The Kane Experimental Forest Carbon Inventory: Carbon Reporting with FVS

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Abstract—As the number of state and regional climate change agreements grows, so does the need to assess the carbon implications of planned forest management actions. At the operational level, producing detailed stock estimates for the primary carbon pools becomes time-consuming and cumbersome. Carbon reporting functionality has been fully integrated within the Forest Vegetation Simulator (FVS), allowing users to produce carbon reports along with traditional FVS output. This added capability can be easily used by managers familiar with FVS and requires just a few additional keywords. All methodologies and computations are consistent with Intergovernmental Panel on Climate Change and U.S. standards. In this paper we present a current carbon inventory for the Kane Experimental Forest, an Allegheny hardwood forest located in northwestern Pennsylvania. Future carbon stocks are also projected using the new carbon budgeting capabilities of FVS.

Overview

Quantification of forest carbon stocks became an important research issue with the advent of the Kyoto Protocol, which permits some carbon uptake from afforestation and reforestation to be counted against a country's carbon emissions. Although the United States did not ratify the protocol, the nation's forest carbon stocks are reported as part of the overall carbon accounting under the U.N. Framework Convention on Climate Change. The United States also has a voluntary greenhouse gas reporting program covered under section 1605(b) of the Energy Policy Act. Under this program, business entities may report their overall emissions budgets; forest carbon sequestration is also reported. The program has carbon accounting rules and guidelines (available at http://www.eia.doe.gov/oiaf/1605/aboutcurrent.html) that are consistent with IPCC (Penman and others 2003) good practice guidance for carbon accounting.

Recently, the increasing number of climate change agreements and action plans at scales ranging from local to international has led to a greater need for information on forest carbon stocks now and in the future. While estimates and tools (Proctor and others 2005; Smith and others 2004; U.S. EPA 2006) are available at the county, state and national level, developing carbon estimates from inventory data for multiple forest stands or entire forests is generally a lengthy and unwieldy process. As forest carbon markets continue to emerge, the question of how forest management practices positively or negatively affect carbon storage becomes increasingly important to answer. Assessing the probable carbon consequences of forest management alternatives, while not difficult in a technical sense, is time consuming and cumbersome and so is often impractical for landowners and managers. The difficulty in accounting for the carbon in harvested wood presents an additional challenge.

Because of this increased demand for forest carbon information, a tool was needed to calculate forest carbon stocks at smaller scales. The following criteria were established: the tool should be accessible to managers and allow the flexibility to assess the carbon outcomes of forest management treatments, and the estimates produced must meet current U.S. carbon accounting rules and guidelines.

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Development History

The development of carbon accounting capabilities within FVS first began in 2003 when Nick Crookston and Dennis Gammel created a prototype to examine the prospect of using the model's output to predict forest carbon storage. They found that using the Fire and Fuels Extension (FFE) to FVS for carbon accounting was promising, but their prototype brought up questions as to how carbon reporting should be added to the model. A few years later in 2005, development of carbon accounting capabilities within FVS took off quickly once a collaboration was established between scientists at the Northern Research Station and the staff at the Forest Management Service Center. Initial consultations to determine the broad outlines of the project included Coeli Hoover, Stephanie Rebain, Rich Birdsey, Nick Crookston, Gary Dixon, Linda Heath, and Jim Smith. It was agreed that many of the necessary components of a stand-level carbon estimate were already being tracked and reported through the Fire and Fuels Extension (Reinhardt and Crookston 2003), and so rather than creating a post-processor the carbon reporting functions would be contained within the FFE and requested using keywords. In the summer of 2005, Rebain met with Hoover, Heath, and Smith to work out the specifics of which variables would be reported and which computation methods would be used, locate documentation for default assumptions, and finalize report design. All methodologies are consistent with U.S. carbon accounting rules and guidelines and the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land Use Change, and Forestry. Don Robinson and Sarah Beukema of ESSA Technologies completed the necessary programming for the carbon reports. The new FVS carbon reports were available in the fall of 2006. Complete documentation of the carbon reporting methods and assumptions is provided in the Fire and Fuels Extension Addendum document (http://www.fs.fed.us/fmsc/fvs/documents/gtrs_ffeaddendum.php).

Report Structure and Options

There are two reports that can be requested: the Stand Carbon Report and the Harvested Carbon Report. The ***Stand Carbon Report*** includes the major carbon pools as defined by the U.S. Carbon Accounting Rules and Guidelines and the IPCC Good Practice Guidance: aboveground live tree, belowground live tree (coarse roots), belowground dead tree, standing dead trees, down dead wood, forest floor, and understory (shrubs/herbs). In addition, the merchantable portion of live tree carbon is reported, as well as total stand carbon, total carbon removed and carbon released from fire (if harvests or fires are simulated). The user has a choice of measurement units: pool sizes can be reported in tons per acre or metric tons per hectare. Biomass is assumed to be 50% carbon for all pools except forest floor, which is 37% carbon (Smith and Heath 2002). Carbon pools in the Stand Carbon Report are defined and calculated as follows:

- Total Aboveground Live: carbon in live trees, including stems, branches, and foliage but excluding roots. Choice of calculation methods: either default FVS-FFE methods or Jenkins and others (2003).
- Merchantable Aboveground Live: carbon in the merchantable portion of live trees; choice of calculation method as above.
- Belowground Live: carbon in coarse roots of live trees; carbon in fine roots is assumed to be part of the soil pool, not currently reported in FVS. Computed from Jenkins and others (2003).
- Belowground Dead: carbon in coarse roots of dead or cut trees. Computed from Jenkins and others (2003); default root decay rate can be adjusted by the user.
- Standing Dead: carbon in dead trees, including stems and any branches or foliage still present, but excluding roots. Calculated with FVS-FFE methods.
- Down Dead Wood: all woody surface material regardless of size; FVS-FFE method.
- Forest Floor: all surface organic material excluding wood (litter and duff); FVS-FFE method.
- Herbs and Shrubs: FVS-FFE method.

Other categories reported are Total Removed Carbon including carbon removed through cutting live or dead trees and hauling away surface fuel, and Carbon Released from Fire, which includes carbon in fuel consumed by simulated wildfires, prescribed burns, and pile-burns. An example of the Stand Carbon Report is shown in figure 1.

****** CARBON REPORT VERSION 1.0 ******
STAND CARBON REPORT
STAND ID: 2010 MGMT ID: NONE

	Aboveground Live		Belowground			Forest			Total	Total	Carbon
					Stand				Stand	Removed	Released
YEAR	Total	Merch	Live	Dead	Dead	DDW	Floor	Shb/Hrb	Carbon	Carbon	from Fire
	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA
2006	133.1	81.1	25.9	3.0	12.0	4.9	14.6	0.7	194.3	0.0	0.0
2011	145.2	88.4	28.3	2.7	10.6	7.9	16.6	0.7	212.0	0.0	0.0
2016	81.0	50.5	16.1	16.9	14.2	33.7	16.9	0.7	179.6	47.4	0.0
2021	87.9	55.6	19.7	13.6	7.5	26.2	15.3	0.7	170.9	0.0	0.0
2026	95.0	59.6	19.7	11.0	3.8	21.8	15.7	0.7	167.7	0.0	0.0
2031	103.7	64.5	20.9	9.0	1.9	19.8	16.5	0.7	172.3	0.0	0.0

Figure 1—Screen shot of sample *Stand Carbon Report* (units are metric tons/hectare).

The ***Harvested Carbon Report*** tracks the fate of carbon in harvested merchantable volume, including salvaged logs (biomass is assumed to be 50% carbon). Carbon in merchantable biomass is allocated into various pools and followed over time; for example, a product in use may be discarded, transferring carbon from the product pool into the landfill pool. Both merchantability specifications and allocation to harvested carbon pools differ by FVS variant; the breakpoints between pulpwood and sawtimber are 9 inches diameter at breast height (dbh) for softwoods and 11 inches dbh for hardwoods by default (these can be adjusted by the user). Carbon in harvested merchantable biomass is allocated following the methods of Smith and others (2006) to the following pools:

- Products in use
- Products in landfills
- Carbon emitted from combustion with energy capture
- Carbon emitted from combustion or decay without energy capture

Carbon in the first two categories of the Harvested Carbon Report is summarized in the Merchantable Carbon Stored column of the report, while the Merchantable Carbon Removed column reflects all of the carbon in merchantable biomass that was removed from the stand. Over time, more of the carbon removed in a particular harvest will shift to one of the emissions categories. An example of the Harvested Carbon Report is given in figure 2. While carbon removed from the stand is reported in the year of harvest in the Stand Carbon Report, the carbon contained in earlier removals is not included, nor is the carbon accounted for once it leaves the stand. If harvesting is simulated, a user must request both reports and add the Merchantable Carbon Stored from the Harvested Carbon Report and Total Stand Carbon from the Stand Carbon Report columns to estimate total carbon sequestered. Both reports may be sent to an external database or spreadsheet using the database extension of FVS.

****** CARBON REPORT VERSION 1.0 ******
HARVESTED PRODUCTS REPORT
STAND ID: 2849 MGMT ID: NONE

					Merch Carbon	
YEAR	Prducts	Lndfill	Energy	Emissns	Stored	Removed
	T/HA	T/HA	T/HA	T/HA	T/HA	T/HA
2006	25.6	0.0	9.4	6.4	25.6	41.4
2011	18.2	3.9	11.3	8.1	22.1	41.4
2016	13.7	6.1	12.5	9.1	19.8	41.4
2021	10.9	7.4	13.2	9.9	18.4	41.4
2026	9.1	8.2	13.7	10.4	17.3	41.4
2031	7.9	8.7	14.1	10.8	16.6	41.4

Figure 2—Screen shot of sample *Harvested Carbon Report* (units are metric tons/hectare).

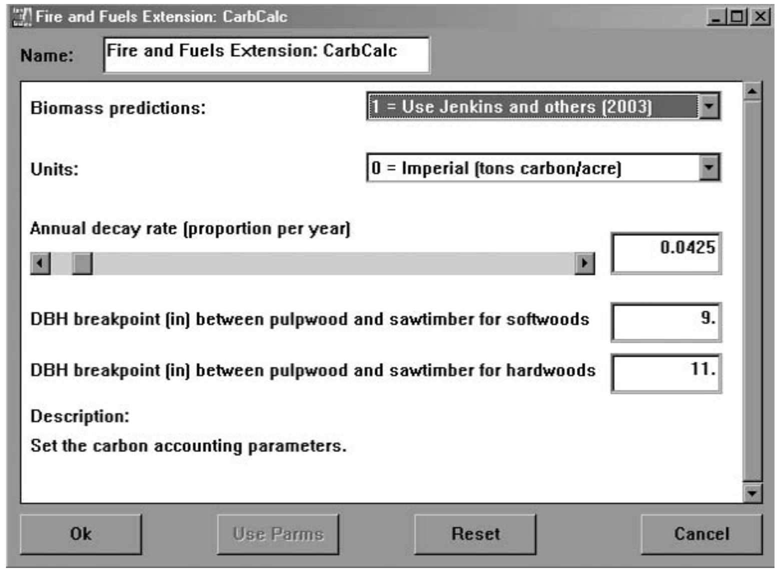

Figure 3—Screen shot of CarbCalc dialog box in Suppose.

Getting There from Here—Carbon Keywords

The keywords needed to generate carbon reports can be found in the FFE menu in Suppose. Three main keywords relate to the carbon accounting functionality. CarbRept requests the Stand Carbon Report and CarbCut requests the Harvested Carbon Report. As with other reports, the user needs to specify the year the report should start, the duration of the reporting period, and the reporting interval. The CarbCalc keyword is used to select the biomass prediction method, reporting units, annual decay rate of coarse roots, and dbh breakpoints for sawtimber and pulpwood. Figure 3 shows the CarbCalc window in Suppose. Both reports can be sent to an external database or spreadsheet using the CarbRpts keyword in the database extension menu in Suppose. Carbon reports can be generated during any simulation and the effects of management actions are reflected in the carbon pool estimates. For example, when the YardLoss keyword is used to adjust the amount of slash left after a thinning or harvest, the amount of carbon in the down dead wood pool is also adjusted. Similarly, a salvage harvest changes the estimates of carbon in the harvested and standing dead pools. The down dead wood and forest floor carbon stocks are derived from variant-specific FFE default values, but can be replaced with inventory data.

The Kane Experimental Forest Carbon Inventory

The Kane Experimental Forest (KEF) is an Allegheny hardwood (cherry-maple) forest of approximately 1,700 acres, located in northwestern Pennsylvania. During the summer of 2006, the forest was the site of a systematic inventory that replicated the original forest survey conducted in 1932. Plots 1/10th acre in size were located 10 chains (660 ft) apart on a grid covering the entire forest; all live and dead trees 1 inch dbh and over were measured. Down dead wood was tallied on transects through the center of each plot, and forest floor samples were collected on each plot. Additional data not related to the carbon inventory were also taken. In total, 153 plots were tallied. The inventory provided an opportunity to assess the feasibility of collecting the additional data required for a full carbon accounting as well as testing the carbon reporting capabilities of FVS. Current carbon stocks for KEF are given in table 1. All estimates are based on inventory data with the exception of the forest floor carbon stocks (these estimates will be updated when the data are available). The data were easily converted into FVS-ready files using the database extension. Without the carbon reporting capability of the FFE, the baseline carbon stock estimates shown in table 1 would have been produced by using allometric equations to compute the aboveground biomass of each sample tree in a plot, repeating the process for the belowground biomass, producing per acre estimates for each plot,

Table 1—Carbon stocks on the Kane Experimental Forest in 2006.

Pool	Tons C/acre	Tons C forest-wide
Live tree [a]	60.2	42,147
Dead tree [b]	5.8	4,059
Down dead wood	2.2	1,561
Forest floor	6.2	4,371
Total	74.5	52,137

[a] All live biomass including coarse roots.
[b] All dead biomass including coarse roots and standing dead trees.

then aggregating to compartment estimates to produce a forest-wide average. Separate computations would be required for the down dead wood and forest floor pools. While feasible for a small number of plots, producing the current carbon estimates for KEF would have taken several weeks using this approach. For a user with FVS-ready data files, generating carbon estimates that are consistent with current carbon reporting guidance can now be done quickly and without specialized knowledge.

Increasingly, forest managers are being asked to consider the potential carbon consequences of forest management actions. The possibility of earning income from the sale of carbon credits further highlights the need for information on projections of forest carbon stocks in the future. While there are multiple carbon registries at this time, many require that forest carbon storage be "additional"—that is, above and beyond business as usual, to receive credit as an emission offset. Determining this baseline level of carbon storage can be difficult, but this is another area where the carbon reporting functions can help managers. As an illustration, the data from KEF were used to run projections of carbon stocks over the next 25 years, with and without simulated management. These projections are a test exercise and are not fine-tuned to reflect actual management prescriptions, although they are a general approximation of Allegheny hardwood management. The test version of the revised northeast variant was used "out of the box"; for the growth only scenario no regeneration was added other than that from stump sprouts included in the base model (a main reason for the relatively short projection period). For the management scenario, stands were treated if they were between 85 and 120 years old and fully stocked. Approximately one-third of the basal area was removed (assuming a thinning from below using a ThinBBA keyword in FVS) and regeneration was added after thinning; seedling numbers were based on data from regeneration surveys conducted during the inventory. Stands that were untreated were grown as in the base projection; two compartments that are described as probable old growth were reserved from harvest. Table 2 shows the carbon stocks from these projections; the estimates from the management projection include the carbon in wood products and landfills. By default in the eastern FVS variants, branches and tops of cut stems are left in the stand and transferred to the down dead wood pool. Modifications to this setting using the YardLoss keyword will alter the distribution of carbon among pools accordingly. This is a short-term simulation; the same management practice may have different carbon outcomes over different time frames, depending on stand growth patterns and product types. If the model is carefully calibrated for local conditions, then long-term simulations may be run to investigate these tradeoffs.

Table 2—Projected carbon stocks on the Kane Experimental Forest. Simulation was for testing purposes; model was not calibrated to site conditions.

Year	Growth only (tons C/acre)	With management (tons C/acre)
2006	75	73
2011	81	77
2016	87	81
2021	94	85
2026	99	88
2031	104	91

Summary

By building on the existing capabilities of the FFE, we were able to integrate easy-to-use, comprehensive carbon accounting capabilities into FVS. Managers familiar with the model are now able to quantify carbon stocks and assess the carbon implications of different management practices alongside more management objectives by using just a few additional keywords. The estimates produced by the model are consistent with U.S. carbon accounting rules and guidelines and cover all pools except for soil carbon. Users can also track carbon in harvested wood products or carbon released in fuels consumed by fire. A test of the new carbon reports was conducted utilizing recent inventory data from the Kane Experimental Forest. Current carbon stocks on the Forest are estimated to be 74.5 tons/acre and are projected to increase to 104 tons/acre by 2031.

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