Exhibit 2

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Storage and Flux of Carbon in Live Trees, Snags, and Logs in the Chugach and Tongass National Forests

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Abstract

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Carbon storage and flux estimates for the two national forests in Alaska are provided using inventory data from permanent plots established in 1995–2003 and remeasured in 2004–2010. Estimates of change are reported separately for growth, sapling recruitment, harvest, mortality, snag recruitment, salvage, snag falldown, and decay. Although overall aboveground carbon mass in live trees did not change in the Tongass National Forest, the Chugach National Forest showed a 4.5 percent increase. For the Tongass National Forest, results differed substantially for managed and unmanaged forest: managed lands had higher per-acre rates of sequestration through growth and recruitment, and carbon stores per acre that were higher for decomposing downed wood, and lower for live trees and snags. The species composition of carbon stores is changing on managed lands, with a carbon mass loss for yellow-cedar but increases for red alder and Sitka spruce. On unmanaged lands, the Chugach National forest had carbon mass increases in Sitka spruce and white spruce, and the Tongass National Forest had increases in western redcedar and red alder.

Keywords: Biomass, carbon cycle, carbon sequestration, phytomass, rain forest.

Summary

Carbon accounting is becoming of increasing importance to forest managers, as markets develop for private forest landowners and public land managers incorporate carbon services into planning and management. In this report, inventory data from permanent plots established in 1995–2003 and remeasured in 2004–2010 are used to provide estimates of aboveground carbon storage and flux for the two national forests in Alaska. Estimates of change are reported separately for growth, sapling recruitment, harvest, mortality, snag recruitment, salvage, snag falldown, and decay.

For the Chugach National Forest, key findings are:

- The overall increase in live tree carbon mass was substantial, estimated as a 4.5 percent increase from 1999–2003 to 2004–2010, equivalent to an increase of
  - 0.8 percent per year
  - 165,000 tons of carbon mass (C) per year for the forest, and
  - 552 lbs of C per forest acre per year

  Although a recent increase in live tree biomass is not unusual for a national forest, the increase for the Chugach National Forest is not attributable to fire suppression or past harvest, unlike most other forests. We do not know whether the observed increase is caused by recovery from past disturbances (e.g., spruce beetle outbreaks) or is a result of warming temperatures in the region.

- Significant increases of live tree carbon mass occurred for the Sitka spruce and white spruce tree species.
- Cottonwood, paper birch, western hemlock, and white spruce forest types all showed significant increases in live tree carbon mass.
- No tree species or forest type showed a significant decrease in live tree carbon mass.

For the Tongass National Forest, key findings from this report are:

- The Tongass National Forest stores massive amounts of forest carbon, more than any other national forest in the United States. The estimated aboveground average carbon density in the forest was 70 tons per acre in live trees, snags, and logs in 9.7 million ac of forest.

- Growth and recruitment of live trees removes from the atmosphere an estimated 760 lbs of carbon per acre per year, but net change in live carbon mass was not significantly different from zero, with mortality and harvest estimated at 670 lbs of carbon per acre per year. Turnover in the live tree and snag pool was estimated as 0.6 percent per year and 2.6 percent per year, respectively.
- On managed forest lands (estimated at 446,000 ac), there were significant increases in Sitka spruce and red alder live tree carbon mass, and a significant decrease in yellow-cedar carbon mass.
- On unmanaged forest (estimated at 6,294,000 ac with an additional 2,974,000 ac of unsampled forest in wilderness), there was a large (6.6 percent) increase in western redcedar carbon mass and also a significant increase in red alder carbon mass.
- Growth and recruitment was much higher in managed forest (1,608 lbs per acre per year) than in unmanaged forest (690 lbs per acre per year), and natural mortality was much lower (278 lbs per acre per year versus 619 lbs per acre per year).
- Carbon density on unmanaged forest was estimated as 72 tons per acre, split as 7 percent logs, 13 percent snags, and 80 percent live trees. Carbon density on managed forest was estimated as 45 tons per acre, split as 38 percent logs, 8 percent snags, and 54 percent live trees.
- Although management choices could potentially increase carbon sequestration in second-growth stands, e.g., by altering rotation lengths or utilization of harvested material, this report does not make any specific recommendations owing to the relatively small number of managed stands (58) that fell within the field plots.

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Introduction

Carbon dioxide (CO_2) is thought to play a major role in global climate change, and as a result, efforts to measure the levels of carbon sequestration, storage, and flux in forests are of increasing interest to forest land managers. For national forests in the United States, this undertaking was reflected in several significant new developments that occurred in 2012:

1. Thirty years after publication of the original forest planning rule under the National Forest Management Act, a new forest planning rule was finalized. Among other requirements, new assessments for each national forest are to include a baseline assessment of carbon stocks, and forests are to monitor changes related to climate change and other stressors.
2. National forests began to use an annual "Climate Change Scorecard" assessment. Questions that forests now consider include progress toward a baseline assessment of carbon stocks, as well as an assessment of how disturbance and management activities are influencing carbon stocks, sequestration, and emissions.

This report is intended to help the two national forests in Alaska, the Chugach and the Tongass, make progress toward these new assessments by providing information on storage and flux of carbon in live and dead trees within the forests based on data collected by the USDA Forest Service Forest Inventory and Analysis (FIA) program. In addition, by providing estimates of temporal flux between carbon pools, the results reported here can improve understanding of some types of recent changes occurring in the national forests and their surrounding ecosystems.

Methods

Data

The estimates in this report are derived from remeasured inventory plots installed by FIA. Only trees of at least 5 in diameter at breast height (d.b.h.) were used for analysis because a change in the plot layout resulted in no remeasurement information for smaller trees. The first inventories were installed from 1995 to 2000 in southeast Alaska (van Hees 2003) and from 1999 to 2003 in south-central Alaska (van Hees 2005). These combined inventories are referred to here as the "periodic" inventory. Many of these plots are being remeasured in the current "annual" FIA inventory system. This report combines those periodic (1995–2003) inventory plots with the remeasurement of those plots from 2004 to 2010; remeasurement intervals are shown for the Chugach National Forest in table 1 and for the Tongass National Forest in table 2. The period for remeasurement, which varied from 1 to 15 years, is a relatively short period to expect to see changes for such a large region. The varied interval of time for plot measurements complicates interpretation, as does the use of average annual values. For example, even if mortality rates were absolutely constant during the inventory period, an annual mortality rate calculated from plots remeasured after 1 year will be a little higher than the rate calculated from plots remeasured after a decade.

Detailed information on how measurements were taken can be found in the respective field manuals at http://www.fs.fed.us/pnw/fia/publications/fieldmanuals. Although the two national forests in Alaska are the focus of this report, the inventory crosses all ownerships (figs. 1 and 2). Plots were identified with each national forest using an administrative ownership variable in the FIA database. About 90.8

Table 1—Number of remeasured forested plots by years of measurement, Chugach National Forest

	Year of first measurement				
Year of second measurement	**1999**	**2001**	**2002**	**2003**	**All years**
2004	7	1	2	1	11
2005	4	2	3	0	9
2006	8	3	1	0	12
2007	7	2	4	0	13
2008	9	1	3	0	13
2009	6	3	3	0	12
2010	8	0	5	0	13
All years	49	12	21	1	83

Table 2—Number of remeasured forested plots by years of measurement, Tongass National Forest

	Year of first measurement					
Year of second measurement	**1995**	**1996**	**1997**	**1998**	**2000**	**All years**
2004	18	25	22	10	3	78
2005	21	15	22	22	2	82
2006	18	28	31	22	3	102
2007	24	24	26	13	0	87
2008	27	20	30	23	2	102
2009	23	20	33	11	2	89
2010	21	34	33	18	4	110
All years	152	166	197	119	16	650

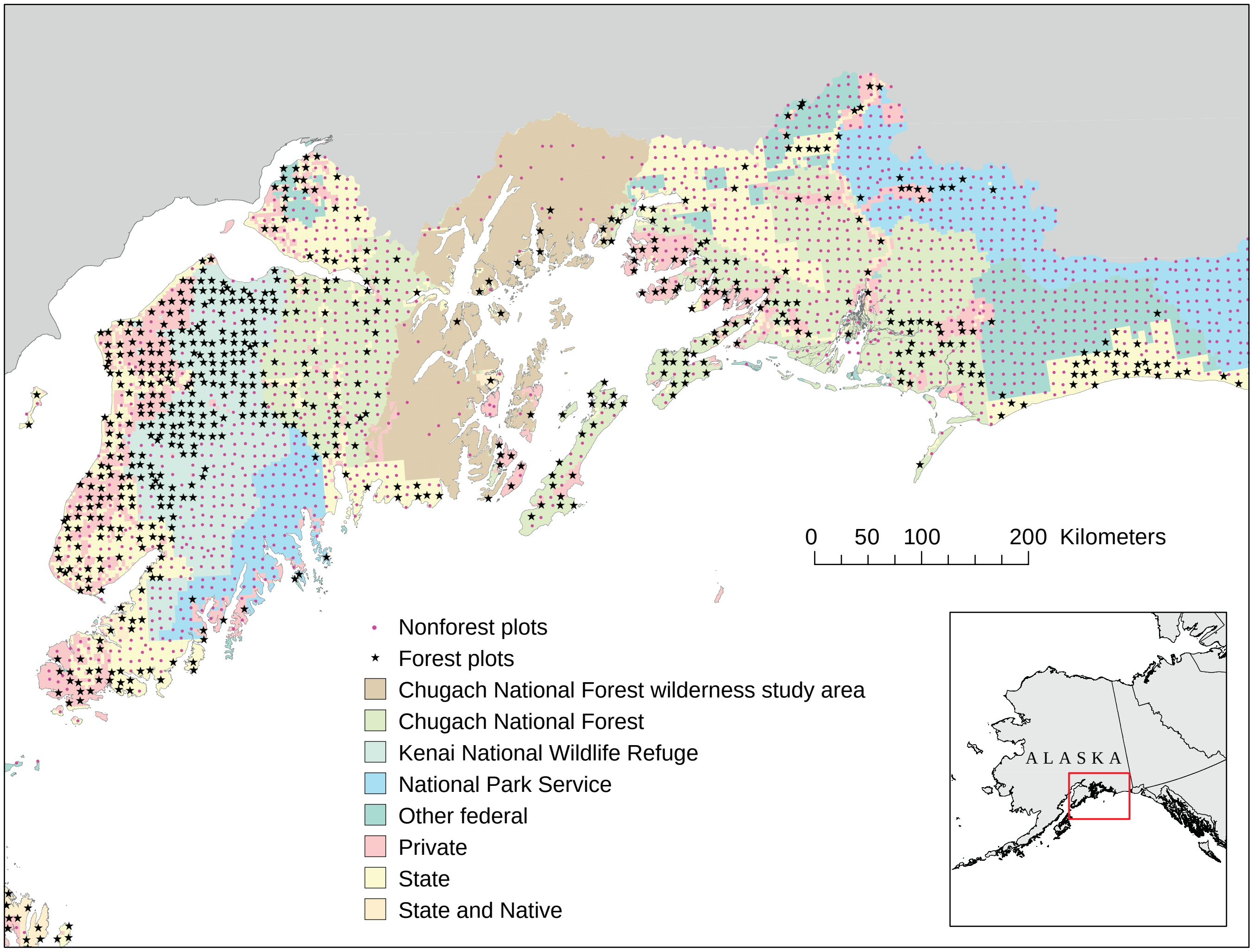

Figure 1—Forest inventory plots and ownership in and surrounding the Chugach National Forest, southeast Alaska. Depicted plot locations are approximate.

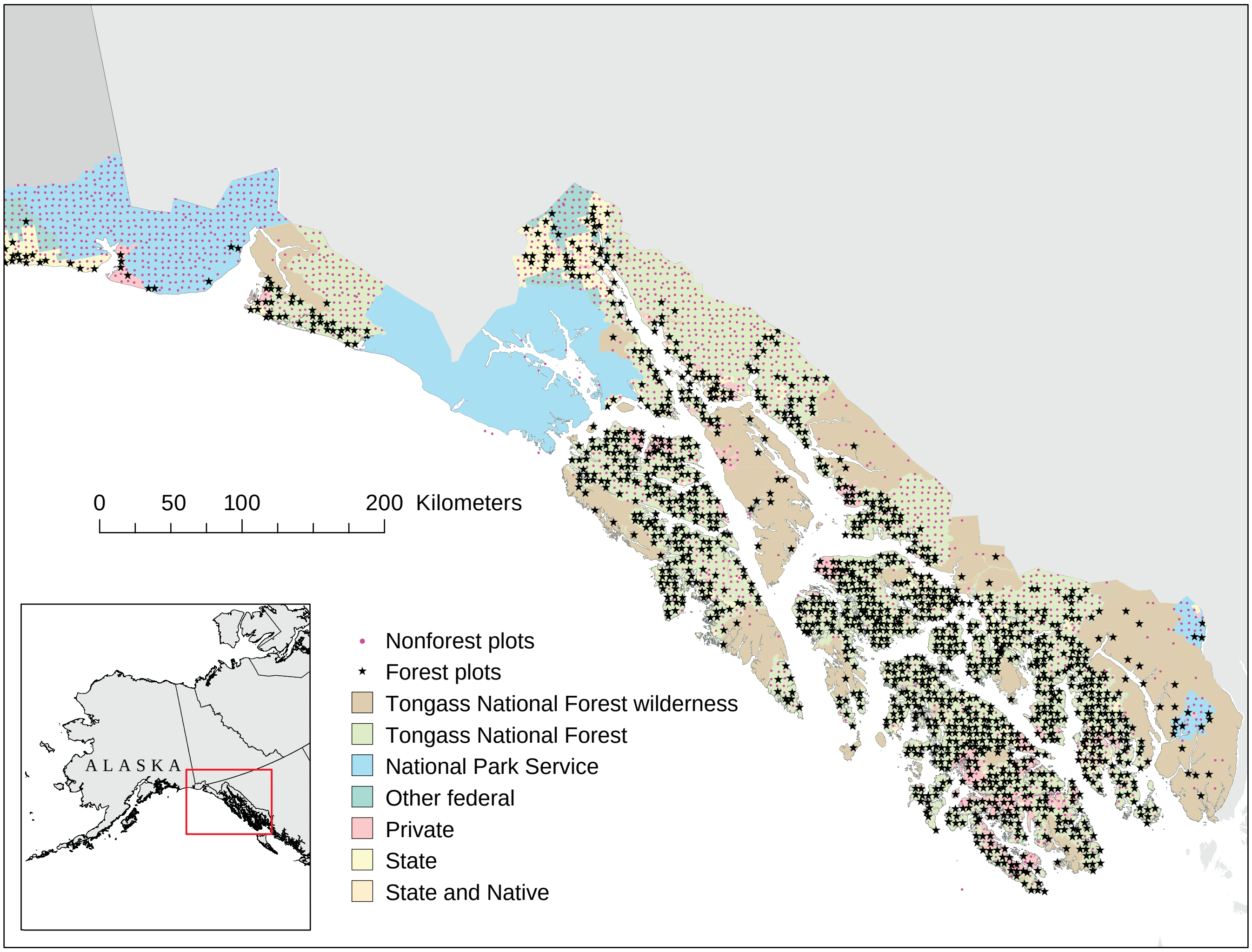

Figure 2—Forest inventory plots and ownership in and surrounding the Tongass National Forest, southeast Alaska. Depicted plot locations are approximate.

percent of the periodic inventory plots are being remeasured in the annual inventory, although plots that are inaccessible in either inventory reduce the number available for analysis. About 70 percent of the periodic plots (a random sample of the 90.8 percent) had been remeasured by the end of the 2010 field season.

For analysis of change, only remeasurement plots and only portions of plots that were forested in both periods were used. That results in estimates that usually are smaller and less precise than when either the full periodic dataset or the full annual dataset is used (tables 3, 4, 5, and 6). In general, the periodic inventory used a more restrictive definition of forest land, by excluding Krummholz forest and by using a canopy cover definition that was less likely to define an area as forest than was the stocking definition used from 2004 to 2010.

Table 3—Effect of different estimation methods on forest type area, Chugach National Forest

Forest type	Without wilderness study area				With wilderness study area[a]		
	Remeasurement plots only[b]		All 2004–2010 plots[c]		All 2004–2010 plots[c]		Adjustment factor[d]
	Total	SE	Total	SE	Total	SE	
	Thousand acres						
Yellow-cedar	—	—	—	—	—	—	—
Black cottonwood	20	12	18	12	18	12	0.90
Black spruce	5	6	5	6	5	6	1.00
Lodgepole pine	—	—	—	—	—	—	—
Mountain hemlock	287	45	351	45	784	158	2.73
Pacific silver fir	—	—	—	—	—	—	—
Paper birch	25	16	20	13	20	13	0.80
Quaking aspen	—	—	—	—	—	—	—
Sitka spruce	111	29	138	31	138	31	1.24
Western hemlock	127	32	140	33	140	33	1.10
Western redcedar	—	—	—	—	—	—	—
White spruce	20	12	23	13	23	13	1.15
All forest types	596	52	703	52	1135	160	1.90

[a] Includes wilderness study area plots measured in 2005. Because of the very small number of plots, this will not do well at representing forest in the wilderness study area.

[b] Does not include land that was defined as forest for only one of the inventories, or plots that were not included in both inventories; this method is what was used for estimates of change in this report and is labeled with "remeasurement plots only."

[c] Estimates also adjust for nonsampled (access denied or hazardous) plots. These estimates should match what would be produced from the national database using the current inventory and are labeled with "all 2004–2010 plots."

[d] For an approximate extrapolation of change estimates to all forest (including the wilderness study area), one could multiply carbon estimates for each forest type by this adjustment factor.

SE = Standard error of the estimate. The total plus or minus the standard error provides a 68 percent confidence interval, and the total plus or minus two standard errors is about a 95 percent confidence interval for the estimate.

Table 4—Effect of different estimation methods on carbon mass in live trees, Chugach National Forest

	Without wilderness study area				With wilderness study area[a]	
	Remeasurement plots only[b]		All 2004–2010 plots[c]		All 2004–2010 plots[c]	
Species	Total	SE	Total	SE	Total	SE
			Thousand tons			
Black cottonwood	358	221	413	243	413	243
Black spruce	—	—	9	7	9	7
Mountain hemlock	7,755	1,492	9,382	1,510	20,839	6,488
Paper birch	147	75	158	77	158	77
Sitka spruce	5,553	1,177	8,309	1,792	10,292	2,409
Western hemlock	6,637	1,919	7,182	1,860	7,270	1,863
White spruce	358	138	497	180	497	180
All species	20,809	2,707	25,951	3,117	39,478	7,822

[a] Includes wilderness study area plots measured in 2005. Because of the very small number of plots, this will not serve well at representing forest in the wilderness study area.

[b] Does not include land that was defined as forest for only one of the inventories, or plots that were not included in both inventories or any trees ≤5 in diameter at breast height; this method is what was used for change estimates in this report and is denoted with the note “remeasurement plots only.”

[c] Estimates also adjust for nonsampled (access denied or hazardous) plots. This method is denoted by the use of “all 2004–2010 plots.”

SE = Standard error.

Table 5—Effect of different estimation methods on forest type area, Tongass National Forest

	Without inaccessible wilderness area				With inaccessible wilderness area[a]		
	Remeasurement plots only[b]		All 2004–2010 plots[c]		All 2004–2010 plots[c]		
Forest type	Total	SE	Total	SE	Total	SE	Adjustment factor[d]
			Thousand acres				
Yellow-cedar	1,261	99	1,433	101	2,199	221	1.74
Black cottonwood	36	18	36	17	98	59	2.72
Lodgepole pine	286	48	348	50	348	50	1.22
Mountain hemlock	820	78	1,229	90	2,013	214	2.45
Red alder	22	12	36	16	36	16	1.64
Sitka spruce	434	60	590	67	839	130	1.93
Subalpine fir	—		4	4	4	4	na
Western hemlock	2,374	117	2,479	114	3,219	222	1.36
Western redcedar	575	66	587	63	960	148	1.67
All forest types	5,808	105	6,741	101	9,715	233	1.67

[a] Includes wilderness area plots measured in 2005.

[b] Does not include land that was defined as forest for only one of the inventories, or plots that were not included in both inventories; this method is what was used for estimates of change in this report and is labeled with "remeasurement plots only."

[c] Estimates also adjust for nonsampled (access denied or hazardous) plots. These estimates should match what would be produced from the national database using the current inventory and are labeled with "all 2004–2010 plots."

[d] Calculated as the estimate from all plots divided by the estimate from remeasurement plots only. For an approximate extrapolation of change estimates to all forest (including the wilderness study area), one could multiply carbon estimates for each forest type by this adjustment factor.

SE = Standard error of the estimate. The total plus or minus the standard error provides a 68 percent confidence interval, and the total plus or minus two standard errors is about a 95-percent confidence interval for the estimate.

Table 6—Effect of different estimation methods on carbon mass in live trees, Tongass National Forest

	Without wilderness study area				With wilderness study area[a]	
	Remeasurement plots only[b]		All 2004–2010 plots[c]		All 2004–2010 plots[c]	
Species	Total	SE	Total	SE	Total	SE
	Thousand tons					
Yellow-cedar	40,539	2,691	45,318	2,695	70,905	5,831
Black cottonwood	480	244	502	247	1,549	978
Lodgepole pine	4,563	485	4,840	488	6,923	1,093
Mountain hemlock	36,213	2,821	42,256	2,958	74,999	9,209
Oregon crab apple	1	1	1	1	1	1
Pacific silver fir	7	9	60	45	60	45
Red alder	717	194	1,824	390	2,092	437
Sitka spruce	65,426	5,916	81,481	6,252	116,012	11,883
Subalpine fir	144	102	127	83	127	83
Western hemlock	153,171	8,100	161,065	7,718	211,628	11,876
Western redcedar	20,174	2,209	21,566	2,144	45,051	8,571
All species	321,436	10,811	359,040	10,391	529,347	19,558

[a] Includes wilderness study area plots measured in 2005. Because of the very small number of plots, this will not serve well at representing forest in the wilderness study area.

[b] Does not include land that was defined as forest for only one of the inventories, or plots that were not included in both inventories or any trees ≤5 in diameter at breast height; this method is what was used for change estimates in this report and is denoted with the note "remeasurement plots only."

[c] Estimates also adjust for nonsampled (access denied or hazardous) plots. This method is denoted by the use of "all 2004–2010 plots."

SE = Standard error.

Helicopter use is not allowed within much of the wilderness on the Tongass and the wilderness study area on the Chugach. Owing to this restriction, these areas were inaccessible during the periodic inventory. During the annual inventory, access was permitted in 2005, and 50 forested plots were measured in Tongass wilderness and 9 forested plots in the Chugach wilderness study area. However, after an environmental assessment, the areas were again removed from the inventory in 2006. Because none of the wilderness plots had remeasurement data, they are excluded from all estimates of change in carbon storage in this report but were included in comparisons of methods of estimations of forest type area (tables 3 and 5) and carbon mass (tables 4 and 6).

On the Chugach, of the 107 nonwilderness annual plots measured between 2004 and 2010, just 83 were remeasured plots and only two of these had a record of past silvicultural activities, thus managed forest is not reported as a separate category for the Chugach National Forest. On the Tongass, there are 801 nonwilderness forested FIA plots that were measured between 2004 and 2010; of those, 650 are remeasured plots that were initially established in the 1995–2000 inventory.

On the Tongass, 58 stands with remeasurement data had a record indicating some type of vegetation manipulation, usually clearcutting. (Note: stands are called "condition classes" by FIA, and denote an area of forest that is homogenous with respect to forest type, owner group, stand size, regeneration status, tree density, and reserved status. Although most plots intersect only a single stand, many plots intersect multiple stands.) Fifty-eight managed stands were sufficient to allow some separate analysis of managed and unmanaged forest, which was helpful because of the substantially different trajectories in carbon storage and flux. Classification as managed forest was based on a combination of time since clearcut harvest (a variable that was collected in the periodic inventory), records of trees harvested between the two inventory measurements, written plot descriptions, and the forest's geographic information system layer for stand management. The managed category also includes some residual trees within harvest areas, and a few stands with selective or salvage logging, and thus the plots in the managed forest category include areas with complex structure and older trees in addition to areas of even-aged second growth.

Estimates of carbon in down wood debris[1] (DWD) are included based on transects that were installed in the periodic inventory (1995–2003). Although DWD was measured on a 1/16th subsample of plots from 2004 to 2010, the small number of these plots means it is not possible to measure change in DWD with sufficient precision for meaningful estimates. Down woody debris measurements were taken only on the first stand (condition class) of each plot, which causes more imprecision compared to live tree or snag estimates. Some plots with forest did not have DWD measurements taken, either because of snow or because only a small portion of the plot contained forest. Although this could create some bias in the estimates, less than 2.4 percent of the sampled forested area fell into this category, so the bias is likely to be minimal.

Because of the many procedural differences between the 1995–2003 inventory and the 2004–2010 inventory, trying to estimate change by simple comparison of

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[1] The term "snag" is equivalent to the term "standing dead tree" used by FIA, and is defined as a dead tree that is at least 5 in d.b.h., has a bole with an unbroken length of at least 4.5 ft, and is less than a minimum number of degrees from vertical. Minimum lean angles used differed between the first and second inventories.

the two inventories would produce inaccurate estimates of carbon and biomass change for Alaska's national forests. To be able to estimate change accurately, a number of edits to the dataset were required:

(1) Building a stratification customized for remeasurement.

(2) Reconciling every tree in the first inventory for its status at remeasurement (live, snag, harvested, or dead and down).

(3) Reconciling the first inventory for (a) trees that would not meet the current definition for inclusion; (b) trees that had been missed; (c) species codes that were incorrect; and (d) incorrect tree status, most typically trees that had been recorded as dead but were found to have a few live branches in the second inventory.

(4) Adjusting for a definition of forest that changed from a cover-based to a stocking-based definition by including only portions of plots that were forested in both periods. Although this was the best choice available, it prevented the calculation of estimates of biomass/carbon change associated either with forest encroachment (such as increasing treeline) or permanent deforestation (such as when land is developed for housing or roads).

Statistical methods for calculating standard errors are the current standard methods used by FIA, as described in Bechtold and Patterson (2005). Some estimates report carbon mass per forest acre; these are produced using a combined ratio of means estimator (Cochran 1977). Where change estimates are called significant, it means that the 95 percent confidence interval (CI) does not contain zero; the 95-percent CI is created by multiplying the estimated standard error by 1.96 and adding (or subtracting) it from the estimated mean.

Standard FIA reports, including the most recent report for coastal Alaska (Barrett and Christensen 2011), drop nonsampled plots (hazardous or access denied) from the stratification process, so that estimates approximate population totals. The disadvantage of doing this is that it requires an assumption that nonsampled plots are no different from the strata mean estimated from remaining plots; as nonsampled plots tend to be on steeper ground (when hazardous) or at high elevation (where snow often prevents access), this assumption can be incorrect. In this report, the nonsampled plots were left in the stratification, with the result that estimated population totals will be smaller. Tables 3 through 6 show the difference that results from using these different methods. In addition, the area that was sampled for remeasurement is smaller than the area currently in the inventory, because the current inventory includes 1 year of data from national forest wilderness and the boundaries for that wilderness shifted between inventories.

If extrapolation to the entire forest is desired, one might multiply per-acre values for specific forest types by the additional estimated land area. For example, in the Chugach National Forest, the area of Sitka spruce forest is estimated as 111,000 ac using the remeasurement data, and 138,000 ac when the wilderness study area is included, or an increase of 24 percent (table 3), and the remeasurement data provides an estimate that carbon mass in Sitka spruce forest type increased at a rate of 56,000 tons per year. One could then make an educated guess that the increase including the wilderness study area was 56,000 × 1.24 = 69,400 tons. This is just a rough approximation, however, as there is no guarantee that Sitka spruce forest in the wilderness study area changed similarly to Sitka spruce forest outside of the wilderness study area.

Carbon Calculations

The aboveground carbon pools estimated in this report are those of (1) the live tree pool; (2) the snag[2] pool; and (3) the DWD (or log) pool (fig. 3). Carbon fluxes that are estimated in this report are (a) recruitment, (b) growth, and (c) mortality for the live tree pool and (d) snag recruitment, (e) decay, and (f) falldown for the snag pool (fig. 3). Net change in the live tree pool is measured as recruitment plus growth, minus mortality and harvest. Net change in the snag pool is equal to snag recruitment (part of live tree mortality) minus decay, falldown, and salvage. Within the forest ecosystem are a number of carbon pools that are not included here, such as carbon within non-tree vegetation, carbon within tree roots and stumps, and carbon in soil and litter. There are also a number of fluxes that are not estimated, including carbon moving from vegetation to soil or water, or decay of logs. Some current research projects are underway in the region to provide information about these processes.

Several different methods are available for calculating biomass and carbon for Alaska forests from individual tree measurements of diameter, species, and height. In this report, species-specific direct biomass estimators published in the research literature have been used, most of them developed for British Columbia (for rain forest species) or Alberta (for boreal species). A different method, which has typically been developed to address species without direct biomass equations, is called the “component ratio” method. In this method, tree volume equations are modified with estimated density to derive biomass estimates for the main part of the bole, and ratios are then applied to estimate biomass of components such as bark, top,

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[2] The data for down wood debris estimates is courtesy of Mikhail Yatskov, Ph.D. candidate, Oregon State University.

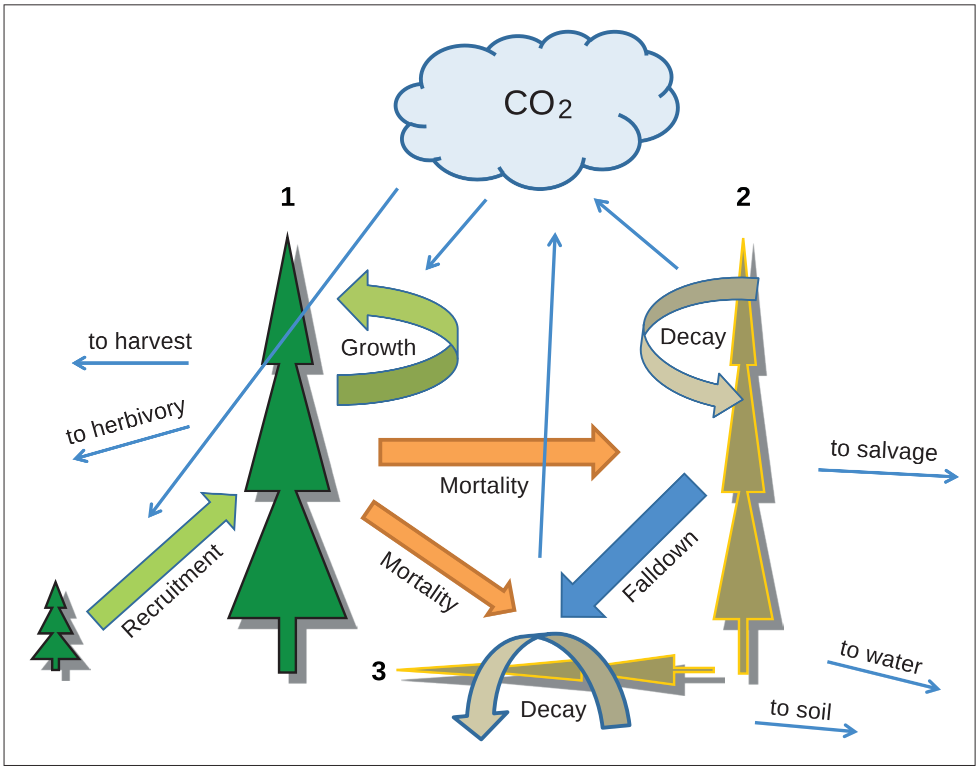

Figure 3—Carbon flux between the (1) live, (2) snag, and (3) log pools of the forest.

branches, and foliage. This method has commonly been used in other states, but because of the low tree species diversity in Alaska, and resulting availability of species-specific biomass equations for all our major species, the component ratio method has not been used by FIA in Alaska. A third method, also not used in this report, has been used to produce many of the biomass variables in the database at the national FIA website (http://www.fia.fs.fed.us/tools-data/default.asp), and it is based on the component ratio method with adjustments based on Jenkins et al. (2003) and others (see Woudenberg et al. 2013, appendix J).

Although attempts to develop a unified national method provides some consistency across regions, when used at a regional level these can produce estimates very different from estimates that use regional equations (e.g., Fried and Zhou 2008). The only way to compare accuracy of competing methods is to test them against independent datasets, which are very scarce because of the cost of drying and weighing trees. In general, because the regional equations are species specific, are based on both diameter and height, were derived from research specifically meant to estimate biomass, and are built from observations for trees typically sampled from ecosystems similar to where they are being applied, the local equations are probably preferable for any use other than national-level estimates. The regional variables are also available as part of the database on the national FIA website, and can be found in a separate tree table. In both this report and standard national FIA applications, carbon mass is assumed to be equal to 0.5 of dry biomass. Because of the simplicity of conversion, estimates are shown for carbon mass, and it is left to the reader to multiply by two if dry biomass estimates are desired.

The regional equation sets for Alaska trees come from the following published sources:

Tree type	**Biomass citation**
Seedlings	Alemdag (1984)
Paper birch	Alemdag (1984)
Black spruce	Manning et al. (1984)
Cottonwood	Singh (1984)
Lodgepole pine[3]	Manning et al. (1984)
Mountain hemlock	Shaw (1979)
Pacific silver fir	Krumlik and Kimmins (1973)
Red alder	Standish (1983)
Sitka spruce	Standish (1983)
Tamarack	Singh (1984)
Western hemlock	Shaw (1979)
Western redcedar	Shaw (1979)
White spruce	Manning et al. (1984)
Yellow-cedar	Standish (1983)

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[3] Based on the location of plots, all sampled lodgepole trees are believed to be the shore pine subspecies (*Pinus contorta* Dougl. Ex Loudon subsp. *contorta*).

Currently, most regions of the country, including Alaska, do not have adjustments for portions of tree tops that are broken off (“missing tops”) in the national or regional biomass variables in the publicly available FIA database. However, missing tops are being increasingly accounted for in biomass or volume variables within some regional databases, thus biomass estimates for snags in this report have been adjusted to account for missing tops using simple conic geometry. No deductions were made for missing tops on live trees (which is much less common than missing tops on snags), because information for this had not been collected in the periodic southeast Alaska inventory.

Deductions for decay class have also typically not been available in national and regional databases. However, a Forest Service publication was recently developed to provide information on adjustments for decay in snags and logs (Harmon et al. 2011) and adjustments to the component-ratio variables in the national database are now being made. For this reason, wood decay deductions based on decay class estimated in the field (using Harmon et al. 2011, table 6) were made for both snags and logs in this report. These decay class deductions, along with missing top deductions, will produce some differences from values for snags published in Andersen (2011). Decay class for snags was set at the values measured during the periodic inventory because of a change in methodology, so estimates of carbon lost in snag decay represent reductions from fragmentation rather than progression to a higher decay class.

Chugach National Forest

Excluding its wilderness study area, tree biomass and carbon on the Chugach National Forest is fairly evenly split between three tree species: mountain hemlock, western hemlock, and Sitka spruce (table 7). White spruce, black cottonwood, and paper birch combined comprise only about 5 percent of total carbon mass, and other species such as black spruce or quaking aspen comprise less than 1 percent of carbon mass. Looking at the distribution by forest type instead of species provides similar results (table 8).

Compared to other species, white spruce has a higher proportion of carbon in snags (table 7; the white spruce proportion is 202/699 = 29 percent compared to proportions of 2 to 9 percent for other species). This is likely the result of spruce beetle outbreaks in the 1990s, as is the slightly elevated proportion of dead Sitka spruce (9 percent) compared to the two hemlock species (4 percent for mountain hemlock and 5 percent for western hemlock).

Although the total carbon mass in mountain hemlock, western hemlock, and Sitka spruce forest types is similar within the Chugach National Forest, the density is much higher for the western hemlock and Sitka spruce forest types (table 9).

Overall, there was a 4.5-percent increase in carbon mass in live trees in the Chugach National Forest from the first inventory (1999–2003) to the second inventory (2004–2010) (table 10). A recent increase in biomass is not unusual among national forests. Most U.S. national forests have been experiencing recent increases in carbon and biomass (Heath et al. 2010), with increases in recent decades generally attributed to temporal changes in harvesting or the long-term effect of fire suppression (Goodale et al. 2002).

What makes the observed 4.5-percent increase interesting is that neither of these causes is a satisfactory explanation for the Chugach National Forest. With few roads, challenging topography, and high recreational and subsistence use, little harvest has occurred on the Chugach during the past half century. Forested areas

Table 7—Carbon mass in live trees and snags on the Chugach National Forest

	Live trees		Snags		All trees	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
			Thousand tons			
Black cottonwood	413	243	11	8	424	243
Black spruce	9	7	1	1	10	8
Mountain hemlock	9,382	1,510	418	96	9,800	1,545
Paper birch	158	77	4	5	162	77
Quaking aspen	—	—	4	4	4	4
Sitka spruce	8,309	1,792	860	281	9,169	1,928
Western hemlock	7,182	1,860	359	111	7,541	1,923
White spruce	497	180	202	124	699	269
All species	25,951	3,117	1,859	345	27,810	3,271

Note: Estimates are created from all 2004–2010 plots but do not include the wilderness study area.

SE = Standard error.

Table 8—Carbon in live trees and snags by forest type within the Chugach National Forest

	Live trees		Snags		All trees	
Forest type	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
			Thousand tons			
Black cottonwood	632	419	33	32	665	425
Black spruce	5	6	6	8	11	14
Mountain hemlock	9,375	1,731	788	222	10,163	1,851
Paper birch	98	82	7	6	105	88
Sitka spruce	7,112	2,277	409	175	7,521	2,402
Western hemlock	8,483	2,373	602	241	9,085	2,494
White spruce	247	139	14	10	260	147
All forest types	25,951	3,117	1,859	345	27,810	3,271

Note: Estimates are created from all 2004–2010 plots but do not include the wilderness study area.

SE = Standard error.

Table 9—Carbon mass per acre in trees by forest type in the Chugach National Forest

Forest type	Live trees Mean	Live trees SE	Snags Mean	Snags SE	All trees Mean	All trees SE
			Pounds per acre			
Black cottonwood	48,962	30,191	2,589	2,133	51,551	30,052
Black spruce	2,023	410	2,504	507	4,527	917
Mountain hemlock	53,403	7,030	4,488	1,090	57,890	7,359
Paper birch	9,871	5,237	694	427	10,565	5,658
Sitka spruce	102,917	23,682	5,922	2,132	108,839	24,889
Western hemlock	121,024	16,960	8,591	2,727	129,616	16,729
White spruce	21,766	3,906	1,197	492	22,964	4,036
All forest types	73,873	7,599	5,292	909	79,165	7,881

Note: Estimates are created from all 2004–2010 plots but do not include the wilderness study area.

SE = Standard error.

Table 10—Change in carbon mass in live trees by species from the first inventory (1999–2003) to the second inventory (2004–2010), Chugach National Forest

Species	Carbon 1999–2003 Total	Carbon 1999–2003 SE	Mortality Total	Mortality SE	Growth Total	Growth SE	Ingrowth Total	Ingrowth SE	Net change Total	Net change SE	Net change as percent of 1999–2003
	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	*Thousand tons*	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	*Percent*
Black cottonwood	358	221	17	13	55	39	1	2	40	41	11
Mountain hemlock	7,755	1,492	151	97	349	162	28	8	226	192	3
Paper birch	147	75			22	15			22	15	15
Sitka spruce	5,553	1,177	205	125	572	134	38	15	405	168	7
Western hemlock	6,637	1,919	125	59	269	175	25	9	168	177	3
White spruce	358	138	6	6	66	29	18	11	78	35	22
All species	20,809	2,707	504	167	1,333	292	110	22	939	325	5

Note: Data are based on remeasurement plots only, which do not include trees < 5 in diameter at breast height.

SE = Standard error.

are within a comparably low fire frequency regime, owing to relatively low temperatures, high cloud cover, and ample precipitation in the summer months.

The last major spruce beetle outbreak in the region occurred in the 1990s, and the area most affected was not within the Chugach boundaries. Although recovery from the spruce beetle could be contributing to some biomass and carbon increase, one might expect the majority of effect to be delayed until regenerating trees approach the point of maximum mean annual increment, which would be quite a few years in the future. However, there was a previous large outbreak in the 1970s and 1980s (Berg et al. 2006), and there could be some ongoing recovery from that.

Likewise, there could have been other disturbances in the past (wind events, long-ago harvests, insect outbreaks) that are now contributing to the net increase of live tree biomass.

Climate change or CO_2 increase could also be contributing to the higher biomass storage. To put the observed changes into context, with the possible exception of a few small refugia, almost all of the Chugach was covered by ice during the last glacial maximum approximately 23,000 years BP (Reger et al. 2007). Pollen studies suggest that migration of coastal tree species back into the contemporary forest lands has been a long, slow process, with mountain hemlock and Sitka spruce moving into Prince William Sound only around 3,000 years BP (Ager 1999). Many of the Sitka spruce and hemlock trees in the Chugach were alive at the end of the Little Ice Age in the 1850s, and warming since then is thought to have facilitated the expansion of black spruce in the Kenai lowlands (Berg et al. 2009). In more recent times, trees included in these inventories would have been affected by the relatively warmer, drier phase of the Pacific Decadal Oscillation, which began in the mid-1970s (Whitfield et al. 2010). Weather station data in the region show that average growing season temperatures during the inventory period (1999–2010) were slightly warmer than the 30-year climate "normal" preceding the start of the inventory (1969–1998) (fig. 4).

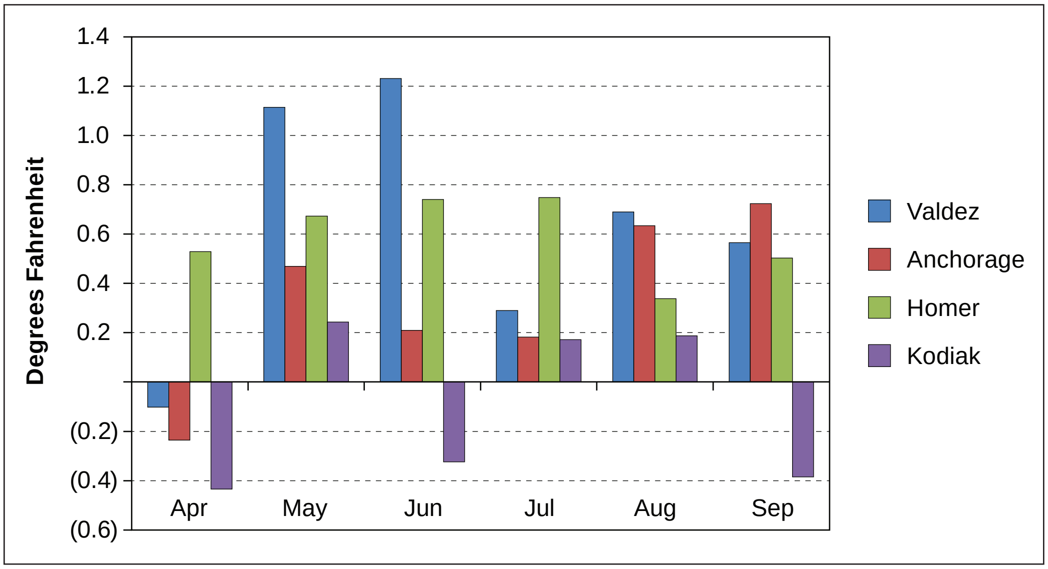

Figure 4—Average summer temperatures in the Chugach area were slightly warmer during the inventory period compared to the climate "normals" preceding the start of the inventory. Bars indicate average inventory summer temperature minus preceding 30-year averages.

Higher elevation treelines and afforestation resulting from lower water tables, although they have been observed in this region (Berg et al. 2009, Dial et al. 2007), are not explanatory causes for the observed carbon mass increase because of the methods that were used, which analyzed only trends within existing forest. However, climate warming and CO_2 increases could be affecting carbon storage and flux in a variety of ways. Growth rates will generally increase with increasing CO_2 or with warmer temperatures, provided that soil water availability is not limiting. Maximum biomass density in forests tends to be relatively constant across a broad range of sites for any given tree species owing to self-thinning (Reineke 1933, White 1981), so that the stand density index (in the absence of disturbance) can be expected to be less affected by climate change or CO_2 increase than either mortality or growth rates. But there could be displacement of lower volume species (such as hardwoods or white spruce) by higher volume species (such as Sitka spruce and western hemlock). Increased stocking could occur in more marginal habitats as growing conditions improve (Vanclay and Sands 2009). More favorable growing conditions might even allow individual trees to reach a taller maximum height (Ryan and Yoder 1997).

Teasing out the best explanations for the observed change is difficult because of the relatively small number of plots. When looked at as an average annual rate, all the tree species show a nominal increase in live tree carbon mass. However, only Sitka spruce and white spruce have increases that are more than 1.96 times the standard error from zero (indicating statistically significant differences for a 95-percent CI), with estimated annual increases of 3.6 percent for white spruce and 1 percent for Sitka spruce (tables 10 and 11). By forest type, the highest increase in per-acre carbon occurred in the cottonwood, western hemlock, and white spruce forest types (table 12).

Although the Chugach's 165,000 tons per year net accumulation in live tree carbon may seem small compared to the live tree carbon pool of 26 million tons, it is a significant local carbon sink. The equivalent CO_2 sequestration rate would be 605,000 tons per year, given the equivalency rate of 3.67 tons of CO_2.

However, the net increase of live tree carbon on the Chugach is just one component of carbon dynamics within the larger regional landscape. During the same period, there was a decrease in live tree carbon mass on private lands in the southeast/south-central region comparable in magnitude to the increase observed on the Chugach. In addition, we do not know if the increase in live tree carbon on the Chugach is being augmented or counterbalanced by changes in the DWD and belowground carbon pools.

Table 11—Annual change in live tree carbon mass by species for the Chugach National Forest

Species	Total	SE
	Thousand tons per year	
Black cottonwood	5	4
Mountain hemlock	65	55
Paper birch	3	2
Sitka spruce	56	23
Western hemlock	22	22
White spruce	13	6
All species	165	67

Note: Data are based on remeasurement plots only, which do not include trees < 5 in diameter at breast height.

SE = Standard error.

Table 12—Per-acre annual change in live tree carbon mass by forest type, Chugach National Forest

Forest type	Mean	SE
	Pounds per acre per year	
Black cottonwood	964	448
Black spruce	23	—
Mountain hemlock	493	406
Paper birch	377	142
Sitka spruce	383	426
Western hemlock	787	354
White spruce	773	297
All forest types	552	225

Note: Data are based on remeasurement plots only, which do not include trees < 5 in diameter at breast height.

SE = Standard error.

There was an estimated 1.6-percent decrease in carbon stored in snags, which was not significantly different from zero (table 13). When this is shown as per-acre annual change, all the forest types except Sitka spruce had a nominal decrease in snags but none was statistically significant at the 95 percent CI except paper birch (table 14). Estimates for snag carbon mass typically have higher sampling error than live trees. In addition, there is some additional uncertainty for the estimates of snag loss, owing to data collection procedures (see discussion of snag estimates for the Tongass National Forest).

When the DWD transects from the periodic inventory were used, there was an estimated 10 (±2) Mg per ha of carbon mass in down logs in forest lands within the Chugach National Forest, or 4.6 (±0.8) tons per acre. There are not enough plots to precisely estimate DWD carbon mass by forest type within the Chugach, so in table 15, values for these forest types within the larger inventory region are shown. Although down wood carbon mass in the white spruce, mountain hemlock, and western hemlock forest within the Chugach is similar to the regional values, the carbon mass in logs in Sitka spruce forest is about half within the Chugach compared to the region.

For the landscape analysis, using the full 2004–2010 dataset and excluding the wilderness study area, there were 26 forested plots in the Copper River landscape, 35 forested plots in the Kenai Peninsula landscape, and 46 forested plots in the

Table 13—Annual carbon mass change in snags by species, Chugach National Forest

Species	Time 1 carbon		Snag recruitment		Snag fragmentation		Snag falldown		Net change	
	Total	SE	Total	SE	Total	SE	Total	SE	Total	SE
					Thousand tons					
Black cottonwood	32	31	1	1	0	0	4	4	-3	4
Black spruce	1	1	—	—	—	—	—	—	—	—
Mountain hemlock	478	111	14	10	1	2	19	7	-6	13
Paper birch	4	5	—	—	0	0	—	—	0	0
Quaking aspen	18	14	—	—	0	0	1	1	-2	1
Sitka spruce	439	175	24	17	6	4	3	3	15	17
Western hemlock	425	144	5	3	7	3	10	5	-12	6
White spruce	342	210	1	1	10	9	13	7	-22	15
All species	1,738	337	46	19	23	11	50	12	-28	27

Note: Data are based on remeasurement plots only, which do not include trees < 5 in diameter at breast height.

SE = Standard error.

Table 14—Per-acre annual change in carbon mass of snags by forest type, Chugach National Forest

Forest type	Mean	SE
	Pounds per acre	
Black cottonwood	-431	398
Black spruce	-343	—
Mountain hemlock	-107	141
Paper birch	-203	98
Sitka spruce	195	279
Western hemlock	-182	78
White spruce	-424	354
All forest types	-95	91

Note: Data are based on remeasured plots only, which do not include trees < 5 in diameter at breast height.

SE = Standard error.

Table 15—Carbon mass in downed logs by forest type

	Chugach National Forest		All of inventory region	
Forest type	Mean	SE	Mean	SE
		Pounds per acre		
Black cottonwood	15,446	8,036	5,268	1,295
Black spruce	580		2,500	580
Mountain hemlock	4,241	1,116	4,152	491
Paper birch	11,205	3,661	5,536	670
Quaking aspen			4,643	1,920
Sitka spruce	9,241	4,196	17,768	3,839
Western hemlock	19,554	5,848	18,973	982
White spruce	7,143	2,857	7,009	2,054
All forest types	9,152	1,607	11,518	670

Note: Estimates use data from the 1995–2003 inventory.

Prince William Sound landscape. For the remeasured dataset, there were 23 forested plots in the Copper River landscape, 25 plots in the Kenai landscape, and 35 plots in the Prince William Sound landscape (fig. 5). Although the relatively small number of plots in each landscape makes estimates imprecise, the nominal carbon mass density decreases as one moves westward from the Copper River landscape, across the Prince William Sound landscape, and into the Kenai landscape (table 16); a decrease in density could be explained by climate limiting the growth of Sitka spruce and western hemlock and becoming more favorable for smaller boreal species (white spruce and hardwoods) as one moves westward across the forest.

For the forest overall, the mean storage of 69,800 lbs per acre (= 78.2 Mg/ha) in live tree carbon density is less than the 94.2 Mg/ha estimated for Chugach National Forest by Heath et al. (2011). The 84,800 lbs per acre (= 95.0 Mg/ha) in aboveground tree carbon is split as 82 percent live trees, 7 percent in snags, and 11 percent in logs (table 16). The carbon in unmeasured pools (forest floor, understory vegetation, soil organic carbon, and roots) could exceed the aboveground tree carbon.

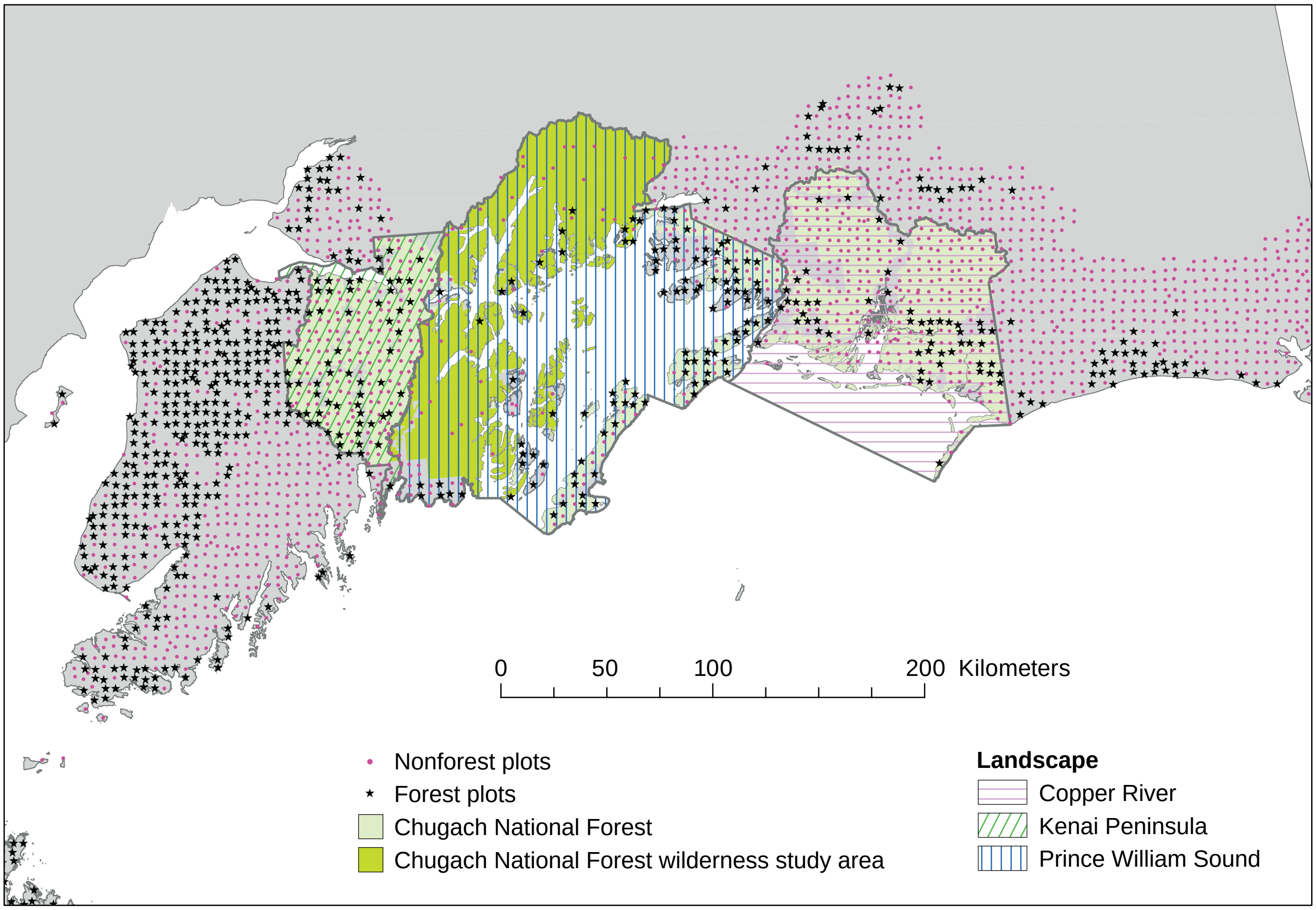

Figure 5—The three landscape areas (Copper River, Kenai Peninsula, and Prince William Sound) within the Chugach National Forest.

Table 16—Carbon pools and flux for three Chugach landscapes

	Landscape							
	Copper River		Prince William Sound		Kenai Peninsula		Chugach National Forest	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Pool:	*Pounds per acre*							
Live trees[a]	76,398	16,659	76,973	12,715	52,834	11,255	69,816	7,692
Snags[a]	4,476	1,530	5,435	933	7,587	2,779	5,832	1,011
Logs[b]	14,701	5,348	7,000	1,786	7,897	1,888	9,138	1,625
Total	95,575		89,408		68,318		84,786	
Flux—live trees:	*Pounds per acre per year*							
Growth	1,362	803	398	170	761	125	733	210
Recruitment	75	26	27	7	75	17	52	9
Mortality	(144)	66	(337)	152	(139)	94	(233)	79
Flux—snags:	*Pounds per acre per year*							
Snag recruitment	65	29	233	129	95	74	153	65
Snag fragmentation	(46)	23	(70)	32	(120)	103	(79)	35
Snag falldown	(134)	79	(131)	45	(258)	75	(169)	37

Note: Does not include trees ≤ 5 in diameter at breast height.

[a] Based on data from remeasurement plots only.

[b] Based on data collected from 1999 to 2003.

SE = Standard error.

Tongass National Forest

Including its wilderness area, aboveground live and snag carbon on the Tongass National Forest is estimated to be 601 (± 21) million tons on an estimated 9.715 million ac of forest. Some 233 million tons (39 percent) of this carbon is on land that is legally excluded from timber harvesting, such as formally designated wilderness. Using the remeasurement database, an estimated 448,000 ac of forest fell into the “managed” category (i.e., had some previous silvicultural activity).

Excluding inaccessible wilderness, the estimated amount of carbon stored in western hemlock trees is more than double that of any other species (table 17). Other species accounting for substantial amounts of carbon are Sitka spruce, yellow-cedar, mountain hemlock, and western redcedar. Sitka spruce and cottonwood forest types have a relatively small amount of tree carbon in snags, only 6 percent of total tree carbon mass, while western redcedar, lodgepole (shore) pine, and yellow-cedar forest types have a relatively large proportion of carbon in snags,

Table 17—Carbon mass in live trees and snags by species on the Tongass National Forest

	Live trees		Snags		All trees	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
			Thousand tons			
Yellow-cedar	45,318	2,695	10,793	975	56,111	3,120
Black cottonwood	502	247	78	54	580	289
Lodgepole pine	4,840	488	1,065	146	5,905	567
Mountain hemlock	42,256	2,958	4,378	490	46,634	3,195
Oregon crab apple	1	1	4	5	5	5
Pacific silver fir	60	45	—	—	60	45
Red alder	1,824	390	51	25	1,874	395
Sitka spruce	81,481	6,252	7,321	1,103	88,802	6,486
Subalpine fir	127	83	40	34	167	93
Western hemlock	161,065	7,718	24,019	1,521	185,084	8,483
Western redcedar	21,566	2,144	3,242	457	24,808	2,454
All species	359,040	10,391	50,991	2,248	410,030	11,119

Note: Data are from all 2004–2010 plots; inaccessible wilderness areas are not included.

SE = Standard error.

at 20, 17, and 17 percent, respectively (table 18). On a per-acre basis, the western hemlock and Sitka spruce forest types have the highest amount of carbon (table 19).

Changes Between Inventories

Change in live tree carbon by species—

There was no significant change in live tree carbon mass overall between the two inventories (table 20), and there was no significant change when looked at separately as unmanaged land (table 21) or managed land (table 22). There was a significant increase of red alder live tree carbon mass on both managed and unmanaged lands. On unmanaged lands, western redcedar live tree carbon mass had a significant increase, estimated as a 6.6-percent increase from the first inventory. On managed lands, there was also a marginally significant increase in Sitka spruce live tree carbon mass (table 22) and a significant decrease in yellow-cedar live tree carbon mass. Annual rates of change are shown in table 23.

Change in live tree carbon by forest type—

Carbon flux attributable to growth and recruitment of live trees is 690 lbs per acre per year on managed lands and 1,608 lbs per acre per year on unmanaged lands. In general, in unmanaged forest, forest types with high carbon flux in growth and

Table 18—Carbon mass in live trees and snags by forest type within the Tongass National Forest

	Live trees		Snags		All trees	
Forest type	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
			Thousand tons			
Yellow-cedar	46,734	4,268	9,372	969	56,105	5,049
Black cottonwood	954	830	65	55	1,019	866
Lodgepole pine	3,428	666	693	160	4,121	794
Mountain hemlock	39,716	4,234	4,265	695	43,981	4,707
Red alder	1,185	646	138	95	1,323	734
Sitka spruce	45,381	6,867	2,721	540	48,102	7,215
Western hemlock	192,176	10,965	26,253	2,138	218,429	12,099
Western redcedar	29,465	3,560	7,485	1,012	36,950	4,389
All forest	359,040	10,391	50,991	2,248	410,030	11,119

Note: Data are from all 2004–2010 plots; inaccessible wilderness areas are not included.

SE = Standard error.

Table 19—Carbon mass per acre in trees by forest type in the Tongass National Forest

	Live trees		Snags		All trees	
Forest type	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
			Pounds per acre			
Yellow-cedar	65,209	3,769	13,076	978	78,285	4,346
Black cottonwood	53,517	37,213	3,662	2,634	57,179	38,518
Lodgepole pine	19,726	2,297	3,988	673	23,714	2,689
Mountain hemlock	64,624	4,926	6,939	1,005	71,563	5,493
Red alder	66,058	17,871	7,689	3,484	73,747	20,752
Sitka spruce	153,936	15,538	9,228	1,516	163,165	16,156
Western hemlock	155,057	5,410	21,182	1,441	176,239	5,666
Western redcedar	100,441	5,829	25,515	2,119	125,957	6,724
All forest types	106,531	2,949	15,130	659	121,661	3,142

Note: Data are from all 2004–2010 plots; inaccessible wilderness areas not included.

Table 20—Change in carbon mass (million tons) in live trees by species from the first inventory (1995–2000) to the second inventory (2004–2010), Tongass National Forest

	Time 1 carbon		Time 2 carbon		Mortality		Harvest		Growth		Ingrowth		Net change	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
							Million tons							
Yellow-cedar	40,539	2,691	40,435	2,680	-1,929	446	-631	284	2,307	265	148	18	-104	533
Black cottonwood	480	244	529	263	-6	6			55	30			49	30
Lodgepole pine	4,563	485	4,430	477	-334	83			167	46	34	7	-133	91
Mountain hemlock	36,213	2,821	36,103	2,866	-1,686	286	-103	115	1,496	201	183	30	-110	339
Oregon crab apple	1	1	1	1					0	0	0		0	0
Pacific silver fir	7	9	8	10					1	1	1		1	1
Red alder[a]	717	194	1,075	269	-72	34			274	74	155	53	358	110
Sitka spruce	65,426	5,916	66,864	5,934	-3,629	1,282	-283	274	4,688	1,348	662	146	1,438	1,903
Subalpine fir	144	102	130	99	-14	14			0	2			-14	14
Western hemlock	153,171	8,100	153,520	8,108	-10,000	1,405	-1,031	436	10,385	837	995	130	349	1,630
Western redcedar	20,174	2,209	20,952	2,267	-334	165	-600	449	1,600	223	112	49	778	536
All species	321,436	10,811	324,047	10,725	-18,003	2,017	-2,646	1,127	20,972	1,699	2,289	275	2,611	2,883

Note: Based on remeasured plots only; does not include trees < 4.5 in diameter at breast height.

[a] Indicates that net change is significantly different using a 95-percent confidence interval.

SE = Standard error.

Table 21—Change in carbon mass (million tons) in live trees by species on unmanaged lands from the first inventory (1995–2000) to the second inventory (2004–2010), Tongass National Forest

	Time 1 carbon		Time 2 carbon		Mortality		Growth		Ingrowth		Net change	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
						Million tons						
Yellow-cedar	39,239	2,644	39,677	2,660	-1,889	445	2,186	250	142	18	439	475
Black cottonwood	480	244	529	263	-6	6	55	30	—	—	49	30
Lodgepole pine	4,563	485	4,429	477	-334	83	167	46	33	7	-134	91
Mountain hemlock	35,942	2,821	35,886	2,862	-1,686	286	1,457	198	174	30	-56	316
Oregon crab apple	1	1	1	1	—	—	0	0	—	—	0	0
Pacific silver fir	7	9	8	10	—	—	1	1	—	—	1	1
Red alder[a]	500	157	676	203	-67	34	163	50	79	36	175	80
Sitka spruce	62,607	5,821	62,814	5,810	-3,348	1,265	3,445	1,301	111	25	208	1,800
Subalpine fir	144	102	130	99	-14	14	0	2	—	—	-14	14
Western hemlock	147,704	8,057	147,789	8,057	-9,731	1,403	9,315	788	501	47	85	1,521
Western redcedar[a]	19,519	2,168	20,811	2,267	-317	164	1,562	221	47	9	1,292	254
All species	310,706	10,870	312,750	10,788	-17,392	2,009	18,350	1,593	1,086	76	2,044	2,503

Note: Based on remeasured plots only and includes only trees > 5 in diameter at breast height; unmanaged land indicates no recorded silvicultural activity.

[a] Indicates that net change is significantly different from zero using a 95-percent confidence interval.

Table 22—Change in carbon mass (million tons) in live trees by species on managed lands from the first inventory (1995–2000) to the second inventory (2004–2010), Tongass National Forest

	Time 1 carbon		Time 2 carbon		Mortality		Harvest		Growth		Ingrowth		Net change	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
							Million tons							
Yellow-cedar[a]	1,301	698	758	509	-40	29	-631	284	121	98	7	3	-543	234
Black cottonwood	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lodgepole pine	—	—	1	1	—	—	—	—	—	—	1	1	1	1
Mountain hemlock	271	177	217	160	—	—	-103	115	39	35	9	5	-54	119
Oregon crab apple	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pacific silver fir	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Red alder[a]	217	118	399	179	-5	4	—	—	111	54	76	40	183	76
Sitka spruce[a]	2,820	1,190	4,050	1,346	-280	204	-283	274	1,243	366	550	145	1,230	622
Subalpine fir	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Western hemlock	5,466	1,618	5,731	1,588	-269	111	-1,031	436	1,070	303	494	123	264	611
Western redcedar	655	466	142	69	-17	17	-600	449	38	28	65	48	-514	469
All species	10,729	2,742	11,297	2,581	-611	245	-2,646	1,127	2,622	661	1,203	269	567	1,463

Note: Data are based on remeasured plots only and include only trees ≥ 5 in diameter at breast height; managed land indicates recorded silvicultural activity.

[a] Indicates that net change is significantly different from zero using a 95-percent confidence interval.

SE = Standard error.

Table 23—Annual live tree carbon mass change by species and management class, Tongass National Forest, Alaska

	Managed		Unmanaged		All forest	
Species	Total	SE	Total	SE	Total	SE
			Thousand tons per year			
Yellow-cedar	-39	18	55	40	16	44
Black cottonwood	—	—	8	5	8	5
Lodgepole pine	0	0	-12	9	-12	9
Mountain hemlock	-10	14	-7	32	-17	35
Oregon crab apple	—	—	0	0	0	0
Pacific silver fir	—	—	0	0	0	0
Red alder	16	7	17	8	33	11
Sitka spruce	115	62	38	179	152	189
Subalpine fir	—	—	-2	2	-2	2
Western hemlock	34	52	-28	162	6	170
Western redcedar	-41	38	122	24	81	46
All species	75	129	190	252	265	281

Note: Data are based on remeasurement plots only and do not include trees < 5 in diameter at breast height.

SE = Standard error.

recruitment also had high carbon flux out of the live tree carbon pool into snag and log pools. In both management classes, the Sitka spruce forest type has the highest rate of growth and recruitment, estimated at about 1,909 lbs of carbon mass per acre per year overall, followed by the western hemlock forest type, with growth and recruitment at about 993 lbs of carbon mass per acre per year (table 24). Across all lands, annual per-acre flux out of the live tree carbon pools is 88.5 percent mortality and 11.5 percent harvest. On managed lands, carbon flux out of the live tree pool is 21.8 percent mortality and 78.2 percent harvest.

On managed lands in the Tongass National Forest, there was a significant decrease of live tree carbon mass for the yellow-cedar forest type, and a significant increase for the red alder forest type (table 25). On unmanaged lands (table 25), there were significant increases of live tree carbon within the cottonwood and western redcedar forest types. Overall on the Tongass, live tree carbon increased in the cottonwood, red alder, and western redcedar forest types, and no forest type had a significant decrease.

Change in carbon in the snag pool—

Overall, the turnover in the snag carbon pool on the Tongass National Forest is about 2 percent per year, with no significant difference between inputs into the

Table 24—Average annual rates of flux in the live tree carbon pool by forest type and management class, Tongass National Forest

	Growth		Recruitment		Mortality		Harvest	
Forest type	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	Pounds per acre per year							
Unmanaged:								
Yellow-cedar	304	37	36	4	323	59	—	—
Black cottonwood	959	378	11	13	—	—	—	—
Lodgepole pine	113	31	16	3	101	35	—	—
Mountain hemlock	344	56	34	7	353	92	—	—
Red alder	266	104	615	306	268	196	—	—
Sitka spruce	1,711	386	36	11	1,245	541	—	—
Western hemlock	909	131	39	4	933	158	—	—
Western redcedar	618	64	41	5	461	90	—	—
All unmanaged	652	59	38	2	619	74	—	—
Managed:								
Yellow-cedar	741	361	20	16	732	514	5,831	1,999
Lodgepole pine	—	—	—	—	—	—	—	—
Mountain hemlock	—	—	—	—	—	—	—	—
Red alder	458	548	436	151	—	—	—	—
Sitka spruce	1,661	475	565	182	335	254	691	499
Western hemlock	895	245	477	91	229	112	809	539
Western redcedar	248	—	1,089	—	—	—	18	0
All managed	1,107	231	501	83	278	110	997	395
All forest:								
Yellow-cedar	313	38	36	4	331	59	112	77
Black cottonwood	959	378	11	13	—	—	—	—
Lodgepole pine	113	31	16	3	101	35	—	—
Mountain hemlock	344	56	34	7	353	92	—	—
Red alder	358	251	529	173	139	127	—	—
Sitka spruce	1,694	302	215	73	938	371	233	176
Western hemlock	908	120	85	13	859	143	85	59
Western redcedar	608	63	68	23	449	88	—	—
All forest	687	58	73	8	593	69	77	32

Note: Data for this table are from remeasured plots only and do not include trees < 5 in diameter at breast height.

SE = Standard error.

Table 25—Per-acre net annual live tree carbon change by forest type, Tongass National Forest

	Managed forest		Unmanaged forest		All forest	
Forest type	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
			Pounds per acre per year			
Yellow-cedar	**-5,802**	2,235	18	60	-94	98
Black cottonwood	—	—	**970**	390	**970**	390
Lodgepole pine	—	—	28	41	28	41
Mountain hemlock	—	—	25	84	25	84
Red alder	**894**	396	612	606	**748**	358
Sitka spruce	1,200	998	502	708	738	578
Western hemlock	334	712	16	207	50	199
Western redcedar	1,319	—	**197**	95	**227**	96
All forest types	333	578	71	94	91	97

Note: Where the standard error is zero, it indicates that only one plot had a stand that fell into this category. Boldface type indicates a change that was significantly different from zero using a 95-percent confidence interval.

Note: Estimates are calculated from remeasured plots only and include only trees ≥ 5 in diameter at breast height.

SE = Standard error.

snag carbon pool (snag recruitment) and outputs from the snag carbon pool (fragmentation, falldown, and salvage). The decay-resistant species of yellow-cedar and western redcedar have lower turnover rates, of roughly 1 percent per year, than do other species (table 26). Salvage of snags is generally incidental to clearcutting, and accounts for only a small proportion (about 2 percent) of flux out of the snag carbon pool. About half of the carbon stored in snags is western hemlock, which had a small (less than 1 percent) but significant decrease (table 26). Lodgepole (shore) pine had a small (1.6 percent) but significant increase of carbon in the snag pool (table 26).

Estimates of flux into and out of the snag pool differed widely among the different forest types (table 27). On a per-acre basis, unmanaged forest had influx into the snag pool that was roughly three times larger than that of managed forest, and outflux from the snag pool was roughly the same. Loss of snags on managed lands was estimated to be about three times snag recruitment, for a net decrease in the snag pool estimated as 239 (± 149) lbs per acre per year.

The reliability of estimates for changes in the snag pool was affected by two data issues. The second inventory used a less inclusive definition for snags, by changing the lean angle used to define snags from 15 to 45 degrees from horizontal.

Table 26—Annual rates of change in snag carbon by species, 1995–2000 to 2004–2012, Tongass National Forest

	Initial carbon (1995–2000)		Snag recruitment		Snag fragmentation[a]		Snag falldown		Salvage		Net change	
Species	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
	Thousand tons		*Thousand tons per year*									
Yellow-cedar	10,996	1,000	93	23	38	9	49	10	13	15	-6	31
Black cottonwood	117	86	1	1	1	1	8	7	—	—	-8	6
Lodgepole pine[b]	928	153	26	6	5	1	5	2	—	—	15	7
Mountain hemlock	3,920	573	120	21	58	14	21	5	2	3	39	25
Oregon crab apple	—	—	—	—	—	—	—	—	—	—	—	—
Pacific silver fir	—	—	—	—	—	—	—	—	—	—	—	—
Red alder	33	21	3	2	1	1	1	0	—	—	2	2
Sitka spruce	5,974	978	241	88	101	29	28	12	1	1	111	94
Subalpine fir	19	19	3	3	0	0	—	—	—	—	3	3
Western hemlock[b]	24,976	1,771	463	58	397	47	243	35	7	5	-185	81
Western redcedar	3,258	501	24	14	14	12	23	9	—	—	-13	17
All species	50,221	2,326	973	109	616	58	377	42	23	18	-43	130

Note: Data are based on remeasurement plots only and do not include trees < 5 in diameter at breast height.

[a] Snag fragmentation includes the loss of mass from shrinkage (smaller diameter and heights) but not the loss of mass from a change in decay class.

[b] Indicates that net change is significantly different using a 95-percent confidence interval.

Table 27—Annual per-acre change in snag carbon by forest type and management class, Tongass National Forest

	Snag recruitment		Snag fragmentation[a]		Snag falldown		Salvage		Net change	
Forest type	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
					Pounds per acre per year					
Unmanaged forest:										
Yellow-cedar	201	29	128	17	118	27	—	—	-46	46
Black cottonwood	—	—	58	60	249	245	—	—	-307	304
Lodgepole pine	95	32	30	11	36	16	—	—	29	37
Mountain hemlock	259	81	114	35	29	9	—	—	116	88
Red alder	—	—	149	109	177	129	—	—	-326	239
Sitka spruce	494	163	314	139	131	62	—	—	49	196
Western hemlock	505	90	341	43	188	29	—	—	-24	103
Western redcedar	354	81	207	54	99	20	—	—	48	94
All unmanaged	354	40	223	21	128	14	—	—	4	47
Managed forest:										
Yellow-cedar	224	76	-12	44	211	76	303	371	-278	349
Red alder	—	—	7	8	—	—	—	—	-7	8
Sitka spruce	123	71	16	12	62	52	197	221	-153	224
Western hemlock	97	85	145	86	221	140	41	37	-310	226
All managed	106	54	86	50	156	81	104	79	-239	149
All forest:										
Yellow-cedar	201	28	125	17	120	26	6	8	-50	46
Black cottonwood	—	—	58	60	249	245	—	—	-307	304
Lodgepole pine	95	32	30	11	36	16	—	—	29	37
Mountain hemlock	259	81	114	35	29	9	—	—	116	88
Red alder	—	—	81	71	92	84	—	—	-172	155
Sitka spruce	369	112	214	94	108	45	67	76	-19	151
Western hemlock	462	81	320	40	192	30	4	4	-54	95
Western redcedar	345	79	202	53	97	19	—	—	46	92
All forest	335	38	212	20	130	14	8	6	-15	45

Note: Data are based on remeasurement plots only, 1995–2000 and 2004–2010.

[a] Snag fragmentation includes the loss of mass from shrinkage (smaller diameter and heights) but not the loss of mass from a change in decay class.

SE = Standard error.

Although these instances should have been coded as procedural changes, which were corrected during analysis, it is possible that some instances were coded identically as snag falldown, leading to overestimates of falldown. The other data issue was that a procedural change for estimating decay class made it impossible to include the decrease in density that occurs as snags age, which would lead to underestimate of snag decay. The missing decay component can be even greater than the volume loss from snag fragmentation for some species and decay classes (Harmon et al. 2000). Although estimates for snag losses are presented here despite these uncertainties, because the estimates are still the best available information, caution should be exercised in use of either the two components of snag carbon loss shown, or the resulting net change in snag carbon.

Change in carbon in the log pool—

Roughly 7 percent of aboveground carbon in unmanaged stands of the Tongass National Forest is stored in the log (DWD) pool. On managed forest, about 37 percent of carbon is in the log pool. The higher volume of carbon in logs is found in the western hemlock, Sitka spruce, and western redcedar forest types, and lower volume in the yellow-cedar, cottonwood, lodgepole (shore) pine, and mountain hemlock forest types (table 28). The red alder forest type also had a high carbon density in the log pool (table 28); this corresponds well with the role of red alder as a pioneering species that establishes after disturbance.

No remeasurement data is available for the log pool. We can make a rough estimate of influx into the log pool on unmanaged lands as:

(mortality – snag recruitment) + snag falldown [low estimate]

which is (619 – 354) + 128 = 393 lbs per acre per year. This will be an underestimate, as some of the input into the log pool comes from breakage of live trees (an unknown rate), and some input into the log pool comes from snag fragmentation. A higher estimate would be to assume that all of snag falldown and fragmentation goes into the log pool:

(mortality – snag recruitment) + snag falldown + snag fragmentation [high estimate]

which is (619 – 354) + 128 + 223 = 616 lbs per acre per year. This range (393–616 lbs per acre per year) would give us a rough estimate of annual inputs into the log pool of 3.8 to 6.0 percent per year, which would provide turnover rates if the log pool were in equilibrium. Decomposition rates of spruce on the Kenai Peninsula of

Table 28—Carbon mass in downed logs by forest type and management class, Tongass National Forest

	Managed		Unmanaged		All	
Forest type	Mean	SE	Mean	SE	Mean	SE
			Pounds per acre			
Yellow-cedar	—	—	6,250	893	6,250	893
Black cottonwood	—	—	3,571	1,786	3,571	1,786
Lodgepole pine	—	—	1,339	446	1,339	446
Mountain hemlock	65,625	1,339	2,679	446	3,571	446
Red alder	15,179	8,929	21,875	10,714	16,518	8,036
Sitka spruce	33,036	4,464	11,607	2,232	15,179	2,232
Western hemlock	33,482	4,018	16,071	893	17,857	893
Western redcedar	57,143	10,268	12,500	1,786	12,946	1,786
All forest types	33,482	3,125	10,268	446	11,607	446

Note: Uses plot measurements from 1995 to 2003.

SE = Standard error.

about 1.9 percent per year (Harmon et al. 2005) suggest that the log pool on unmanaged lands might be increasing; better monitoring information for logs would improve the ability to track forest carbon over time. The log pool on managed lands is unlikely to be in equilibrium, given the temporal variation in harvesting.

Combined live tree, snag, and log pools—

Overall, gross flux (growth + recruitment) from the atmosphere to live trees in the Tongass National Forest is estimated at about 760 lbs per acre per year (table 29). Growth is mostly balanced by mortality and harvest, so that net flux (based on increases in the live tree pool) from the atmosphere to the forest is estimated at 91 (standard error = 97) lbs per acre per year, reduced by an estimated slight decrease in the snag pool of 15 (standard error = 45) lbs per acre per year. This estimated net sequestration rate is not significantly different from zero, and also does not include any changes in the log pool. There may be some additional sequestration occurring because the combined harvest and salvage (85 lbs per acre per year) would have some portion that became durable wood products.

Aboveground tree carbon on the Tongass National Forest is 79.3 percent in the live tree pool, 12.4 percent in the snag pool, and 8.3 percent in the log pool (table 29). Turnover in the live tree carbon pool is about 0.6 percent per year, turnover of the snag carbon pool is about 2.9 percent per year, and the approximated turnover in the log pool, assuming equilibrium, is 3.8 to 6.0 percent per year.

Table 29—Carbon pools and flux for aboveground trees in the Tongass National Forest

	Management class				Tongass National Forest	
	Managed		Unmanaged			
	Mean	SE	Mean	SE	Mean	SE
Pool:			*Pounds per acre*			
Live trees[a]	48,102	10,199	115,896	3,731	110,689	3,515
Snags[a]	7,524	2,249	18,107	818	17,294	778
Logs	33,482	3,125	10,268	446	11,607	446
Total	89,108		144,271		139,590	
Flux—live tree pool:			*Pounds per acre per year*			
Growth	1,107	231	652	59	687	58
Recruitment	501	83	38	2	73	8
Mortality	278	110	619	74	593	69
Harvest	997	395	—	—	77	32
Flux—snag pool:			*Pounds per acre per year*			
Snag recruitment	106	54	354	40	335	38
Snag fragmentation[b]	86	50	223	21	212	20
Snag falldown	156	81	128	14	130	14
Snag salvage	104	79	—	—	8	6

[a] Uses remeasurement plots and initial (1995–2003) data. To keep flux and pools in correct proportions, does not include trees < 5 in diameter at breast height.

[b] Snag fragmentation includes the loss of mass from shrinkage (smaller diameter and heights) but not the loss of mass from a change in decay class.

SE = Standard error.

Discussion

A number of carbon pools and fluxes were not included in this report: (1) carbon in nonforested lands, which includes alpine environments, wetlands, grasslands, and shrublands; (2) below-ground carbon, including roots, soils, and organic materials; (3) carbon in nontree vegetation and litter within forest; (4) carbon in a few pools currently not measured by FIA, which includes stumps below 4.5 feet and dead saplings; and (5) (with the exception of tables 4 and 6) carbon in forest lands in inaccessible wilderness. The missing carbon in the belowground pools could be as large as the aboveground stores.

The overall carbon mass stored in just aboveground trees, snags, and logs in the Tongass National Forest is huge. Using the per-acre values by forest types, and extrapolating to include the uninventoried wilderness areas, provides a rough estimate of about 650 million tons in aboveground tree carbon, equivalent to 2.4 billion tons of CO_2.

Carbon storage and flux are very different between managed and unmanaged forests. Harvesting on the Tongass was very low before 1955, peaked in the early 1970s at more than 500 million board feet (MMBF) per year, and then dropped over time to current rates at less than 100 MMBF per year (Brackley 2009). On managed lands, this results in an age class structure with a large cohort of stands 30 to 50 years old, very few stands older than 60 years, and relatively few stands under 20 years of age. The cohort of stands 30 to 50 years old are contributing to a nominal (not statistically significant) net increase of carbon in live trees, but they probably have several decades to go before reaching a point of maximum mean annual increment. For instance, Taylor (1934) estimated that the maximum mean annual increment occurs at around 70 years. In contrast to what is happening on the Tongass, privately owned managed forest in southeast Alaska is showing a statistically significant decrease in carbon mass in live trees, a consequence of harvesting that peaked in the 1990s (resulting in a relatively younger stand distribution for second-growth) and current harvesting levels that are above that of the Tongass.

Some species shifts occurred when old-growth forest was converted to second growth; the data reflects this by the observed net decrease in yellow-cedar and net increase in Sitka spruce on managed lands, as well as by the higher proportion of carbon mass in Sitka spruce observed on managed lands (35 percent) relative to unmanaged lands (20 percent). Managed lands had almost triple the density of carbon mass in logs compared to unmanaged lands, but less than half the snag density and live tree density. Carbon flux among pools is also substantially different, with much higher growth and recruitment and lower mortality in managed stands.

The Tongass National Forest is unique within the National Forest System in the large amount of old growth outside of wilderness, and unique in the proportion of harvesting that has occurred in old growth rather than second growth during recent decades. Harvesting of old growth creates an initial net release of CO_2 into the atmosphere relative to leaving stands unmanaged, which can continue for years as logs and snags left after harvest decompose (Harmon et al. 1990). Some of the carbon from harvest is stored in wood products, with transmission back into the atmosphere over time. Because harvest levels peaked in the 1970s, and much of the resulting wood products would now be in landfills, wood products from the Alaska region are now believed to be a net emitter of carbon (Loeffler et al. 2012). Theoretically, at some point in the future, the managed second-growth stands that follow harvest could result in a greater net sequestration of carbon than leaving stands unmanaged, but the relatively low growth rates of most stands in the Tongass and the relatively high amount of dead wood left after harvest would reduce this potential. Although there is a substantial amount of recent literature about the effects of forest management on carbon stores, different authors have reached widely different conclusions about net sequestration because of different assumptions about the timeframe of interest, initial volume, postharvest residuals, decay rates, the amount of energy expended in harvest and transport, utilization rates, lifespan of wood products, future growth rates of second-growth stands, temporal discounting, and substitution effects.

Including consideration of carbon sequestration into management of existing second growth is likely to be less controversial. Possible management actions to increase carbon sequestration for these situations could include altering rotation age (for even-age stands) or structural composition (for uneven-age stands) or increasing utilization of woody material from harvest sites. Although the carbon estimates made in this report provide information about overall carbon storage and flux in the Tongass National Forest, providing specific management recommendations for second growth would benefit from additional inventory in second-growth.

Several other sets of estimates for carbon in the Tongass National Forest have been published. Some of the data used in this report, specifically the 1995–1999 data, was used in Leighty et al. (2006), in their paper “Effects of Management on Carbon Sequestration in Forest Biomass in Southeast Alaska.” The log data used in that paper had a systematic error that resulted in overestimates of carbon in logs; those errors have been corrected in this report. In addition, this report uses standard national FIA methods for statistical estimation, which differ substantially from the map-based approach used by Leighty et al. (2006), and this report uses measured data for flux rather than modeled approximations.

The live tree density reported here, of 53.3 tons per acre on average (table 19) for the nonwilderness areas, is equivalent to 119.3 Mg/ha. This is very similar to the 123 Mg/ha reported by Heath et al. (2012) for the Tongass National Forest overall, particularly considering the difference in methods of calculation. Estimates in this report will also differ somewhat from those published in Barrett and Christensen (2011) owing to the addition of data from 2009 to 2010 and improved estimates for snags. That report also found a significant decrease in lodgepole (shore) pine; data from 2009 to 2010 had relatively little mortality in lodgepole (shore) pine, so that while there is still a nominal decrease in lodgepole (shore) pine of 3 percent (tables 21 and 23) it is no longer significant at the 90-percent CI. However, there was a significant increase in lodgepole (shore) pine snag carbon (table 26), providing indirect evidence of higher than normal mortality for this species.

Conclusion

The Tongass National Forest stores substantially more forest carbon than any other national forest in the United States, with an approximated estimate of 650 million tons of carbon in live trees, snags, and logs. Both managed and unmanaged forest shows nominal net annual increases in live tree carbon (of 0.68 and 0.06 percent, respectively) that were not significantly different from zero. However, changes in species composition have been occurring. On unmanaged lands, there were increases in western redcedar and red alder. On managed lands, there were increases in red alder and Sitka spruce, and a decrease in yellow-cedar.

This report provides the first estimates of annual flux and turnover rates in live tree and snag carbon pools in Alaska based on remeasured data. Overall, live trees in the Tongass National Forest remove about 2,787 lbs of atmospheric CO_2 per acre per year through growth and recruitment, which is largely (estimated 90 percent) balanced by CO_2 returning to the atmosphere from mortality and harvest, assuming eventual decay of those trees. Carbon storage and flux differed substantially between managed and unmanaged lands, and by forest type.

Although the Chugach National Forest stores less carbon in aboveground trees than the Tongass National Forest, it also is exhibiting greater change in carbon stores. The Chugach's location on a very major ecoregional transitional zone (boreal forests to the north, shrubland to the west and southwest on the Alaskan Peninsula, and temperate rainforest to the east and south) may make it much more vulnerable to large disturbances and climatic shifts.

Common and Scientific Names

Black cottonwood	*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw
Black spruce	*Picea mariana* (Mill.) Britton, Sterns & Poggenb.
Lodgepole pine, shore pine	*Pinus contorta* Dougl. ex Loud.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Pacific silver fir	*Abies amabilis* (Douglas ex Louden) Douglas ex Forbes
Paper birch[4]	*Betula neoalaskana* Sarg.; *Betula kenaica* (W.H. Evans); *Betula papyrifera* Marshall
Quaking aspen	*Populus tremuloides* Michx.
Red alder	*Alnus rubra* Bong.
Sitka spruce	*Picea sitchensis* (Bong.) Carrière
Subalpine fir	*Abies lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western redcedar	*Thuja plicata* Donn ex D. Don
White spruce	*Picea glauca* (Moench) Voss
Yellow-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach

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[4] Alaska paper birch, Kenai paper birch, and western paper birch are not recorded as different species by FIA and are included together as “paper birch” in this report.

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Metric Equivalents

When you know:	Multiply by:	To find:
Acres	.405	Hectares
Pounds	.453	Kilograms
Pounds per acre	1.12	Kilograms per ha
Tons	0.97	Tonnes or megagrams
Tons per acre	2.24	Megagrams per hectare

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