

Carbon Pool	1990	2005	2013	2014	2015	2016	2017
Yard Trimmings	**156.0**	**203.1**	**221.1**	**223.4**	**225.7**	**228.0**	**230.3**
Branches	14.6	18.1	19.8	20.0	20.2	20.4	20.6
Leaves	66.7	87.4	95.6	96.6	97.7	98.7	99.8
Grass	74.7	97.7	105.8	106.8	107.8	108.9	109.9
Food Scraps	**17.9**	**33.2**	**41.2**	**42.2**	**43.3**	**44.3**	**45.3**
Total Carbon Stocks	**173.9**	**236.3**	**262.3**	**265.7**	**269.0**	**272.3**	**275.5**

Note: Totals may not sum due to independent rounding.

Uncertainty and Time-Series Consistency

The uncertainty analysis for landfilled yard trimmings and food scraps includes an evaluation of the effects of uncertainty for the following data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decay rate, and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are respective uncertainties associated with each of these factors.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate for 2017. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-83. Total yard trimmings and food scraps CO_2 flux in 2017 was estimated to be between -18.9 and -4.9 MMT CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo stochastic simulations). This indicates a range of 58 percent below to 59 percent above the 2017 flux estimate of -11.9 MMT CO_2 Eq.

Table 6-83: Approach 2 Quantitative Uncertainty Estimates for CO_2 Flux from Yard Trimmings and Food Scraps in Landfills (MMT CO_2 Eq. and Percent)

Source	Gas	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO_2	(11.9)	(18.9)	(4.9)	-58%	59%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net C sequestration.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for *Landfilled Yard Trimmings and Food Scraps* included checking that input data were properly transposed within the spreadsheet, checking calculations were correct, and confirming that all activity data and calculations documentation was complete and updated to ensure data were properly handled through the inventory process.

Order of magnitude checks and checks of time-series consistency were performed to ensure data were updated correctly and any changes in emissions estimates were reasonable and reflected changes in activity data. An annual change trend analysis was also conducted to ensure the validity of the emissions estimates. Errors that were found during this process were corrected as necessary.

Recalculations Discussion

EPA made the following recalculations:

- The current Inventory has been revised to reflect updated data from the most recent *Advancing Sustainable Materials Management: Facts and Figures* report.

- Decay rates (presented in Table 6-81) were also updated using new population distributions from the 2010 U.S. Census.

Recalculations based on these updates resulted in less than 1.0 percent change in the annual carbon stocks and sequestration values as compared to the previous inventory values, except for 2014 and 2015. The largest changes occurred in the most recent years: a 1.4 percent increase in sequestration in 2014, a 4.3 percent increase in sequestration in 2015, and a 0.88 percent decrease in sequestration in 2016.

Planned Improvements

Future work is planned to evaluate the consistency between the estimates of C storage described in this chapter and the estimates of landfill CH_4 emissions described in the Waste chapter. For example, the Waste chapter does not distinguish landfill CH_4 emissions from yard trimmings and food scraps separately from landfill CH_4 emissions from total bulk (i.e., municipal solid) waste, which includes yard trimmings and food scraps. In future years, as time and resources allow, EPA will further evaluate both categories to ensure consistency.

In addition, data from recent peer-reviewed literature will be evaluated that may modify the default C storage factors, initial C contents, and decay rates for yard trimmings and food scraps in landfills. Based upon this evaluation, changes may be made to the default values.

EPA will also investigate updates to the decay rate estimates for food scraps, leaves, grass, and branches. Currently the inventory calculations use 2010 U.S. Census data. EPA will evaluate using decay rates that vary over time based on Census data changes over time.

Yard waste composition will also be investigated to determine if changes need to be made based on changes in residential practices, a review of available literature will be conducted to determine if there are changes in the allocation of yard trimmings. For example, leaving grass clippings in place is becoming a more common practice, thus reducing the percentage of grass clippings in yard trimmings disposed in landfills. In addition, agronomists may be consulted for determining the mass of grass per acre on residential lawns to provide an estimate of total grass generation for comparison with Inventory estimates.

Finally, EPA will review available data to ensure all types of landfilled yard trimmings and food scraps are being included in Inventory estimates, such as debris from road construction and commercial food waste not included in other chapter estimates.

6.11 Land Converted to Settlements (CRF Category 4E2)

Land Converted to Settlements includes all settlements in an Inventory year that had been in another land use(s) during the previous 20 years (USDA-NRCS 2015).[76] For example, cropland, grassland or forest land converted to settlements during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended by IPCC (2006). This Inventory includes all settlements in the conterminous United States and Hawaii, but does not include settlements in Alaska. Areas of drained organic soils on settlements in federal lands are also not included in this Inventory. Consequently, there is a discrepancy between the total amount of managed area for *Land Converted to Settlements* (see Section 6.1 Representation of the U.S. Land Base) and the settlements area included in the inventory analysis[77].

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[76] NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 2001. This may have led to an underestimation of *Land Converted to Settlements* in the early part of the time series to the extent that some areas are converted to settlements from 1971 to 1978.

[77] For the land representation, land use data for 2013 to 2017 were only partially updated based on new Forest Inventory and Analysis (FIA) data. These updates led to changes in the land representation data for settlements through the process of

Land use change can lead to large losses of carbon (C) to the atmosphere, particularly conversions from forest land (Houghton et al. 1983). Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally (Schimel 1995), although this source may be declining globally according to a recent assessment (Tubiello et al. 2015).

IPCC (2006) recommends reporting changes in biomass, dead organic matter, and soil organic C (SOC) stocks due to land use change. All soil C stock changes are estimated and reported for *Land Converted to Settlements*, but there is limited reporting of other pools in this Inventory. Loss of aboveground and belowground biomass, dead wood and litter C are reported for *Forest Land Converted to Settlements*, but not for other land use conversions to settlements.

Forest Land Converted to Settlements is the largest source of emissions from 1990 to 2017, accounting for approximately 74 percent of the average total loss of C among all of the land use conversions in *Land Converted to Settlements.* Losses of aboveground and belowground biomass, dead wood and litter C losses in 2017 are 37.5, 7.4, 6.9, and 10.2 MMT CO_2 Eq. (10.2, 2.0, 1.9, and 2.8 MMT C). Mineral and organic soils also lost 22.5 and 1.8 MMT CO_2 Eq. in 2017 (6.1 and 0.5 MMT C). The total net flux is 86.2 MMT CO_2 Eq. in 2017 (23.5 MMT C), which is a 37 percent increase in CO_2 emissions compared to the emissions in the initial reporting year of 1990. The main driver of net emissions for this source category is the conversion of forest land to settlements, with large losses of biomass, deadwood and litter C.

Table 6-84: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes for *Land Converted to Settlements* (MMT CO_2 Eq.)

	1990		2005		2013	2014	2015	2016	2017
Cropland Converted to Settlements	**4.1**		**11.9**		**10.3**	**10.2**	**10.2**	**10.1**	**10.1**
Mineral Soils	3.5		10.7		9.4	9.4	9.3	9.3	9.2
Organic Soils	0.6		1.2		0.9	0.9	0.8	0.9	0.8
Forest Land Converted to Settlements	**54.7**		**59.9**		**62.9**	**63.2**	**63.2**	**63.2**	**63.2**
Aboveground Live Biomass	32.6		35.5		37.2	37.5	37.5	37.5	37.5
Belowground Live Biomass	6.4		7.0		7.3	7.4	7.4	7.4	7.4
Dead Wood	5.9		6.5		6.8	6.9	6.9	6.9	6.9
Litter	8.9		9.7		10.1	10.2	10.2	10.2	10.2
Mineral Soils	0.9		1.3		1.3	1.3	1.3	1.3	1.3
Organic Soils	+		+		0.1	+	+	+	+
Grassland Converted Settlements	**4.0**		**13.5**		**12.4**	**12.4**	**12.4**	**12.3**	**12.2**
Mineral Soils	3.5		12.3		11.5	11.5	11.4	11.4	11.3
Organic Soils	0.5		1.2		0.9	0.9	0.9	0.9	0.9
Other Lands Converted to Settlements	0.2		**0.7**		**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Mineral Soils	0.2		0.6		0.6	0.6	0.6	0.6	0.6
Organic Soils	+		0.1		0.1	0.1	0.1	0.1	0.1
Wetlands Converted to Settlements	+		**0.1**		**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Mineral Soils	+		0.1		0.1	0.1	0.1	0.1	0.1
Organic Soils	0.0		0.0		0.0	0.0	0.0	0.0	0.0
Total Aboveground Biomass Flux	**32.6**		**35.5**		**37.2**	**37.5**	**37.5**	**37.5**	**37.5**
Total Belowground Biomass Flux	**6.4**		**7.0**		**7.3**	**7.4**	**7.4**	**7.4**	**7.4**
Total Dead Wood Flux	**5.9**		**6.5**		**6.8**	**6.9**	**6.9**	**6.9**	**6.9**
Total Litter Flux	**8.9**		**9.7**		**10.1**	**10.2**	**10.2**	**10.2**	**10.2**
Total Mineral Soil Flux	**8.0**		**24.9**		**22.9**	**22.8**	**22.7**	**22.6**	**22.5**
Total Organic Soil Flux	**1.1**		**2.5**		**2.0**	**1.9**	**1.9**	**1.9**	**1.8**

combining FIA data with land use data from the National Resources Inventory and National Land Cover Dataset (See "Representation of the U.S. Land Base" section for more information). However, an inventory was not compiled for settlements in this Inventory, but rather the emissions and removals are based on a surrogate data method. Therefore, the area estimates in this section are based on the land representation data from the previous Inventory.

Total Net Flux	62.9		86.0		86.4	86.5	86.5	86.4	86.2

+ Does not exceed 0.05 MMT CO_2 Eq.

Table 6-85: Net CO_2 Flux from Soil, Dead Organic Matter and Biomass C Stock Changes for *Land Converted to Settlements* (MMT C)

	1990		2005		2013	2014	2015	2016	2017
Cropland Converted to Settlements	**1.1**		**3.2**		**2.8**	**2.8**	**2.8**	**2.8**	**2.7**
Mineral Soils	0.9		2.9		2.6	2.6	2.5	2.5	2.5
Organic Soils	0.2		0.3		0.2	0.2	0.2	0.2	0.2
Forest Land Converted to Settlements	**14.9**		**16.3**		**17.2**	**17.2**	**17.2**	**17.2**	**17.2**
Aboveground Live Biomass	8.9		9.7		10.2	10.2	10.2	10.2	10.2
Belowground Live Biomass	1.7		1.9		2.0	2.0	2.0	2.0	2.0
Dead Wood	1.6		1.8		1.9	1.9	1.9	1.9	1.9
Litter	2.4		2.6		2.8	2.8	2.8	2.8	2.8
Mineral Soils	0.3		0.4		0.3	0.3	0.3	0.3	0.3
Organic Soils	+		+		+	+	+	+	+
Grassland Converted Settlements	**1.1**		**3.7**		**3.4**	**3.4**	**3.4**	**3.4**	**3.3**
Mineral Soils	0.9		3.4		3.1	3.1	3.1	3.1	3.1
Organic Soils	0.1		0.3		0.2	0.2	0.3	0.2	0.2
Other Lands Converted to Settlements	**+**		**0.2**		**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Mineral Soils	+		0.2		0.2	0.2	0.2	0.2	0.2
Organic Soils	+		+		+	+	+	+	+
Wetlands Converted to Settlements	**+**		**+**		**+**	**+**	**+**	**+**	**+**
Mineral Soils	+		+		+	+	+	+	+
Organic Soils	0.0		0.0		0.0	0.0	0.0	0.0	0.0
Total Aboveground Biomass Flux	**8.9**		**9.7**		**10.2**	**10.2**	**10.2**	**10.2**	**10.2**
Total Belowground Biomass Flux	**1.7**		**1.9**		**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Total Dead Wood Flux	**1.6**		**1.8**		**1.9**	**1.9**	**1.9**	**1.9**	**1.9**
Total Litter Flux	**2.4**		**2.6**		**2.8**	**2.8**	**2.8**	**2.8**	**2.8**
Total Mineral Soil Flux	**2.2**		**6.8**		**6.2**	**6.2**	**6.2**	**6.2**	**6.1**
Total Organic Soil Flux	**0.3**		**0.7**		**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Total Net Flux	**17.2**		**23.5**		**23.6**	**23.6**	**23.6**	**23.6**	**23.5**

+ Does not exceed 0.05 MMT CO_2 Eq.

Methodology

The following section includes a description of the methodology used to estimate C stock changes for *Land Converted to Settlements*, including (1) loss of aboveground and belowground biomass, dead wood and litter C with conversion of forest lands to settlements, as well as (2) the impact from all land use conversions to settlements on mineral and organic soil C stocks.

Biomass, Dead Wood, and Litter Carbon Stock Changes

A Tier 2 method is applied to estimate biomass, dead wood, and litter C stock changes for *Forest Land Converted to Settlements.* Estimates are calculated in the same way as those in the *Forest Land Remaining Forest Land* category using data from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (USDA Forest Service 2018), however there is no country-specific data for settlements so the biomass, litter, and dead wood carbon stocks on these converted lands were assumed to be zero. The difference between the stocks is reported as the stock change under the assumption that the change occurred in the year of the conversion. If FIA plots include data on individual trees, aboveground and belowground C density estimates are based on Woodall et al. (2011). Aboveground and belowground biomass estimates also include live understory which is a minor component of biomass defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For this Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density are based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). If FIA plots include data on standing dead trees, standing dead tree C density is estimated following the basic method applied to live trees (Woodall et al. 2011) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). If FIA plots include data on downed dead wood, downed dead wood C density is estimated based on measurements of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. If FIA plots include litter material, a modeling approach using litter C measurements from FIA plots is used to estimate litter C density (Domke et al. 2016). See Annex 3.13 for more information about reference C density estimates for forest land and the compilation system used to estimate carbon stock changes from forest land.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Land Converted to Settlements* according to land-use histories recorded in the 2012 USDA NRI survey for non-federal lands (USDA-NRCS 2015). Land use and some management information were originally collected for each NRI survey location on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). However, this Inventory only uses NRI data through 2012 because newer data were not available.

NRI survey locations are classified as *Land Converted to Settlements* in a given year between 1990 and 2012 if the land use is settlements but had been classified as another use during the previous 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an underestimation of *Land Converted to Settlements* in the early part of the time series to the extent that some areas are converted to grassland between 1971 and 1978. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 2 method (Ogle et al. 2003) is applied to estimate C stock changes for *Land Converted to Settlements* on mineral soils from 1990 to 2012. Data on climate, soil types, land-use, and land management activity are used to classify land area and apply appropriate stock change factors (Ogle et al. 2003, 2006). Reference C stocks are estimated using the National Soil Survey Characterization Database (USDA-NRCS 1997) with cultivated cropland as the reference condition, rather than native vegetation as used in IPCC (2006). Soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (USDA-NRCS 1997) than are soils under a native condition, and therefore cultivated cropland provide a more robust sample for estimating the reference condition. U.S.-specific C stock change factors are derived from published literature to determine the impact of management practices on SOC storage (Ogle et al. 2003, Ogle et al. 2006). However, there are insufficient data to estimate a set of land use, management, and input factors for settlements. Moreover, the 2012 NRI survey data (USDA-NRCS 2015) do not provide the information needed to assign different land use subcategories to settlements, such as turf grass and impervious surfaces, which is needed to apply the Tier 1 factors from the IPCC guidelines (2006). Therefore, the United States has adopted a land use factor of 0.7 to represent the loss of soil C with conversion to settlements, which is similar to the estimated losses with conversion to cropland. More specific factor values can be derived in future inventories as data become available. See Annex 3.12 for additional discussion of the Tier 2 methodology for mineral soils.

A linear extrapolation of the trend in the time series is applied to estimate soil C stock changes from 2013 to 2017 because NRI activity data are not available for these years. Specifically, a linear regression model with autoregressive moving-average (ARMA) errors (Brockwell and Davis 2016) is used to estimate the trend in stock changes over time from 1990 to 2012, and in turn, the trend is used to approximate stock changes from 2013 to

2017. The Tier 2 method described previously will be applied to recalculate the 2013 to 2017 emissions in a future Inventory.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Settlements* are estimated using the Tier 2 method provided in IPCC (2006). The Tier 2 method assumes that organic soils are losing C at a rate similar to croplands, and therefore uses the country-specific values for cropland (Ogle et al. 2003). To estimate CO_2 emissions from 1990 to 2012, the total area of organic soils in *Land Converted to Settlements* is multiplied by the Tier 2 emission factor, which is 11.2 MT C per ha in cool temperate regions, 14.0 MT C per ha in warm temperate regions and 14.3 MT C per ha in subtropical regions (See Annex 3.12 for more information). Similar to the mineral soil C stocks changes, a linear extrapolation of the trend in the time series is applied to estimate the emissions from 2013 to 2017 because NRI activity data are not available for these years to determine the area of *Land Converted to Settlements*.

Uncertainty and Time-Series Consistency

The uncertainty analysis for C losses with *Forest Land Converted to Settlements* is conducted in the same way as the uncertainty assessment for forest ecosystem C flux in the *Forest Land Remaining Forest Land* category. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. For additional details see the Uncertainty Analysis in Annex 3.13. The uncertainty analysis for mineral soil C stock changes and annual C emission estimates from drained organic soils in *Land Converted to Settlements* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-86 for each subsource (i.e., biomass C stocks, mineral soil C stocks and organic soil C stocks) and the method applied in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), i.e., as described in the previous paragraph. There are also additional uncertainties propagated through the analysis associated with the data splicing methods applied to estimate soil C stock changes from 2013 to 2017. The combined uncertainty for total C stocks in *Land Converted to Settlements* ranges from 29 percent below to 29 percent above the 2017 stock change estimate of 86.2 MMT CO_2 Eq.

Table 6-86: Approach 2 Quantitative Uncertainty Estimates for Soil, Dead Organic Matter and Biomass C Stock Changes occurring within *Land Converted to Settlements* (MMT CO_2 Eq. and Percent)

Source	2017 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Settlements	**10.1**	**7.8**	**12.4**	**-23%**	**23%**
Mineral Soil C Stocks	9.2	6.9	11.5	-25%	25%
Organic Soil C Stocks	0.8	0.5	1.1	-36%	36%
Forest Land Converted to Settlements	**63.2**	**38.2**	**88.1**	**-40%**	**39%**
Aboveground Biomass C Stocks	37.5	14.2	60.8	-62%	62%
Belowground Biomass C Stocks	7.4	2.8	11.9	-62%	62%
Dead Wood	6.9	2.6	11.1	-62%	62%
Litter	10.2	3.9	16.5	-62%	62%
Mineral Soil C Stocks	1.3	1.0	1.5	-20%	20%
Organic Soil C Stocks	+	+	+	-39%	39%
Grassland Converted to Settlements	**12.2**	**9.7**	**14.8**	**-21%**	**21%**
Mineral Soil C Stocks	11.3	8.8	13.9	-22%	22%
Organic Soil C Stocks	0.9	0.5	1.2	-41%	41%
Other Lands Converted to Settlements	**0.7**	**0.5**	**0.9**	**-24%**	**24%**
Mineral Soil C Stocks	0.6	0.5	0.7	-24%	24%
Organic Soil C Stocks	0.1	+	0.2	-80%	80%
Wetlands Converted to Settlements	**0.1**	**+**	**0.1**	**-42%**	**42%**

Mineral Soil C Stocks	0.1	+	0.1	-42%	42%
Organic Soil C Stocks	+	+	+	0%	0%
Total: Land Converted to Settlements	**86.2**	**61.0**	**111.4**	**-29%**	**29%**
Aboveground Biomass C Stocks	**37.5**	**14.2**	**60.8**	**-62%**	**62%**
Belowground Biomass C Stocks	**7.4**	**2.8**	**11.9**	**-62%**	**62%**
Dead Wood	**6.9**	**2.6**	**11.1**	**-62%**	**62%**
Litter	**10.2**	**3.9**	**16.5**	**-62%**	**62%**
Mineral Soil C Stocks	**22.5**	**19.1**	**25.9**	**-15%**	**15%**
Organic Soil C Stocks	**1.8**	**1.1**	**2.5**	**-38%**	**38%**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations are applied to the latter part of the time series (2013 to 2017) using the linear time series model described above. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data are properly handled throughout the inventory process. Inventory reporting forms and text are reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

Methodological recalculations are associated with extending the time series from 2013 through 2017 using a linear time series model, and an update of biomass and dead organic matter losses with *Forest Land Converted to Settlements*. The recalculation led to a 31 percent greater loss of C on average. This change is almost entirely attributed to the update of biomass and dead organic matter losses for *Forest Land Converted to Settlements* with newly available re-measurement data for the western United States. New stock changes were estimated at the plot-level with the new data consistent with the compilation methods described in the *Forest Land Remaining Forest Land* section. In the previous Inventory, state-level averages from the plot data had been used to approximate the losses of C with *Forest Land Converted to Settlements* due to a lack of re-measurement data.

Planned Improvements

A planned improvement for the *Land Converted to Settlements* category is to develop an inventory of C stock changes in Alaska. This includes C stock changes for biomass, dead organic matter and soils. There are plans to improve classification of urban trees in settlements and to include transfer of biomass from forest land to those areas in this category. There are also plans to extend the Inventory to included C losses associated with drained organic soils in settlements occurring on federal lands. New land representation data will also be compiled, and the time series recalculated for the latter years in the time series that are estimated using data splicing methods in this Inventory.

6.12 Other Land Remaining Other Land (CRF Category 4F1)

Land use is constantly occurring, and areas under a number of differing land-use types remain in their respective land-use type each year, just as other land can remain as other land. While the magnitude of *Other Land Remaining Other Land* is known (see Table 6-7), research is ongoing to track C pools in this land use. Until such time that reliable and comprehensive estimates of C for *Other Land Remaining Other Land* can be produced, it is not possible to estimate CO_2, CH_4 or N_2O fluxes on *Other Land Remaining Other Land* at this time.

6.13 Land Converted to Other Land (CRF Category 4F2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to other land each year, just as other land is converted to other uses. While the magnitude of these area changes is known (see Table 6-7), research is ongoing to track C across *Other Land Remaining Other Land* and *Land Converted to Other Land*. Until such time that reliable and comprehensive estimates of C across these land-use and land-use change categories can be produced, it is not possible to separate CO_2, CH_4 or N_2O fluxes on *Land Converted to Other Land* from fluxes on *Other Land Remaining Other Land* at this time.