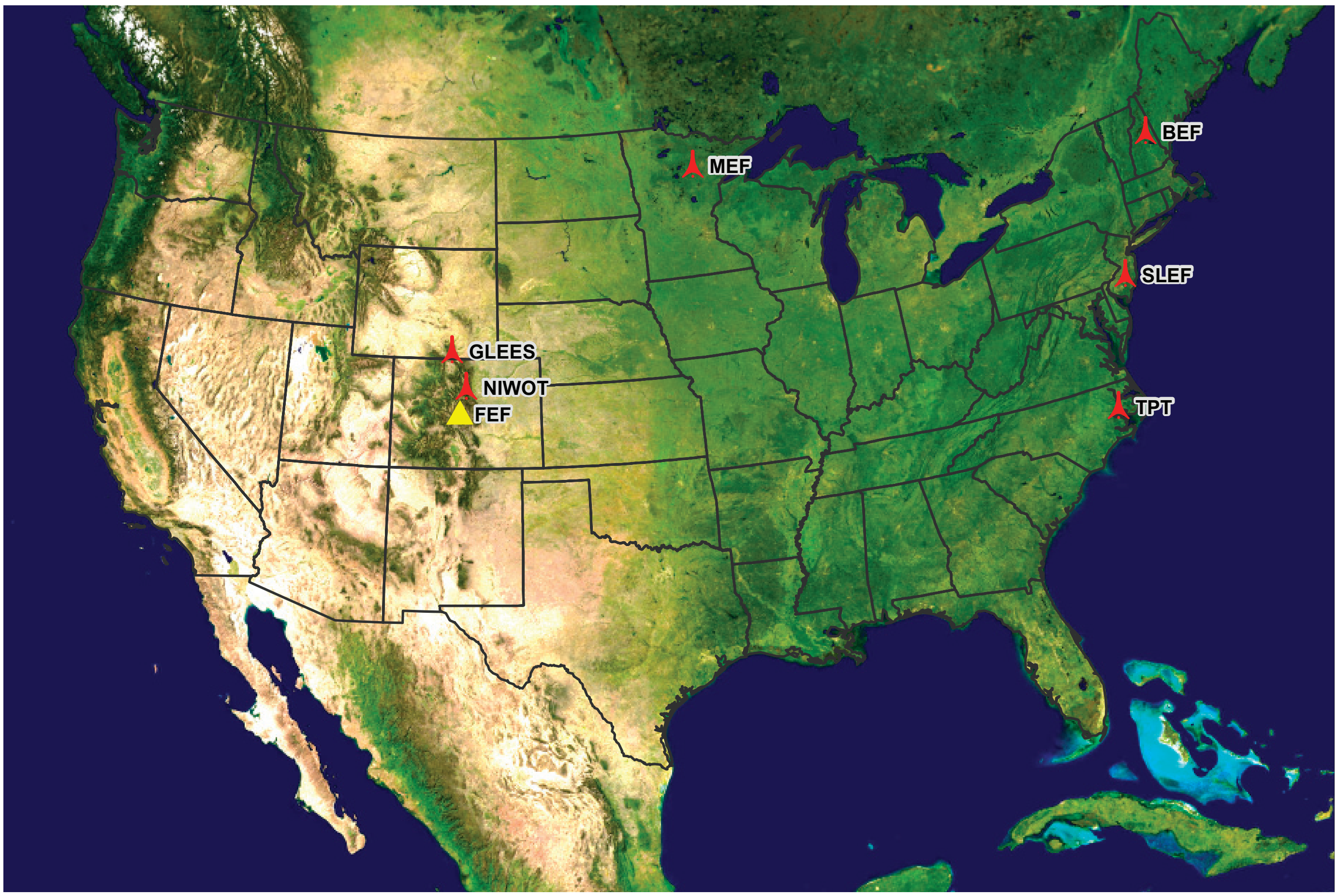
United States Department of Agriculture

Database for Landscape-Scale Carbon Monitoring Sites



Forest Service

Northern Research Station

General Technical Report NRS-119

September 2013

Abstract

This report describes the database used to compile, store, and manage intensive ground-based biometric data collected at research sites in Colorado, Minnesota, New Hampshire, New Jersey, North Carolina, and Wyoming, supporting research activities of the U.S. North American Carbon Program (NACP). This report also provides details of each site, the sampling design and collection standards for biometric measurements, the database design, data summary examples, and the uses of intensive ground-based biometric data. Additional information on location descriptions, data, databases, and documentation may be accessed at http://www.nrs.fs.fed.us/data/lcms.

Manuscript received for publication 22 January 2013

Published by:

U.S. FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073

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INTRODUCTION

This report describes the methodology used to collect, compile, and manage multi-tier land monitoring data at a network of long-term forest monitoring sites supporting the U.S. North American Carbon Program (NACP). The NACP is a multidisciplinary research program developed to obtain a scientific understanding of North America's carbon sources, sinks, and changes in carbon stocks needed to meet societal concerns. The program also aims to provide tools for decisionmakers. The two main goals of the NACP are to (1) develop the scientific basis in support of full carbon accounting on regional and continental scales; and (2) support long-term quantitative measurements of fluxes, sources, and sinks of atmospheric CO_2 and CH_4, and develop forecasts for future trends.

Managing forests to sustain or increase carbon stocks and to offset emissions requires knowledge of how management practices and natural disturbances affect carbon pools over time, and cost-effective techniques for monitoring and reporting. Accurate landscape-scale estimates and maps of carbon dynamics based on remote sensing, inventories, and intensive measurements are relevant to land managers and climate change policy because of the need to estimate and report carbon stocks and changes in carbon stocks to state, regional, national, international, and private greenhouse gas registries. Intensively monitored landscapes serve as "benchmarks" or "reference sites" to validate more spatially extensive observations from space, predictions from ecosystem models, and estimates compiled from national forest inventories. The data can be used to improve decision-support for carbon management by documenting the expected effects of management decisions on the most important carbon pools, and "factoring out" changes in carbon stocks that are not due to direct human influence, such as natural disturbances and climate variability.

A national network of landscape-scale monitoring sites should be representative of the diversity of forest conditions and geographic context. Networks such as AmeriFlux[1] have limited representation of mountainous terrain and highly disturbed landscapes and do not consistently represent land that is managed or disturbed, and locations where it is difficult to install and operate intensive monitoring equipment (mountains, wetlands, etc.). Extensive monitoring by the U.S. Forest Service Forest Inventory and Analysis (FIA) program is statistically representative of U.S forests but lacks detailed ecosystem measurements needed to investigate the complex dynamics associated with a diversity of forest carbon pools and fluxes (Birdsey 2004). A report on ecological indicators identified critical gaps in monitoring data which include forest carbon indicators (Heinz Center 2002). Indicators needing improved data availability included major components of forest carbon accounting: biomass, soils, forest floor and down woody debris, and wood products. Of these, only biomass on timberland was reported; the other components were judged by the Heinz Center to be deficient in data availability through ongoing monitoring programs. Although resource inventory programs, such as FIA's, continue to make progress for reporting carbon statistics in most circumstances (Woodall 2012), data gaps and technical advances are best addressed through intensive site research studies and related modeling efforts (e.g., Birdsey and Heath 1995, Heath et al. 2003).

Data reported here were collected at a network of landscape monitoring sites representing forests with different management, disturbance histories, and vegetation to bridge the gap between flux towers and national inventory programs. Key information for each site includes (1) estimates of carbon stocks and quantified impacts of management activity; (2) estimates of net ecosystem production (NEP) and changes in carbon pools; and (3) estimates of forest/atmosphere carbon fluxes. The database described in this report was developed to provide detailed, well-documented, and consistent information from a network of long-term observation sites in the United States. The design of the sampling protocol and database provide examples for applications in other regions.

[1]The AmeriFlux network provides continuous observations of ecosystem level exchanges of CO_2, water, and energy, spanning diurnal, synoptic, seasonal, and interannual time scales and is currently composed of sites from North America, Central America, and South America. For more information, see http://public.ornl.gov/ameriflux/

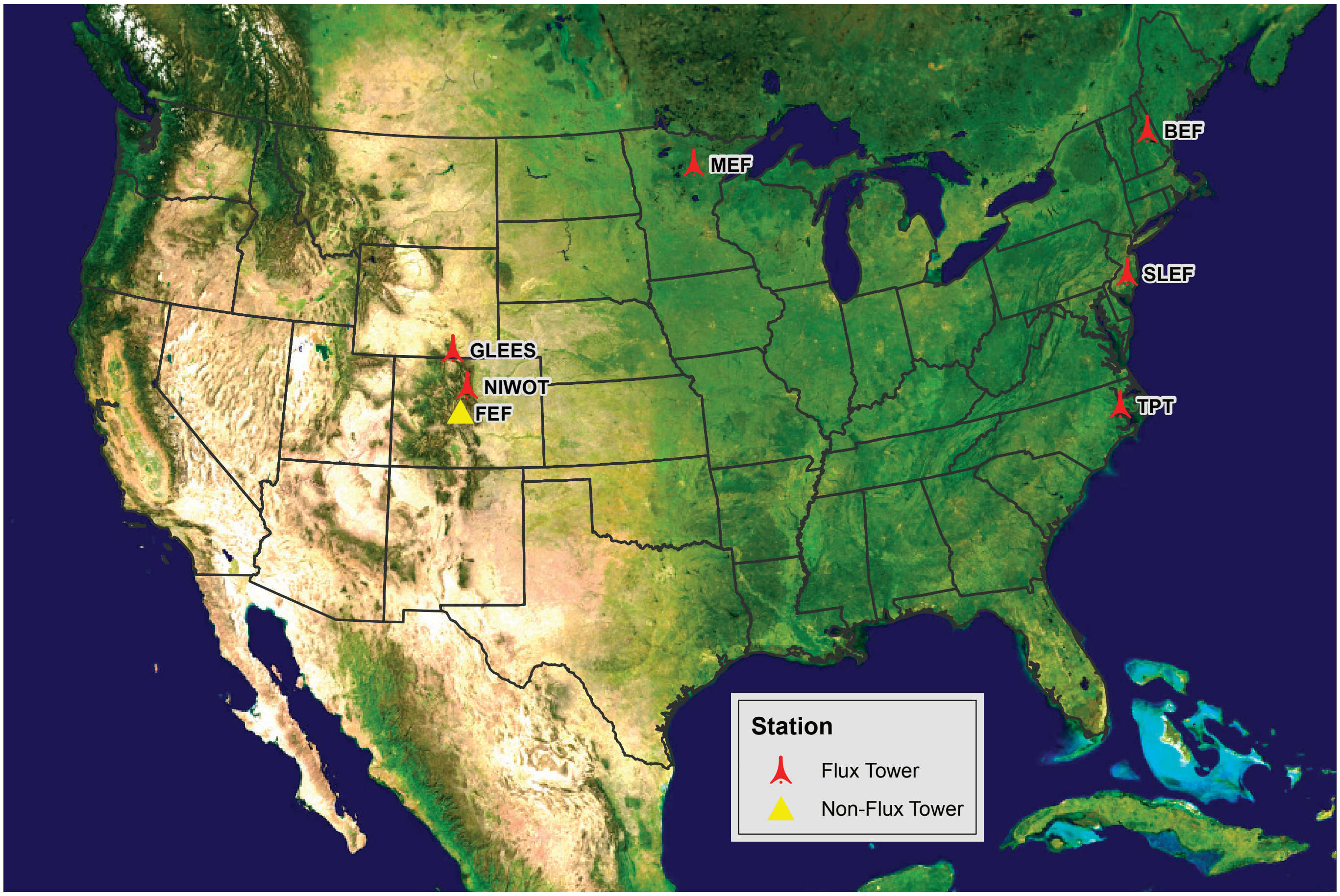

Figure 1—Carbon monitoring station locations overlaid on MODIS imagery. Two stations, TPT and SLEF include two and three intensively monitored sites, respectively. See Table 1 for explanation of station abbreviations.

STATION DESCRIPTIONS

The landscape-scale carbon monitoring project consists of 10 intensively monitored sites at seven locations or "stations" (Table 1), representing a variety of forest types scattered across the United States (Figure 1). All stations collect biometric, meteorological, and eddy flux measurements except for Fraser Experimental Forest, which collects only biometric and meteorological data. A brief description of each station is provided in this report; for a complete description of each station including available data, refer to the supplemental information available on the project Website.[2]

Bartlett Experimental Forest

Bartlett Experimental Forest (BEF) is located within the Saco Ranger District in the White Mountain National Forest of New Hampshire. The station consists of relatively even-age stands of red maple (*Acer rubrum*), paper birch (*Betula papyrifera*), aspen (*Populus* spp.), and American beech (*Fagus grandifolia*) that developed after logging in the late 19th century. Red spruce (*Picea rubens*) stands occur on the highest slopes with white pine (*Pinus strobus*) confined to the lower elevations. Summer high temperatures occasionally reach above 32 °C and winter temperatures as low as -35 °C with a mean annual precipitation of 1,270 mm. A hurricane caused widespread damage in 1938 and an ice storm in 1998 was the most recent widespread natural disturbance affecting mostly higher elevation stands and paper birch at lower elevations.

BEF has one intensively monitored site:

- BEF NACP Tier III (NACP)

[2] http://www.nrs.fs.fed.us/data/lcms

Table 1.—The landscape-scale carbon monitoring station and site codes with location

Station code	Station	Site code	Site	State	Location
BEF	Bartlett Experimental Forest	NACP	BEF NACP Tier III	New Hampshire	White Mountain National Forest
FEF	Fraser Experimental Forest	FC	Fool Creek	Colorado	Arapaho/Roosevelt National Forest
GLEES	Glacier Lakes Ecosystem Experiments Site	BL	Brooklyn Lake	Wyoming	Medicine Bow Mountain Range
MEF	Marcell Experimental Forest	MEF	Marcell Experimental Forest	Minnesota	Chippewa National Forest
NIWOT	Niwot Ridge Long-term Ecological Reseach Site	NRAT	Niwot Ridge Ameriflux Tower	Colorado	Front Range of the Rocky Mountains
SLEF	Silas Little Experimental Forest	CB	Cedar Bridge	New Jersey	Pinelands National Reserve
		FD	Fort Dix		
		SL	Silas Little		
TPT	The Parker Tract	NCCC	North Carolina Clearcut	North Carolina	Plymouth
		NCLP	North Carolina Loblolly		

Fraser Experimental Forest

Fraser Experimental Forest (FEF) is located in the near Fraser, CO, in the Arapaho/Roosevelt National Forest of the southern Rocky Mountains. The vegetation is characteristic of subalpine forests and subalpine wetlands where the dominant tree species are subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) in higher elevations and lodgepole pine (*Pinus contorta*) in lower elevations. The mean annual temperature and precipitation are 0 °C and 737 mm respectively, with about two-thirds of the precipitation falling as snow. In the 1950s, half of the timber in the Fool Creek watershed in FEF was harvested as part of an experiment to examine the effects of timber removal on water yield. The harvest was executed in alternating strips of cut and unharvested forest, ranging from 20 to 110 m wide. Recently, widespread overstory tree mortality has been caused by the mountain pine beetle (*Dendroctonus ponderosae*).

FEF has one intensively monitored site:

- Fool Creek (FC)

Glacier Lakes Ecosystem Experiments Site

Glacier Lakes Ecosystem Experiments Site (GLEES) station is located in the Snowy Range of the Medicine Bow Mountain Range of the Rocky Mountains in Wyoming. The vegetation is characteristic of subalpine forests and subalpine wetlands where the dominant tree species are subalpine fir and Engelmann spruce; many trees are more than 400 years old. The mean annual temperature and precipitation are -2 °C and 1,000 mm, respectively, and most of the precipitation falls as snow. Recent, widespread overstory mortality has been caused by the spruce beetle (*Dendroctonus rufipennis*) and the western balsam bark beetle (*Dryocoetes confusus*).

GLEES has one intensively monitored site:

- Brooklyn Lake (BL)

Marcell Experimental Forest (MEF)

Marcell Experimental Forest (MEF) is located in the Chippewa National Forest in Minnesota. The vegetation includes mainly aspen (*Populus* spp.), birch (*Betula* spp.), and other northern hardwoods on upland sandy loam till soils; red and jack pine (*Pinus resinosa, P. banksiana*) in fire origin stands or plantations; mixed stands of aspen, white birch (*Betula papyrifera*), balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*) on upland sandy outwash soils; and black spruce (*Picea mariana*) and tamarack (*Larix laricina*) in forested peatlands. The mean annual temperature and precipitation are -3.4 °C and 771 mm, respectively, with most precipitation falling in the snow-free period.

MEF has one intensively monitored site:

- Marcel Experimental Forest (MEF)

Niwot Ridge Long-term Ecological Research Site

Niwot Ridge Long-term Ecological Research Site (NIWOT) station is located in the Front Range of the Rocky Mountains in Colorado. The vegetation is characteristic of subalpine forests where the dominant tree species are subalpine fir and Engelmann spruce in higher elevations; and lodgepole pine in lower elevations. The mean annual temperature and precipitation are 1.5 °C and 800 mm, respectively; most of the precipitation falls as snow. NIWOT was clearcut between 1900 and 1910, and evidence suggests that the forest was about 200 years old at the time.

NIWOT has one intensively monitored site:

- Niwot Ridge Ameriflux Tower (NRAT)

Silas Little Experimental Forest

Silas Little Experimental Forest (SLEF) is located in the northern section of the New Jersey Pinelands National Reserve of New Jersey. The vegetation consists of oaks (*Quercus* spp.), shortleaf pine (*Pinus echinata*), and pitch pine (*Pinus rigida*) on upland sandy soils (52 percent of the area); pitch pine and low-grade oaks on upland highly infertile sands (22 percent of the area); pitch pine and mixed hardwood swamp forests on lowland poorly drained soils (14 percent of the area); and mixed hardwood swamp forests (12 percent of the area). July is the warmest month with temperatures ~25 °C and February is the coldest month with temperatures around -1 °C. The mean annual precipitation is ~1,140 mm, with reduced rainfall in the spring and fall.

SLEF includes three intensively monitored sites:

- Silas Little (SL) oak/pine forest
- Fort Dix (FD) pine/oak forest
- Cedar Bridge (CB) pine/scrub oak forest

These sites are within 13 km of each other. Prescribed burning is used regularly in the Pinelands to reduce fuel loads and to restore native vegetation. Recent disturbances include occasional wildfires (1946, 1963, 1995), wind damage (especially 1991), and a number of significant gypsy moth defoliation events, with the most recent occurring from 2006-2008.

The Parker Tract

The Parker Tract (TPT) is located in the lower coastal plain near Plymouth, NC. The region is considered a maritime temperate climate zone with mean annual temperature and precipitation of 15.5 °C and 1,320 mm, respectively. TPT is an intensively managed loblolly pine (*Pinus taeda*) plantation.

TPT includes two intensively monitored sites:

- North Carolina Loblolly Pine (NCLP).
- North Carolina Clearcut (NCCC) - approximately 4 km from NCLP.

The sites are intensively managed wetland plantations ditched and bedded to improve seedling survival and growth rates. A typical silvicultural management practice includes site preparation, planting of loblolly pine seedlings, fertilization, thinning, and clearcut harvest 27 to 35 years after planting. The NCLP site was planted in 1992 and thinned in 2009 to remove approximately 50 to 60 percent of the pine biomass. Loblolly pine seedlings were planted at the NCCC site in 2005 after clearcutting a mixed pine hardwood site.

Sampling Design and Data Collection Standards

The NACP approach to biophysical measurements involves hierarchical, multi-tier monitoring that integrates current, extensive inventory and monitoring programs (such as FIA) with intensive monitoring and process studies at long-term research sites. The intermediate monitoring tier at the landscape scale is designed to link extensive monitoring with intensive monitoring using medium-intensity biometric measurements from a few selected sites such as Long-term Ecological Research sites, AmeriFlux sites, and U.S. Forest Service network of Experimental Forests. These measurements represent the land conditions selected by investigators to answer specific research questions and include clusters of measurement sites that represent a range of conditions over selected land areas. One goal of landscape monitoring is to include sites that are managed or disturbed by natural events, representing different stages of succession following disturbance.

Table 2.—Selected land measurement variables and scale of measurement

Example variable	Extensive monitoring	Landscape monitoring	Intensive monitoring
Land cover	X	X	X
Leaf area	X	X	X
Disturbance	X	X	X
Live biomass	X	X	X
C in soil, litter, and coarse woody debris		X	X
Litterfall		X	X
Soil CO_2 flux		X	X
Methane flux		X	X
Dissolved organic C		X	X
Net ecosystem exchange of CO_2			X

Workshops in summer 2003[3] identified both a desired list of variables and a sampling design, and started the process of developing a field manual (Hoover 2008). A summary list of variables is shown in Table 2. Similar to intensive monitoring, important variables that define the ecosystem "state"—vegetation type, foliage nitrogen concentration, and the ratio of soil carbon to nitrogen—are measured along with automated measurements of key "driving variables" such as light, temperature, and precipitation that control the rate of ecosystem carbon uptake and loss. These state and driving variables are measured at different vegetation conditions within landscapes, allowing estimates of net primary production (NPP) and net ecosystem production (NEP) to be derived as closely as possible from field measurements. The variables are supplemented by statistical models of ecosystem carbon components, such as biomass equations, that are parameterized for each landscape monitoring location.

Figure 2 illustrates the idealized sampling scheme for landscape monitoring sites. At the center is either a flux tower or other intensive ecosystem monitoring system if a flux tower is not available. Sample locations are arrayed in a 1 km^2 by 1 km^2 grid surrounding the flux tower, an area that approximates the source area, or footprint, of air moving past the flux tower. The FIA protocol for regional sampling is the basis for vegetation measurements, with the supplemental ecosystem carbon measurements applied to these sample locations. By using the FIA standard protocol for regional inventories (U.S. Forest Service 2002), estimates from landscape-scale monitoring can be related to commonly measured variables and extrapolated to similar sites over a larger area using geostatistical techniques.

Field methods and techniques employed in landscape-scale forest carbon monitoring are described in Hoover (2008). This handbook provides detailed descriptions

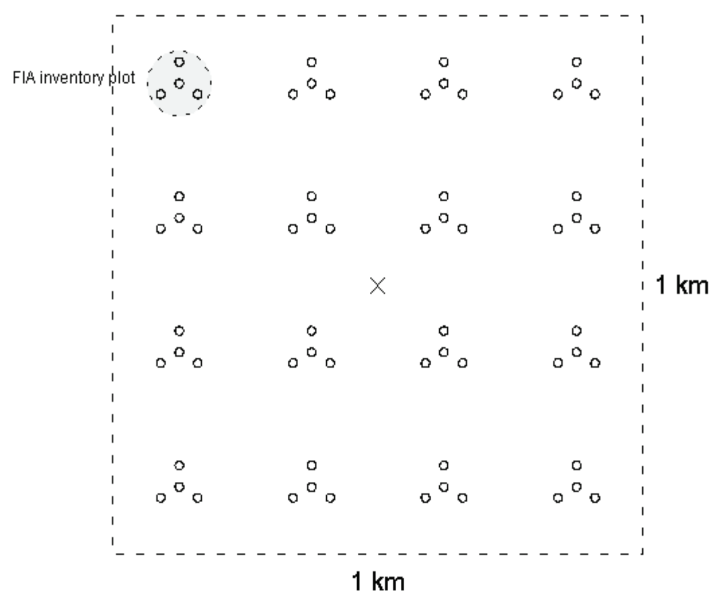

Figure 2—A landscape-scale sampling design using 16 FIA inventory plots. The exact number and configuration of sample plot locations were determined by variability of the landscape and number of sampling strata. The X at the center represents a flux or meteorological tower.

[3] Portsmouth, NH: more than 40 scientists representing government agencies, academia, and nonprofit research organizations from Canada, United States, and Mexico.

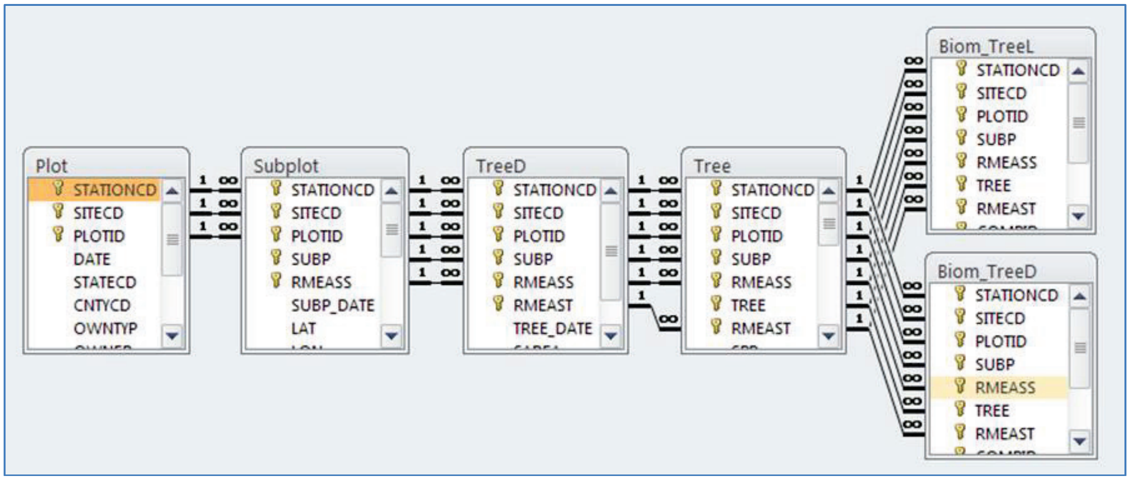

Figure 3—Relationship diagram illustrating the one-to-many relationships for plot, subplot, tree, and tree biomass tables.

of the measurements needed to characterize the standing stocks of carbon in a forest, assess key fluxes in forest carbon, and collect related data such as forest canopy nitrogen concentrations and meteorological measurements that are often needed to drive process models, develop predictive relationships, and link to remote sensing data. It is intended that the established sampling locations be remeasured at appropriate intervals to estimate changes in carbon stocks of different ecosystem components, which can be aggregated to periodically estimate productivity and forest-atmosphere carbon fluxes.

Database Description

The biometric database (Cole et al. 2013) for the landscape-scale carbon monitoring sites is a relational database initially implemented in Microsoft Access 2007®. The database includes measured and estimated data with a series of lookup tables (LUT) to describe the data. The database is designed to house data from multiple providers where the variables, collection methods, and calculations vary. Storing data from multiple providers with varying collection and processing methods necessitated the incorporation of documentation in the database that directly ties the documentation to the variable it describes. This allows direct access to the exact methods used at each site and allows common collection methods and processes to be grouped for viewing or further processing. The LUT provide transparency, documenting every process and/or procedure, making them repeatable.

To reduce redundancy, data were broken out into subject-based tables. The base tables hold information repeated in all records in the corresponding tables. For example, the plot table (*Plot*) describes general information about the plot (e.g., state, county, ownership, etc.), the subplot table (Subplot) is a series of subsamples on the plot (e.g. ,slope, aspect, area, etc.), the tree date table (*TreeD*) defines the date and area of trees sampled on the subplot, the tree table (*Tree*) includes individual tree attributes (e.g., status, crown class, dbh, height, etc.), and biomass tables (*Biom_TreeL* and *Biom_TreeD*) contain tree live and dead component biomass, respectively, as shown in Figure 3.

Table relationships were established for all tables within the database. Table relationships require that the corresponding LUT are populated before data can be entered into a data table, forcing the documentation to be created before data can be entered. The same applies to data tables—data in a base table must be entered before data can be entered into subsequent dependent tables.

The biometric data are stored in multiple tables within the database. The tables are based on core variables, collection interval, and data type. This was done to limit null values and information repetition, which can lead to confusion and problems during analysis. The tables were separated by collection interval or collection period, as some variables may be collected more frequently than others (e.g., plot and subplot information may be collected every 15 years while tree data may be collected every 5 years) or collected during different site visits (e.g., tree data was collected during a separate a visit from soils data). The data were further broken down by data type, as the data collection and methods for determining biomass may vary between variable type.

Some data may be missing from the biometric database. Missing data appear in two forms: data fields with null values, or an entire sites' data missing from a table. Columns with null data values are due to the lack of data collection, either by the variables missed in the field or the variable not being collected by the site. Tables missing an entire sites' data are due to the sites not collecting any of the table's variables. Missing data from estimated variable tables, where the necessary field data has been collected, are due to the lack of an acceptable estimating methodology. These variables may be estimated later when the required procedures are available.

The biometric database includes both measured and estimated data. Measured data include general descriptive information and detailed measurements. General descriptive information defines the sample area at the station, site, plot, and subplot level. Detailed measurements include tree, shrub, nonwoody vegetation, down woody material, stump, litter, forest floor, agricultural crop, leaf area index, fine root, and soils. Tree data were separated into three size classes: seedling, sapling, and tree. Soil data include chemistry, characteristics, respiration, water content, and capacity.

Biomass is estimated by component for individual subjects including trees by size class, shrubs, down woody material, and stumps. Components are the subject's section of interest (e.g., stem, branch, foliage, roots, etc.). Aboveground component biomass estimates are summarized by subject type to the subplot, plot, and site level in a separate summary database.

For a copy of the data including a detailed user's guide describing the data, refer to Cole et al. (2013) or the project Website.[2]

Summary Data and Biomass Maps for Each Site

Comparing the intensely monitored area at each site, the Rocky Mountain sites (BL, FC, and NRAT) generally had higher total aboveground carbon than eastern sites, mostly due to higher biomass in both the live and dead tree pools (Figure 4). The exception was NACP, which had the highest live tree and live sapling carbon of all the sites. Substantial amounts of carbon were stored in the dead pools at the western sites, in contrast to most eastern sites. For example, FC had about 31 percent of its carbon in dead pools while FD only had about 5 percent. Additionally, 55 percent of the carbon at NCCC was in the coarse woody debris pool, with the rest being roughly split into the live sapling and shrub pools, due to recent clearcutting.

LiDAR-based aboveground live carbon maps show the spatial distribution of the tree biomass carbon pool (Figures 5 and 6) (methods described in Sherrill et al. 2008, Skowronski 2011) and are compared with Jenkins et al. (2004) live tree biomass estimates (Table 3). An incomplete sampling of the BL site resulted in a bias toward forested conditions within the intensely

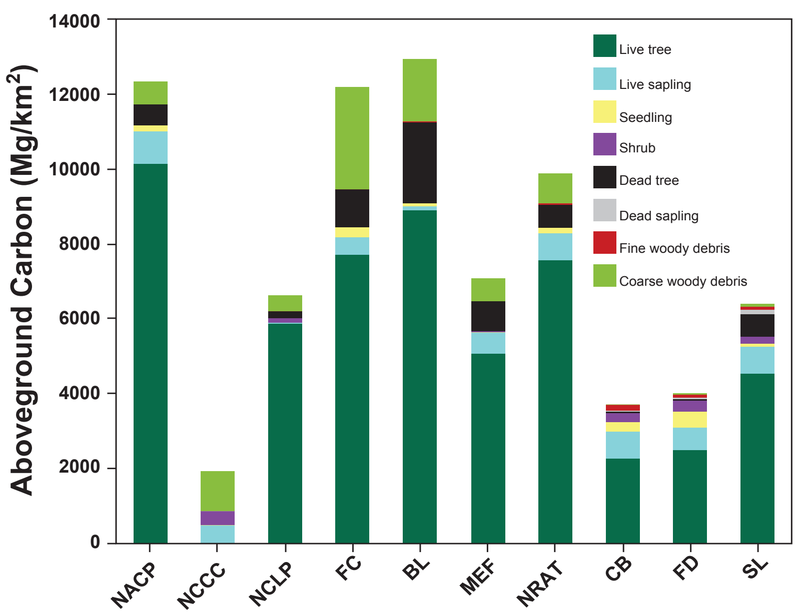

Figure 4.—Total aboveground carbon and proportions of available carbon pools (megagrams/km^2) for all 10 of the intensely monitored areas. The BL estimate was multiplied by 0.8 to adjust for under representation of nonforest area in the field data.

monitored area. Thus, to compare with the other sites, a factor of 0.8 was applied (Figure 4 and Table 3). This reflected the percentage of plots from the uniform grid in Figure 2 identified as having trees determined from photo imagery.

CONCLUSION

Better understanding and monitoring of forests and the global carbon cycle are required to develop climate change mitigation strategies, including improved forest management and reduced impacts of tropical deforestation. Pan et al. (2011) compiled worldwide forest inventory data and concluded that improving sampling of soil, litter, and dead wood was critical to resolving data gaps in many parts of the world. National forest inventories, such as FIA's, conduct frequent and extensive sampling of biomass, data for the other carbon pools comes from sites such as those described in this report. The literature is full of reports from such sites, however sampling may not be done on a frequent or recurring basis. The methods used are inconsistent and often poorly documented, which sometimes hinders effective site comparison or aggregation of data. Moreover, the data are often not easily accessible except in summary form in scientific or technical publications.

Data about carbon stocks and fluxes from intensive monitoring sites are used for many purposes. The main products of this research include precise statistical estimates and maps of carbon stocks and productivity for a variety of forest landscape conditions. Data may be used to improve ecosystem process models at ecoregion and stand scales; to validate estimates from remote-sensing driven models; and for decision-support tools for land managers interested in carbon management. As such, the data are integral to establishing monitoring, reporting, and verification (MRV) systems for reporting the effects of land management and other disturbances on carbon stocks. The MRV systems are emerging as greenhouse gas markets and registries are becoming more common, raising the need for consistent estimation of the quantity of carbon sequestered and emissions reduced by different forestry activities, as these estimates will be used

Table 3.—Live tree carbon estimates (megagrams/km^2) for all 10 intensely monitored areas from field data using Jenkins et al. (2004) biomass equations compared with LiDAR derived estimates (methods described in Sherrill et al. 2008, Skowronski 2011).

Site	Number of Plots	Live tree	LiDAR
		---------*Mg C/km^2*---------	
NACP	12	10,141	9,332
NCCC	12	0	N.d.
NCLP	13	5,877	N.d.
FC	9	7,728	8,633
BL[a]	9	8,887	9,452
MEF	16	5,055	5,553
NRAT	9	7,584	5,892
CB	12	2,276	1,712
FD	12	2,499	2,454
SL	16	4,534	4,263

[a] BL estimate was multiplied by 0.8 to adjust for underrepresentation of nonforest area in field data. N.d. = no data.

to determine the value of the credits. The accounting rules and guidelines must be based on solid scientific and technical work to be credible, and must not impose an excessive burden on voluntary reporters. Enhancing observations at experimental forests have additional benefits such as facilitating use of these sites for carbon management research and demonstration projects, and providing the basis for an "early warning" capability to detect the initial impacts of climate change.

The data and examples described in this report and in the online database represent only part of the data available for each site. At most of the sites, sample plots have been measured more than once, allowing users to estimate rates of tree growth and mortality, changes in many of the ecosystems carbon pools, and factors that cause observed changes. Data from each site as well as the data and site descriptions will be updated periodically.

ACKNOWLEDGMENTS

The research was supported in part by a grant from the National Aeronautical and Space Agency (NNH08AH971).

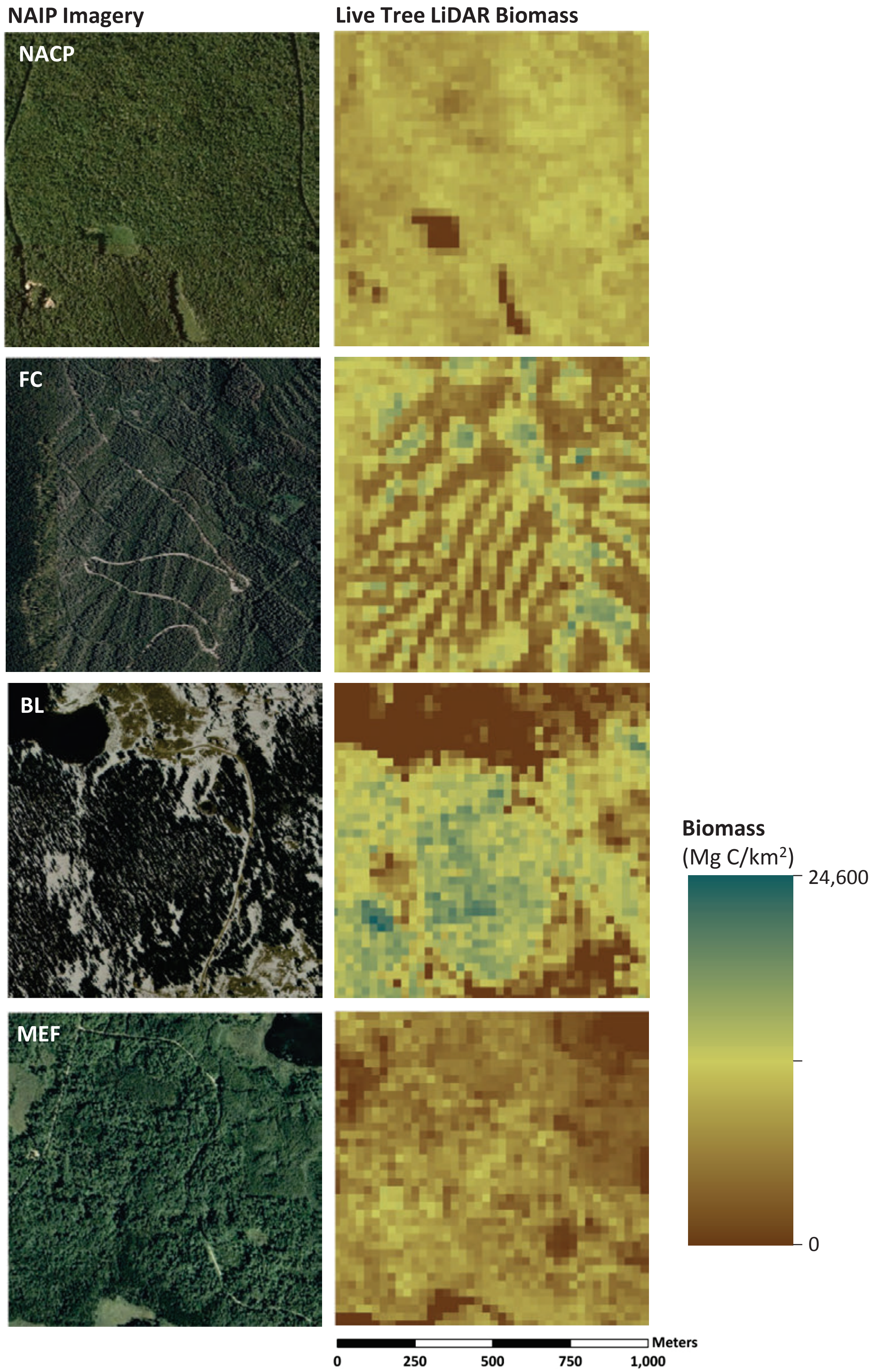

Figure 5.—National Agriculture Imagery Program (NAIP) 2008 imagery on left with corresponding LiDAR derived biomass map (megagrams carbon/km^2) (methods described in Sherrill et al. 2008) on right for the intensely monitored area at sites: NACP, FC, BL and MEF.

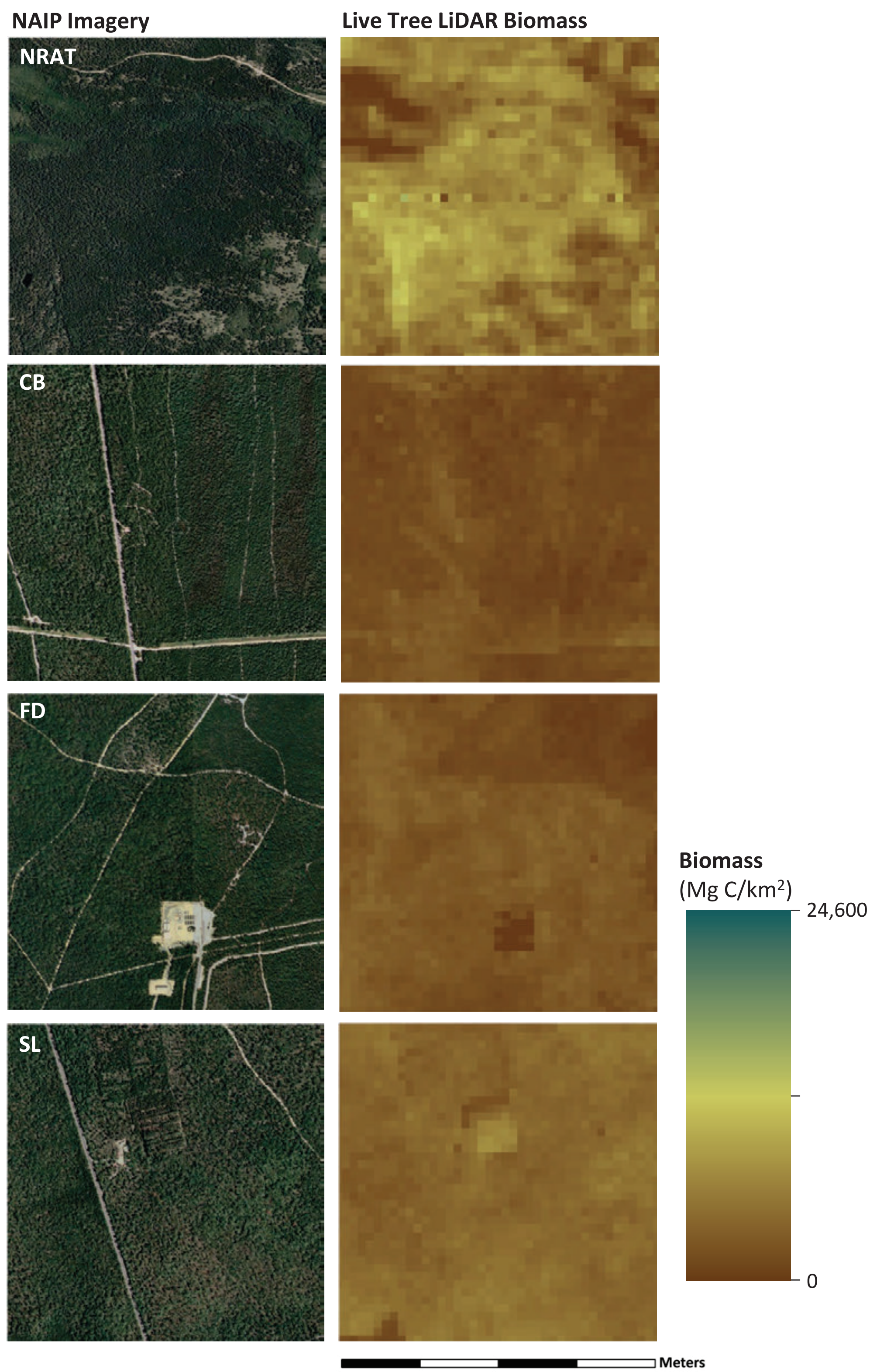

Figure 6.—National Agriculture Imagery Program (NAIP) 2008 imagery on left with corresponding LiDAR derived biomass map (megagrams carbon/km^2) (methods described in Sherrill et al. 2008, Skowronski 2011) on right for the intensely monitored area at sites: NRAT, CB, FD and SL.

LITERATURE CITED

Birdsey, R.A. 2004. **Data gaps for monitoring forest carbon in the United States: an inventory perspective.** In: Mickler, R.A., ed. Environmental Management. 33(Supplement 1): S1-S8.

Birdsey, R.A.; Heath, L.S. 1995. **Carbon changes in U.S. forests.** In: Joyce L.A., ed. Productivity of America's forests and climate change. Gen. Tech. Rep. RM-271. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service: 56-70.

Cole, J.; Johnson, K.; Birdsey, R.A.; Pan, Y.; Wayson, C.; McCullough, K.; Hoover, C.; Hollinger, D.; Bradford, J.; Ryan, M.; Kolka, R.; Weishampel, P.; Clark, K.; Skowronski, N.; Hom, J.; Ollinger, S.; McNulty, S.; Gavazzi, M. 2013. **North American Carbon Program biometric database.** Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://dx.doi.org/10.2737/RDS-2013-0008.

Heath, L.S.; Smith, J.E.; Birdsey, R.A. 2003. **Carbon trends in U.S. forestlands: a context for the role of soils in forest carbon sequestration.** In: Kimble, J.; Heath, L.S.; Birdsey, R.A.; Lal, R. The potential of U.S. forest soil to sequester carbon and mitigate the greenhouse effect. Boca Raton, FL: CRC Press: 35-46 p.

Heinz Center. 2002. **The state of the Nation's ecosystems.** New York, NY: Cambridge University Press. 270 p.

Hoover, C.M., ed. 2008. **Field measurements for forest carbon monitoring: A landscape-scale approach.** New York, NY: Springer. 242 p.

Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. 2004. **Comprehensive database of diameter-based biomass regressions for Northern American tree species.** Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p.

U.S. Forest Service. 2002. **Forest Inventory and Analysis national core field guide, volume I: field data collection procedures for phase 3 plots, version 1.6.** Washginton, DC: U.S. Department of Agriculture, Forest Service. Available at http://www.fs.fed.us/ne/fia/datacollection/manualver1_6/index.html (Accessed April 2012).

Pan, Y.; Birdsey, R.A.; Fang, J.; Houghton, R.; Kauppi, P.E.; Kurz, W.A.; Phillips, O.L.; Shvidenko, A.; Lewis, S.L. 2011. **A large and persistent carbon sink in the world's forests.** Science. 333(6045): 988-993.

Sherrill, K.R.; Lefsky, M.A.; Bradford, J.B.; Ryan, M.G. 2008. **Forest structure estimation and pattern exploration from discrete-return lidar in subalpine forests of the central Rockies.** Canadian Journal of Forest Research. 38: 1-16.

Skowronski, N.S. 2011. **Quantifying three-dimensional vegetation structure and its responses to disturbances using laser altimetry in the New Jersey Pinelands.** New Brunswick, NJ: Rutgers University. 303 p. Ph.D. dissertation.

Woodall, C.W. 2012. **Where did the US forest biomass/carbon go?** Journal of Forestry. 110(2): 113-114.

Cole, Jason A.; Johnson, Kristopher D.; Birdsey, Richard A.; Pan, Yude; Wayson, Craig A.; McCullough, Kevin; Hoover, Coeli M.; Hollinger, David Y.; Bradford, John B.; Ryan, Michael G.; Kolka, Randall K.; Wieshampel, Peter; Clark, Kenneth L.; Skowronski, Nicholas S.; Hom, John; Ollinger, Scott V.; McNulty, Steven G.; Gavazzi, Michael J. 2013. **Database for landscape-scale carbon monitoring sites.** Gen. Tech. Rep. NRS-119. Newtown square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 12 p.

This report describes the database used to compile, store, and manage intensive ground-based biometric data collected at research sites in Colorado, Minnesota, New Hampshire, New Jersey, North Carolina, and Wyoming, supporting research activities of the U.S. North American Carbon Program (NACP). This report also provides details of each site, the sampling design and collection standards for biometric measurements, the database design, data summary examples, and the uses of intensive ground-based biometric data. Additional information on location descriptions, data, databases, and documentation may be accessed at http://www.nrs.fs.fed.us/data/lcms.

KEY WORDS: database, biometric data, inventory data, biomass, landscape-scale, carbon stocks

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