United States Department of Agriculture

Draft Carbon Stocks Assessment

Tongass National Forest Plan Revision

Forest Service | Alaska Region | Tongass National Forest | December 2024

Cover Photo: Aboveground live tree biomass and soil carbon pools contribute the majority of stored carbon on the Tongass National Forest.

Draft Carbon Stocks Assessment
Tongass National Forest Plan Revision

Forest Service, Alaska Region

Prepared by:

Todd Ontl
Carbon Stewardship Specialist
USDA Forest Service, Washington Office

Stephanie Rebain
Regional Planner
USDA Forest Service, Alaska Region

This page intentionally left blank.

Table of Contents

Tables

Figures

This page intentionally left blank.

Introduction

The Tongass Carbon Stocks Assessment provides an evaluation of existing information on baseline carbon storage (i.e., carbon stocks) in vegetation and soils within forested and non-forested ecosystems, including products generated from them, known as biogenic carbon. The 2012 Planning Rule requires an evaluation of existing information on baseline carbon stocks (36 CFR 219.6(b)(4)). The Land Management Planning Handbook describes the purpose of the carbon assessment as helping the USDA Forest Service understand current trends in carbon uptake and storage as a critical ecosystem service provided by forest and non-forest ecosystems (FSH 1909.12.4).

The information within this assessment can help land managers understand carbon stocks, fluxes, and impacts of disturbances at the forest level. This includes understanding:

- The Tongass National Forest's role in carbon uptake and storage;
- Where carbon is stored (carbon pools);
- The influence of past disturbances and management activities on carbon;
- How disturbance and management may affect carbon in the future; and,
- Existing conditions and future status of the plan area as a carbon sink or source.

Scope and Scale of Assessment

With a focus on producing a concise public document that supports the development of a revised plan, general information about the carbon cycle in forest ecosystems is not repeated here but can be found in other sources such as D'Amore and McGuire (2020) and other literature cited in this report.

This report relies on models and data to characterize biogenic carbon dynamics at the national forest level. Results and information are derived from a variety of models, data sources, and qualitative analyses. Available datasets described below vary in terms of their coverage, uncertainty, and limitations. For instance, plot level data (such as Forest Inventory and Analysis (FIA)) provides data across all carbon pools and the level of uncertainty can be assessed, but it has limited spatial coverage. Additionally, soil carbon pools are measured on a subset of FIA plots, so the statistical models used to predict carbon stocks may limit the applicability of soil carbon predictions from FIA for the Tongass National Forest. Other datasets, such as remotely sensed data, may have broader coverage across the forest, but may only include some (but not all) carbon pools or include less information about uncertainty and/or different caveats. There are additional data limitations related to carbon in non-forested areas relative to forested areas, particularly due to a lack of FIA plots in these cover types. Non-forest carbon is likely a small but significant fraction of the total carbon on the Tongass NF and is included in some datasets we present here.

Information is presented from a variety of scientific publications, such as Leighty (2006), Zhu and McGuire (2016), and others. Additionally, as you'll see below, this carbon assessment describes a suite of results using FIA data, some at the national forest level and others at the USDA Forest Service regional level. At the national forest level, this report characterizes carbon stocks and fluxes, drivers of non-soil carbon dynamics, and stand dynamics. Estimates of aboveground live tree, belowground live tree, understory, standing dead, downed dead wood, litter, and soil organic carbon are estimated for the years 2005 to 2023 for key forest ecosystem carbon pools, using FIA data. The impact of disturbances, including harvest, are estimated for 1990 to 2011 using The Forest Carbon Management Framework (ForCaMF; Birdsey et al. 2019; Healey et al. 2014; Raymond et al. 2015; Healey et al. 2016). Years of coverage reflect spans of data available for each tool/dataset. In addition, data from several modeling projects describe a variety of carbon estimates relative to several unit measurements, displayed in Table 1. "Carbon" is abbreviated as "C" throughout the document.

Table 1. Carbon Units. The following table provides a crosswalk among various metric measurement units used in the assessment of carbon stocks and emissions.

Multiple	Name	Symbol
10^0	Gram	G
10^6	Megagram	Mg
10^{12}	Teragram	Tg
10^{15}	Petagram	Pg

Status and Trends

Tongass National Forest Carbon Stocks

The first comprehensive evaluation of carbon stocks on the Tongass was conducted by Leighty et al. (2006). The total estimated carbon stock was 2.8 Pg C in 1995 including carbon in trees, seedlings/saplings, snags, coarse woody debris, understory, roots, and soil. Soils in the coastal temperate rainforest store large amounts of carbon (D'Amore and McGuire 2020, Leighty et al. 2006). In this initial evaluation, soil carbon was the largest pool and estimated at 1.86 Pg C (Leighty et al. 2006).

Another estimate for the Alaska Region (R10) estimated that the Tongass had 1.269 Pg C in non-soil (live tree, standing dead, down dead, understory, forest floor) pools (Heath et al., 2011). This was followed by a subsequent evaluation of FIA C stock of 1.270 Pg C for the Tongass (Smith et al., 2019)[1].

More recently DellaSala et al. (2022) quantified woody biomass (includes live trees, roots, woody debris, seedlings/saplings, snags, and understory vegetation) and soil organic carbon across the Tongass National Forest, estimating total soil organic and woody biomass carbon to be 2.7 Pg. Much of this carbon was soil carbon (1.6 Pg) with a lower amount in woody biomass (1.1 Pg).

Recent work integrates multiple soil carbon models to produce an ensemble average model to estimate soil carbon at two depths for the Tongass. Soil carbon (0-30 cm) is estimated at 1.12 Pg and soil carbon (0-100 cm) is estimated at 1.81 Pg (Jones and D'Amore 2024).

Overall, given this compilation of information, total ecosystem carbon on the Tongass National Forest is estimated at 2.7-2.8 Pg C or higher, with soil carbon as the largest carbon pool.

Carbon stocks on the Tongass National Forest compose about 10 percent of the carbon on National Forest System (NFS) lands (Heath et al. 2011, Law et al. 2023). As such, the Tongass is considered to be a carbon reservoir of national significance (DellaSala et al. 2022, Law et al. 2023, Shanley et al. 2024, D'Amore 2020).

U.S. Geological Survey LandCarbon Program Estimates

The USGS LandCarbon program developed carbon stock estimates and flux predictions for all regions of the United States, including Alaska (Zhu and McGuire 2016). The LandCarbon project used the

1 An adjustment to the reported total of 1385 Tg C in Smith was made by subtracting the estimated total for the Chugach of 115 Tg from Heath to derive a Tongass estimate.

Terrestrial Ecological Model (TEM) to estimate carbon through model algorithms of biomass accumulation and loss based on variable measurements from Southeast Alaska. The approach is not a direct measurement, but a prediction or estimation based on convergence of ecological variables and known growth limits for specific vegetation types.

As seen later in this document, while the original LandCarbon analysis was at the scale of the whole state (Zhu and McGuire 2016), for this assessment, data specific to a general, buffered area surrounding and including the Tongass is presented in the tables and figures in the section below titled "Projections of Future Carbon Stock Changes" and was provided by Helene Genet at University of Alaska Fairbanks. Additional information from the LandCarbon program may be added or revised in this assessment in the future.

Forest Inventory and Analysis

Based on FIA plot data, total carbon stocks in the Tongass National Forest increased from 891.8 teragrams of carbon (Tg C) in 2005 to 914.5 ± 25.3 Tg C in 2023, an approximate 2.5 percent increase over this period (Figure 1; see Box 1 for carbon units' description) (USDA 2024). This incorporates carbon stocks for all pools, including live and dead vegetation and soils. FIA data suggest carbon stocks in the Tongass National Forest have increased from 2005 to 2023 (Figure 1), with some uncertainty in annual stock estimates. However, FIA plots are not located within Wilderness Areas on the Tongass National Forest (approximately 3 million acres of forested area are within wilderness on the Tongass), so these estimates do not capture the carbon stored in soils, live, and dead carbon pools in these locations (Figure 2) and as such, underestimates the total amount of stored carbon on the Forest. FIA measurements from 2005-2023 estimate a rate of carbon accrual of 1.26 Tg C y^{-1}. Of note, uncertainty in the 2023 estimate (±25.3 Tg C) was greater than the change across the time period from 2005 to 2023.

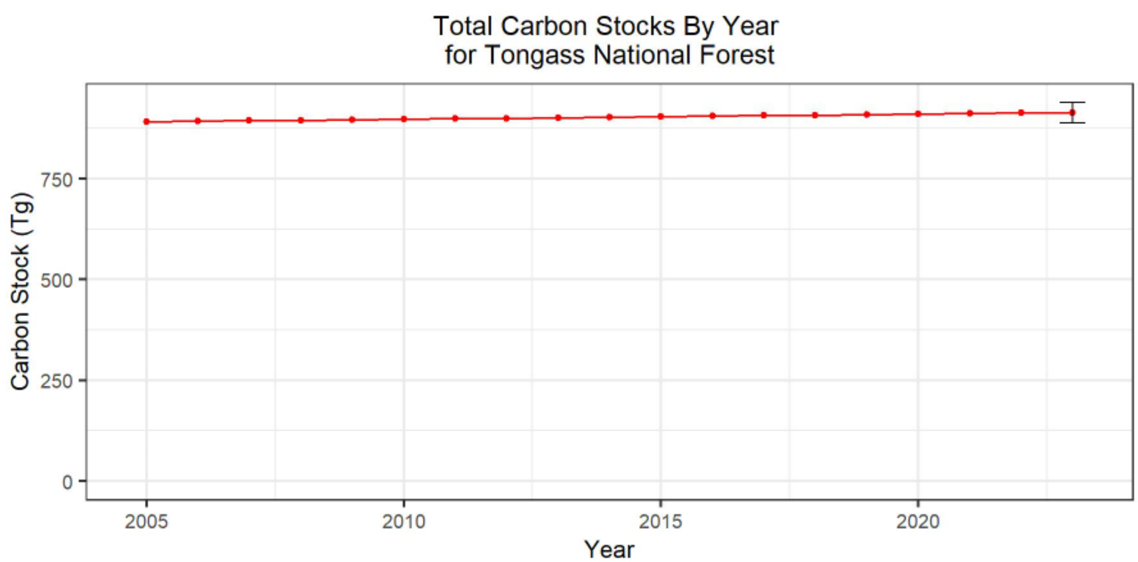

Figure 1. Total forest carbon stocks (Tg) for the years 2005 to 2023, based on FIA estimates. Error bars represent a 95 percent confidence interval (only available for 2023).

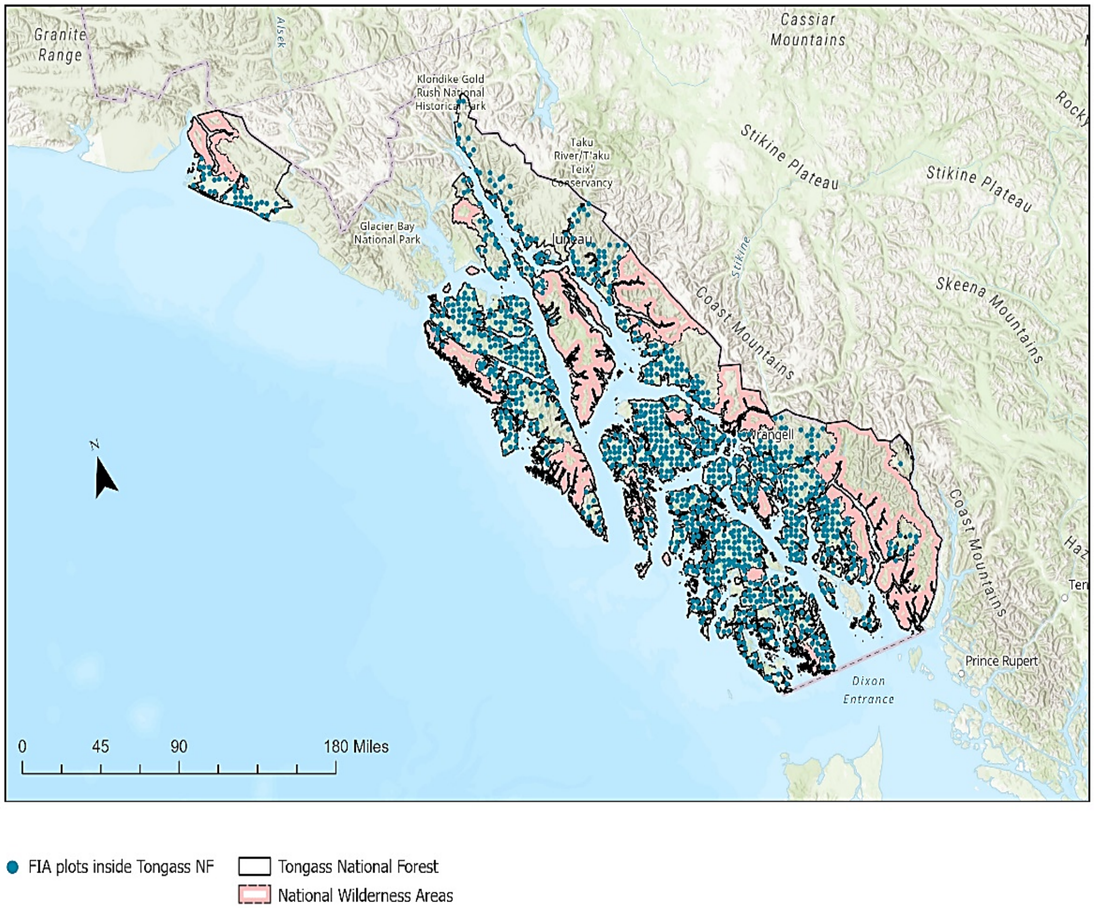

Figure 2. Map of approximate FIA plot locations and Wilderness Areas within the Tongass National Forest.

Live and dead vegetation may be a substantial proportion of total carbon stocks in the Tongass National Forest. Based on FIA, live vegetation, including aboveground live trees, belowground live trees (roots), and understory vegetation comprise about 37.5 percent of the carbon in the Tongass National Forest (Figure 3; Table 2). Standing dead wood, downed dead wood, and litter together make up about 16.22 percent of total forest carbon there (Figure 3; Table 2).

Approximately 46.3 percent of forest carbon is stored in soils (Figure 3). This is a modeled estimate and reflects the total soil organic carbon (SOC) in the soil profile (Domke et al., 2016, 2017, and 2023). The current uncertainty associated with the soil carbon estimate is unknown but includes both model uncertainty and sample uncertainty. In most temperate forest ecosystems, soils represent the largest ecosystem carbon pool (Walters et al., 2023) and offer, through their protection and management, an opportunity to mitigate rising atmospheric carbon dioxide concentrations (Bossio et al., 2020).

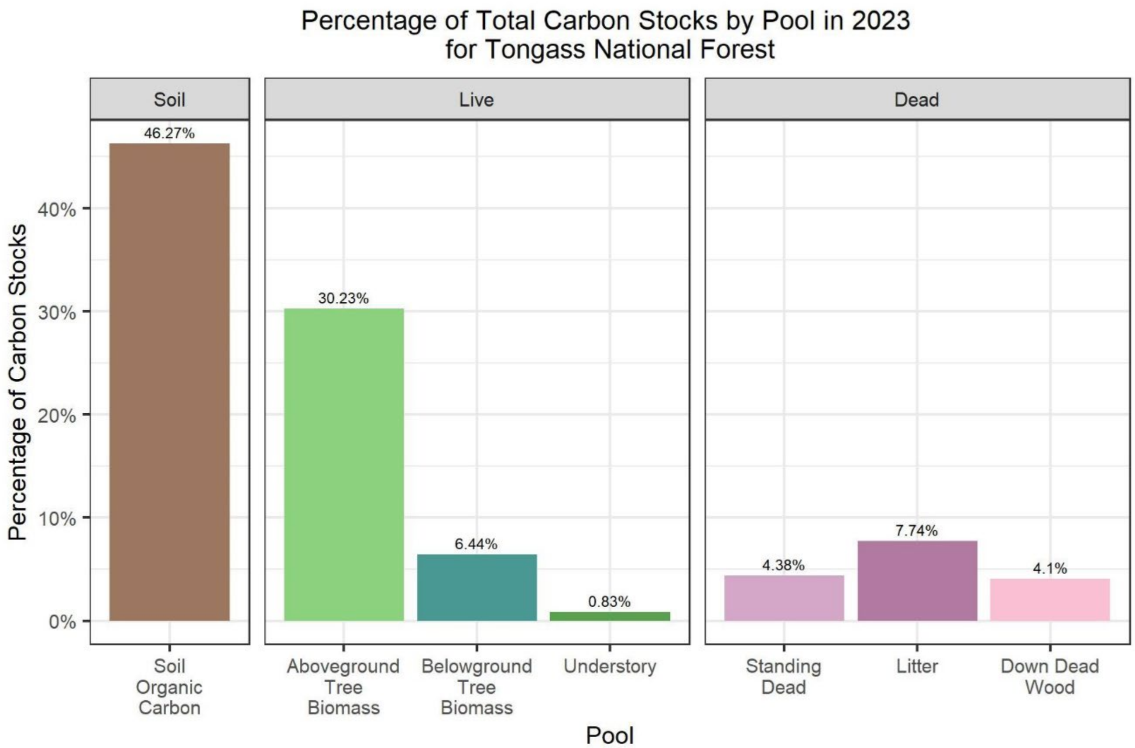

Figure 3. Percentage of total carbon stocks by pool in 2023.

Changes in total carbon storage and forested area collectively determine changes in carbon density. Forested area sampled by FIA on the Tongass National Forest changed from 2,656,448 hectares (ha) in 2005 to 2,719,735 ha in 2023, a net increase of 63,287 ha (Table 2); these estimates do not include areas within Wilderness, which are neither sampled nor estimated. Minor changes in forested area may result from sampling intensity issues or weighting strata rather than actual changes in forested area. Given the increasing stocks of total ecosystem carbon and increase in forested area on the Tongass National Forest, carbon density increased from about 335.71 Mg C/ha in 2005 to 336.23 Mg C/ha in 2023 (Table 2). However, without estimates of uncertainty for these estimates, it is not possible to know if the observed change is significant or not.

Table 2. Carbon stocks and forested area estimates.

Measure	Year 2005	Year 2023	Net change (2023-2005)	% change (2023-2005)
Mean stock[2] +/- confidence interval (Tg)	891.8	914.46 ± 25.3	22.67	2.54
% stocks, soil organic carbon[3]	47.4	46.27		
% stocks, live	36.5	37.51	0.96	2.64
% stocks, downed dead wood and detritus	16.0	16.22	0.2	1.26
Carbon density (Mg/ha)	335.7	336.23	0.52	0.16
Area (ha)	2,656,448	2,719,735	63,287	0.02

[2] As noted above, this is an underestimate given FIA data is not collected within Wilderness Areas on the Tongass National Forest.
[3] Net change not reported given limitations associated with FIA soil carbon estimates.

Stock Change

The estimate of net change across the studies described here have identified the Tongass National Forest as a net sink for carbon. Alaska's temperate coastal forests absorb more carbon from the atmosphere than they release. They function as carbon "sinks" in part because cool temperatures slow decomposition and lead to an accumulation of carbon in woody debris and soils (D'Amore and McGuire 2020). The Forest also has a relatively small area that has been harvested (~4 percent of the total forest area), with the intact forest maintaining growth and diversification of the stands through small-scale disturbance and an almost complete lack of fire in the region.

"Net ecosystem carbon balance" (NECB) is the complete ecosystem balance of inputs and outputs representing the true net sink or source in the ecosystem. This estimate includes aboveground and belowground plant production, soil respiration, and lateral losses of carbon (see Chapin et al. 2006). It is considered the "gold standard" regarding estimates of stock change and determining whether an area is a carbon sink or source.

- Modeled estimates for all components of the carbon cycle have a positive NECB (Genet et al., 2016). For the general, buffered area surrounding and including the Tongass, NECB is estimated at 3.4 Tg C y^{-1} (see Table 4). Modeled NECB from field and remote sensing information on the Tongass estimated the flux at 1.48 Mg C Ha y^{-1} (D'Amore et al. 2016), indicating the Tongass is a carbon sink.
- FIA data also indicates the Tongass is a carbon sink. The carbon stock change estimate from FIA data (2005 – 2023), as described earlier, is 1.26 Tg C y^{-1}.
- Other estimates of the annual rate of change in carbon also support the Tongass as a carbon sink, but are lower given their limited coverage in terms of carbon pools and/or geographic coverage on the Forest (such as Leighty et al. (2006), Barrett (2014)).

Carbon in Harvested Wood Products

Harvested wood products (HWP) are a source of ongoing carbon storage which can reduce net greenhouse gas emissions, depending on regional markets, product end use, and species composition (Lippke et al., 2011; McKinley et al., 2011; Skog et al., 2014). The Intergovernmental Panel on Climate Change (IPCC) recognizes wood as a renewable resource that when sustainably managed can mitigate climate change (IPCC 2022b, 2023). Assessing impacts of harvest on GHGs thus should include carbon storage estimates from wood products.

The duration of carbon persistence in harvested wood products (HWP) depends on the commodity type. For example, paper, pulp, or small-piece biomass will not retain carbon as long as timber does. Carbon stored in HWP increases with HWP commodity production. Landfills (also known as solid waste disposal sites or SWDS) also store discarded forest products and may continue to store carbon for many decades, as decomposition is slowed under oxygen-poor conditions. Wood products used in place of steel or concrete, as well as wood-derived biomass used in energy production in place of coal and natural gas, may reduce net greenhouse gas emissions as well, via their substitution for higher greenhouse gas-emitting products (Gustavsson et al., 2006; Lippke et al., 2011).

In the Alaska Region, harvest levels were low until the 1950s then increased and peaked in the mid-1970s, resulting in an increase in biogenic carbon storage in HWP (Figure 4) (Loeffler et al., 2014). Timber harvesting fluctuated from the late-1970s to 1990s. HWP and landfill carbon storage peaked in 1996 at about 13.5 Tg C. However, because of a decline in timber harvesting in the late 1990s (to 1930s levels) HWP carbon stocks began to decrease. In the Alaska Region, the contribution of national forest timber harvests to the HWP carbon pool is less than the decay of retired products, causing a net decrease in product-sector carbon stocks. The carbon stocks in use as harvested wood products in 2013 represents an estimated 1.28 percentage of regional carbon stocks of that year.

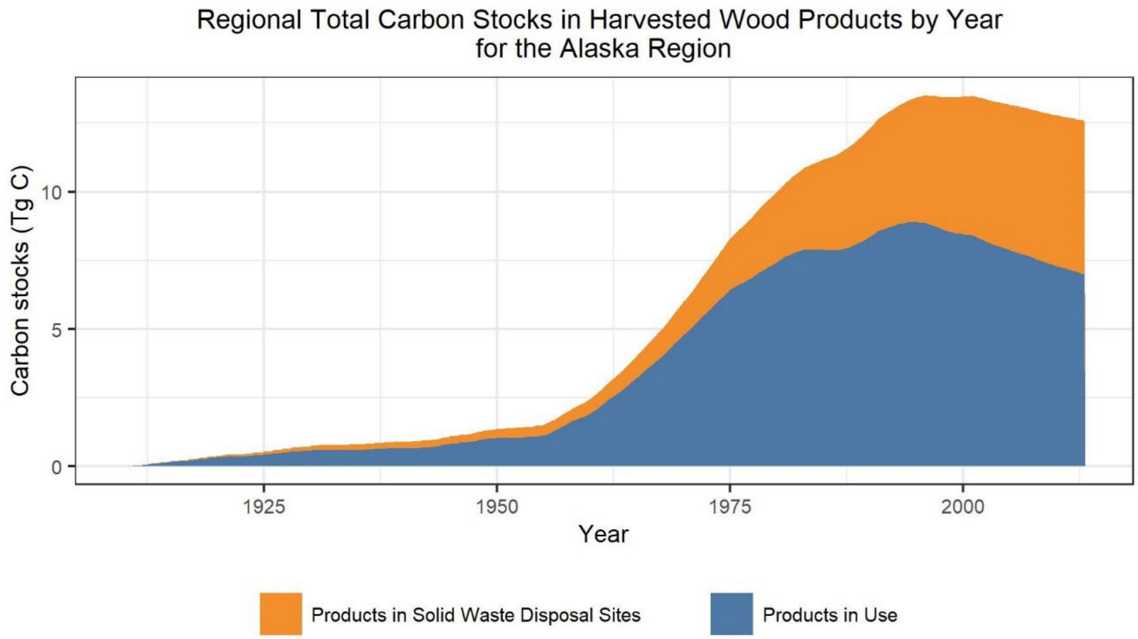

Figure 4. Total region-wide carbon stocks (Tg) in harvested wood products in use and at solid waste disposal sites (SWDS) from 1910 to 2013.

Factors Influencing Forest Carbon Dynamics

Disturbance

The impact of disturbances, including harvest, on carbon dynamics are estimated for 1990 to 2011 using The Forest Carbon Management Framework (ForCaMF; Birdsey et al. 2019; Healey et al. 2014; Raymond et al. 2015; Healey et al. 2016). This data and framework indicates that the low frequency of disturbance on the Tongass has not significantly impacted overall carbon stocks historically. Harvest is the dominant disturbance, with minimal impacts to carbon density.

From 1990 to 2011, harvest was the most leading disturbance type in the forested areas of the Tongass National Forest (Figure 5; Table 3). Harvest affected about 0.9 percent (approximately 24,872 ha) of total area included in the model analysis (2,749,499 ha) over this period. On average, harvest affected 0.04 percent of the total forested area per year (Figure 5).

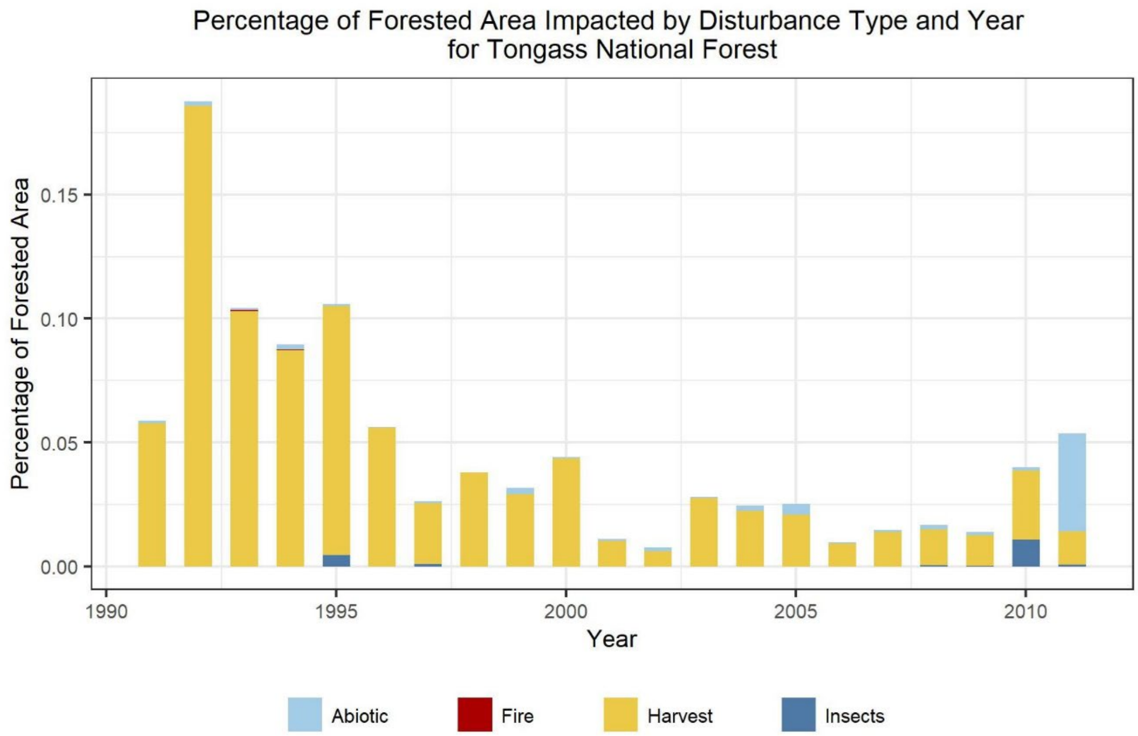

Figure 5. Percentage of forested area disturbed from 1990 to 2011 by disturbance type.

Table 3: Disturbance effects. NA indicates data not available.

Change from 1990 to 2011	Abiotic	Disease	Fire	Harvest	Insects
Reduction in carbon (Mg/ha)	0.00	NA	0	-0.45	0.00
Percentage change in carbon	0.00	NA	0	0.27	0.00
Percentage of forest impacted	0.06	NA	0	0.90	0.02
Total forest area impacted (ha)	1762	NA	18	24872	497
Average annual percentage of forest impacted	0.00	NA	0	0.04	0.00

Harvest on the Tongass National Forest had the greatest impact on carbon stocks from 1990-2011, resulting in -0.45 Mg/ha lost potential storage of carbon that would have been present over the time period, in the absence of this disturbance type (Figure 6). Carbon stocks may have been approximately 0.27 percent higher without harvest during that time (USDA 2024). Other disturbances did not have a measurable impact on potential carbon storage between 1990 and 2011 (USDA 2024).

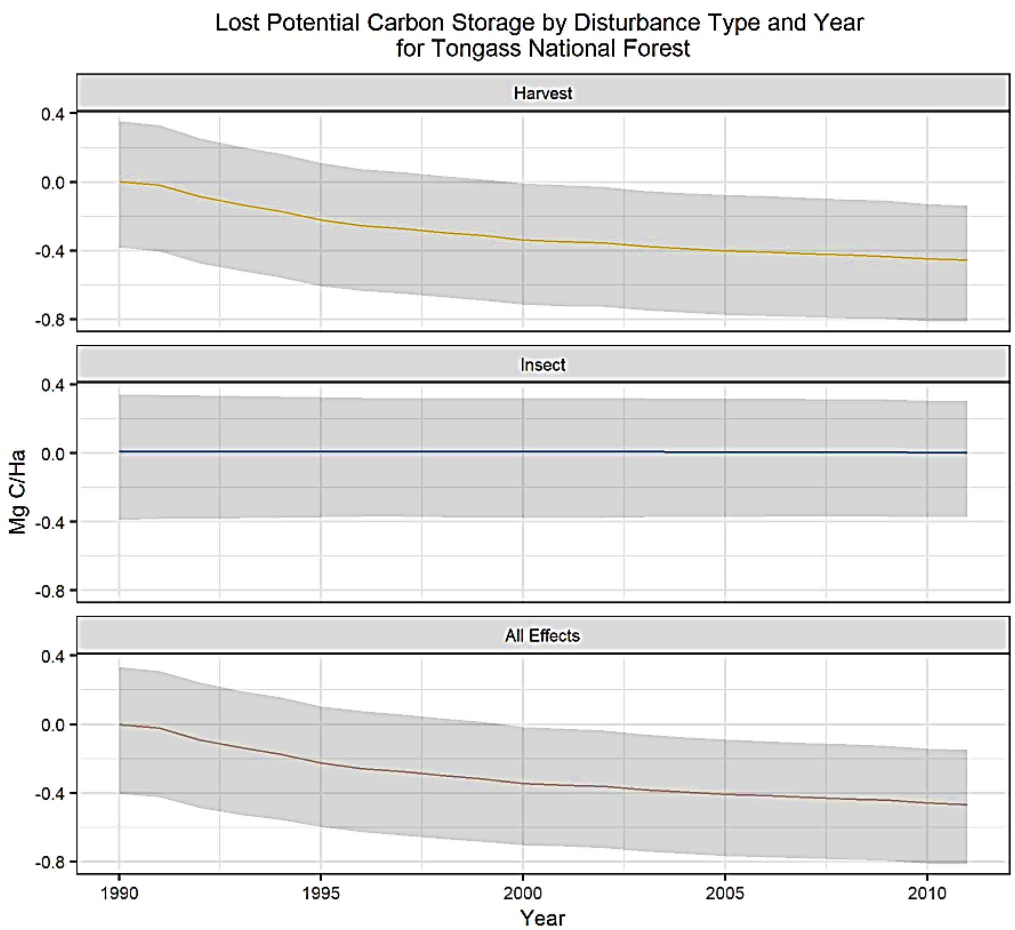

Figure 6. Lost potential storage of carbon (Mg/ha) relative to a hypothetical no-disturbance baseline (zero line), resulting from disturbances from 1990 to 2011. Gray lines are 95 percent confidence intervals. Soil carbon is not included.

All disturbance effects combined (including abiotic disturbances) resulted in the loss of -0.47 Mg/ha, or 0.28 percentage reduction in carbon storage (USDA 2024). All estimates of carbon related to disturbance from 1990 to 2011 do not include soil carbon. Multiple disturbance types may have affected the same area during a given time interval so individual disturbances are not necessarily additive to all effects combined. Low-grade disturbances would also not be detected unless they affected canopy closure given the disturbance estimation methods used (Healey et al., 2018). Additionally, chronic lower-severity forest disturbances (such as insect effects) may be overestimated in this framework because the same incidence may be recorded in multiple years, depending on duration and intensity of canopy impact (Healey et al., 2018).

Although harvest is the predominant disturbance type in the Tongass National Forest, the impacts on forest carbon storage were far below the national average, due to the extensive areas of forest within the region that are not actively managed for timber. Unlike forests across much of the United States during the period up to 2011, the Tongass experienced little detectable disturbance from other disturbance agents, such as fire, insects, and drought, likely a result of the region’s climate.

These results indicating harvest having a larger effect on carbon stocks relative to natural disturbances is consistent with other local literature (Carter and Buma 2024).

Stand Development and Dynamics

Forests are generally considered to follow a multi-stage model of progressive stand development after a severe disturbance: stand initiation, stem exclusion, understory re-initiation, and old growth. However, in a stand affected by frequent moderate-severity disturbance (such as windthrow or landslides) trees may cycle between intermediate stages for centuries (standing dead trees and/or old living trees of low abundance). While these stands generally follow the four stages of development, progressing from seedling to old growth, the period spent in each stage varies. Setbacks to earlier stages may result from limitations in site conditions (hydrology, soils, or climate) or intermediate disturbances, making the stand origin or endpoint difficult to determine (e.g., Franklin et al., 2007; Palik et al., 2020).

Stand age can serve somewhat as a proxy for past disturbances and management activities (Y. Pan et al., 2011). When a forest stand is disturbed by a high severity disturbance, stand age returns to zero until regeneration commences. Relative percentages of forested area in given age classes might reflect stand-replacing disturbance events in situations where a given stand age class predominates. Uneven-aged stands may reflect lower severity disturbance regimes and have more complex patterns.

The coastal temperate rainforests of the Tongass National Forest sustain both high carbon accumulation rates and high carbon storage due to a climate that promotes abundant biomass production and depressed decomposition. The most common forest type groups by area in areas sampled by FIA plot data within Tongass National Forest are Hemlock/Sitka Spruce[4] and Fir/Spruce/Mountain Hemlock,[5] with smaller amounts of Lodgepole pine, across all stand age classes (Figure 7). The most common stand age class is stands that are over 200 years old, comprising 55 percent of the forest area sampled. Stands from 150–200 years old make up 18.5 percent of the sampled forested area.

[4] Includes the western hemlock, Sitka spruce, and western redcedar forest types.
[5] Includes the mountain hemlock and Alaska yellow-cedar forest types.

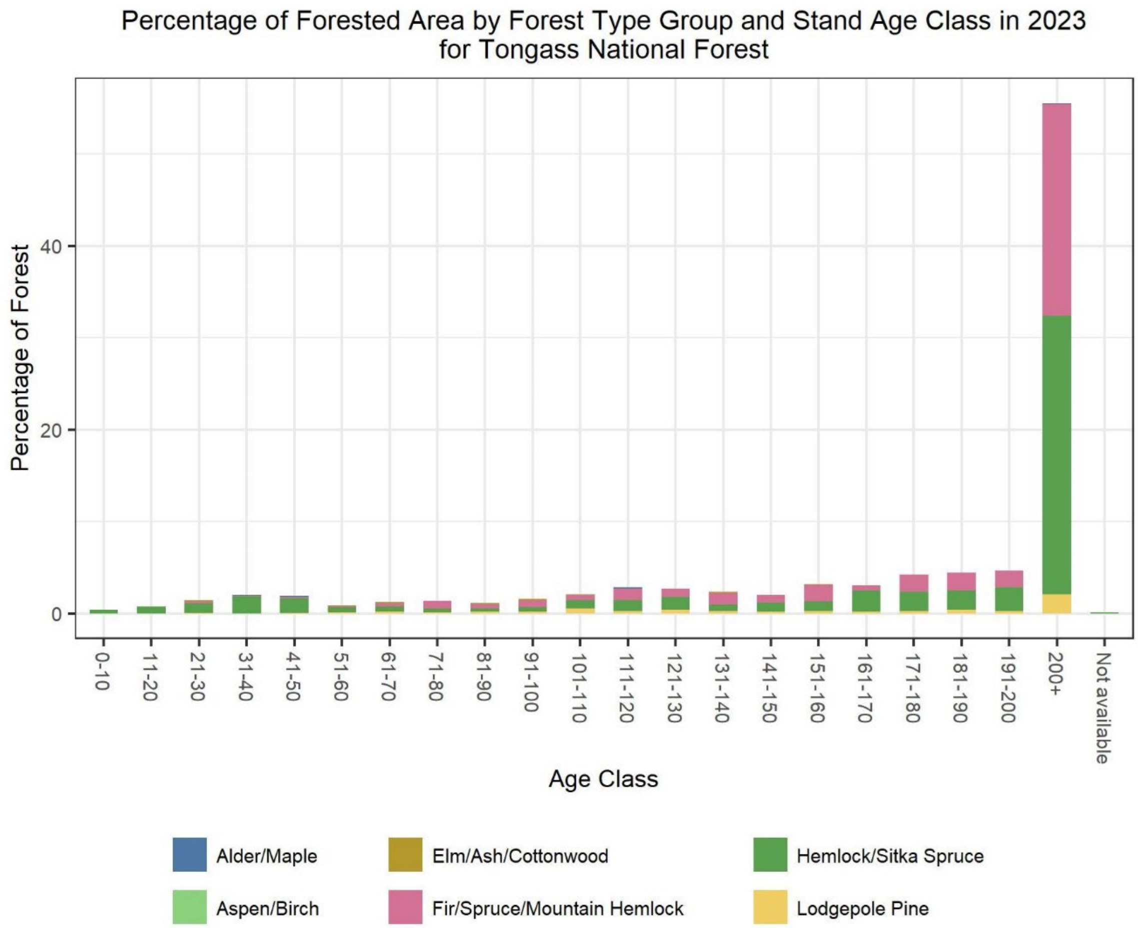

Figure 7. Percentage of forested area by FIA forest type group and stand age class in 2023.

In general, middle-aged forests (about 50 to 100 years old) sequester carbon at a faster rate than older forests (D'Amore and McGuire 2020). Older forest ecosystems take up carbon more slowly than younger forests. However, longer periods of carbon accumulation result in these forests having higher carbon stocks, especially in forest floor and downed dead wood components (Gray et al., 2016; Hoover et al., 2012; Hoover & Smith, 2023, D'Amore and McGuire 2020).

Uncertainty and Data Limitations of current and historical carbon data

Because of the lack of FIA plot locations within the 19 Wilderness areas within the Tongass National Forest, ecosystem carbon stocks estimated from FIA measurements (Figure 1) do not provide an accurate estimate of total carbon on the National Forest.

Soil carbon is influenced by many different abiotic and biotic factors. One of the major ideas in soil carbon change is the concept of soil carbon persistence. Previous models of soil carbon partitioned the stock into pools that turned over at rates defined as fast, intermediate, and slow. Many ecosystem models still use concepts of soil carbon stock change related to these concepts. Recent recognition of the soil carbon stock has demonstrated that the soil matrix is much more dynamic than previously recognized and there are rapid and varying changes in the soil carbon pool. However, the net change remains small overall making the determination of the direction of change difficult. Several models have demonstrated promise in improving prediction of soil carbon stock change, but these are applied to smaller areas such as watershed or project areas (Weider et al. 2015). Management influence on soil carbon is hard to determine, though few documented changes have been identified on the Tongass.

Estimates of soil stock change are extremely difficult due to the small change within a very large stock and variability in the landscape. A large number of samples and estimates of the range of variability in the samples is needed, but not practical under most circumstances. Models offer a method to provide estimates of the direction and potential magnitude of change by integrating known drivers of soil carbon cycles within soils. Verification is difficult, but with highly controlled pedon (soil profile) sampling and C measurements is possible. The current approach of survey methods using soil cores is highly suspect as a method for estimating stock change due to the lack of control on local soil C variability.

Factors Influencing Potential Future Carbon Dynamics

Forest Aging

Future carbon uptake, storage, and stability are influenced by forest stand age dynamics. Older stands tend to have slower growth rates and declining net primary productivity (NPP). Landscape-wide, forest aging may result in some decline in rates of carbon uptake. Based on FIA estimations, given the age distribution across the Tongass (see Figure 7 earlier in this document), and assuming old-growth stands dominate the forested areas of wilderness, it is unlikely that growth rates and NPP will change without a future increase in natural disturbances that lead to elevated tree mortality rates.

Although live biomass may approach peak levels and stabilize or decline in older stands, ecosystem carbon stocks may continue to increase as dead wood and detritus, as well as soil carbon stocks, accumulate (Pregitzer & Euskirchen, 2004). Stand structural heterogeneity, as individual trees die via gap dynamics, can increase over time, with resulting shifts of carbon among pools, and total carbon stocks. Past and present aging trends can inform future conditions with respect to carbon uptake, storage, and stability. However, the interpretations of past stand and landscape dynamics effects on carbon uptake, storage, and stability may be limited, because potential changes in management activities, disturbance, and future climate variability are likely to affect future stand age distributions and forest growth rates (S. C. Davis et al., 2009; Keyser & Zarnoch, 2012) as well as their variability across broader areas.

Due to the low frequency and intensity of natural disturbances on the Tongass National Forest, the most substantial source of change in the carbon stock on the Tongass could be the manipulation of young-growth stands. These stands are rapidly increasing carbon in aboveground biomass across a range of ages since harvest. If these stands are harvested via regeneration harvest like clearcut or shelterwood, there will be a decrease in the overall carbon storage of the young-growth stands. This biomass removal will be partially offset by use of the wood in durable harvested wood products, but the net change with be a reduction in the carbon pool on the Tongass. That being said, the amount of young growth on the forest relative to the amount of old growth is small. As described in the Terrestrial Ecosystem and Timber Resource assessments, there are approximately 5 million acres of productive old growth, approximately 400,000 acres of generally productive young growth, and more than 4 million acres of unproductive forestland.

Projections of Future Carbon Stock Changes

Projections of Future Carbon Stock Changes are presented in Table 4 and Figures 8–10, from the LandCarbon model.

These projections of carbon suggest the Forest will remain a carbon sink through the end of the century, although some areas/ecosystems are projected to lose carbon.

Total vegetation and soil carbon over time and net ecosystem carbon balance from the 2016 LandCarbon analysis (Zhu and McGuire 2016) are shown in Table 4. The 2016 LandCarbon analysis was at the scale of the whole state (Zhu and McGuire 2016); data and results here are limited to a general, buffered area surrounding and including the Tongass, as provided by Helene Genet at University of Alaska Fairbanks. Of particular note are the three landcover types that compose the large majority of the vegetated portions of the Tongass: maritime upland forest, maritime fen, and maritime lowland forest. These three landcover types all show a positive net ecosystem carbon balance.

Table 4. Distribution of historical and future carbon stocks (in gC/m^2) by land cover type, as well as the net ecosystem carbon balance (NECB, in $gC/m^2/yr$). Historical and future carbon stocks are averages across the [2000-2009] and [2090-2099] time periods respectively. NECB is computed from stock changes, representing the [2005-2095] time period. Results shown here are for a general buffered area surrounding and including the Tongass. Spatial standard deviations (s.d.) are indicated in parentheses. The three landcover types that compose the large majority of the vegetated portions of the Tongass are italicized and at the top – Maritime Upland Forest, Maritime Fen, and Maritime Lowland Forest.

Landcover	Area km^2	Total vegetation C [2000-2009] gC/m^2	Total soil C [2000-2009] gC/m^2	Total vegetation C [2090-2099] gC/m^2	Total soil C [2090-2099] gC/m^2	NECB [2005-2095] $gC/m^2/yr$
Maritime Upland Forest	*31,095*	*30,070 (s.d. 8,269)*	*24,132 (s.d. 3,778)*	*34,863 (s.d. 7,945)*	*23,175 (s.d. 2,749)*	*43 (s.d. 34)*
Maritime Fen	*22,583*	*3,648 (s.d. 7,316)*	*75,858 (s.d. 16,692)*	*5,050 (s.d. 8,628)*	*82,920 (s.d. 17,732)*	*94 (s.d. 53)*
Maritime Lowland Forest	*4,597*	*15,228 (s.d. 8,043)*	*31,739 (s.d. 13,620)*	*19,728 (s.d. 9,046)*	*32,628 (s.d. 14,066)*	*61 (s.d. 65)*
Shrub Tundra	2,647	2,138 (s.d. 1,461)	95,143 (s.d. 47,876)	2,745 (s.d. 2,193)	97,359 (s.d. 47,282)	31 (s.d. 222)
Alpine Alder Shrubland	381	1,543 (s.d. 4,000)	29,865 (s.d. 11,409)	1,967 (s.d. 4,595)	30,113 (s.d. 3,660)	7 (s.d. 93)
Deciduous Forest	10,302	6,307 (s.d. 2,335)	47,532 (s.d. 33,615)	6,542 (s.d. 3,632)	48,237 (s.d. 33,514)	10 (s.d. 116)
Heath Tundra	11,350	446 (s.d. 2,035)	53,812 (s.d. 15,595)	504 (s.d. 2,326)	47,565 (s.d. 9,839)	-69 (s.d. 95)
White Spruce Forest	6,429	3,725 (s.d. 1,831)	40,667 (s.d. 47,383)	4,014 (s.d. 2,128)	44,659 (s.d. 48,841)	47 (s.d. 141)
Wetsedge Tundra	234	981 (s.d. 380)	120,259 (s.d. 21,276)	1,267 (s.d. 675)	112,776 (s.d. 18,165)	-80 (s.d. 175)
Black Spruce Forest	3,583	1,877 (s.d. 645)	57,062 (s.d. 54,129)	2,072 (s.d. 1,080)	57,939 (s.d. 51,364)	11 (s.d. 139)
Tussock Tundra	3,994	233 (s.d. 112)	53,693 (s.d. 9,602)	322 (s.d. 188)	52,466 (s.d. 8,177)	-13 (s.d. 28)

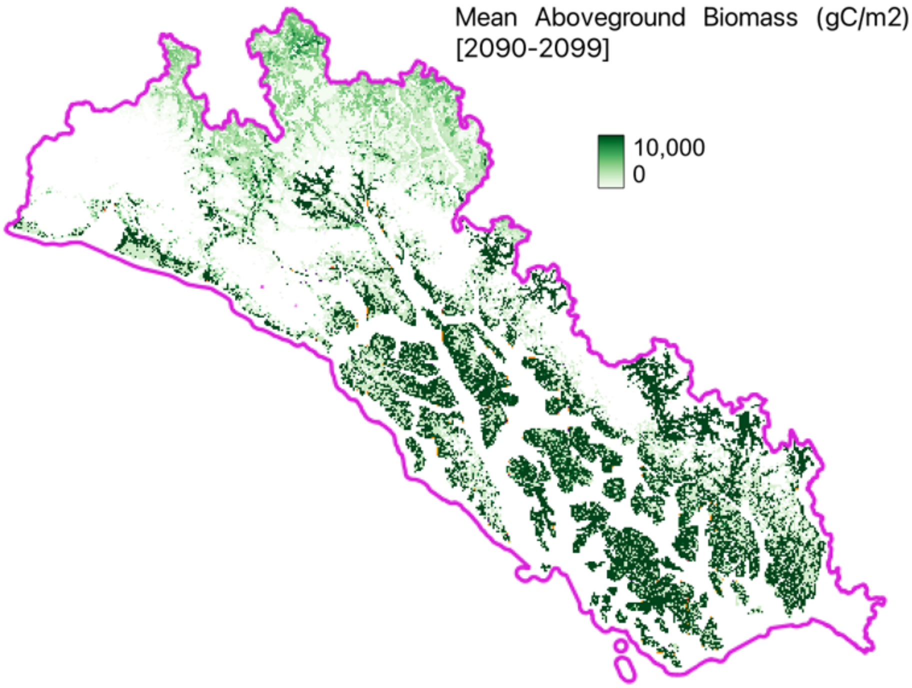

Figure 8. Mean aboveground biomass in gC/m2 for the period [2090-2099], averaged across the six climate scenarios combining three AR3 emission scenarios (B1, A1b, A2) and two global circulation models (CCCMA, and ECHAM5). Aboveground biomass was estimated from total vegetation applying a 80 percent ratio. (Data for the region provided by H. Genet, University of Alaska Fairbanks, from Zhu and McGuire 2016).

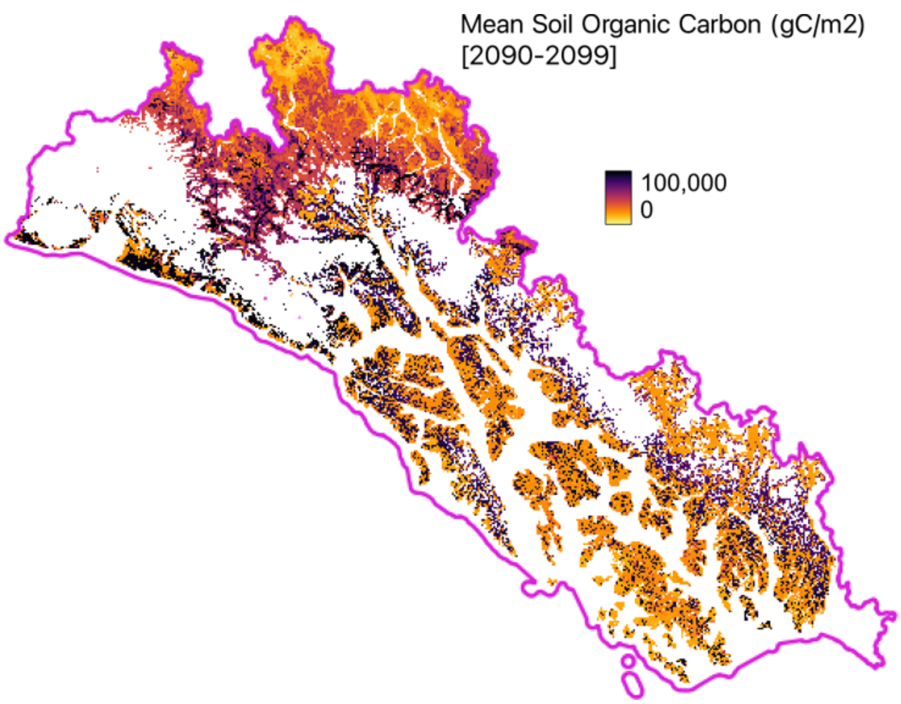

Figure 9. Mean soil organic carbon in gC/m2 for the period [2090-2099], averaged across the six climate scenarios combining three AR3 emission scenarios (B1, A1b, A2) and two global circulation models (CCCMA, and ECHAM5). (Data for the region provided by H. Genet, University of Alaska Fairbanks, from Zhu and McGuire 2016)

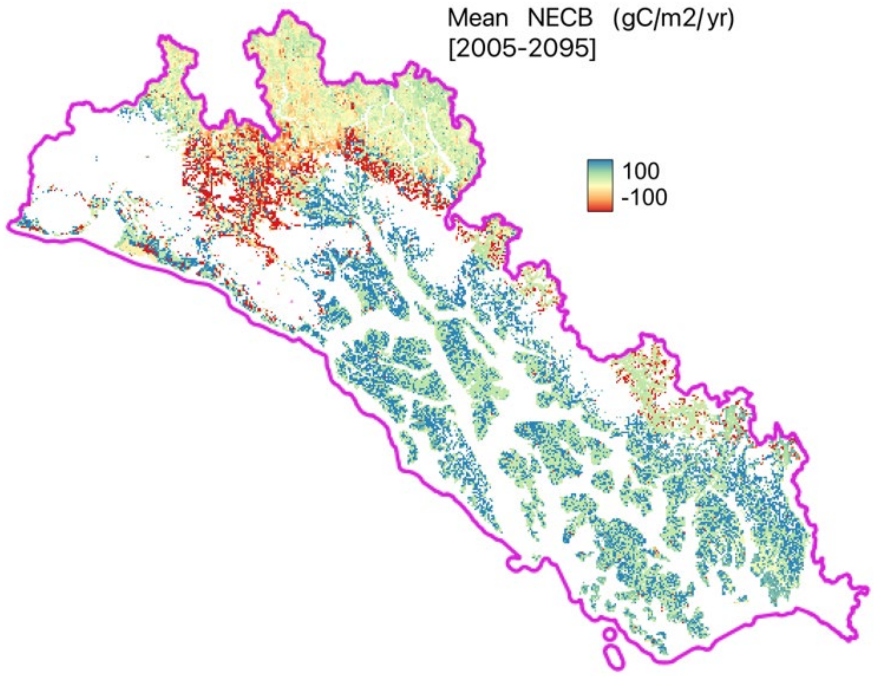

Figure 10. Net ecosystem carbon balance (NECB) in gC/m2/yr for the period [2005-2095], averaged across the six climate scenarios combining three AR3 emission scenarios (B1, A1b, A2) and two global circulation models (CCCMA, and ECHAM5). Blue shades represent ecosystem carbon sinks. Red shades represent ecosystem carbon sources. (Data for the region provided by H. Genet, University of Alaska Fairbanks, from Zhu and McGuire 2016)

Changing Temperatures and Environmental Effects on Potential Future Carbon Dynamics

The relationship between carbon sequestration and changes in climate was recognized as an important thing to consider, according to the feedback heard at the Community Workshops (during the Assessment engagement). Temperature is a key driver of physiological processes and productivity. As such, predicted increases in temperature may affect carbon stocks in a few different ways. First, it may lead to longer growing seasons and increased growth rates, yielding higher aboveground vegetation carbon stocks. For instance, increases in temperatures are resulting in alpine areas accumulating a smaller snowpack and experiencing a longer growing season. With warmer temperatures at higher elevations plants can colonize these areas that were historically not suitable.

On the contrary, increased temperatures may lead to higher decomposition, yielding lower carbon stocks. Temperature is a major control for organic matter decomposition and the increase in temperature that has already occurred on the Tongass and will continue to rise is well documented (Fellman et al. 2017, Halofsky et al. 2024). Thus, higher temperatures may increase the loss of carbon through decomposition of the recent litterfall (Fellman et al. 2017) and woody debris. Whether the net change is an increase or decrease in carbon storage will depend on which of those factors outweighs the other – changes in tree and other vegetation growth vs changes in decomposition.

In addition, changes in climate will affect carbon storage given its impacts on disturbances. For instance, there may be decreased carbon sequestration rates in heavily affected western hemlock stands due to projected increases in the incidence and severity of hemlock dwarf mistletoe (Halofsky et al. 2024). If increases in atmospheric rivers occur (see Drivers, Stressors, and Climate Change Assessment), there may be increased carbon loss from erosion and landslides.

In general, there is a lot of uncertainty regarding how a changing climate may affect future carbon stocks and dynamics.

Key Takeaways

- The Tongass National Forest has very high total carbon stocks and carbon density, with total ecosystem carbon estimated at 2.7 – 2.8 Pg C or higher. (1 Pg = 1 billion metric tons.) Carbon density in forested portions is estimated to be 336 MgC/ha, over five times higher than the average carbon density on NFS lands (60.6 MgC/ha).
- Aboveground live tree biomass and soil carbon pools contribute the majority of stored carbon; estimates vary across sources due to limitations in data.
- The low frequency of disturbance on the Tongass has not significantly impacted overall carbon stocks historically. Harvest is the dominant disturbance, with minimal impacts to carbon density.
- The Tongass is currently a carbon sink. Modeled projections of carbon suggest the Forest will remain a carbon sink through the end of the century, although some areas are projected to lose carbon.
- Carbon uptake and storage in the Tongass National Forest may be vulnerable to numerous threats related to climate change and its interactions with forest patterns and processes. The Tongass National Forest will consider carbon and carbon stewardship as part of its holistic approach to land management.

This page intentionally left blank.

References

Barrett, T.M. Storage and Flux of Carbon in Live Trees, Snags, and Logs in the Chugach and Tongass National Forests; Gen. Tech. Rep.PNW-GTR-889; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Portland, OR, USA, 2014; 44p.

Birdsey, R.A.; Dugan, A.J.; Healey, S.P.; Dante-Wood, K.; Zhang, F.; Mo, G.; Chen, J.M.; Hernandez, A.J.; Raymond, C.L.; McCarter, J. Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks of U.S. National Forests; Gen. Tech. Rep. RMRS-GTR-402; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO, USA, 2019.

Bossio, DA; Cook-Patton, SC; Ellis, PW; Fargione, J; Sanderman, J; Smith, P; Wood, S; Zomer, R.J; Von Unger, .; Emmer, IM; Griscom, BW. 2020 The role of soil carbon in natural climate solutions. Nature Sustainability, 3, 391-398.

Carter, Trevor A. and Buma, Brian. 2024. The distribution of tree biomass carbon within the Pacific

Coastal Temperate Rainforest, a disproportionally carbon dense forest. Can. J. For.Res. 54: 956–977

Caspersen, JP; Pacala, SW; Jenkins, JC; Hurtt, GC; Moorcroft, PR; Birdsey, RA. 2000. Contributions of land-use history to carbon accumulation in U.S. Forests. Science, 290, 1148-1151.

Chapin, F.S., Woodwell, G.M., Randerson, J.T. et al. Reconciling Carbon-cycle Concepts, Terminology, and Methods. Ecosystems 9, 1041–1050 (2006). https://doi.org/10.1007/s10021-005-0105-7

D'Amore, D.V., F. E. Biles, S.M. Nay, and S. Rupp. 2016. Watershed carbon budgets in the southeastern Alaskan coastal forest region. Chapter 4 *In*: Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of Alaska. Zhu, Z., and A.D. McGuire, eds. U.S. Geological Survey Professional paper 1826, 196 p.

D.V. D'Amore. 2020. Appendix A: Regional Summaries: Alaska. In: Forest and Rangeland Soils of the United States under changing conditions: A comprehensive science synthesis. Pouyat, R.V., D.S. Page-Dumroese, T. Patel-Weynand, L.H. Geiser, eds. Springer. https://doi.org/10.1007/978-3-030-45216-2

D'Amore, D.; McGuire, A.D. Forestry as a Natural Climate Solution: The Positive Outcomes of Negative Carbon Emissions. USDA Forest Service PNW Research Station. 2020. Available online: https://www.fs.usda.gov/pnw/sciencef/scifi225.pdf

DellaSala, D.A., S. R. Gorelik, W.S. Walker. 2022. The Tongass National Forest, southeast Alaska, USA: A natural climate solution of global significance. Land 11, 717. https://doi.org/10.3390/land1105717.

Domke, G., Perry, C., Walters, B., Nave, L., Woodall, C. & Swanston, C. 2017. Toward inventory-based estimates of soil organic carbon in forests of the United States. Ecological Applications, 27, 1223-1235.

Domke, G.M., Perry, C.H., Walters, B.F., Woodall, C.W., Russell, M.B., & Smith, J.E. 2016. Estimating litter carbon stocks on forest land in the United States. Science of the Total Environment, 557-558, 469--478.

Domke, G. M., B. F. Walters, C. L. Giebink, E. J. Greenfield, J. E. Smith, M. C. Nichols, J. A. Knott, S. M. Ogle, J. W. Coulston and J. Steller. 2023. Greenhouse gas emissions and removals from forest land, woodlands, urban trees, and harvested wood products in the United States, 1990–2021. Resource Bulletin WO-101. Washington, D.C., U.S. Department of Agriculture, Forest Service, Washington Office. 10 p.

Fellman, J.B., D.V. D'Amore, E. Hood, P. Cunningham. 2017. Vulnerability of wetland soil carbon stocks to climate warming in the perhumid coastal temperate rainforest. Biogeochemistry 133:165-179. https://doi 10.1007/s10533-017-0324-y

Franklin, J.; Hemstrom, M.; Van Pelt, R.; Buchanan, J.; Hull, S.; Crawford, R.; Curry, S.; Obermeyer, W. 2007. Extent and distribution of old forest conditions on DNR-managed state trust lands in eastern Washington. Washington Department of Natural Resources. 44 p.

Genet, H., Y. He, A.D. McGuire, Q. Zhuang, Y. Zhang, F. Biles, D.V. D'Amore, X. Zhou, K. Johnson. 2018. The role of driving factors in historical and projected carbon dynamics of upland ecosystems in Alaska. Ecological Applications 28:5-27.

Genet, H., Y. He, A.D. McGuire, Q. Zhuang, Y. Zhang, F. Biles, D.V. D'Amore, X. Zhou, K. Johnson. 2016. Terrestrial carbon modeling: Baseline and projections in upland ecosystems. Chapter 6 *In*: Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of Alaska. Zhu, Z., and A.D. McGuire, eds. U.S. Geological Survey Professional paper 1826, 196 p.

Gustavsson, L., Madlener, R., Hoen, H. F., Jungmeier, G., Karjalainen, T., Klöhn, S., . . . Spelter, H. 2006. The role of wood material for greenhouse gas mitigation. Mitigation and Adaptation Strategies for Global Change, 11, 1097-1127.

Healey, S.P., Urbanski, S.P., Patterson, P.L. & Garrard, C. 2014. A framework for simulating map error in ecosystem models. Remote Sensing of Environment, 150, 207-217.

Healey, S.P., Raymond, C.L., Lockman, I.B., Hernandez, A.J., Garrard, C. & Huang, C. 2016. Root disease can rival fire and harvest in reducing forest carbon storage. Ecosphere, 7, Article e01569.

Healey, S.P., Cohen, W.B., Yang, Z., Kenneth Brewer, C., Brooks, E.B., Gorelick, N., Hernandez, A.J., Huang, C., Joseph Hughes, M., Kennedy, R.E., Loveland, T.R., Moisen, G.G., Schroeder, T.A., Stehman, S.V., Vogelmann, J.E., Woodcock, C.E., Yang, L. & Zhu, Z. 2018. Mapping forest change using stacked generalization: An ensemble approach. Remote Sensing of Environment, 204, 717-728.

Heath, L. S., J. E. Smith, C. W. Woodall, D. L. Azuma, and K. L. Waddell. 2011. Carbon stocks on forestland of the United States, with emphasis on USDA Forest Service ownership. Ecosphere 2(1):art6 doi:10.1890/ES10-00126.1

Intergovernmental Panel on Climate Change. 2022a. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Intergovernmental Panel on Climate Change. 2022b. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J.

Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.

Intergovernmental Panel on Climate Change. 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.

Intergovernmental Panel on Climate Change. 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.

Johnson, K., J. Harden, A.D. McGuire, N. Bliss, J. Bockheim, M. Clark, T. Hollingsworth, M. T. Jorgenson, E. Kane, M. Mack, J. O'Donnell, C.L. Ping, E. Schuur, M. Turetsky, D. Valentine. 2011. Soil carbon distribution in Alaska in relation to soil-forming factors. Geoderma 167:71-84.

Jones, Dryw A., **D.V. D'Amore**, 2024. Ensemble model and input model rasters for soil organic carbon stock mean and uncertainties for Alaska, British Columbia, Washington, Oregon, California, and Hawai'i. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2024-0009.

Krofcheck, D. J., Remy, C. C., Keyser, A.L., & Hurteau, M. D. (2019). Optimizing Forest Management Stabilizes Carbon Under Projected Climate and Wildfires. *Journal of Geophysical Research: Biogeosciences*, *124*, 3075-3087. https:// doi.org/10.1029/2019JG005206.

Leighty, W.W.; Hamburg, S.P.; Caouette, J. Effects of Management on Carbon Sequestration in Forest Biomass in Southeast Alaska. Ecosystems 2006, 9, 1051–1065.

Lippke, B., Oneil, E., Harrison, R., Skog, K., Gustavsson, L. & Sathre, R. 2011. Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns. Carbon Management, 2, 303-333.

Loeffler, D., Anderson, N., Stockmann, K., Skog, K., Healey, S., Jones, J. G., Morrison, J., and Young, J. 2014. Estimates of carbon stored in harvested wood products from United States Forest Service Alaska Region, 1910-2012.

McGuire, A.D., H. Genet, Y. He, S. Stackpoole, D.V. D'Amore, T.S. Rupp, B. Wylie, X. Zhou, and Z. Zhu. 2016. Alaska greenhouse gas flux and carbon balance. Chapter 9 *In*: Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of Alaska. Zhu, Z., and A.D. McGuire, eds. U.S. Geological Survey Professional paper 1826, 196 p.

McGuire, A.D., H. Genet, Z. Lyu, N. Pastick, S. Stackpoole, R. Birdsey, D.V. D'Amore, Y., He, T.S. Rupp, R. Striegl, B.K. Wylie, X. Zhu, Q. Zhuang, Z., Zhu. 2018. Assessing historical and projected carbon balance of Alaska: A synthesis of results and policy/management implications. Ecological Applications 28:1396-1412.

McKinley, D.C., Ryan, M.G., Birdsey, R.A., Giardina, C.P., Harmon, M.E., Heath, L.S., Houghton, R.A., Jackson, R.B., Morrison, J.F., Murray, B.C., Pataki, D.E. & Skog, K.E. 2011. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications, 21, 1902-1924.

McNicol, G., Bulmer, C., D.V. D'Amore, P. Sanborn, S. Saunders, I. Giesbrecht, S. Gonzalez-Arriola, A. Bidlack, D. Butman, B. Buma. 2019. Large, climate-sensitive carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest. Environmental Research Letters. https://doi.org/10.1088/1748-9326/aaed52

Page-Dumroese, Deborah S.; Abbott, Ann M.; Rice, Thomas M. 2009. Forest Soil Disturbance Monitoring Protocol: Volume I: Rapid assessment. Gen. Tech. Rep. WO-GTR-82a. Washington, DC: U.S. Department of Agriculture, Forest Service. 31 p.

Page-Dumroese, Deborah S.; Abbott, Ann M.; Rice, Thomas M. 2009. Forest Soil Disturbance Monitoring Protocol: Volume II: Supplementary methods, statistics, and data collection. Gen. Tech. Rep. WO-GTR-82b. Washington, DC: U.S. Department of Agriculture, Forest Service. 64 pp.

Palik, B.J.; D'Amato, A.W.; Franklin, J.F.; Johnson, K.N. 2020. Ecological silviculture: foundations and applications. Longrove, IL: Waveland Press. 343 pp.

Pan, Y., Birdsey, R., Hom, J. & McCullough, K. 2009. Separating effects of changes in atmospheric composition, climate and land-use on carbon sequestration of US Mid-Atlantic temperate forests. Forest Ecology and Management, 259, 151-164.

Pan, Y., Chen, J.M., Birdsey, R., McCullough, K., He, L. & Deng, F. 2011. Age structure and disturbance legacy of North American forests. Biogeosciences, 8, 715-732.

Raymond, C.L., Healey, S., Peduzzi, A. & Patterson, P. 2015. Representative regional models of post-disturbance forest carbon accumulation: Integrating inventory data and a growth and yield model. Forest Ecology and Management, 336, 21-34.

Shanley, C.S., Graves, R.A., Drever, C.R. *et al.* Mapping forest-based natural climate solutions. *Commun Earth Environ* **5**, 502 (2024). https://doi.org/10.1038/s43247-024-01678-z.

Skog, K.E., McKinley, D.C., Birdsey, R.A., Hines, S.J., Woodall, C.W., Reinhardt, E.D. & Vose, J.M. 2014. Chapter 7: Managing Carbon. In: Climate Change and United States Forests, Advances in Global Change Research, 57, 151-182. https://doi.org/10.1038/s43247-024-01678-z.

Smith, J.E.; Domke, G.M.; Nichols, M.C.; Walters, B.F. Carbon stocks and stock change on federal forest lands of the United States. Ecosphere **2019**, 10, e02637.

USDA Forest Service. Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System

Units. Alaska Region. Climate Change Advisors Office of the Chief. Alaska Region, 34p. 6 March 2015. Available online:

https://www.fs.fed.us/climatechange/documents/AlaskaRegionCarbonAssessment.pdf (accessed on 5 April 2022). 19 pp.

USDA Forest Service Office of Sustainability and Climate[USDA]. (2024). *USFS Carbon Dashboard to support land management planning in the National Forest System.* Retrieved Fall 2024, from https://public.tableau.com/app/profile/usda.forest.service/viz/Carbon_Dashboard_Public_17056983339290/Dashboard.

US Environmental Protection Agency. 2023. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2023. EPA 430-R-22-003. Washington, DC: U.S. Environmental Protection Agency. https://www.epa.gov/greenvehicles/tailpipe-greenhouse-gas-emissions-typical-passengervehicle#:~:text=typical%20passenger%20vehicle%3F-,A%20typical%20passenger%20vehicle%20emits%20about%204.6%20metric%20tons%20of,8%2C887%20grams%20of%20CO2

Walters, B.F., Domke, G.M., Greenfield, E.J., Smith, J.E., & Ogle, S.M. 2023. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2021: Estimates and quantitative uncertainty for individual states, regional ownership groups, and National Forest System regions. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2023-0020

Yatskov, M.A., Harmon, M.E., Barrett, T.M, and Dobelbower, K.R. 2019. Carbon pools and biomass stores in the forests of Coastal Alaska: Uncertainty of estimates and impact of disturbance. Forest Ecology and Management 434:303–317.

Zhu, Zhiliang, and McGuire, A.D., eds., 2016. Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of Alaska: U.S. Geological Survey Professional Paper 1826, 196 p. http://dx.doi.org/10.3133/pp1826.

This page intentionally left blank.

Glossary

Adaptation - Adjustment in natural or human systems to a new or changing environment. Adaptation includes, but is not limited to, maintaining primary productivity and basic ecological functions such as energy flow; nutrient cycling and retention; soil development and retention; predation and herbivory; and natural disturbances. Adaptation occurs primarily by organisms altering their interactions with the physical environment and other organisms.

Biogenic carbon – carbon which cycles through living organisms, such as soil carbon, carbon stored in trees, or other plant parts.

Biomass - The mass of living organic matter (plant and animal) in an ecosystem. Biomass also refers to organic matter (living and dead) available on a renewable basis for use as a fuel; biomass includes trees and plants (both terrestrial and aquatic), agricultural crops and wastes, wood and wood wastes, forest and mill residues, animal wastes, livestock operation residues, and some municipal and industrial wastes.

Carbon carrying capacity – the amount of carbon that can be stored in a system as a function of prevailing climatic conditions and natural disturbance regimes, and a potential foundation for carbon management plans.

Carbon flux -The transfer of carbon from one carbon pool to another.

Carbon pool - Different types of biomass found within forests. The amount of carbon stored in pools changes over time and in response to various factors. Any natural region or zone, or any artificial holding area, containing an accumulation of carbon or carbon-bearing compounds or having the potential to accumulate such substances. Pools can be defined in several ways, but generally include the following: live aboveground biomass (trees, shrubs, herbs, grasses), live belowground biomass (roots), dead wood (standing dead trees, stumps, logs), forest floor (leaves, small branches), and soil (mineral soil, decaying organic matter).

Carbon sequestration - The process of plants using sunlight to capture CO2 from the air and convert it into plant biomass, including wood, leaves, and roots. The process of increasing the carbon content of a carbon reservoir other than the atmosphere; often used narrowly to refer to increasing the carbon content of carbon pools in the biosphere and distinguished from physical or chemical collection of carbon followed by injection into geologic reservoirs, which is generally referred to as "carbon storage."

Carbon sink - In general, any process, activity, or mechanism that removes a greenhouse gas or a precursor of a greenhouse gas or aerosol from the atmosphere; in this report, a sink is any regime or pool in which the amount of carbon is increasing (i.e., is being accumulated or stored).

Carbon source - In general, any process, activity, or mechanism that releases a greenhouse gas or a precursor of a greenhouse gas or aerosol into the atmosphere; in this report, a source is any regime or pool in which the amount of carbon is decreasing (i.e., is being released or emitted).

Carbon stock - The amount or quantity of carbon contained in the inventory of a pool or reservoir.

Carbon storage - The amount of carbon retained long-term within the forest, stored in "carbon pools."

Climate change adaptation – see "Adaptation"

Climate change mitigation – see "Mitigation"

Greenhouse gases - Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

Mitigation - In the context of climate change, actions that reduce the amount of heat-trapping greenhouse gases, such as CO2, in the atmosphere to minimize changes in the Earth's climate. Actions can include avoiding or reducing emissions of greenhouse gases into the atmosphere, as well as removing greenhouse gases that are already present in the atmosphere.

Net Ecosystem Carbon Balance-This is the complete ecosystem balance of inputs and outputs representing the true net sink or source in the ecosystem. This estimate includes aboveground and belowground plant production, soil respiration, and lateral losses of carbon (see Chapin et al. 2006).

Resilience - The ability of an ecosystem and its component parts to absorb, or recover from the effects of disturbances through preservation, restoration, or improvement of its essential structures and functions and redundancy of ecological patterns across the landscape.