Using FIA data to inform United States forest carbon national-level accounting needs:1990-2010

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Introduction

Forests are partially made up of carbon. Live vegetation, dead wood, forest floor, and soil all contain carbon. Through the process of photosynthesis, trees reduce carbon dioxide to carbohydrates and store the carbon in wood. By removing carbon dioxide from the atmosphere, forests mitigate climate change that may be brought on by increased atmospheric CO_2. However, the specific role of forests in climate mitigation continues to be debated. Several decades ago, the debate was whether forest carbon could be measured accurately enough to include it in national inventories related to greenhouse gases (GHGs), especially carbon dioxide (CO_2). Today, this debate has expanded to include all lands, including non-forest land. It includes the specifics of how to best design and conduct land-based inventories for greenhouse gases, as well as how to design carbon markets or set policies to best manage land, especially forestland, to mitigate climate change.

For the last several decades, forest carbon estimates for reporting and planning in the U.S. have often been based on data collected by the USDA Forest Service, Forest Inventory and Analysis (FIA) Program. Smith et al. (2004a) is an introductory publication describing methods to derive forest carbon estimates. Carbon estimates can be reported in terms of carbon dioxide using the elemental weights and proportions of the carbon and oxygen atoms in carbon dioxide compared to carbon. That is, multiplying carbon mass by 44/12 gives the corresponding mass in terms of carbon dioxide. In this paper, I discuss the evolving use of FIA data as a basis for forest carbon estimates for broad-scale, policy-related needs from the 1990's to 2010. I briefly discuss the FIA survey and the improving availability of data, explain indirect and direct methods that were used to calculate carbon stock and change estimates from FIA data, and present examples of policy-relevant reports that use FIA-based estimates and web tools that can provide customized estimates to users.

A brief description of FIA survey

The USDA Forest Service began conducting forest surveys in response to the McSweeney-McNary Act of 1928, but it was not until the 1990's that plot-level data became publicly available for much of the forested areas of the United States. State-level statistics were available periodically in reports starting in the early 1950's, with plot-level datasets becoming internally available associated with the statistics in Waddell et al. (1989). After aerial photography became available, forest surveys consisted of two phases: phase one – using aerial-derived informa-

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tion to increase precision, and phase two – taking measurements on plots in the field. From the 1950's through the end of the 1990's, FIA periodically moved into a state, conducted the survey and then moved into other states, to return 5-10 years later to each state for another survey (LaBau et al. 2007). These were the type of surveys used for the earlier state-level reports, and which were eventually made available internally as plot-level only datasets. Some of the periodic surveys also had individual tree datasets (for example, Woudenberg and Farrenkopf 1995) made available to the public.

An annualized survey, with a core national plot design (Bechtold and Patterson 2005) was implemented in most states in the 2000's, meaning that a subset of plots are measured each year in each state with all plots in a state measured after about 5 years in the eastern U.S., and after 10 years in the western United States. Comparing results from the annualized survey to those of the periodic survey means that some apparent differences between surveys will be caused by changing the design, rather than from real forest change. Carbon has also been measured more intensely on a subset of the field plots called the phase 3 Forest Health Monitoring plots. Forest floor carbon and soil organic carbon are sampled (although the organic soils order of Histosols is not sampled), and down woody material is measured; these measurements can be expressed in units of carbon. Because these carbon data have only recently been released in the public FIA database (Woodall et al. 2010), they have not been consistently utilized in calculating carbon estimates described here.

Calculating carbon estimates and projections based on FIA data

In the early 1990's, Birdsey (1992) published carbon storage and accumulation estimates in U.S. forest ecosystems based directly on FIA data associated with year 1987. The results featured four ecosystem components: trees, understory, forest floor, and soil. Regional or state-level tree biomass and area statistics were converted to carbon using various factors; basic models were used to estimate other

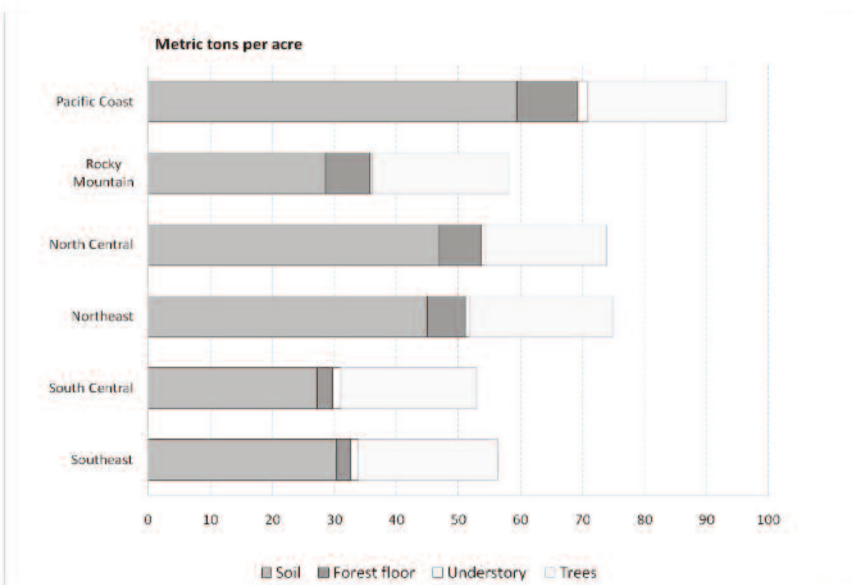


Figure 1. Estimates of average carbon storage in U.S. forest ecosystems by ecosystem component and region for report year 1987 (Source: Birdsey 1992).

Examples to convert wood statistics to units of carbon:

Wood may be reported as mass, in terms of tons of green or dry weight, or in volumetric units, such as cubic feet or cords. The carbon in bark differs from the amount in wood so how bark is to be handled must also be considered. Some simple examples follow.

RULE OF THUMB: Green weight wood is about 1/2 water, and about 1/2 of dry weight wood is carbon. Thus: 1 ton green wgt. x 0.5 = 0.5 tons dry weight wood; 0.5 tons dry weight wood x 0.5 carbon/dry mass = 0.25 tons carbon. One ton wood (green wgt.) is about a quarter ton of carbon.

If the wood is northern red oak, in terms of green weight, it is 45% water (Miles and Smith 2009), and eastern hardwoods are on average 49.8% carbon (Birdsey 1992). One green weight ton of northern red oak wood (assuming no bark) is 1 ton times 55% which is 0.55 tons wood dry weight. Multiplying by 0.498 carbon/mass results in 1 ton green weight wood equal to 0.274 tons carbon. To convert this to CO_2 units, multiply by 44/12 which equals 0.274 x (44/12) = 1.00 tons CO_2.

1000 cu ft northern red oak (green volume) x 34.9 lbs dry mass/cu ft (green vol.; Miles and Smith 2009) = 17.45 tons mass x 0.498 carbon/mass = 8.69 tons carbon.

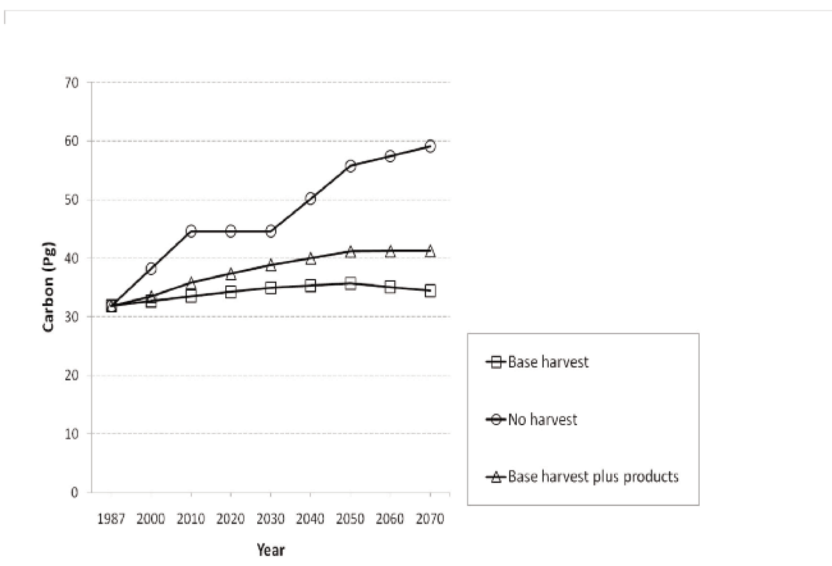


Figure 2. Projected forest carbon (Pg) in timberlands in the U.S. for two scenarios, including carbon in products in use from the base scenario harvests (Based on estimates from Heath and Birdsey 1993).

components. Figure 1 is an example of the results reported in Birdsey (1992). Partially due to the coarse spatial resolution of the information, the two southern regions and two northern regions are quite similar on a per area basis. The tree carbon per area is very similar for all regions, with almost all of the difference between regions due to soil carbon differences.

A model, called FORCARB, was developed by Plantinga and Birdsey (1993) at about the same time to provide decadal forest carbon projections through the year 2040. The model was developed as an extension of the Forest Service's national-level timber assessment models. The projection system was built in response to the Forest and Rangeland Renewable Resources Planning Act (RPA), which required new sets of long-term (50-year) resource projections every decade, with updates every 5 years. FIA data were used to provide the historical basis for trends in forestland area, volumes, growth, removals, and mortality (for example, see Smith et al. 2009).

The TAMM/ATLAS modeling system was developed to project these historical and current inventory data into the future. ATLAS is a timber inventory model (basically a timber accounting model) that simulated growth and yield, and harvested inventories based on forest types, regions, and owners, in U.S. forests. Growth was based on FIA data as was the initial inventory, whereas harvest projections were calculated based on economic supply and demand relationships in tandem with the Timber Assessment Market Model (TAMM). FIA data from utilization and timber product output studies also contributed to projecting harvest. The FORCARB model was linked to the ATLAS model, taking tree volume output from the model and converting it to carbon, but also adding in functions that project carbon in dead wood, forest floor carbon, and soil. FORCARB included a wood products module that estimated the carbon in wood products in use and landfills, as illustrated in Heath et al. (1996). Heath and Birdsey (1993) used the FORCARB model to study the carbon benefits from a theoretical scenario of stopping all regeneration harvests in U.S. forests, by comparing the output to

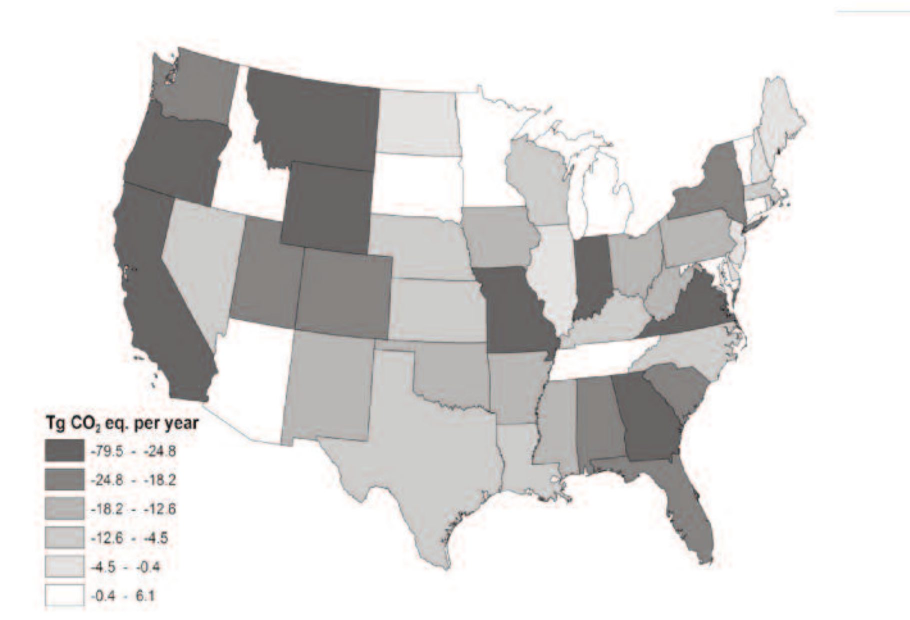


Figure 3. Net carbon stock change (in terms of Tg CO2 per year) for forestland in the U.S. for the year 2005 (Source: Smith and Heath 2008). Note negative values indicate carbon sequestration into forests. Forest change estimates from older reports are likely opposite in sign: negative values may indicate carbon loss.

a business as usual, RPA scenario (for example, see Haynes et al. 2003). Carbon in products in use were added to the base harvest projections to examine how the results from the no harvest scenario, and carbon in harvested forests and products compared. Birdsey and Heath (1995) show another example. Results of the projections are shown in Figure 2. This model was updated and renamed FORCARB2 (Heath et al. 2010). FORCARB2 was modified as described by Chen et al. (2010) and used to produce forest carbon estimates for the Province of Ontario, Canada.

As improved computer technology became available, FIA plot-level datasets became accessible internally to the Forest Service (datasets corresponding to statistics in Waddell et al. (1989) and Powell et al. (1993)). Forest carbon could then be calculated at the plot-level, and aggregated to the state-level, which results in more accurate estimates rather than aggregating plot-level biomass and areas to the state-level, and then converting to carbon. The biomass conversion and expansion factors of Smith et al. (2003) were developed for use with plot-level data. Similarly, the empirical model of Smith and Heath (2002) was developed for forest floor carbon. Datasets of the FIA plots, which by this time included individual tree data, soon became publicly available (Hansen et al. 1992; Woudenberg and Farrenkopf 1995), which allowed for even more accurate conversion to tree carbon. However, a few issues still needed to be addressed. These datasets did not consistently present biomass for standing dead trees, live tree biomass could be quite different between comparable trees for different regions, and estimates for belowground tree biomass were not included. To improve the estimates, biomass equations were compiled (Jenkins et al. 2004) based on tree diameter only (because height was not necessarily included in the datasets). These compiled equations were the basis for generalized tree biomass equations (Jenkins et al. 2003). The generalized equations were used because they represented a well-documented and nationally consistent basis for carbon estimation within the individual tree datasets to produce tree biomass. Biomass was multiplied by 0.50 to produce estimates in units of carbon.

The annualized survey design began to be adopted in the late 1990's in various states. Data became available from the annualized survey in evolving publicly available FIA datasets starting with Miles et al. (2001), with the current database called the

Stock Component	1990	1994	1998	2002	2005	2008
			Mt C			
Forest	42,540	43,177	43,763	44,207	44,762	45,337
Aboveground Biomass	15,027	15,443	15,856	16,209	16,529	16,854
Belowground Biomass	2,986	3,068	3,150	3,221	3,284	3,348
Dead Wood	2,949	2,982	3,015	3,035	3,053	3,073
Forest Floor	4,755	4,803	4,831	4,837	4,880	4,925
Soil Organic Carbon	16,823	16,882	16,911	16,905	17,016	17,136
Harvested Wood	1,859	1,996	2,124	2,244	2,325	2,412
Products in Use	1,231	1,295	1,355	1,404	1,436	1,471
Landfilled Wood	628	701	769	840	890	941
Total Stock	44,399	45,172	45,887	46,450	47,087	47,748
Forest area (million hectares)	268	270.6	272.9	274.7	276.8	279

Source: U.S. EPA (2010); Heath et al. (2011)

Table 1. Forest carbon stock (million metric tons C) by pool, including harvested wood products, at beginning of listed year, and forestland area.

FIADB version 4.0 (USDA Forest Service 2010b). Smith et al. (2007) developed the Carbon Calculation Tool (CCT; new version Smith et al. 2010) which used the FIADB data as inputs and produced forest carbon stock and change results by state. CCT can be used to present carbon stock change for U.S. forests by state. Figure 3 shows CO_2 change by state calculated for the year 2005 (Smith and Heath 2008) using CCT.

Policy-relevant reports, web tools, and data

Some of the methods described above have been used to contribute to policy-relevant reports on national-level carbon or GHG inventories. One of the most crucial reports is the annual "Inventory of U.S. GHG emissions and sinks". Another report series, although periodic, is the National Report on Sustainable Forests. A third major use of these data was to create default carbon accumulation curves for the 1605b Voluntary Reporting Program. A web tool, COLE, was developed to allow users to customize forest carbon outputs for their use, and the data are increasingly directly available through FIA websites. These are all discussed in more detail below.

National GHG Inventories

During the first five years of the 1990's, over 140 nations, including the United States, developed, signed, and ratified the United Nations Framework Convention on Climate Change. One outcome of this framework was that many countries agreed to conduct an annual GHG inventory of emissions and sinks covering all sectors. Net sequestration and emissions of carbon dioxide from land use change and forestry were included in the initial inventories. FIA data have been used indirectly and directly for carbon stock and carbon dioxide change estimates since the inception of these inventories. The forest estimates are from USDA Forest Service scientists, who also provide chapter text and review comments; U.S. EPA employees and contractors have also written substantial text, and asked questions to improve the chapter. Table 1 presents a selection of years of carbon stock data as published in the latest National GHG inventory (U.S. EPA 2010; Heath et al. 2011). USDA also presents a version of the national GHG inventories that highlights state-level information (Smith et al. 2004b; Smith and Heath 2008).

In the early years of conducting the inventories, carbon output from the FORCARB model was used as the forest carbon stock and change in terms of CO_2 estimates (see Woodbury et al. 2007). However, the average 5 to 10 year output from long-term projections was coarse compared to the annual estimate needed by the GHG inventories. FIA data were becoming more available electronically, and more data from the annualized design were being collected. By about 2006, the GHG inventory forest estimates were based directly on the FIA data rather than the FORCARB model. Documentation and methods continue to improve, and more data are collected over time.

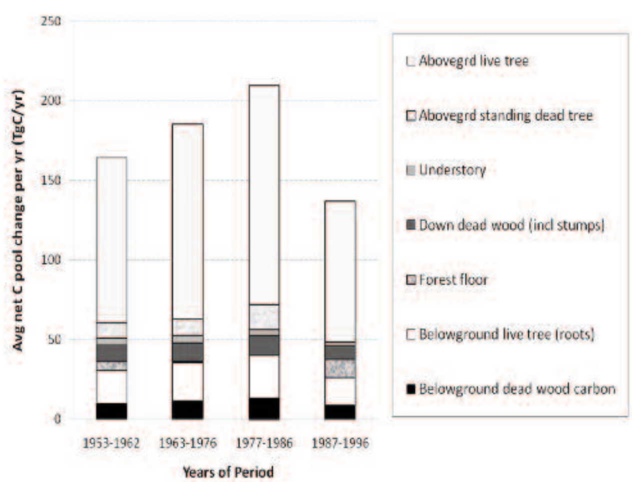
Meanwhile additional information is needed by GHG inventories. The entire land base is now considered because any land management decision has the potential to affect CO_2 and other GHG gases. Categorizing the land area change by non-forest becoming forest, forest remaining forest, and forest becoming non-forest by certain dates has become important for international climate negotiations, and an approach is needed to provide this information. FIA data will be increasingly used in combination with other sources of information such as remote sensing (for example, see Blackard et al. 2008), and models in providing carbon information in the future.

National Report on Sustainable Forests

The Montreal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forest (Montreal Process Working Group 2010) featured seven criteria, one of which specifically dealt with carbon. The 2003 U.S. report (USDA Forest Service 2004) makes extensive use of the FIA data. Carbon in the 2003 report (Heath and Smith 2004a) relied on state-level statistics, with some plot-level statistics used in the most recent period. Criterion 5 was titled "Maintenance of forest contribution to global carbon cycles", and included 3 indicators: forest carbon stocks (Heath and Smith 2004b), forest carbon change (Heath and Smith 2004c), and forest products carbon (Heath and Skog 2004). Figure 4 shows the carbon change results from this report. The carbon indicators were revised in 2007, but FIA data continue to be used for forest ecosystem stocks and change (USDA Forest Service, 2010a). Similar carbon estimates and approaches were used in the State of the Nation's Ecosystem series (Heinz Center 2002, 2008). Regional analyses were also conducted (Heath 2003, 2007; Mickler et al. 2004).

U.S. Voluntary Reporting of GHGs Program (1605(b))

In 2002, the President directed some executive branch agencies to prepare improvements to measurement guidance and reporting to the existing U.S. voluntary GHG registry (Birdsey 2006). This registry was developed in response to the Energy Policy Act of 1992 Section 1605(b) and so is often referred to as the "1605(b) program." Existing default guidance for forest carbon sequestration projects consisted of tables of carbon by age class for selected commercial species, which were derived in the early 1990's from FIA data and yield-growth curves developed for the RPA timber assessment (Haynes et al. 1993). Smith et al. (2006) provided more comprehensive carbon accumulation tables in the sense that more forest types and carbon pools were included, and the methodology for carbon in harvested wood products was expanded and clarified. Figure 5 illustrates typical forest carbon output from the updated tables, which continued to be based on FIA data and updated yield-growth curves used in the RPA timber assessment; for example see Zhou et al. (2007). These tables are also published in Technical Appendix I of the guidance (USDOE 2007). The framework of this approach allows for and encourages the use of site-specific information. As average net estimates derived over broad areas, these tables do not well represent the carbon being sequestered on any specific site. However, they provide an approximation for planning purposes.
Figure 4. Average annual net change in forest ecosystem non-soil carbon pools (TgC/yr) for all forestland of the conterminous U.S., 1953-1996 (Source: Heath and Smith 2004c). All net C stock changes are positive, indicating absorption of carbon by the forest from the atmosphere. The only net emission of carbon (-1.7 TgC/yr) occurred for



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Web tools and available data

The Carbon On Line Estimator (COLE) web suite of applications (Van Deusen and Heath 2010) was originally developed to allow users to customize forest carbon output for sustainability or GHG inventories for their areas of interest (Proctor et al. 2005). During most of the first decade of the 2000's, COLE was the only web tool that provided access to forest carbon FIA plot-level estimates matching those used in the national GHG inventories. During the 1605b program update, COLE was so successful it was adopted by the Forest Service as the official web tool for the forest portion of that program. Users can choose forests of interest, and a 1605b report with customized forest carbon curves, similar to the regional-forest type curves in Smith et al. (2006), based on the chosen forests. COLE can also still be used to calculate carbon stocks in various pools for chosen areas.

Tools and data access summary

http://www.ncasi2.org/COLE/
COLE—web suite of applications, 1605b

http://fia.fs.fed.us/tools-data/default.asp
FIDO – create forest inventory tables and maps
FIA DataMart – download publicly available FIA data

http://nrs.fs.fed.us/pubs/2394
Carbon Calculation Tool – generates state-level GHGinventory estimates

Today, COLE is an interface that uses the carbon estimates which are now housed in the publicly available FIA database, FIADB4.0 (USDA Forest Service 2010b). The plot-condition level estimates used for the national GHG inventories were recently placed in the FIADB4.0, along with a new set of biomass estimates (Heath et al. 2008) that are consistent with cubic foot volume estimates and pro-

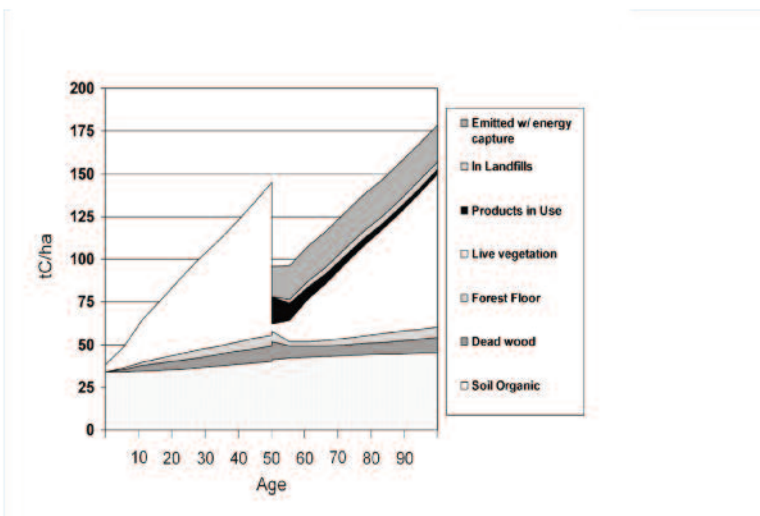

Figure 5. Regional estimates of carbon stocks and carbon in harvested wood products over time on forestland after clearcut harvest for oak-hickory stands in the southeastern United States (Source: Smith et al. 2006).

duce estimates of carbon in bark. However, estimates based on the generalized national equations of Jenkins et al. (2004) may be calculated from coefficients listed in the database. Users may download the data directly using the FIA DataMart (USDA Forest Service 2010b). The FIA program has been developing a tool called Forest Inventory Data Online (FIDO), to which carbon reports were recently added (USDA Forest Service 2010b). Finally, the Carbon Calculator Tool (CCT; Smith et al. 2010) is a program that allows a user to download the latest FIA data from FIADB4.0 for input to CCT, with resulting estimates matching those in the national GHG inventories.

Summary

The purpose of this publication was to review how FIA data have been used to meet and influence national-level U.S. carbon accounting needs. Use has evolved as computer technology and database management has improved, and more annualized data become available. How the FIA data are used to meet U.S. forest carbon national-level accounting needs will continue to evolve quickly. Users now have a number of choices to understand and analyze the data themselves, and web tool development and access to data continues.

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