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The Potential of U.S. Forest Soils to Sequester Carbon

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INTRODUCTION

Previous work (Lal et al., 1998; Follett et al., 2001) described the potential of U.S. cropland and grazing land soils to sequester carbon (C) and be managed to help mitigate greenhouse gas emissions. Activities to sequester C in croplands included land conversion, land restoration, improved cropping systems, and intensified management using conservation tillage and improved water and fertility management. Lal et al. (1998) estimated that cropland soils could sequester 75 to 208 million metric tons C per year (Mt C/yr) (mean=142), while 43 Mt C/yr was estimated to be emitted from production inputs. Thus, the net potential sequestration was estimated at 100 Mt C/yr on a cropland area of 136.6 million hectares (Mha) (Lal et al., 1998). Activities to sequester C in grazing lands included controlling soil erosion losses, restoring eroded and degraded soils, land conversion, and improved pasture and rangeland management, which involved fertility management, planting improved species, and grazing management. The overall potential of U.S. grazing lands to sequester C ranged from 29.5 and 110 Mt C/yr (mean=69.8 Mt C/yr) during a 25-year period, with emission losses of 12.0 to 19.5 Mt C/yr (mean = 15.8 Mt C/yr). The net potential sequestration of grasslands was about 53.5 Mt C/yr on a land base of approximately 336 Mha.

The potential to sequester C in forest soils has received little attention in the Guidelines for National Greenhouse Gas Inventories (IPCC, 1997), the Kyoto Protocol, or other studies where the focus has been on aboveground biomass through forest-related land use change, such as afforestation and deforestation, or forest management (Kimble et al., ch. 1). Yet the soil in U.S. forests contains about 60% of total forest ecosystem C (Birdsey and Heath, 1995). In terms of the dynamics of C on a global basis, attempts to balance the input and output of C have revealed a "missing sink." Houghton et al. (1998) estimated this sink at 1.8 ± 1.5 Pg C/yr, some of which was likely to be contained in terrestrial ecosystems in the Northern Hemisphere, namely soils and vegetation (Pacala et al., 2001). Thus, there is a need to better understand the capacity and dynamics of vegetation or forest C sinks both above- and belowground.

The purpose of this chapter is to synthesize key information from the present volume for easy reference. The main topics are the characteristics of forests and forest soils and how to measure and monitor them; C dynamics and soils processes including the activity of soil organisms; forest management activities and their impacts on soils; and discussions of specific forest ecosystems with unique soil C dynamics or management needs. The typical managed forest in the conterminous U.S. is relatively productive, closed-canopy, temperate deciduous or coniferous forest. The soil C in boreal regions, high elevations, the arid West, wetlands, and sub-tropical areas, as well as urban areas and areas of agroforestry, may have distinct features and so forests in these areas are treated separately. Finally, quantitative estimates of the potential of forest soils to sequester C are provided.

Characteristics of forests and forest soils

The amount of C in forests and forest soils is determined by the area of forests and the amount of C per hectare. Birdsey and Lewis (ch. 2) present a quantitative area analysis of land use, forest management, and natural disturbance in forests. About 33% of the land area of the U.S., constituting about 302 Mha, is forest. About 17% of this area is in Alaska. The total area of forestland in the conterminous U.S. has been stable over the last century; however, significant regional changes have occurred. The Northeast and North Central regions gained 43% and 7% in forest area, respectively, over the century, while the Pacific Coast and South Central regions both lost about 13% in forest area (Birdsey and Lewis, ch. 2). Since 1907 deforestation has affected a cumulative area of 70 Mha of forestland; afforestation has affected a cumulative area of 62 Mha. Another major change in the latter half of the 20th century is in the area of grazed forests, which has fallen 60% or by 61 Mha. Poorly stocked forest areas declined 90% over the same period, to 1.7 Mha, due to efforts to increase stocking and to reduce uncontrolled fires. Over 64% of the forestland area in the East is in the oak-hickory (*Quercus-Carya*), maple-beech-birch (*Acer-Fagus-Betula*), oak-pine (*Quercus-Pinus*), and oak-gum-cypress (*Quercus-Liquidambar/Nyssa-Taxodium*) forest types. In the West, over 67% of the forestland area is in the pinyon-juniper (*Pinus* species *edulis, cembroides, quadrifolia, and monophylla-Juniperus*), Douglas-fir (*Pseudotsuga*), Ponderosa pine (*Pinus ponderosa*), and fir-spruce (*Abies-Picea*) forest types.

Whereas forests are often categorized by vegetation such as forest type, forest soils are classified using the standard Soil Taxonomy (Soil Survey Staff 1999; Johnson and Kern, ch. 4). Seventy percent of forests in the contiguous U.S. are found on four soil orders: Alfisols, Mollisols, Inceptisols, and Ultisols. The mass of organic C in forests in the conterminous U.S. to a depth of one meter is 25,780 Mt C. Approximately 25% of the C is found in Histosols. With 250 Mha of forest in the conterminous United States, the average C per hectare in soil is about 105 metric ton (t). Forest area is 52 Mha in Alaska, 0.7 Mha in Hawaii, and 0.3 Mha in Puerto Rich. Forest soil in Alaska contains about 10,430 Mt C in the first meter, forest soil in Hawaii contains 96 Mt C, and forest soil in Puerto Rico contains 33 Mt C. The estimated area by forest type in Johnson and Kern (ch. 4) differ from the estimates of Birdsey and Lewis (ch. 2) because chapter 2 area estimates are based on field measurements from forest inventories, whereas chapter 4 area estimates are based on a land classification from satellite-based imagery. The chapter 2 area estimates are consistent with the most recent national forest inventory compilation reported by the USDA Forest Service (Smith et al., 2001). The oak-hickory forest type contains more soil C than any other forest type in the contiguous U.S., only slightly less than the soil C in the softwood forest type in Alaska (Johnson and Kern, ch. 4). The large amount of soil C in oak-hickory is due mainly to the large area that oak-hickory covers. Forest types containing a high percentage of Histosols (and therefore high soil C per hectare) are aspen-birch (*Populus-Betula*) in the East and fir-spruce in the West, as well as white-red-jack pine (*Pinus strobus-Pinus resinosa-Pinus banksiana*), longleaf-slash pine (*Pinus palustris-Pinus elliottii*), maple-beech-birch, and oak-gum-cypress (Johnson and Kern, ch. 4).

For context, the total stock of C in forests of the conterminous United States is 52,245 Mt C (Heath et al., ch. 3). About 50% of the C is in the soil, 34% is in live vegetation, 8% is in the forest floor, and the rest is in standing dead trees or downed dead wood. Over the period 1953 to 1997, total forest ecosystem C increased about 155 Mt C/yr on average, while the land area dropped by 3 Mha. However, Heath et al. (ch. 3) did not include effects of land use history on soil C, which is expected to cause C increases on the order of 20 to 40 Mt C/yr. In addition, a net of 31 Mt C/yr is being sequestered in harvested wood products in use, and in landfills. Summing the 155 Mt C/yr in forest ecosystems, plus the 31 Mt C/yr in products, results in forests and forest products sequestering at least 185 Mt C/yr over the period 1953-1997, with an additional 20 to 40 Mt C/yr in soils from land use change. Most of the 185 Mt C/yr increase is due to increases in live tree biomass, or the associated products produced from wood. An additional 45 Mt C/yr of C, which is not counted as part of the forest sequestration because these are net estimates, is being burned for energy production (Heath et al., ch. 3). This is a comparatively large amount that may be of interest as an offset to the burning of fossil fuels.

How do we know what we think we know about soil C? Techniques are available to measure C sequestration in forest soils (Palmer, ch. 5). Analytical techniques for the measurement of soil C are commercially available, with sample preparation costing about $4 per sample, and the median analytical technique costing $5.60 to $11 (Palmer, ch. 5). To estimate soil C on an areal basis, bulk density and coarse rock fragment contents must be measured. To monitor total soil C change, these characteristics must also be measured over time. Careful design of the survey must include all characteristics of interest, such as forest floor C, and plan for spatial and temporal variability. As in all surveys, a designated level of precision is met by selecting an appropriate sample size.

FOREST C CYCLE AND SOILS PROCESSES INCLUDING THE ACTIVITY OF SOIL ORGANISMS

The factors that regulate soil properties and therefore C accumulations are climate, biota (organisms and vegetation), topography, parent material and time (Brady and Weil, 1999; Morris and Paul, ch. 7). Biota is the main factor that can be affected by management. Soil organisms represent only about 5% of total organic matter in forest soils (Grigal and Vance, 2000), but they control the process of transforming and decomposing soil organic C (Pregitzer, ch. 6). Management for C sequestration in forest soils must include an understanding of soil organisms and the factors that control their growth and maintenance (Morris and Paul, ch. 7). The potential of soil C storage in forests is great because the inputs into the soil contain compounds such as lignins, which are difficult to decompose, and forests also contain organisms that can optimize forest net primary productivity while maintaining belowground C stocks. Chapter 7 describes the major groups of soil organism and the roles that they play in forest soil C transformations.

To understand how management can impact C cycling and storage in forests, one must also have a fundamental understanding of how C is sequestered in various pools and the mechanisms that control the flow from one pool to another (Pregitzer, ch. 6). Most C in forest ecosystems is fixed during photosynthesis. Influencing the genetic composition of the forest and increasing the availability of resources that limit stand-level photosynthesis are the most direct ways to increase C sequestration at the ecosystem level. However, much remains to be learned about the rest of the C cycle, including belowground allocation to coarse roots, fine roots, and mycorrhizae (Pregitzer, ch. 6), as well as decomposition and transformation processes. A major factor controlling ecosystem C balance over decades is heterotrophic soil respiration (Pregitzer, ch. 6). Many fundamental questions on the C cycle remain for future research.

Two C pools important in forest soils—pools that are not important in cropland and grazing land—are forest floor and downed woody debris (Currie et al., ch. 8). The forest floor is defined as the surface organic horizon (O horizon), whose characteristics depend on climate, litter production rates, litter quality, and soil organism activities. Although the forest floor pool was estimated to contain only 8% of C in an average U.S. forest ecosystem (Heath et al., ch. 3), it is important as a responsive reservoir that provides much of the C ultimately stored in soil (Currie et al., ch. 8). Downed woody debris is similar to the forest floor in that inputs to the pool occur when part of the tree dies and falls to the ground and losses occur through decomposition and fragmentation. Results of limited studies in the U.S. suggest that about 10% of the mass may be lost to dissolved organic C leaching and 25-50% may be lost from the pool due to fragmentation (Mattson et al., 1987; Currie et al., ch. 8). Both processes have the potential to add significant quantities of C to organic C pools in mineral soil.

At the broader landscape level, disturbances are a significant component of the forest C cycle. Early in the 20th century, ecological theory adopted Clements' (1916, 1928) model of succession toward a stable climax state (Overby et al., ch. 10). Disturbance was thought only to interrupt the development toward equilibrium. By the late 20th century, Hollings (1995) introduced the concept of nonequilibrium succession (Overby et al., ch. 10). C accumulates in ecosystems until released by disturbance. The system then begins to reaccumulate C. Major natural disturbances are fire, insects, disease, drought, and wind. Interactions between disturbance agents complicate the study of their individual effects on forests and soil C. Overby et al. (ch. 10) concluded that much research is needed to understand and quantify the effects that natural disturbances have on forests and forest soil C.

DISTURBANCES AND MANAGEMENT IMPACTS ON FOREST SOILS

Disturbances and management impacts can cause mineral soil C to increase, decrease, or remain unchanged. Land use change has the potential for the greatest effect, due to the large changes in soil C per hectare from land conversion and because of the large area affected (Post, ch. 12;

Murty et al., 2002). Soil C is most affected when land is converted from forest to cultivation or from cultivation to forest. Studies to date on shifts from grassland to forest or forest to grassland have shown small changes. Fertilization and planting nitrogen-fixing species (Hoover, ch. 14) have a large effect on a per-area basis, increasing the soil C density by an average of about 25%. However, the area of forest currently fertilized or planted with N-fixing species is a small percentage of the total forest. Table 23.1 is a summary of soil C information from the other chapters in this volume relating to disturbances and management impacts on U.S. forests.

Reducing soil erosion in U.S. forests would lead to only a small increase in soil C sequestration, about 0.2 to 0.5 Mt C/yr (Elliot, ch. 11). Little is known about how compaction from forest operations affects soil C (Lal, ch. 15). Studies on wildfire or prescribed fire have produced mixed results. Generally, wildfires can affect the forest floor C pool greatly, but there is little affect on mineral soil C (Page-Dumroese et al., ch. 13; Hoover, ch. 14). Formation of charcoal in the surface soil enhances long-term C storage; however, no studies featuring estimates of C in charcoal following fire were cited (Page-Dumroese et al., ch. 13; Hoover, ch. 14). Individual studies have shown harvesting effects and site preparation effects, but collectively, the results are highly variable (Johnson and Curtis, 2001). On average, there is no significant change in soil C from these disturbances. However, specific studies have shown large increases or large losses for similar treatments. This suggests that results are highly site-specific and may also indicate that the differences in methodology make study comparisons difficult.

U.S. FOREST ECOSYSTEMS THAT HAVE UNIQUE SOIL C DYNAMICS OR MANAGEMENT NEEDS

Most of the forestland in the United States is in the temperate zone and is occupied by coniferous or deciduous trees that are relatively productive. Most of the chapters in the book were written to address these typical forests. However, there are some forest ecosystems that have unique soil C dynamics or that need special management considerations or both, and specific chapters were written for these areas. Some forest ecosystems of special interest with respect to C sequestration are boreal forests (Hom, ch. 16), high-elevation forests (Bockheim, ch. 17), arid and semiarid interior West (Neary et al., ch. 18), wetland forests (Trettin and Jurgensen, ch. 19), forests managed under agroforestry (Nair and Nair, ch. 20), urban forests (Pouyat et al., ch. 21), and tropical forests (Silver et al., ch. 22). The topic of grazed forests and soil C was also considered to be of interest, but this is an area requiring further research (and perhaps researchers).

Three forest ecosystems—boreal, high-elevation, and arid and semiarid Interior West—tend to be of lower-than-average productivity (Table 23.2). Fire is a major disturbance in forests of the boreal region and the Interior West. Climate has a major influence in all these forests, because the climate tends to be marginal for tree growth, and small climatic changes can have noticeable effects. The soils in boreal forests are high in organic matter. The focus in these soils is not to increase C as much as to retain existing C. Climate change is thought to be the main factor that may affect these forest soils in the future. The dry forests of the Interior West represent a special case due to the cumulative effects of fire suppression and overgrazing. Downed wood and forest floor C pools have significantly increased, increasing total ecosystem C reserves (Neary et al., ch. 18). Fires in areas with such high fuel loads may be so severe as to affect soil C. Mechanical incorporation of organic material into soils is limited due to soil, physical, and institutional constraints (Neary et al., ch. 18). Neary et al. (ch. 18) conclude that there are virtually no management opportunities for increasing C sequestration in these forests. The most fruitful management activities are probably those that can prevent the forests from losing C if the climate changes. Almost any management activities chosen to return the forests to health will probably involve reducing the high wood fuel loads in the forests, resulting in C emissions.

Tropical and sub-tropical forests store very little of the soil C in the United States because of their small area (Table 23.2). However, they offer unique opportunities for scientific study because of their variety and the fact that changes occur more rapidly in tropical forests (Silver et al., ch. 22). Wetland forests (Trettin and Jurgensen, ch. 19) comprise less than 10% of forestlands in the U.S., but their soils are rich in C. Protecting current C stores or restoring C that has been lost due to land use change could be substantial. Managing these areas should be explored further. Harvesting and drainage studies have had mixed results.

Two other managed forest systems that are not typically considered for management but that may provide sequestration opportunities are urban forests and forests managed for agroforestry. Agroforestry is the deliberate growing of trees on the same unit of land used for agricultural crops or animals. Nair and Nair (ch. 20) estimated that all agroforestry practices in the United States have the potential to sequester 90 Mt C/yr for a limited number of years (Table 23.2). Forests of urban areas, which are increasing in size, also may provide opportunities to increase soil C, particularly on lawns that are highly maintained for recreational use (Pouyat et al., ch. 21). Table 23.2 is a summary of the types of forests, their areas, soil C statistics, and possible activities or characteristics related to the unique forest ecosystems discussed in this section.

THE POTENTIAL FOR C SEQUESTRATION IN FOREST SOILS

In chapter 1, Kimble et al. cited a study which offered a potential rate of C gain in temperate forest soils of 0.53 t C/ha/yr (IPCC, 2000). Based on a productive forestland base of 204 Mha, the potential for C sequestration in forest soils of the U.S. is 108.1 Mt C/yr. We constructed a table of activities and their potential forest C sequestration, based on the information presented in this book, along with information from other forest soil studies and two books on sequestering C in cropland and grazing land soils. The results are displayed in Table 23.3.

The activities are summarized under four main headings: forest management, land use change, agroforestry, and urban forest management. A low, medium, and high average rate of soil C sequestration is presented, to help convey the uncertainty of the estimates. There is also uncertainty in the area of land that will be affected by the activity, however, that type of uncertainty is not included here. The potential net C sequestration in soils ranges from 48.9 to 185.8 Mt C/yr, with an average of 105.9 Mt C/yr. Generally, the medium rates of C sequestration are lower than the 0.53 t C/ha/yr cited from previous studies. This is due to the lower rates of C sequestration cited from chapters in this volume. Past studies however, have not been designed specifically to increase soil C. Activities designed with a goal of increasing soil C should result in higher soil C sequestration rates.

Table 23.3. Estimated potential forest soil carbon changes resulting from management of U.S. forestlands for increased forest soil carbon.

Activity	Area (Mha)	Rate of C sequestration in soil (kg/ha/yr)			Quantity sequestered (Mt C/yr)		
		Low	Medium	High	Low	Medium	High
All forest management					24.5	56.4	103.2
Regeneration	59.7	70	223	419	4.2	13.3	25.0
Fertilization	20.0	875	1749	3061	17.5	35.0	61.2
Restoration of degraded lands (mine reclamation)	1.0	89	487	1295	0.1	0.5	1.3
More partial cutting/less clearcuts	1.5	0.0	448	1195	0.0	0.7	1.8
Lengthen rotations	0.7	0.0	448	1195	0.0	0.3	0.9
Soil erosion reduction	21	9.5	16.7	23.8	0.2	0.35	0.5
Fire management	?[a]	?[a]	?[a]	?[a]	?[a]	?[a]	?[a]
Manage to increase soil C	125	20	50	100	2.5	6.3	12.5
Land Use Change					7.5	26.2	51.4
Increase afforestation	10	0	338	676	0.0	3.4	6.8
Reduce deforestation	0.8	1740	2367	3461	1.3	1.8	2.6
Past afforestation continuing to accrue C[b]	62	100	338	676	6.2	21	42
Agroforestry					16.9	22.3	28.2
Alleycropping	80	173	230	288	14	18.5	23
Riparian buffers	--	--	--	--	0.4	0.5	0.6
Silvopasture	70	25	33	41	1.8	2.3	3.3
Windbreaks	85	8	12	15	0.7	1	1.3
Urban forest					0	1	3
Urban management	1	0	1000	3000	0	1	3
TOTAL NET C SEQUESTRATION					48.9	105.9	185.8

[1] Note that the estimates in Table 23.3 include only the C sequestered in soil. The amount sequestered in tree biomass and forest floor pools may be 4 to 6 times the amount in soil C.

[a] Impact of management activities on wildfire are not clear.

[b] Although past afforestation is not an activity that can now be influenced, it is included here as a contribution to total potential soil carbon changes.

Forest management activities have the potential to sequester the most soil C, mostly from fertilization, regeneration, and managing specifically to increase soil C. Note that we have not accounted for emissions that will be associated with fertilization. Question marks are shown for fire management because, based on current information about fire, it is unclear how much change, if any, will occur due to fire management. A modest afforestation program sequesters about half the total amount of the forest management activities listed, and agroforestry activities sequesters about the same amount.

CONCLUSIONS

Forests of the United States sequestered a net annual average of 155 Mt C/yr over the period 1953 to 1997 in biomass and aboveground mass. Sequestration into wood in products and landfills contributed an additional 31 Mt C/yr (Heath et al., ch. 3). Average soil C increases from land use change were at least 20 Mt C/yr. An average of 45 Mt/yr of C in harvested wood was burned for energy or converted to an energy source, with the potential of substituting for the burning of fossil fuel.

Forest soils have not been intentionally managed for C sequestration previously. A number of processes, such as fire, deforestation, and climate change can cause soils to emit CO_2 or methane. Some management activities, such as erosion control, managing forest ecosystems to minimize loss of C from fires, and designing silvicultural operations to minimize emissions, increase net C sequestration by reducing potential emissions. Other management activities, such as fertilization and planting nitrogen-fixing species, intensively managing urban forest soils for recreational uses, and adopting a management system like agroforestry, increase C sequestration in both soils and biomass. With many management activities, it is unclear whether C will be sequestered or emitted. Literature reviews are often mixed, indicating that results may be site-specific and dynamic. Thus, future experiments need to be carefully designed to produce useful information about C sequestration.

The potential net C sequestration in forest soils ranges from 48.9 to 185.8 Mt C/yr, with an average of 105.9 Mt C/yr. Forest management activities have the potential to sequester the most soil C, mostly from fertilization, regeneration, and managing specifically to increase soil C. A modest afforestation program sequesters about half the total amount of the forest management activities listed, and agroforestry activities sequesters about the same amount. These potential estimates do not include the amount sequestered in tree biomass and forest floor pools. Considering that the non-soil C sequestration may be 4 to 6 times the amount in soil C, the potential average total C sequestration in U.S. forest may be 420 to 630 Mt C/yr.

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Table 23.1. Current forest soil carbon changes from disturbances and management impacts on U.S. forests, as summarized from the current volume.

Management/Event	Area (Mha)	Soil C change	Soil C (Mt C/yr)	Major activities/factors potentially affecting soil C
Soil erosion reduction (Elliot, ch. 11)	21[a]	Avg annual C loss (kg/ha/yr): •Forest roads: 0.12 •Forest operations: <5 •Wildfires: 5 •Landslides: 0.25	0.2 – 0.5	• Erosion rates may be high immediately following disturbance, usually decreases rapidly. • Careful management will minimize soil erosion. • Reducing soil erosion can lead to only a small increase in C sequestration.
Land use change: Forest establishment (Post, ch. 12)	61.9, with time of establishment distributed since 1907.[b]	Avg annual C change (kg/ha/yr)[c]: • Forest establishment on cropland: 338 •Grassland establishment on cropland : 332 • Species change to cool coniferous forest: 30	20, assuming afforested lands continue to be forested. Over period since 1907, 805 Mt C has been sequestered.	• Greatest change with forest establishment is change in vertical distribution of soil organic matter. • Large amount of variation in rates of actual soil organic carbon change
Wildfire effects (Page-Dumroese et. al, ch. 13)	Affects 1.6 Mha/yr[b]		A small loss of 1 gC/m^{-2} during year of fire is equivalent to 0.016 Mt C/yr	• Most of C in forest floor would likely be destroyed while long-term mineral soil losses are small. • Experimental studies should monitor forest floor and soil C separately
Fire suppression (in long-term can lead to species composition changes) (Page-Dumroese et al., ch. 13)				• Example: pine stands have a greater C proportion in surface mineral soil while mixed fir/pine have more C in forest floor and down wood.
Harvesting and site prep Prescribed fire and wildfire Fertilization and N-fixing species (Hoover, ch. 14)	4.0/yr, 1980-1990[b] 1.6/yr, 1988-1997 No estimate	Generally not significant Mixed results Positive effect on soil C, avg. about 25% increase		• Experiments need to be designed to measure total carbon changes, not just percent C. • For harvesting and fire, results are highly site-specific, and time since activity greatly affect results. • Most increases to fertilization or N-fixing range between –10 to 60%, perhaps averaging about 25% (based on estimates in Johnson and Curtis, 2001)
Compaction (Lal, ch. 15)	No estimate	Studies are needed.		• In long-term, soil compaction may have negative impacts on biomass, soil carbon, and productivity. • In short-term, compaction may increase soil organic carbon density because of an increase in mass of soil per unit volume.
Land use change: Conversion from forest to agriculture (Murty et al, 2002)	70.4, with time of establishment distributed since 1907.[b]	Conversion to cultivated land, loss of 20% for soils sampled to more than 45 cm. Conversion to uncultivated grassland, no change on average	6.7 emitted, assuming half of area loss is converted to cultivated land[d].	• Rapid initial loss, reaching a new equilibrium within 5-10 years.

[a] Based on 7% of US forests in a disturbed condition, and total US forestland of 302 Mha.

[b] Birdsey and Lewis (ch. 2).

[c] Post and Kwon, 2000.

[d] Based on average 105 t/ha soil carbon density from Heath et al. (ch. 3), a 20% change over 10 years, and area loss of 6.4 Mha/yr in 1988-1997 (Birdsey and Lewis, ch. 2)

Table 23.2. Summary of forest soil C information currently available for U.S. forest ecosystems having unique soil C dynamics or management needs.

Specific Forest Ecosystem/ Chapter	Area (Mha)	Soil C density (t/ha, 1 m depth)	Soil C (Mt C)	Major activities/factors potentially affecting soil C
Boreal Forest (Hom, ch. 16)	47.1[a]	385[b]	18,133	• Forests are of low productivity and soils contain large amounts of C. Thick forest floors serve as insulation, maintaining cold soil temp. Climate is a key driver in this system. • Fire is a major disturbance. No experimental studies are cited; implication is fire causes increases in soil temperature, resulting in increased decomposition.
High Elevation forest (Bockheim, ch. 17)	19.0	220±20.2 (range 20.8-860)	38 to 46	•Soil C affected most by small burrowing animals •Large amounts of nutrients discharged thru snowmelt •Climate likely to be important to C dynamics
Arid-semiarid interior West forest (Neary et al., ch. 18)	73.4	25-136, depending on vegetation 78 for woodland		•Erosion can be major factor in soil loss •Grazing at low to moderate levels may increase soil C; high intensity grazing may decrease. •Prescribed fire-no studies •Climate key driver to soil C inputs • Wildfire suppression and overgrazing has significantly increased FF and down wood C pools. Must lose carbon for forest health. • Virtually no opportunities for increasing C sequestration in these ecosystems
Wetland forest (Trettin and Jurgensen, ch. 19)	26.4	457	12,100	• Land use conversion results in a substantial loss • DOC is principal pathway for hydrologic C losses • Restoration may be major activity to increase C • Water mgmt or drainage biggest factor contributing to losses in short-term. Mixed results in long-term. • Harvesting contributes to losses in short-term. Mixed results in long-term.
Agroforestry (Nair and Nair, ch. 20)				• Alleycropping could result in sequestering 73.8 Mt C/yr (all C not just soil) on 80 ha. • Silvopasture may result in 9.0 Mt C/yr (all C not just soil) on 70 Mha. • Windbreaks on 85 Mha may sequester 4.0 Mt C (all C not just soil). • Riparian buffers, short rotation woody crops may sequester 2.0 Mt C/yr.
Urban forest (Pouyat et al., ch. 21)	28.1, with tree cover of 27%	Residential – 155 Undisturbed – 93 Other - 52 US– urban avg 82		• Direction of change in urban soils depend on initial SOC status of native soil. • Highly maintained recreation use lawns have 10.3 t/ha more soil C than minimal maintained soils. • Atmospheric pollution effect unknown. • Invasive species such as Asian earthworm altering decomposition rates
Tropical/Subtropical forests (Silver et al., ch. 22)	3.2	Hawaii - 91 (depth 0-25 cm) Puerto Rico - 75 (depth 0-25 cm) Land use diff. in PR only (0-50 cm): Forestland – 143.5 Cropland – 85.1 Grassland – 86.8		• Peat subsidence from soil drainage. Takes 100 years to form 30 cm of peat, but 10 yrs to oxidize due to excess drainage. • SOC pools may increase with stand age after reforestation. However, limited number of studies indicate soils previously under pasture may lose carbon. • Land use greatly affects soil C, with forests featuring higher soil C density.

[a] Estimated from forest cover of aspen-birch and softwoods in Alaska in Johnson and Kern (ch. 5).

[b] Estimated from soil carbon densities and areas of aspen-birch and softwoods in Alaska in Johnson and Kern (ch. 5).