THE CLIMATE CHANGE PERFORMANCE SCORECARD AND CARBON ESTIMATES FOR NATIONAL FORESTS

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Abstract.—The U.S. Forest Service manages 20 percent of the forest land in the United States. Both the Climate Change Performance Scorecard and the revised National Forest Management Act require the assessment of carbon stocks on these lands. We present circa 2010 estimates of carbon stocks for each national forest and recommendations to improve these estimates.

INTRODUCTION

The climate change performance scorecard is the mechanism through which the U.S. Forest Service seeks to increase its capacity to respond to climate change (U.S. Forest Service 2011). Under this paradigm, there are four dimensions (organizational capacity, engagement, adaptation, and mitigation) that span a range of important components relevant to climate change (Fig. 1). Here we focus on the mitigation and sustainable consumption dimension with particular focus on carbon (C) assessment and stewardship in support of the climate change performance scorecard.

The revised regulations (Code of Federal Regulations: 36 CFR 219, 2012) for implementing the National Forest Management Act also include requirements for assessments of C stocks for each new national forest plan or plan revision. Long-term C storage is described as a “regulating” ecosystem service of forests, rangelands, and grasslands. Plans must include components that provide for social and economic sustainability, taking into account the ecosystem services and reasonably foreseeable risks. Responsible officials should use the assessment of C stocks to understand (1) how the plan area plays a role in sequestering and storing C and (2) how disturbances, management, and resource uses influenced C stocks in the past and may affect them in the future.

Quantifying and tracking changes in C stocks are key objectives for the U.S. Forest Service on National Forest System (NFS) lands, which account for 20 percent of U.S. forest land. The Forest Inventory and Analysis (FIA) Program provides a consistent monitoring and assessment framework across all lands and ownerships, which can be used to consistently estimate C stocks across landscapes. Through regional or local partnerships between FIA and NFS, the base FIA sample can be intensified to increase the precision of estimates at the NFS administrative forest level.

Several studies have provided C estimates for national forests at the region, state, and individual forest spatial scales (e.g., Heath et al. 2011). In some cases, these approaches have relied on estimating the areal extent of each national forest (the population of interest) and therefore can be improved by (1) explicitly defining the areal extent of the populations of interest, and (2)

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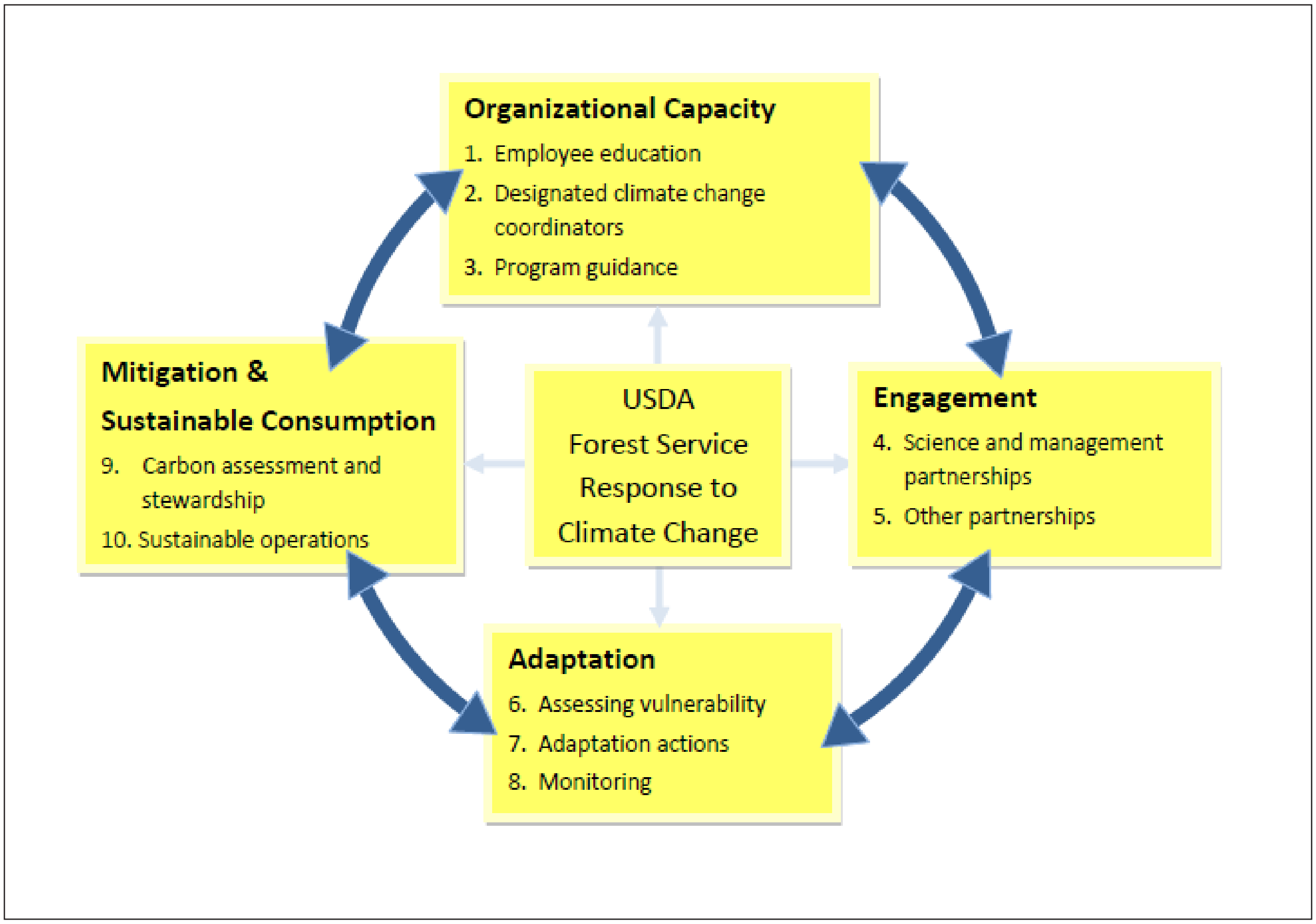

Figure 1.—The four dimensions and ten elements of the U.S. Forest Service climate change performance scorecard (source U.S. Forest Service 2011).

including inventory plot intensifications on NFS lands. Our goal here is to incorporate these improvements and identify additional areas for improvement in support of C estimates for the climate change performance scorecard, for forest planning, and for monitoring

METHODS

To construct C estimates for each national forest, we used field-based observations from FIA and intensified national forest data collected using FIA protocols (Southern and Eastern NFS regions). Most national forest intensifications were either 2x or 3x the intensity of the standard FIA sample. The area of each national forest was obtained from the Automated Lands Project (ALP) geospatial database available through the corporate U.S. Forest Service Citrix environment. The 2001 NLCD percent tree canopy cover data (Homer et al. 2007) were obtained from the Multi-Resolution Land Characteristics consortium.

The standard FIA post-stratified estimator was used to estimate population totals and the standard error of the estimates (Bechtold and Patterson 2005). The population total was $\hat{Y} = A_t \sum_h^H W_h \bar{Y}_h$ where A_t was the population area as defined by the ALP database, W_h was the weight of each h stratum, and $\bar{Y}_h$ was the within strata average from the plot level observations. The strata weights were developed from the NLCD percent tree canopy cover data using an automated stratification routine. $W_h = A_h/A_t$ where A_h is the area of the population in stratum *h*. The standard error of the estimate was then $S.E(\hat{Y}) =$

$$\sqrt{\frac{A_t^2}{n}\left[\sum_h^H W_h n_h v(\bar{Y}_h) + \sum_h^H (1 - W_h)\frac{n_h}{n} v(\bar{Y}_h)\right]}$$

where *n* was the total number of plots in the population, n_h was the number of plots in each stratum, and $v(\bar{Y}_h)$ was the variance of the plot level values within each *h* stratum. Estimates of the following C pools were made for each administrative forest: down dead wood, litter, overstory trees above ground, overstory trees below ground, standing dead wood, soil organic carbon, understory story trees above ground, and understory trees below ground. Plot level estimates of forest C stocks were a combination of empirically measured tree/site attributes combined with a series of individual tree/site models (see USEPA 2012 for methods). To estimate stocks at aggregate levels (NFS administrative region and for all NFS lands), basic error propagation techniques were used.

RESULTS

Across all pools there are approximately 10.88 billion tons (0.4 percent sampling error) of C stored on NFS lands. The majority of the C is stored in national forests in the western United States (Fig. 2). This finding is primarily due to the larger areal extents of these forests. For example, the Tongass National Forest in southern Alaska stores 1.17 billion tons

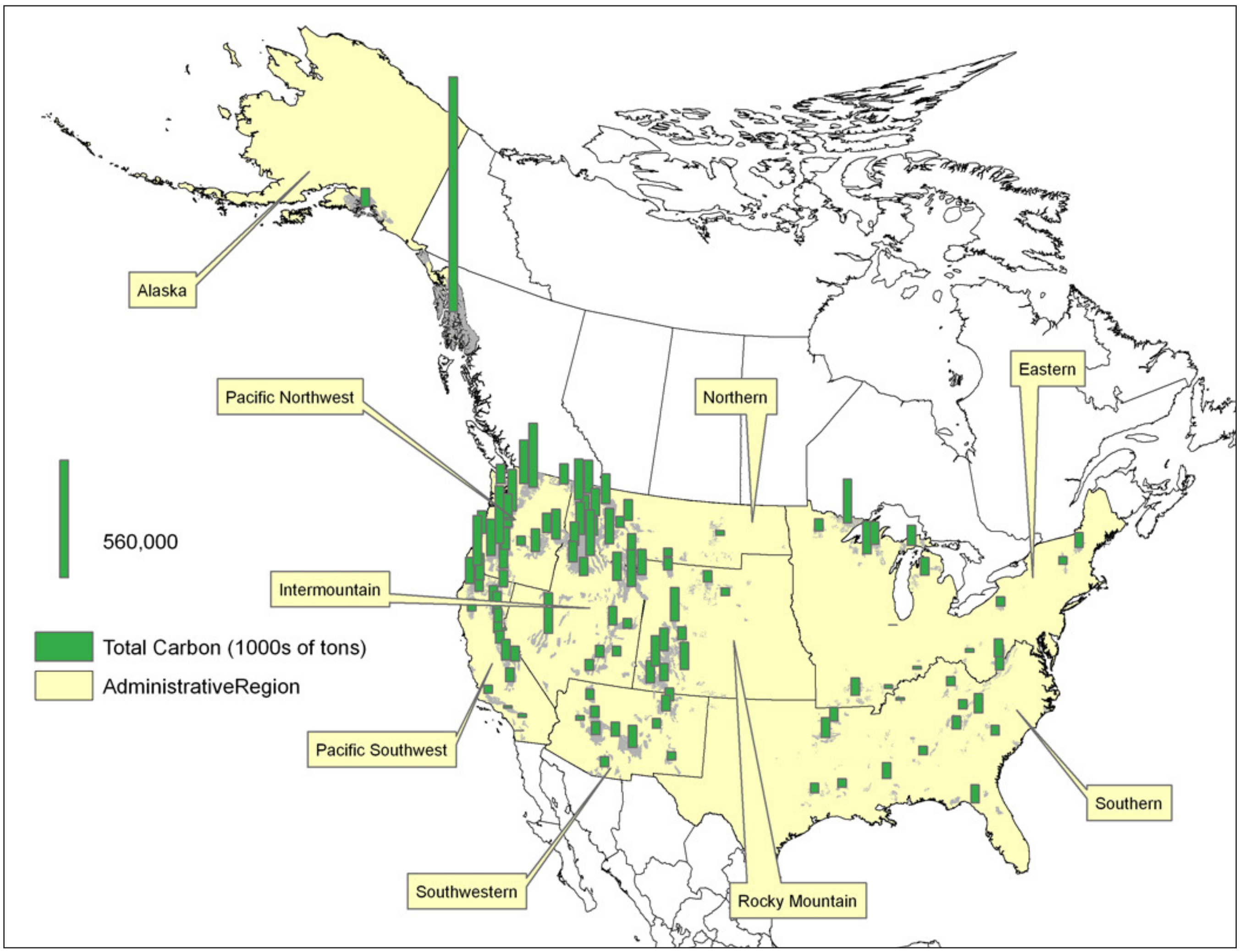

Figure 2.—Estimates of total C stocks (i.e., all pools) in thousands of tons for each administrative forest.

(1.9 percent sampling error) of C and occupies about 16.8 million acres. On a per acre basis, NFS lands on average have a C density of 57 tons per acre; the lowest density occurs in southern California and the highest density occurs in the Pacific Northwest region (Fig 3).

The Pacific Northwest region has an average total C density of approximately 103 tons per acre (1.06 percent sampling error) (Table 1). These substantial stocks are primarily driven by highly productive forests (e.g., large overstory trees) combined with considerable input to detrital forest components with concomitantly slow decay rates (e.g., C in soil organic carbon and dead wood). The Eastern region has the second highest C densities (87 tons per acre, 0.56 percent sampling error) primary driven by storage in organic soils (50 tons per acre, 0.68 percent sampling error).

DISCUSSION

The intent of the climate change performance scorecard is to increase the capacity of the U.S. Forest Service to respond and adapt to climate change (U.S. Forest Service 2011). The revised planning regulations include requirements to assess and sustain C in forest, rangeland, and grassland management. Monitoring C stocks and fluxes is a fundamental step toward

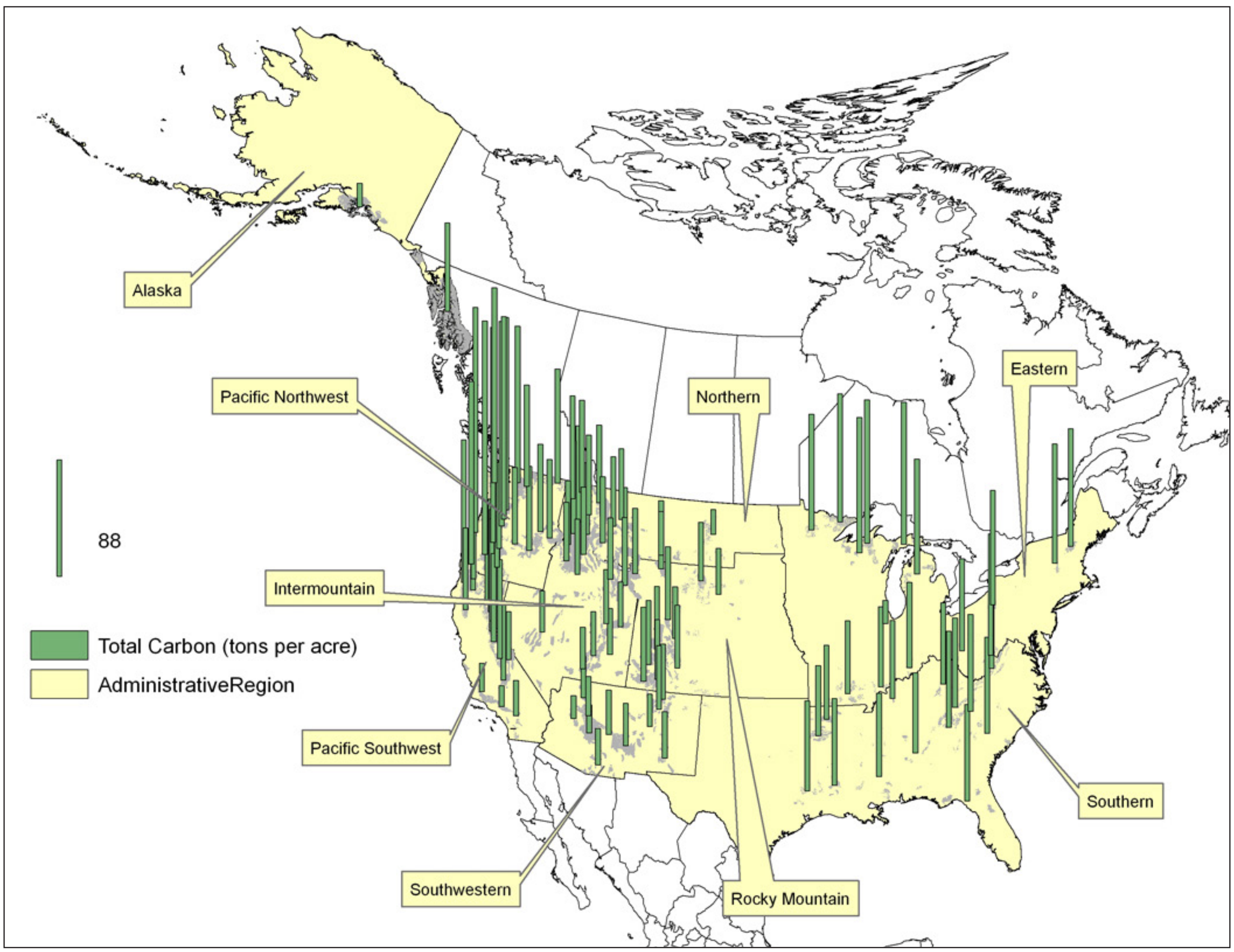

Figure 3.—Estimates of total C density (i.e., all pools) in tons C per acre for each administrative forest.

Table 1.—Carbon density estimates (tons C/acre) and sampling errors (percent, in parentheses) for each carbon pool and administrative region

National Forest System Region	Carbon Pool								
	Down dead wood	Litter	Overstory trees above ground	Overstory trees below ground	Standing dead wood	Soil organic Carbon	Understory trees above ground	Understory trees below ground	Total Carbon
Northern	2.51 (1.22%)	12.25 (0.69%)	17.91 (1.47%)	4.1 (1.46%)	2.97 (3.08%)	15.09 (3.08%)	0.8 (1.01%)	0.09 (1.01%)	55.71 (0.78%)
Rocky Mountain	1.88 (1.17%)	9.38 (0.87%)	12.35 (1.52%)	2.77 (1.51%)	1.87 (3.06%)	10.65 (0.98%)	0.61 (1.6%)	0.07 (1.6%)	39.59 (0.91%)
Southwestern	1.02 (1.87%)	8.33 (0.89%)	7.71 (1.76%)	1.74 (1.74%)	1.04 (3.98%)	8.02 (0.89%)	0.79 (1.24%)	0.09 (1.24%)	28.73 (1.02%)
Intermountain	1.52 (1.85%)	9.29 (1.01%)	8.94 (1.88%)	2.02 (1.87%)	1.8 (3.34%)	10.84 (1.07%)	0.79 (1.39%)	0.09 (1.39%)	35.3 (1.08%)
Pacific Southwest	4.03 (1.61%)	10.99 (0.87%)	23.57 (1.79%)	5.19 (1.79%)	1.77 (4.72%)	13.94 (0.84%)	0.92 (1.53%)	0.1 (1.53%)	60.5 (1.14%)
Pacific Northwest	6.26 (1.09%)	14.02 (0.76%)	37.56 (1.8%)	8.45 (1.79%)	3.28 (3.23%)	31.76 (0.69%)	1.12 (0.71%)	0.12 (0.71%)	102.58 (1.06%)
Southern	2.71 (0.76%)	4.33 (0.57%)	22.81 (1.28%)	4.69 (1.27%)	0.53 (5.28%)	22.68 (0.64%)	1.13 (0.4%)	0.13 (0.4%)	59.01 (0.7%)
Eastern	2.81 (0.72%)	7.91 (0.97%)	21 (1.01%)	4.27 (0.97%)	0.66 (3.05%)	49.7 (0.68%)	0.67 (0.43%)	0.07 (0.43%)	87.11 (0.56%)
Alaska	3.02 (2.43%)	10.58 (1.67%)	17.49 (2.94%)	3.96 (2.91%)	1.9 (5.26%)	20.09 (1.8%)	0.59 (2.06%)	0.07 (2.06%)	57.69 (1.89%)

these goals. Here we provide baseline estimates of C stocks by national forest. However, for brevity, we have presented summarized results by NFS region. Regardless, all pool estimates (circa 2010) are available by national forest. Continued monitoring of C stocks will allow the U.S. Forest Service to track the changes in individual pools in response to disturbance and management. FIA provides a consistent framework for providing these estimates in support of the climate change performance scorecard and forest planning.

In this paper we presented solutions to two shortcomings in FIA-based carbon estimates for national forests. These solutions included explicitly defining the areal extent of the populations of interest and including NFS intensified data in the eastern United States. We also incorporated improvements in estimating C in the standing dead pool. The standing dead C estimates available through FIA's database were model based and developed by Smith et al. (2003) and are not based on direct summaries of observed standing dead tree measurements. The alternative used here was to estimate standing dead C from observed data on standing dead trees and incorporating appropriate decay reduction factors (Domke et al. 2011); however, this approach, although now a part of the national greenhouse gas inventory (USEPA 2012), is not slated to be fully incorporated in the FIA compilation procedures until early in 2013. We incorporated the Domke et al. (2011) methods for this analysis for each plot where standing dead tree data were available. An effort is underway to revisit each C pool delineated within FIA's inventory system to improve the accuracy and precision of estimates (Woodall 2012). This investment should yield reductions in total uncertainty when coupled with other efforts described subsequently.

The second area of improvement is in the ALP geospatial database, which was used to define the populations and their areal extents. As described in the methods section, population totals and sampling errors are developed by multiplying per acre estimates of each pool by the total area and the total area squared, respectively. However, reported acreages in the ALP database often differ from reported acreages in the Land Area Report of areal extent (U.S. Forest Service 2012). The total calculated area from the ALP data is approximately 880,000 acres lower than the acreages reported in the Land Area Report. Given the magnitude of this discrepancy, the total C stored on national forests may be 50 million tons larger than reported here just because of the accuracy of the boundary layer. Also note that the ALP boundary layer is used in part to determine strata weights. Clearly, if the boundary is not correctly reflected, the strata weights may be incorrect because they are determined by spatial overlay of the ALP layer and the NLCD percent tree canopy cover layer. Errors from incorrectly specifying the population are not reflected in the reported sampling errors. Typically one assumes that the population is defined without error. Increased precision of national forest boundaries and geographic extents will make this assumption more tenable.

The third area of improvement is to ensure that the NFS funded intensified data are incorporated into the public FIA database and state-level estimates. Several NFS regions have invested in these intensifications so that the precision of estimates will meet their individual requirements. Typically, intensifications have been either 2x or 3x the base FIA sample. The basic rule of thumb is that a 4x intensification will reduce the width of the 95 percent confidence interval of an estimate by half. Clearly, these intensifications will have a substantial influence on the sampling errors. However, to date the Northern Research Station FIA unit is the only program that incorporates intensified national forest data into state-level estimates and treats each national forest as an individual population. Other FIA units should take the opportunity to incorporate these intensified data into state-level estimates and treat national forests as individual populations, which will increase the precision of both FIA's traditional state-level estimates and estimates for national forests.

In conclusion, the FIA program is a foundational component of Forest Service research, and data collected as part of the FIA program can be used to estimate C storage on NFS lands. Providing these estimates in a consistent way to our NFS partners will allow for timely reporting of C storage in support of the climate change performance scorecard and forest planning. We have identified three areas of improvement in support of this effort. These improvements require efforts from both FIA and the NFS regions, but will foster more accurate, more comprehensive, and timelier estimates of C.

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